WEST BASIN MUNICIPAL WATER DISTRICT
OCEAN WATER DESALINATION INTAKE
CORROSION STUDY

Prepared for: TETRA TECH

Date: November 2014

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V&A Project No.: 13-0376

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ES EXECUTIVE SUMMARY

West Basin Municipal Water District (West Basin) is pursuing ocean water desalination as an added source of water for its clients. The intent of the study is to measure the extent of corrosion and biofouling on bare and coated metal coupons. Twenty four samples made from four different alloys were identified and installed on a testing apparatus at the West Basin Ocean Water Desalination Intake location near El Segundo, CA. One coupon from each alloy will be removed after 3, 6, 9 and 11 months and will be sent to a laboratory for analysis. The purpose of the corrosion study is the following:

A. To determine the corrosion rates and modes of anticipated corrosion that will occur on the selected materials.
B. To determine the effectiveness of several antifouling control strategies for future design, implementation and operation of intake facilities.
C. To determine the effect of a foul release protective coating will have on biological growth on the test samples.
D. To select materials that are readily available for manufacture of the wedge wire intake screen for use at the full scale West Basin Desalination Plant.

The purpose of this report is to provide the results of the on-site and in-situ testing of metal coupons and wedge wire screen samples after the first 91 days of immersion in the Pacific Ocean seawater. The samples were installed on June 17, 2014 and removed on September 16, 2014. Table ES-1 summarizes the corrosion rate results for four different alloys.

Table ES-1. Corrosion Rates of Four Alloys after 91 days in Seawater Exposure

Alloy	Sample Type	Surface Area (sq. in.)	Maximum Pitting Depth over 90 days (mils)	Overall Average Corrosion Rate (mils/year)
2205 Duplex SS Uncoated	1-inch by 3-inch coupon	8.2	0.71	0.004
	Wedge Wire Screen	96.7	None observed	0.013
2205 Duplex SS with Foul Release Coating	1-inch by 3-inch coupon	8.2	0.79	0.079
	Wedge Wire Screen	96.7	None observed	0.079
CDA 715 70-30 Cu-Ni	1-inch by 3-inch coupon	8.2	1.97	0.827
	Wedge Wire Screen	65.0	10	0.866
CDA 706 90-10 Cu-Ni	1-inch by 3-inch coupon	8.2	3.15	0.866
	Wedge Wire Screen	79.1	<10	5.08
Z Alloy	1-inch by 3-inch coupon	8.2	7.87	0.590
	Wedge Wire Screen	96.3	<10	4.45

Pitting and general corrosion were the primary mechanisms of corrosion on the coupons. Based on the data over 91 days, 2205 Duplex Stainless Steel has the lowest pitting depths and average corrosion rates of the four metal alloys for both the coupons and screens tested in this study. However, the uncoated 2205 Duplex Stainless Steel samples were the most heavily fouled by marine life.

As can be seen in Table ES-1, the highest overall average corrosion rate was observed on the 90-10 Cu-Ni coupons and screens. The highest pitting rate was observed on the Z Alloy coupons. Pits on the small cross sectional areas of the wire screens were difficult to measure, however the pit measurements on the screens indicate the screens followed the same trend between the different alloys as the coupons. The 90-10Cu-Ni, 70-30Cu-Ni and Z alloy screens had approximately 10 mils pitting depth while no pits were observed on the stainless steel screens after 90 days of exposure in seawater.

The overall average corrosion rates of the 90-10Cu-Ni and Z Alloy screens were 6 to 7.5 times higher than the coupons of the same alloy. The 90-10 Cu-Ni coupons were provided from a different vendor than the screens and they may have a different chemical composition. However the same cannot be said for the Z Alloy samples because they were provided from the same vendor. Tenera Environmental indicated that the 70-30 Cu-Ni samples exhibited more marine life fouling on the coupons and screens than the 90-10 Cu-Ni and Z alloy metals. It is possible that the corrosion rate is reduced by the amount of marine life fouling present on the samples because it limits the exposure of the metal to the seawater. The ability of the metal to create a passivation layer on the surface of each alloy may also affect the corrosion rate.

1.0 INTRODUCTION

West Basin Municipal Water District (West Basin) is pursuing ocean water desalination as an added source of water for its clients. Five test samples made from four different alloys were identified, through review of the literature for similar studies, and installed on a testing apparatus at the West Basin Ocean Water Desalination Intake location near El Segundo, CA. The intent of the study is to measure the extent of corrosion and biofouling on bare and coated metal coupons. The samples were installed and ten coupons were removed after 90 days. Six additional coupons will be removed after 6, 9 and 11 months until all 24 coupons are removed. Once removed, the samples will be sent to a lab for analysis. The overall objectives for the study are the following:

- To determine the corrosion rates and modes of anticipated corrosion that will occur on the selected materials.
- To determine the effectiveness of several antifouling control strategies for future design, implementation and operation of intake facilities.
- To determine the effect of a foul release that the protective coating will have on biological growth on the test samples. This will substantiate the ultimate selection of intake screen material and the benefit of providing an anti-fouling coating on the intake screen.
- To determine proper material selection, manufacturer quality control, and proper installation of screens.
- To select materials that are readily available for manufacture of the wedge wire intake screen for use at the full scale West Basin Desalination Plant.
- To present information with material selection options, showing overall capital cost, and O&M costs.

The purpose of this report is to provide the results of the on-site and in-situ testing of metal coupons and wedge wire screen samples after 91 days of immersion in the Pacific Ocean seawater.

2.0 METHODS

The purpose of this section is to describe the testing study procedures for on-site and in-situ testing of metal coupons and wedge wire screen samples in order to assess corrosion impact relative to material selection and operating practices. The results presented in this report are for the samples that were removed after 3 months of seawater exposure.

2.1 Procurement of Materials

A total of 24 testing samples were obtained for testing of the corrosion coupons and 24 testing samples were obtained for the wedge wire screens (4 samples for each material type). The metal coupons are 1 inch wide by 3 inches long by 1/16 of an inch thick and the wedge wire screens are 4 inches by 4 inches with a 2 mm spacing, except the 90-10 Cu-Ni screens which has 4 mm spacing, between the screen wires.

V&A coordinated with the coupon vendors and screen manufacturers for the procurement of the testing samples. Metal Samples Company of Munford, Alabama, provided the 1-inch by 3-inch long by 1/16-inch thick coupons in 90-10 Copper-Nickel (Cu-Ni), 70-30 Cu-Ni, and the 2205 Duplex Stainless Steel. Metal Samples also provided the 4-inch by 4-inch by 1/8-inch thick flat plate in the same metal alloys. Holes were made on each 1-inch by 3-inch and 4-inch by 4-inch metal sample in order to secure it to the testing rack with plastic zip ties.

Johnson Screens/Bilfinger Water Technologies of New Brighton, Minnesota provided the 4-inch by 4-inch wedge wire screens in the 90-10 Cu-Ni, 2205 Duplex Stainless Steel, and Z alloys. They also provided the 1-inch by 3-inch by 1/16 inch thick coupons and the 4-inch by 4-inch flat plate in the Z alloy.

Hendrick Screen Company of Owensboro, Kentucky, provided the 4-inch by 4-inch wedge wire screens in 70-30 Cu-Ni.

2.2 Coating for Stainless Steel Screens and Coupons

V&A searched for a coating that would provide an NSF Standard 61-approved coating for drinking water contact and was known to prevent the attachment of marine life on hydraulic structures. The US Bureau of Reclamation has been testing several types of antifouling and foul release coatings from different manufacturers since 2008. V&A identified the following foul release coating system for the stainless steel samples from the reports and discussions with manufacturers:

A. 1st coat - Sherwin Williams Macropoxy 646 PW immersion grade epoxy primer at 6 mils dft
B. 2nd coat - Sherwin Williams Seaguard Sher-Release beige silicone Tie Coat at 6 mils dft
C. 3rd coat - Sherwin Williams Seaguard Sher-Release white silicone Surface Coat at 6 mils dft

Photo 2-1 through Photo 2-17 show the samples before they were immersed in seawater.

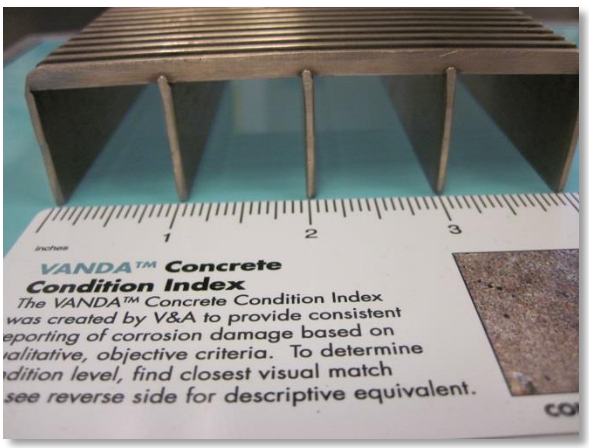


Photo 2-1. Z alloy 4-inch by 4-inch wedge wire screen.

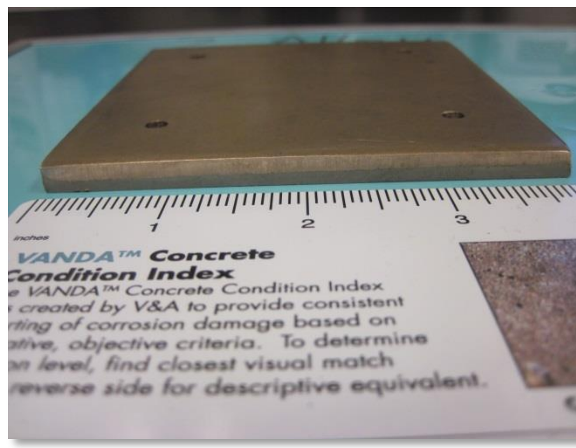


Photo 2-2. Z alloy 4-inch by 4-inch flat plate

Photo 2-3. Z alloy 1-inch by 3-inch coupon with weld.

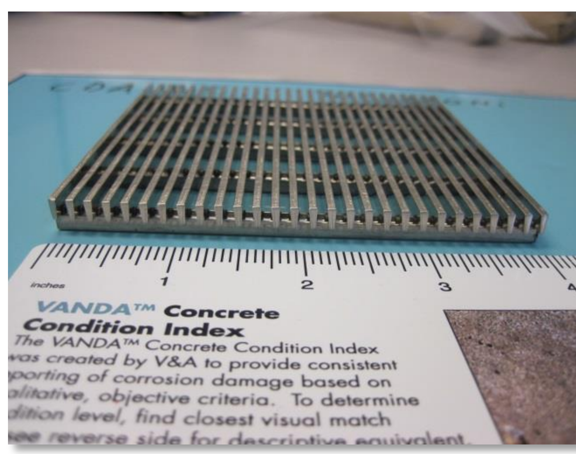


Photo 2-4. 70-30 Cu-Ni 4-inch by 4-inch wedge wire screen

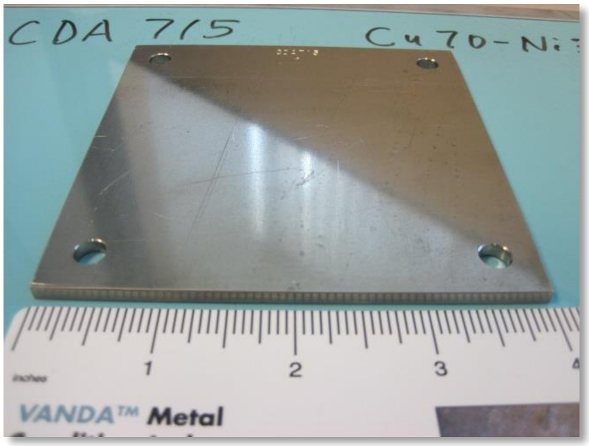


Photo 2-5. 70-30 Cu-Ni 4-inch by 4-inch flat plate

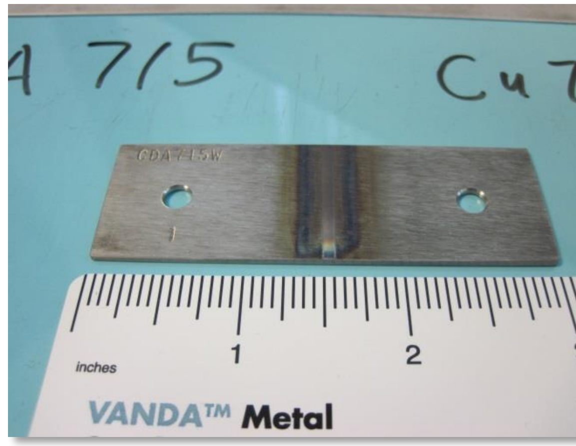


Photo 2-6. 70-30 Cu-Ni 1-inch by 3-inch coupon with weld

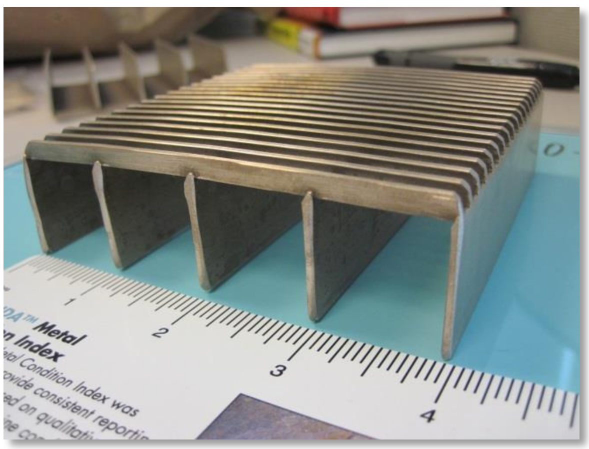


Photo 2-7. 90-10 Cu-Ni 4-inch by 4-inch wedge wire screen

Photo 2-8. 90-10 Cu-Ni 4-inch by 4-inch flat plate.

Photo 2-9. 90-10 Cu-Ni 1-inch by 3-inch coupon with weld

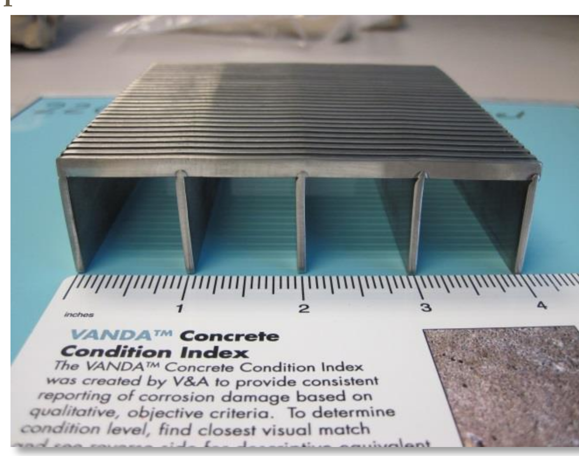


Photo 2-10. 2205 Duplex stainless steel 4-inch by 4 inch wedge wire screen.

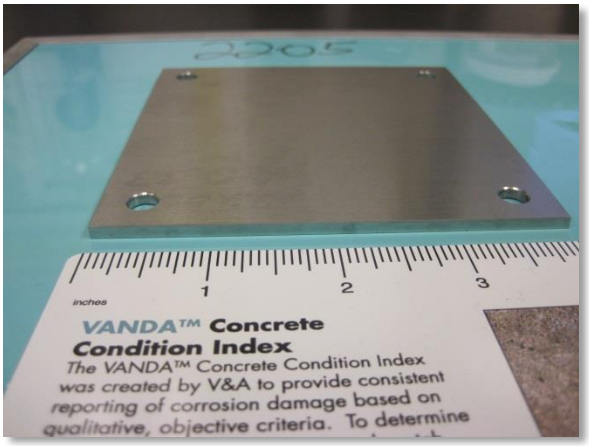


Photo 2-11. 2205 Duplex Stainless Steel 4-inch by 4-inch flat plate.

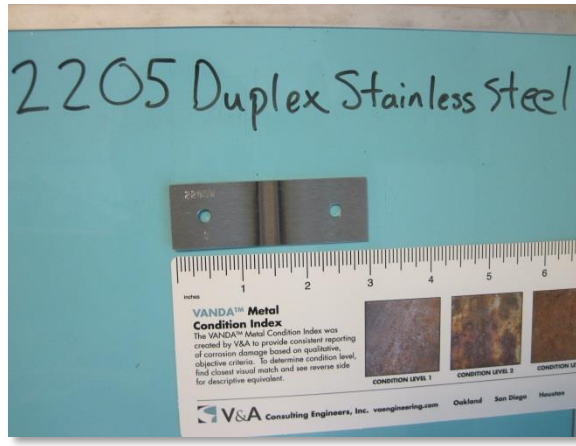


Photo 2-12. 2205 Duplex stainless Steel 1-inch by 3-inch coupon with a weld.

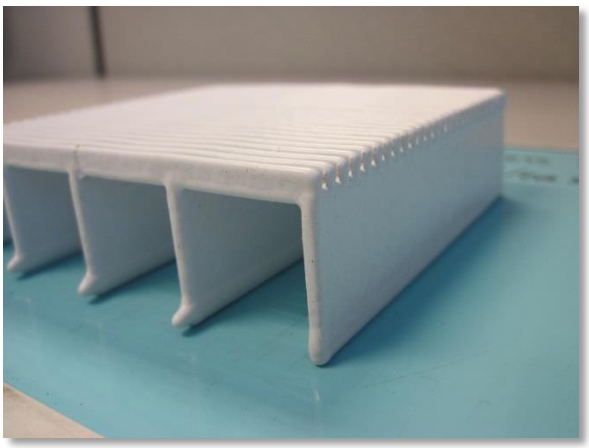


Photo 2-13. Coated 2205 Duplex Stainless Steel 4-inch by 4-inch wedge wire screen.

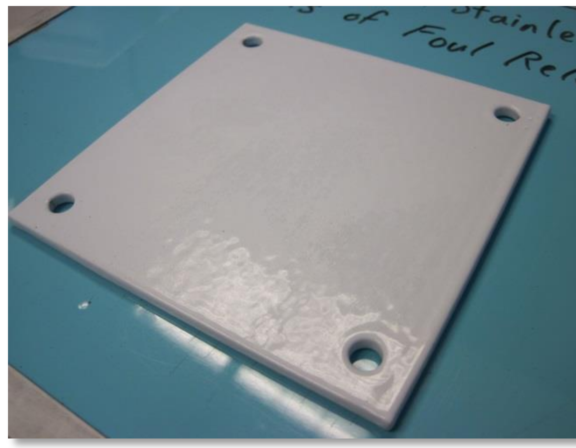


Photo 2-14. Coated 2205 Duplex Stainless Steel 4-inch by 4-inch flat plate.

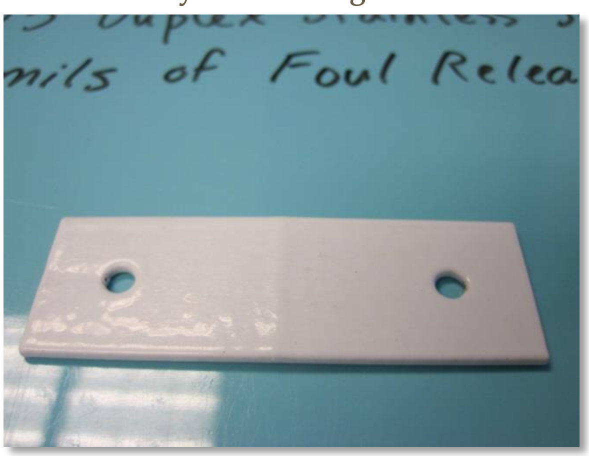


Photo 2-15. Coated 2205 Duplex stainless Steel 1-inch by 3-inch coupon with a weld.

2.3 Lab Analysis

2.3.1 Chemical Analysis by EDS

Anamet, Inc. of Hayward, California, performed a quantitative chemical analysis by Energy Dispersive x-ray Spectra (EDS) on a baseline control sample and on the samples after they were immersed in seawater. Anamet's report contains images of the spectra and are included as Appendix A.

2.3.2 Scanning Electron Microscopy

Anamet, Inc. of Hayward, California, performed Scanning Electron Microscopy (SEM) on the samples. The SEM uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. The signals that derive from electron-sample interactions reveal information about the sample including texture, chemical composition, and crystalline structure.

2.3.3 Metallography

Optical macrographs of the samples were also recorded by Anamet Inc. before and after cleaning of the samples and are attached in Anamet's reports. A metallographic examination of a cross section of each sample was recorded.

2.3.4 Corrosion Rate Analysis

Samples were weighed by Anamet Laboratories in Hayward, CA before they were installed. The samples were analyzed by the lab after they were exposed to the seawater environment per ASTM G1 *Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens* and ASTM D2688 *Standard Test Method for Corrosivity of Water in the Absence of Heat Transfer (Weight Loss Method)*. The samples were cleaned with either nitric acid or hydrochloric acid. Plots of mass loss versus cleaning cycles for each sample are attached in Anamet's report. Pitting examination was performed per ASTM G46 *Standard Guide for Examination and Evaluation of Pitting Corrosion*.

2.4 Procedures

After the initial baseline parameters were obtained, the samples were shipped to Tenera Environmental for installation at the project site. Tenera Environmental assembled the testing rack and affixed the coupons and wedge wire screens prior to immersion in the ocean source water. The wedge wire screens were secured to the testing rack with plastic zip ties. There was one test rack for each set of samples to be removed at each specified interval.

The testing samples consisted of metal coupons, wedge wire screens and flat plates (coated and uncoated) for installation on the in-situ testing apparatus installed by Tenera Environmental divers.

Samples and cleaning were performed per ASTM G-1 *Preparing, Cleaning, and Evaluating Corrosion Test Specimens* and ASTM D2688 *Standard Test Method for Corrosivity of Water in the Absence of Heat Transfer (Weight Loss Method)*. ASTM G-1 includes procedures in Sections 14.10 through 14.14 that involve weighing and classifying the types of pits. This test method covers the determination of the corrosivity of water by evaluating pitting and by measuring the weight loss of metal specimens. Pitting is a form of localized corrosion: weight loss is a measure of the average corrosion rate.

A metallographic examination was performed per ASTM E3 *Standard Guide for Preparation of Metallographic Specimens*. The primary objective of metallographic examinations is to reveal the constituents and structure of metals and their alloys by means of a light optical or scanning electron microscope.

Before installation the samples were examined for the following baseline parameters:

1. Weigh all samples per ASTM G1. Samples to be coated will be weighed before and after coating application.
2. Examine samples visually to 40X
3. Color photograph, one of each material type
4. Photomicrograph @ 10X, one of each material type
5. Photomicrograph @ 50X, one of each material type
6. Scanning Electron Micrograph (SEM) @ 100X, one of each material type
7. Energy Dispersive Spectroscopy (EDS), one of each material type

Samples removed after 3, 6, 9 and 11 months of exposure have been and will be examined for the following:

1. Sample cleaning & weighing per ASTM G1 & ASTM D2688
2. Pitting examination per ASTM G46
3. Dimensional inspection (micrometers or NOGO gauge) Wedge wire and gap dimensions.
4. Photomicrograph @ 10X, one of each material type After Cleaning (AC)
5. Photomicrograph @ 50X, one of each material type AC
6. Scanning Electron Micrograph @ 100X, one of each material type AC
7. Elemental analysis with EDS, one of each material type AC
8. Metallographic examination per ASTM E3, one of each material type

2.5 Corrosion Mechanisms

Corrosion is an electrochemical phenomenon that takes place at the interface of the metal and electrolyte, which in this case is seawater. When the metal is in contact with the electrolyte, a difference in potential develops at the electrolyte/metal interface. When corrosion reactions take place, they generate a current between the metal and the electrolyte. Factors that may impact the corrosion rate include the following:

- Presence of inclusions in the metal or a Heat Affected Zone due to welding
- Mechanical stressed caused by welding, forming or temperature
- Water velocity and tidal fluctuations at the surface of the coupon (not possible in a lab)
- Alloy resistance to corrosion due to high chloride concentrations in seawater
- Water temperature, dissolved oxygen, sulfates, and chlorides

The following sections explain some possible corrosion mechanisms for the metals based on V&A's research.

2.5.1 Uniform Corrosion

If all metal surfaces are attacked via corrosion at an equal rate, the corrosion is termed uniform. As far as failure rate, the uniform corrosion rate is expressed in terms of pipe penetrating rates (rate of pipe wall loss) in thousandths of inches (mils) per year (mpy).

2.5.2 Localized and Pitting Corrosion

When corrosion of the metal surface is localized, the surface under the most aggressive attack becomes recessed with respect to the rest of the pipe surface and visible pits are formed. In such instances, the attack is said to be nonuniform, localized, or pitting corrosion. Theoretically, corrosion pitting in metals is divided into two phases: pit initiation and propagation.

2.5.3 Stress Corrosion Cracking

The occurrence of Stress Corrosion Cracking (SCC) depends on the simultaneous achievement of three requirements: 1) a susceptible material; 2) a chemical environment that causes SCC for that material and 3) sufficient tensile (mechanical) stress within the material. The mechanical stresses may be caused during welding, forming, and temperature.

Photo 2-16 and Photo 2-17 show samples of the cracking that might occur for copper alloys, duplex stainless steel under mechanical and chemical stresses. These photos are not of the metal samples that are part of this study and are presented for demonstrative purposes only.

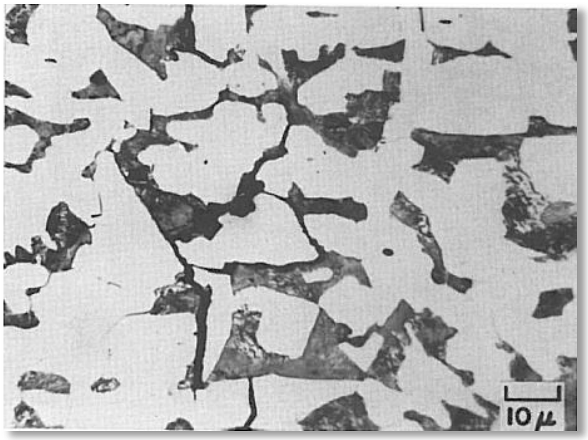


Photo 2-16. Intergranular Stress Corrosion Cracking in a Steel Pipe.[6]

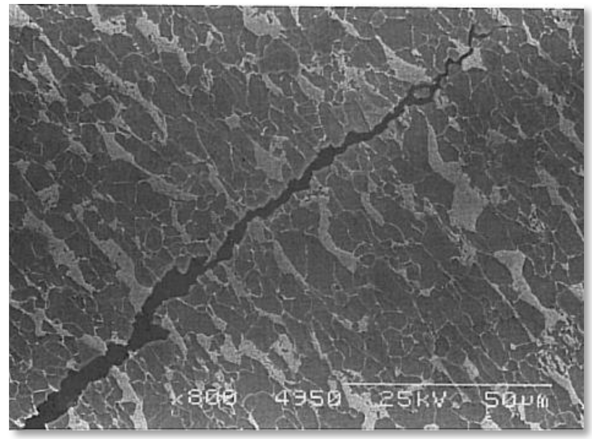


Photo 2-17. Transgranular Stress Corrosion Cracking in a Steel Pipe.[6]

2.6 Reference Corrosion Rates from Studies Performed by Others

V&A researched seawater corrosion rates for the alloys in this study to compare the corrosion rate of the alloys with the results of this study. Table 2-1 summarizes the information found in corrosion control literature.

Table 2-1. Average Corrosion Rates from Literature Review for Alloys in Seawater

Material	UNS	Corrosion Rate (mils/yr)	Reference
90-10 Cu-Ni	C70600	0.15	ASM Volume 13B p.140, Fig 13 (Efird & Anderson, Mater. Perform., 1975)
70 Cu-30Ni	C71500	0.13	ASM Volume 13B p. 140 Fig 14 (Efird & Anderson, Mater. Perform., 1975)
2205 duplex stainless steel	S32205	0.03	McGuire, Stainless Steels for Design Engineers, p. 101, 2008

Figure 2-1 shows a graph of the average corrosion rates for several metal alloys in seawater. As seen in the graph, 70-30 Cu-Ni and 90-10 Cu-Ni have a corrosion rate of 0.15 to 0.5 mils per year.

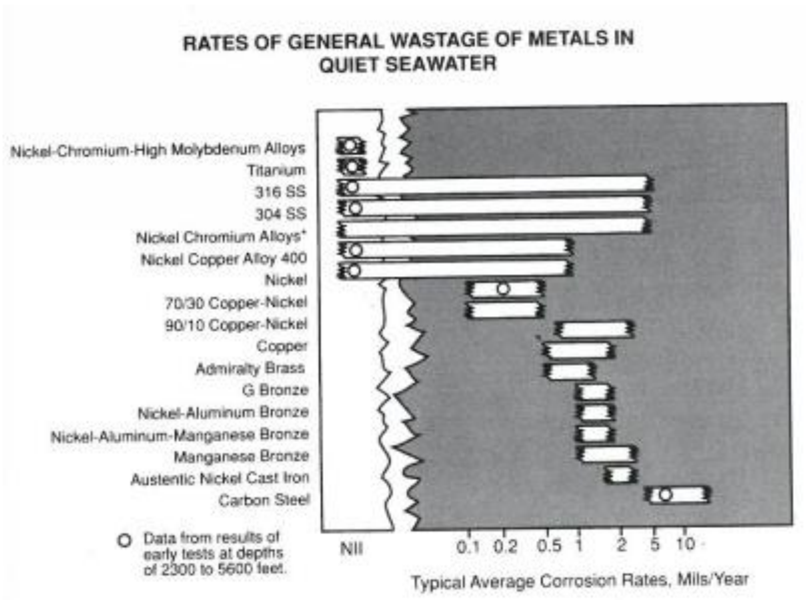


Figure 2-1. Graph of Average Corrosion Rates of Different Alloys in Seawater

3.0 FINDINGS

The first set of ten coupons and screens was installed on Tuesday June 17, 2014 and retrieved on Tuesday September 16, 2014. Photographic documentation and lab results and analysis are presented below.

3.1 Corrosion Rates After 90 Days

Table 3-1 summarizes the results of the corrosion rate analysis conducted by Anamet Inc. after the samples were exposed to seawater for 90 days starting on June 17, 2014.

Table 3-1. Corrosion Rates of Four Alloys After 90 days in Seawater Exposure

Alloy	Sample Type	Surface Area (sq. in.)	Maximum Pitting Depth over 90 days (mils)	Overall Average Corrosion Rate (mils/year)
2205 Duplex SS Uncoated	1-inch by 3-inch coupon	8.2	0.71	0.004
	Wedge Wire Screen	96.7	None observed	0.013
2205 Duplex SS with Foul Release Coating	1-inch by 3-inch coupon	8.2	0.79	0.079
	Wedge Wire Screen	96.7	None observed	0.079
CDA 715 70-30 Cu-Ni	1-inch by 3-inch coupon	8.2	1.97	0.827
	Wedge Wire Screen	65.0	10	0.866
CDA 706 90-10 Cu-Ni	1-inch by 3-inch coupon	8.2	3.15	0.866
	Wedge Wire Screen	79.1	<10	5.08
Z Alloy	1-inch by 3-inch coupon	8.2	7.87	0.590
	Wedge Wire Screen	96.3	<10	4.45

Based on the data over 90 days, 2205 Duplex Stainless Steel has the lowest pitting depths and average corrosion rates of the four metal alloy coupons and screens tested in this study. However, the uncoated 2205 Duplex Stainless Steel samples were the most heavily fouled by marine life.

Of the copper alloy samples, the Z alloy 1-inch by 3-inch coupon indicated the lowest overall average corrosion rate and the 90-10 Cu-Ni coupon had the highest corrosion rate. The 90-10 Cu-Ni screens had the highest corrosion rate of all of the screens after 90 days of exposure. The highest pitting rate was observed on the Z Alloy coupons. Pits on the small cross sectional areas of the wire screens were difficult to measure, however the pit measurements on the screens indicate the screens followed the same trend between the different alloys as the coupons. The 90-10Cu-Ni, 70-30Cu-Ni and Z alloy screens had approximately 10 mils pitting depth while no pits were observed on the stainless steel screens after 90 days of exposure in seawater.

The overall average corrosion rates of the 90-10Cu-Ni and Z Alloy screens were 6 to 7.5 times higher than the coupons of the same alloy. The 90-10 Cu-Ni coupons were provided from a different vendor than the screens and they may have a different chemical composition. However the same cannot be said for the Z Alloy samples because they were provided from the same vendor. Tenera Environmental indicated that the 70-30 Cu-Ni samples exhibited more marine life fouling on the coupons and screens than the 90-10 Cu-Ni and Z alloy metals. It is possible that the corrosion rate is reduced by the amount of marine life fouling present on the samples because it limits the exposure of the metal to the seawater. The ability of the metal to create a passivation layer on the surface of each alloy may also affect the corrosion rate.

4.0 CONCLUSIONS

Based on the literature research and the lab analysis, V&A presents the following conclusions.

4.1 Coupons

1. The average corrosion rate of the Uncoated 2205 Duplex Stainless Steel coupons was the lowest of the four alloys that were included in this study.
2. The average corrosion rate of the 90-10 Cu-Ni coupons was the highest of the four alloys that were included in this study.
3. The lowest pitting depth was measured on the 2205 Duplex Stainless Steel coupons after 90 days of exposure in seawater.
4. The highest pitting depth was measured on the Z Alloy coupons after 90 days of exposure in seawater.
5. Pitting and general corrosion were the primary modes of corrosion on the coupons.
6. There is a large difference in the overall corrosion rate between the coupons and screens for the 90-10Cu-Ni and Z Alloy samples.
7. The overall average corrosion rates of the 90-10Cu-Ni and Z Alloy screens were 6 to 7.5 times higher than the coupons of the same alloy.
8. The overall average corrosion rates were higher than the data found in the literature summarized in Table 2-1.

4.2 Screens

1. The average corrosion rate of the Uncoated 2205 Duplex Stainless Steel screens was the lowest of the four alloys after 90 days of exposure.
2. The average corrosion rate of the 90-10 Cu-Ni screens was the highest of the four alloys that were included in this study.
3. Pitting and general corrosion were the primary modes of corrosion on the coupons.
4. The maximum pitting depth of the screens followed the same trend between the different alloys as the coupons. The 90-10Cu-Ni, 70-30Cu-Ni and Z alloy screens had approximately 10 mils pitting depth while no pits were observed on the stainless steel screens after 90 days of exposure in seawater.
5. The overall average corrosion rates of the 90-10Cu-Ni and Z Alloy screens were 6 to 7.5 times higher than the coupons of the same alloy.
6. The overall average corrosion rates were higher than the data found in the literature summarized in Table 2-1.

APPENDIX A. LAB ANALYSIS REPORTS

Anamet, inc Materials Engineering & Laboratory Testing
26102 EDEN LANDING ROAD, SUITE 3 • HAYWARD, CALIFORNIA 94545 • (510) 887-8811 • FAX (510) 887-8427

Report No. 5005.0361 **November 7, 2014**

CORROSION EVALUATION OF 2205 DUPLEX STAINLESS STEEL COUPONS AND SCREENS

Customer Authorization: Verbal

Report To: V & A Engineering
Attn: Manuel Najar
155 Grand Avenue, Suite 700
Oakland, CA 94612

1.0 INTRODUCTION

Five coupons, five wedge wire screens, and one plate were submitted by V&A Engineering for corrosion evaluation. The coupons were 1-inch by 3-inches by ¼-inch thick. The wedge wire screens were 4-inches by 4-inches by 1-inch tall with 4 mm spacing. The plate was 4-inches by 4-inches by 1/8-inch thick. The sample was reportedly a 2205 duplex stainless steel alloy.

Four coupons and four screens were to be placed in seawater for a period up to one year. After every 3 month interval, one coupon and one screen were to be removed from the test system and examined for corrosion. The purpose of this evaluation was to document the samples in the baseline as-received condition, then again after 3, 6, 9, and 12 months of water exposure, record any loss in mass, examine for any pitting corrosion, and estimate the corrosion rate.

The samples were evaluated by the following laboratory procedures:

1) Visual examination and weighing
2) Cleaning per ASTM G1[1]
3) Scanning electron microscopy
4) Metallography

The results of the evaluation showed minimal mass loss and corrosion for the coupon and screen after 3 months of corrosion testing. Both the coupon and screen had a corrosion rate less than 0.0005 millimeters per year.

[1] G1: Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

2.0 EVALUATION[2]

2.1 Visual Examination

The sample identifications for the coupons and wedge wire screens and their corresponding immersion times are shown in Table 1. The coupons had identification numbers stamped on the front face by V&A Engineering. A number of notches, corresponding to the sample number, were sawed at the edge of each screen for identification after the corrosion test. The weights of the samples were recorded. Coupons 6 – 9 and screens 1 – 5 were sent back to V&A for corrosion testing. Coupon 10 was the baseline sample and documented by photography, optical stereoscopy and scanning electron microscopy for comparison to the tested samples. Screen 5 was documented as a baseline by photography and optical stereoscopy, and then sent to V&A for testing.

Photographs of the baseline coupon are shown in Figure 1. Photographs of coupon 1, after 3 months of corrosion testing, are shown in Figure 2. A photograph of the baseline screen is shown in Figure 3. A photograph of screen 1, after 3 months of corrosion testing, is shown in Figure 4.

2.2 Cleaning

The coupon and screen were cleaned with solution C.7.1 per ASTM G1.[3] Prior to the actual cleaning cycles, the marine life was removed by repeatedly immersing the samples in solution C.7.1, then prying off the marine life with a chisel. One cleaning cycle was approximately 5 minutes. After each cleaning cycle, the samples were rinsed in water, dried, and weighed. The cleaning and weighing cycle was completed five times for the coupon and screen. The weights of the samples as-received, after corrosion testing but before cleaning, and after each cleaning cycle are presented in Table 2.

Optical macrographs of the baseline coupon and screen are shown in Figures 5 and 8, respectively. Representative optical macrographs of the samples before and after cleaning are shown in Figures 6 – 7 and 9 – 10.

The mass loss versus the number of cleaning cycles was plotted, shown in Figure 11. The equations for best fit lines AB and BC, calculated using IGOR Pro, are listed in Table 3. Point B, indicated by the red circle in each plot, corresponds to the mass loss due to corrosion during the cleaning process for each sample. The marine life on the coupons and screen had to be removed before proceeding with the actual cleaning process. It is likely that corrosion products were also removed during this pre-cleaning step, which can account for the relatively low amount of mass loss from corrosion during the cleaning process.

This mass loss was subtracted from the weight of the sample before cleaning and from the weight of the sample as-received to determine the total mass loss from corrosion. The corrosion rate of each sample was determined by the formula specified in Section 8.1 of ASTM G1:

[2] The magnifications of the optical and scanning electron micrographs in this report are approximate and should not be used as a basis for dimensional analyses unless otherwise indicated.
[3] 100 mL nitric acid + 900 ml reagent water.

$$Corrosion\ Rate = \frac{K\ x\ W}{A\ x\ T\ x\ D}$$

where K = 8.76 x 10^4, T = time of exposure in hours, A = area in cm^2, W = mass loss in grams, and D = density in g/cm^3. The total mass loss from corrosion and the calculated corrosion rate of each sample is shown in Table 4.

2.3 Scanning Electron Microscopy

The baseline coupon and coupon 1 were examined with a scanning electron microscope. Representative scanning electron micrographs of the baseline coupon are shown in Figure 12. Representative scanning electron micrographs of coupon 1 after cleaning are shown in Figure 13. Energy dispersive x-ray spectra of the baseline coupon and the coupon after cleaning are shown in Figure 14. The coupon was not analyzed by scanning electron microscopy and energy dispersive x-ray spectroscopy before cleaning due to the amount of biological products on it.

2.4 Metallography

Cross sections were taken from the coupon and prepared for a metallographic examination. Optical micrographs of the surface for coupon 6 are shown in Figure 15. Small, narrow pits were observed in coupon 1, measuring 18 µm deep.

3.0 DISCUSSION

The coupon and screen showed minimal mass loss and pitting after 3 months of corrosion testing. The coupon had lost less than 0.001 grams of material and had a corrosion rate less than 0.0005 millimeters per year. The weight loss is beyond the measurement capabilities of the balance. The screen had lost 0.04 grams of material and had a corrosion rate less than 0.0005 millimeters per year.

4.0 CONCLUSIONS[4]

The following conclusions are based upon the submitted samples and the evidence gathered:

1. The coupon, after 3 months of corrosion testing, had a mass loss less than 0.001 grams and a corrosion rate less than 0.0005 mm / year.

2. The screen, after 3 months of corrosion testing, had a mass loss of 0.04 grams and a corrosion rate less than 0.0005 mm / year.

[4] The conclusions in this report are based upon the available information and evidence provided by the client and gathered by Anamet, within the scope of work authorized by the client, and they are hereby presented by Anamet to a reasonable degree of engineering and scientific certainty. Anamet reserves the right to amend or supplement its conclusions or opinions presented in this report should additional data or information become available, or further work be approved by the client.

Prepared by:	Reviewed by:
Norman Yuen	Audrey A. Fasching, Ph.D., P.E.
Materials Engineer	Senior Materials Engineer

Table 1
Sample Identifications

Description		V&A Engineering Identification (As-Received)	Anamet Identification (in report)	Notes
Alloy	Part			
2205 Duplex Stainless Steel	**Flat Plate** 4-inch x 4-inch x 1/8-inch	2205 2	Plate	None
	Coupon 1-inch x 3-inch x 1/8-inch with autogenous weld bead	2205W 6	Coupon 6	3 Month Immersion
		2205W 7	Coupon 7	6 Month Immersion
		2205W 8	Coupon 8	9 Month Immersion
		2205W 9	Coupon 9	12 Month Immersion
		2205W 10	Coupon 10	Baseline Sample (no exposure)
	Wedge Wire Screen 4-inch x 4-inch x 1-inch with 2 mm spacing	None	Screen 1	3 Month Immersion
		None	Screen 2	6 Month Immersion
		None	Screen 3	9 Month Immersion
		None	Screen 4	12 Month Immersion
		None	Screen 5	12 Month Immersion

Table 2
Sample Weights

Sample	Baseline Measurement	Measurements after 3 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 6	22.1525	22.1531	22.1529	22.1527	22.1515	22.1514	22.1513
Screen 1	311.70	311.78	311.66	311.66	311.66	311.67	311.67

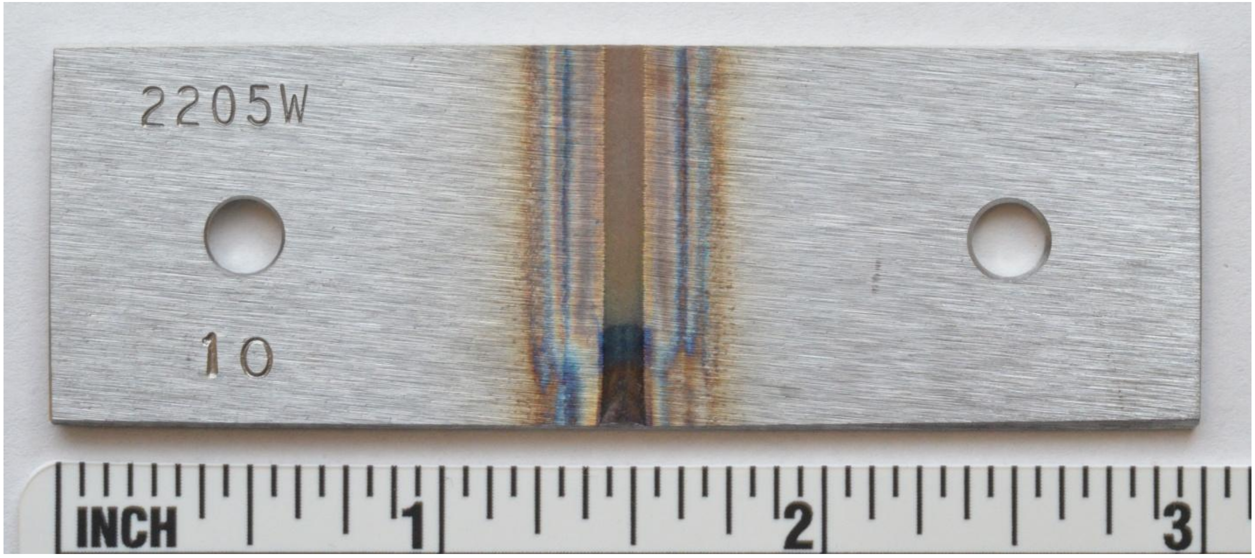
Table 3
Equations of Lines AB and BC for Corrosion Testing Samples

Sample	Line AB	Line BC	Point B (Approximate Mass Loss from Corrosion During Cleaning)
Coupon 6	y = 0.0004x	N/A	0 grams
Screen 1	y = 0.12x	y = 0.120	0.12 grams

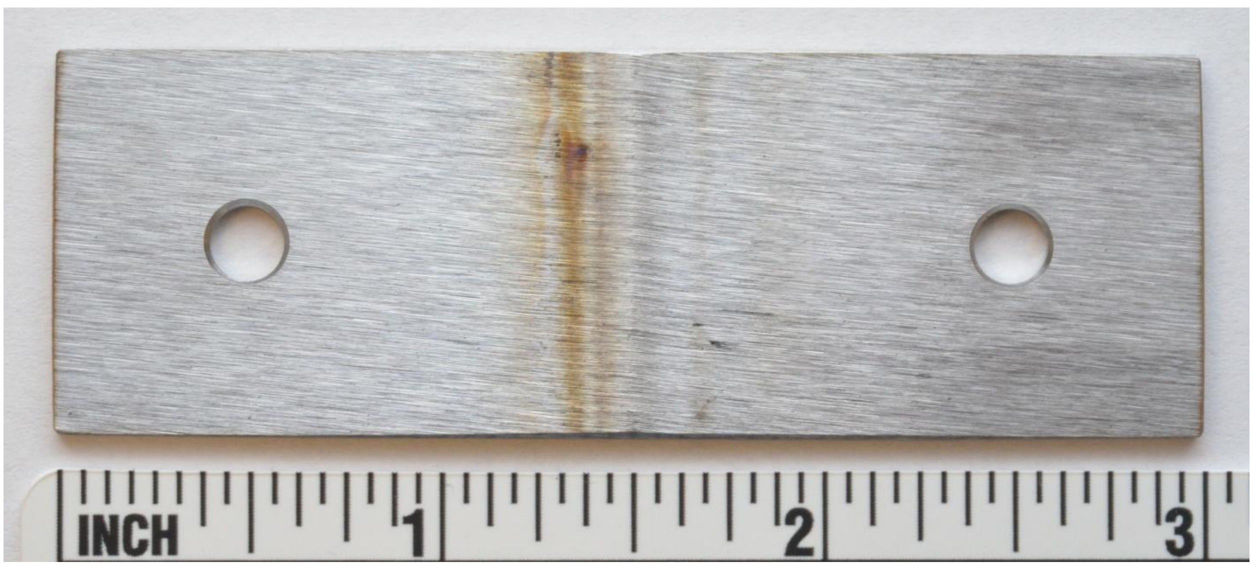
Table 4
Total Mass Loss from Corrosion and Corrosion Rate

Sample	Total Mass Loss from Corrosion*	Corrosion Rate
Coupon 6	< 0.001 grams	< 0.0005 mm / year
Screen 1	0.04 grams	< 0.0005 mm / year

* Weight As-Received – (Weight Before Cleaning – Mass Loss from Corrosion During Cleaning)



(a) Duplex 2205 Stainless Steel Baseline Coupon, Front Side



(b) Duplex 2205 Stainless Steel Baseline Coupon, Back Side

Figure 1 Photographs of the duplex 2205 stainless steel baseline coupon (a) front and (b) back side.

(a) Duplex 2205 Stainless Steel Coupon 6, Front Side

(b) Duplex 2205 Stainless Steel Coupon 6, Back Side

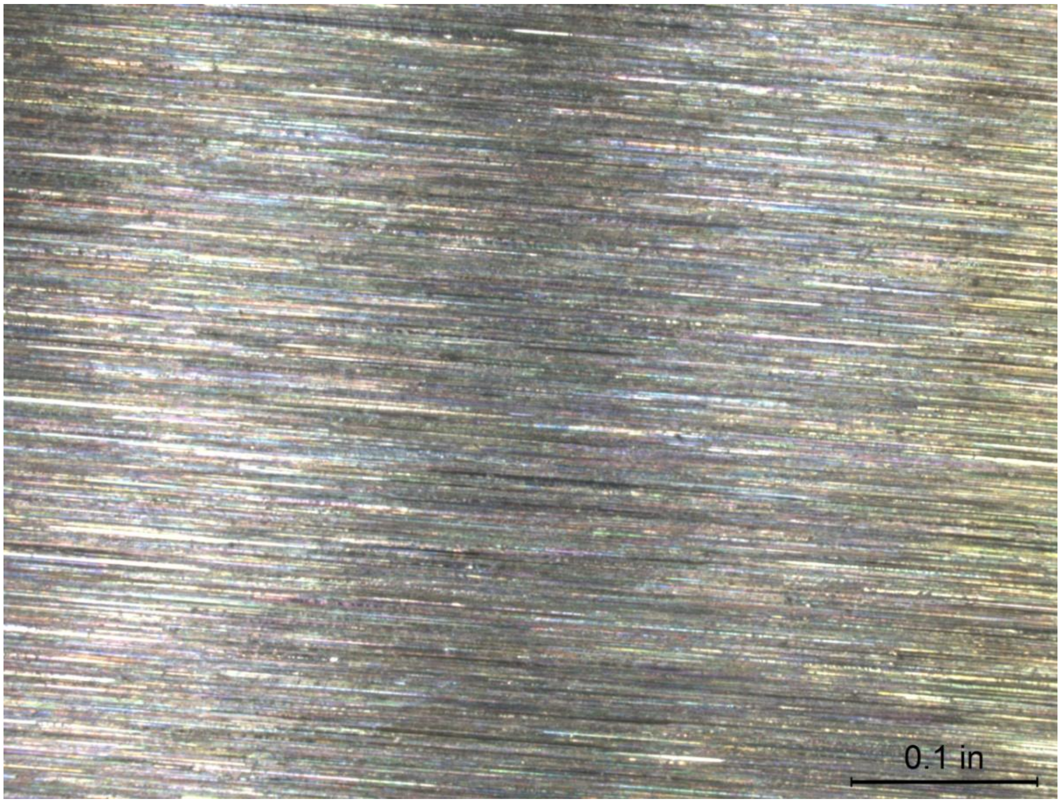
Figure 2 Photographs of duplex 2205 stainless steel coupon 6 (a) front and (b) back side after a 3 month corrosion test.

(a) Duplex 2205 Stainless Steel Baseline Screen

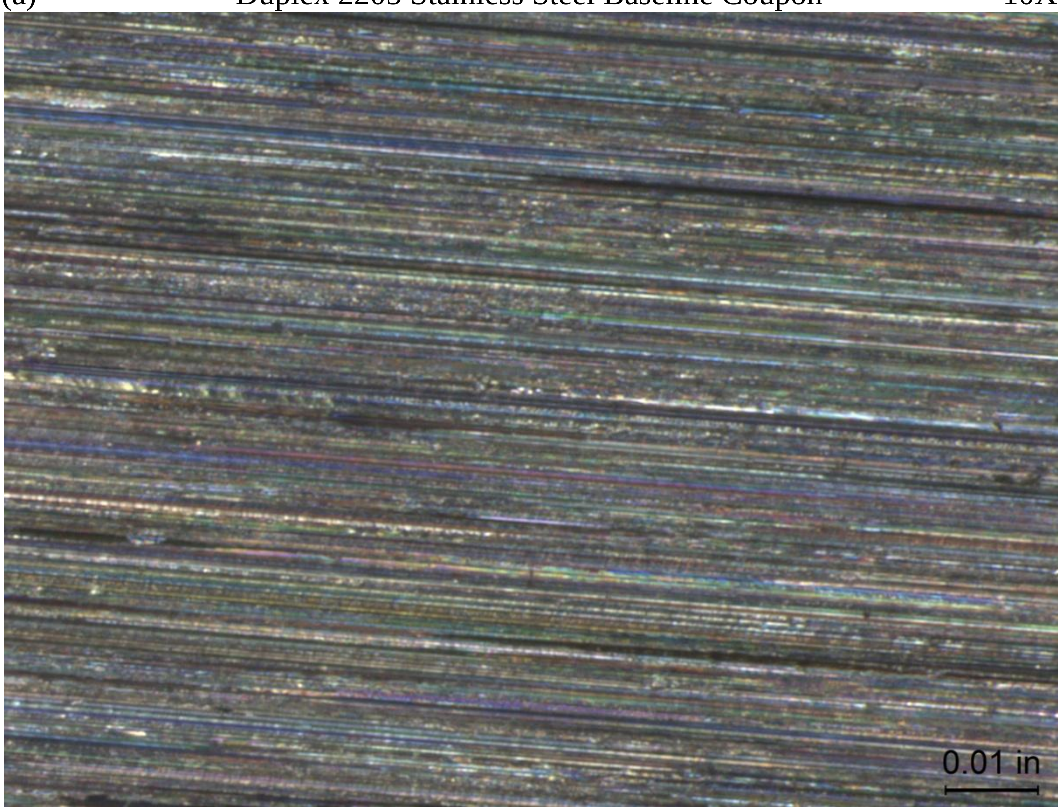
Figure 3 Photograph of the duplex 2205 stainless steel baseline screen.

(a) Duplex 2205 Stainless Steel Screen 1

Figure 4 Photograph of duplex 2205 stainless steel screen 1 after a 3 month corrosion test.



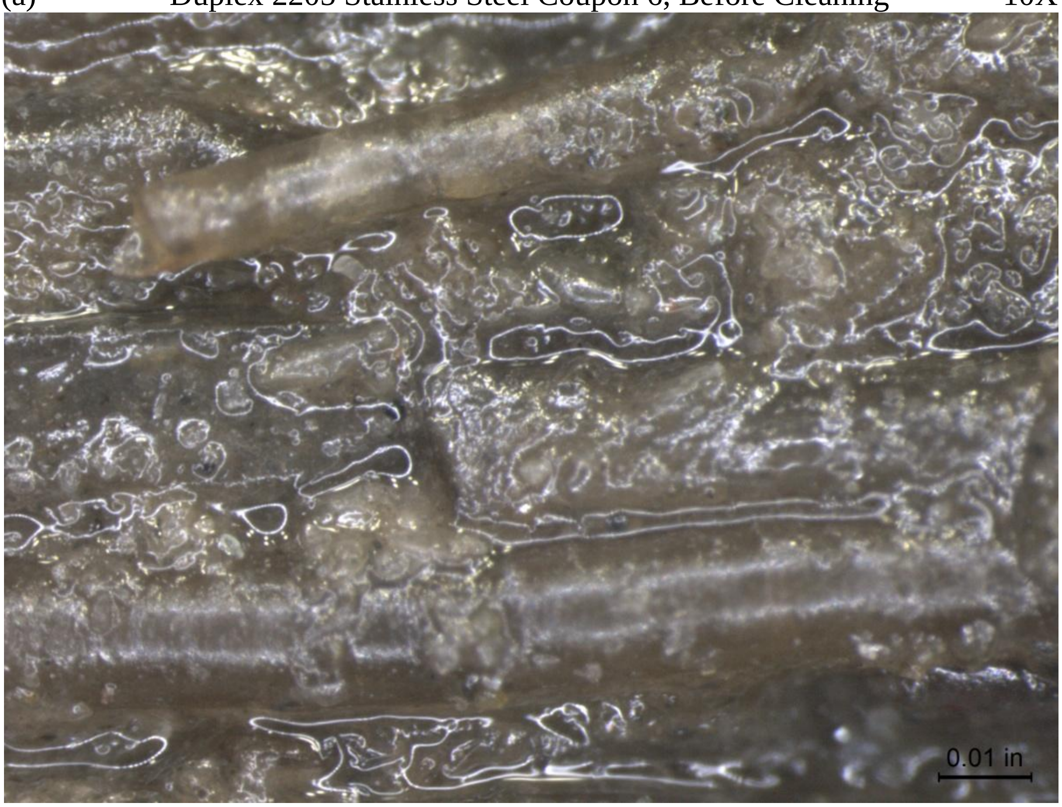
(a) Duplex 2205 Stainless Steel Baseline Coupon 10X



(b) Duplex 2205 Stainless Steel Baseline Coupon 50X

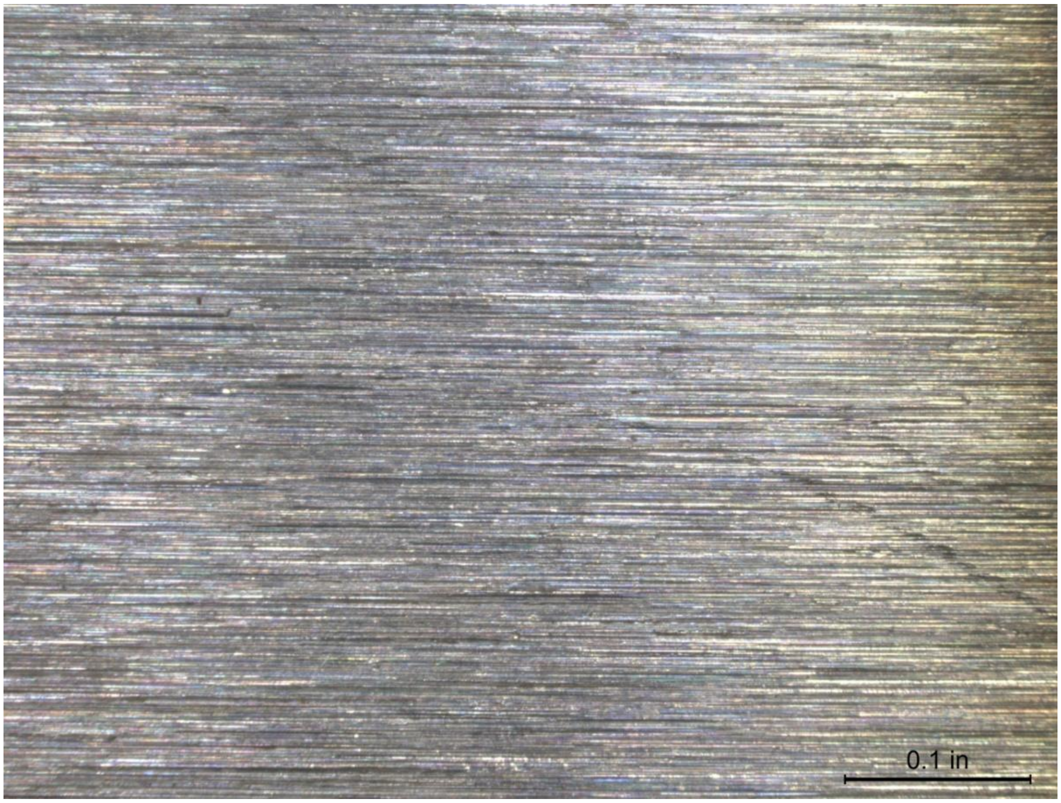
Figure 5 Optical macrographs of the duplex 2205 stainless steel baseline coupon.

(a) Duplex 2205 Stainless Steel Coupon 6, Before Cleaning 10X

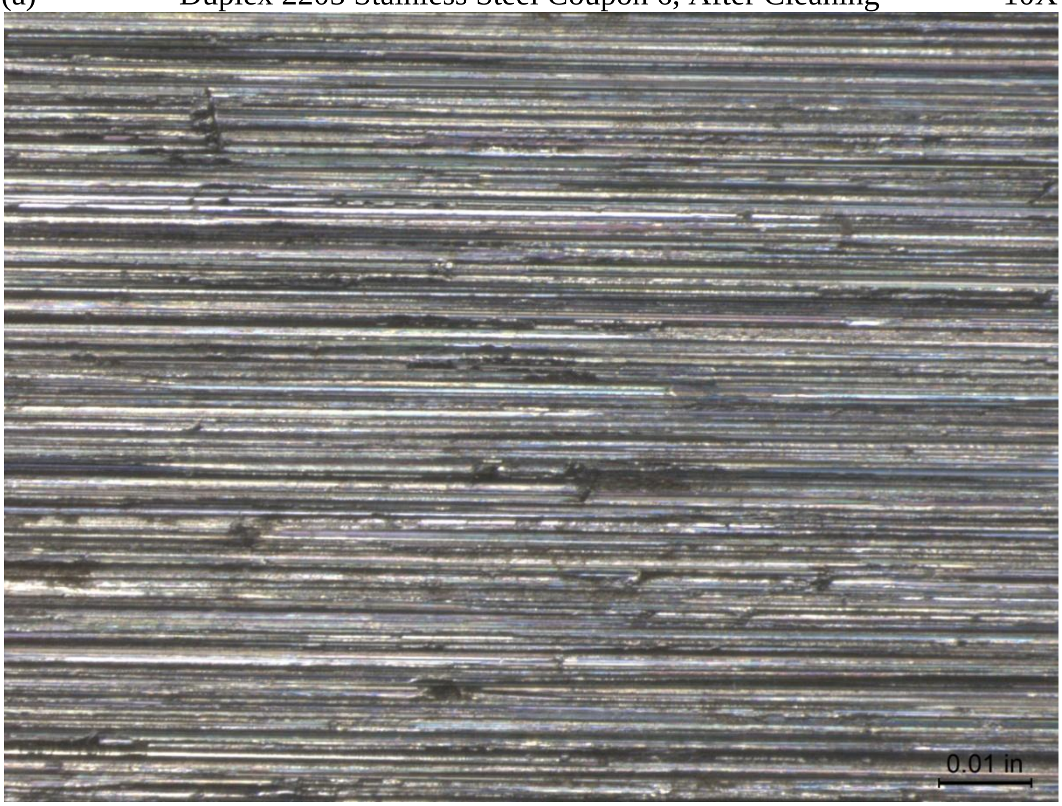


(b) Duplex 2205 Stainless Steel Coupon 6, Before Cleaning 50X

Figure 6 Optical macrographs of duplex 2205 stainless steel coupon 6 after a 3 month corrosion test, before cleaning.

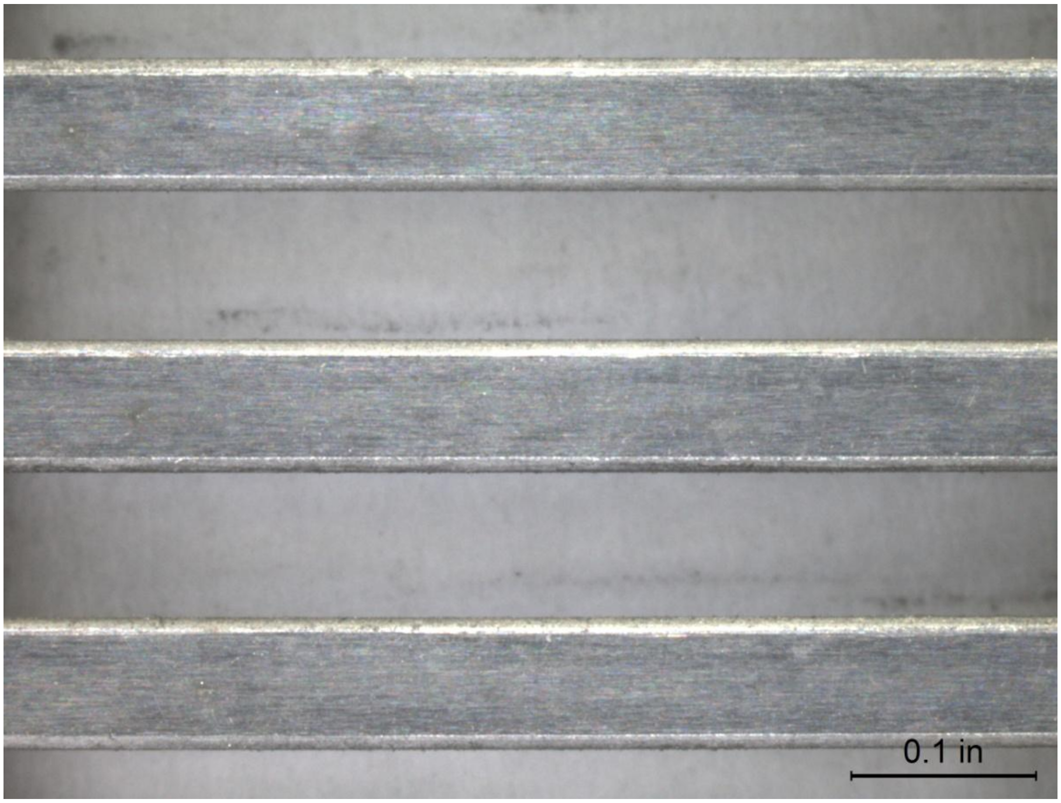


(a) Duplex 2205 Stainless Steel Coupon 6, After Cleaning 10X

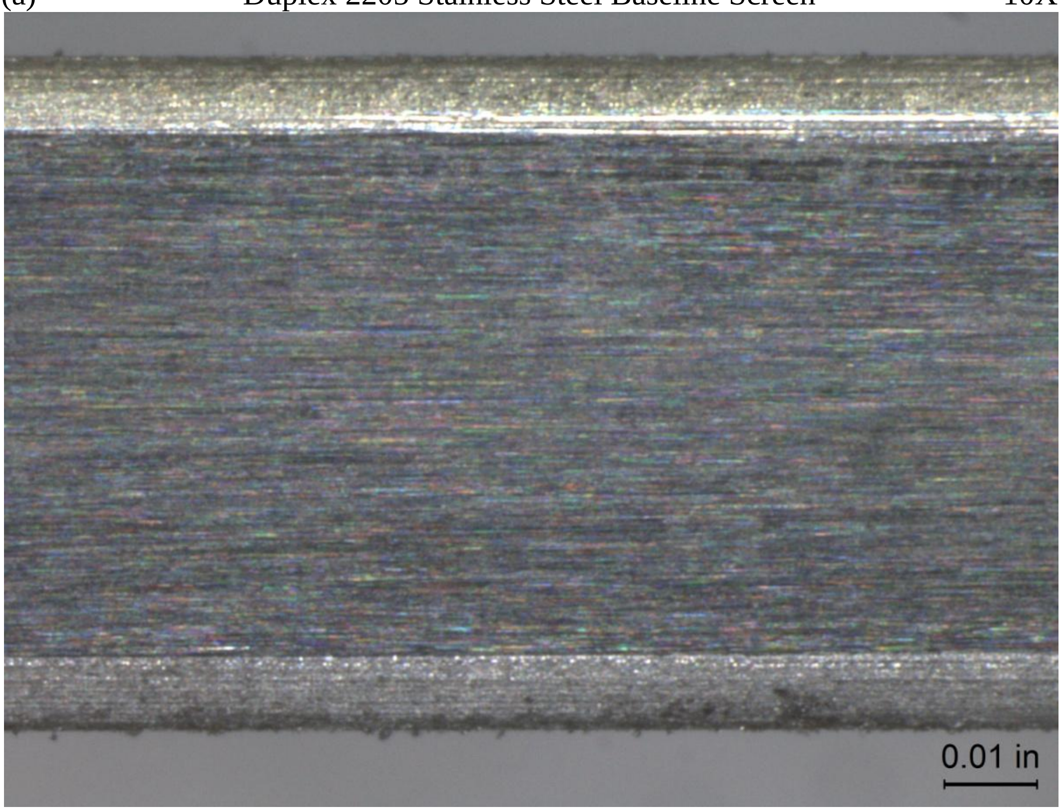


(b) Duplex 2205 Stainless Steel Coupon 6, After Cleaning 50X

Figure 7 Optical macrographs of duplex 2205 stainless steel coupon 6 after a 3 month corrosion test, after cleaning.

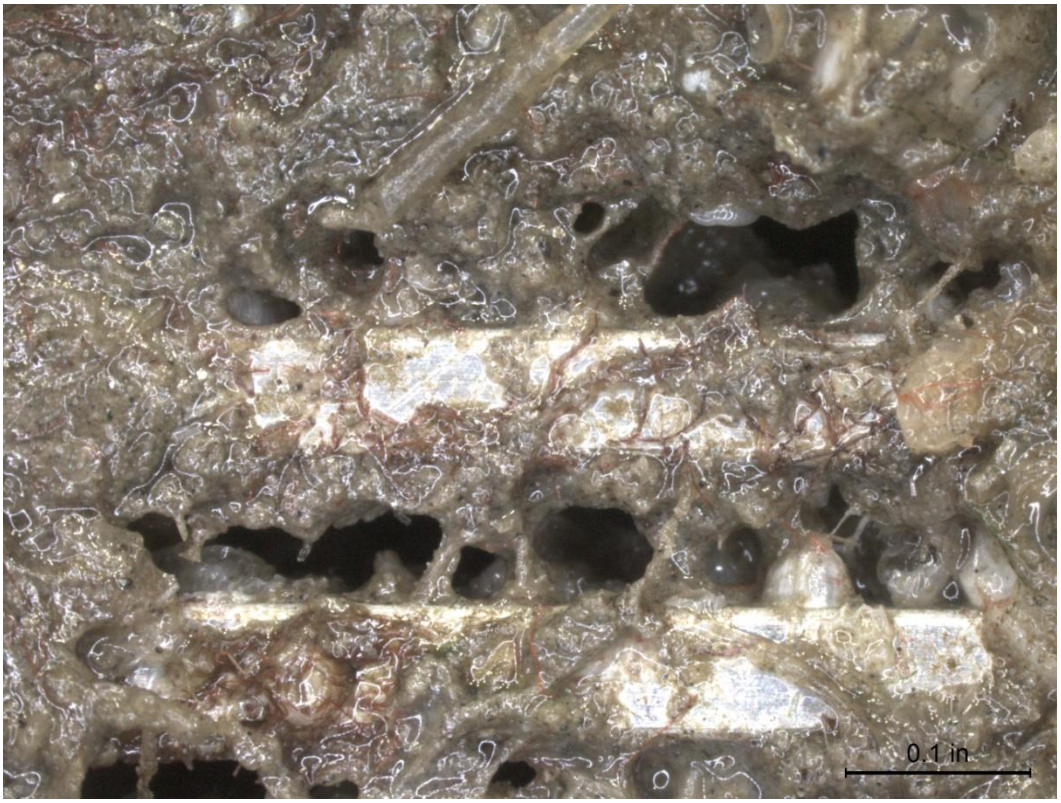


(a) Duplex 2205 Stainless Steel Baseline Screen 10X

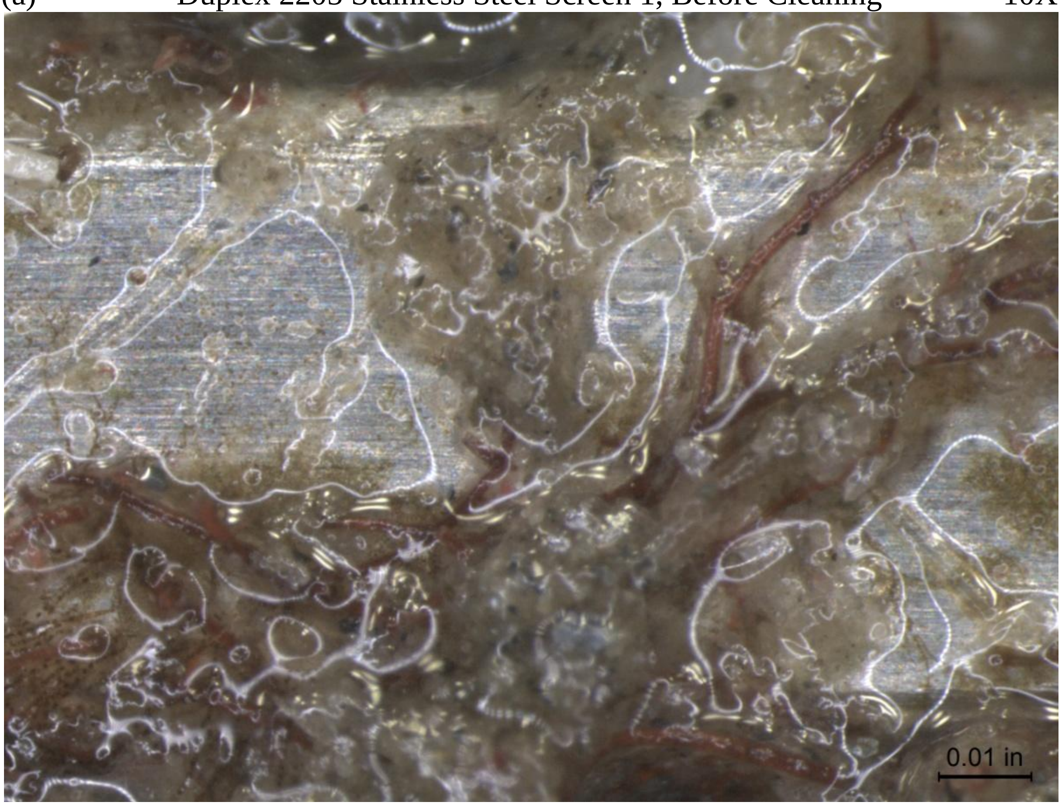


(b) Duplex 2205 Stainless Steel Baseline Screen 50X

Figure 8 Optical macrographs of the duplex 2205 stainless steel baseline screen.

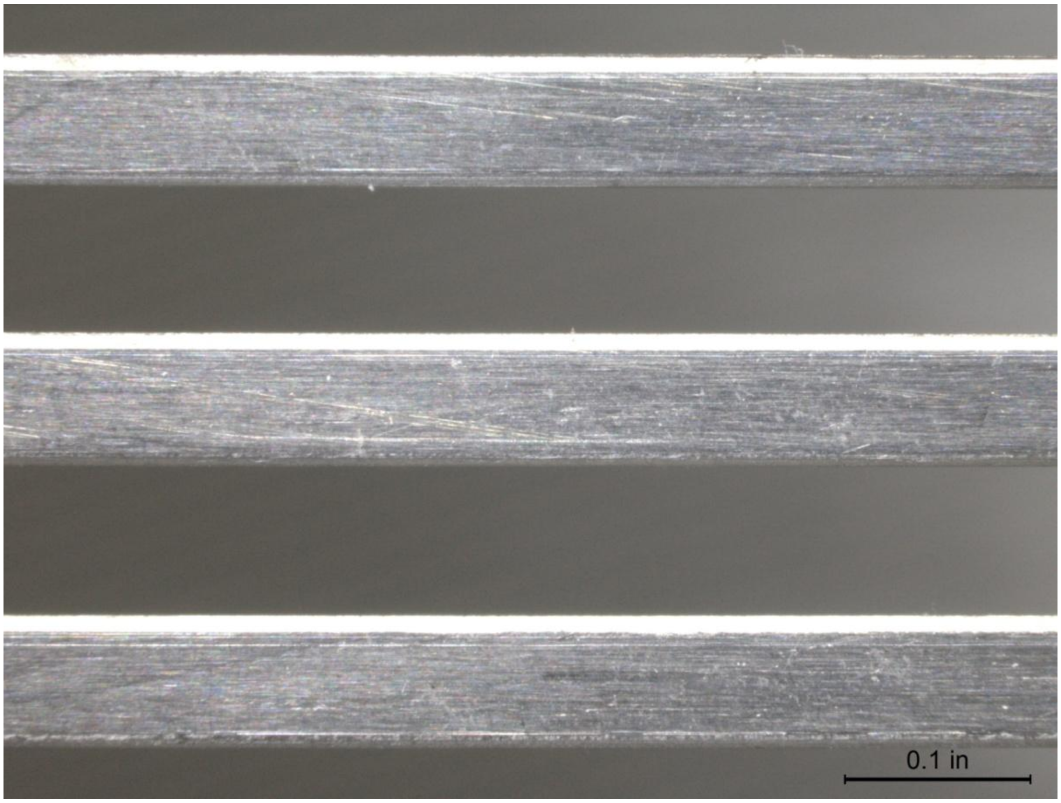


(a) Duplex 2205 Stainless Steel Screen 1, Before Cleaning 10X

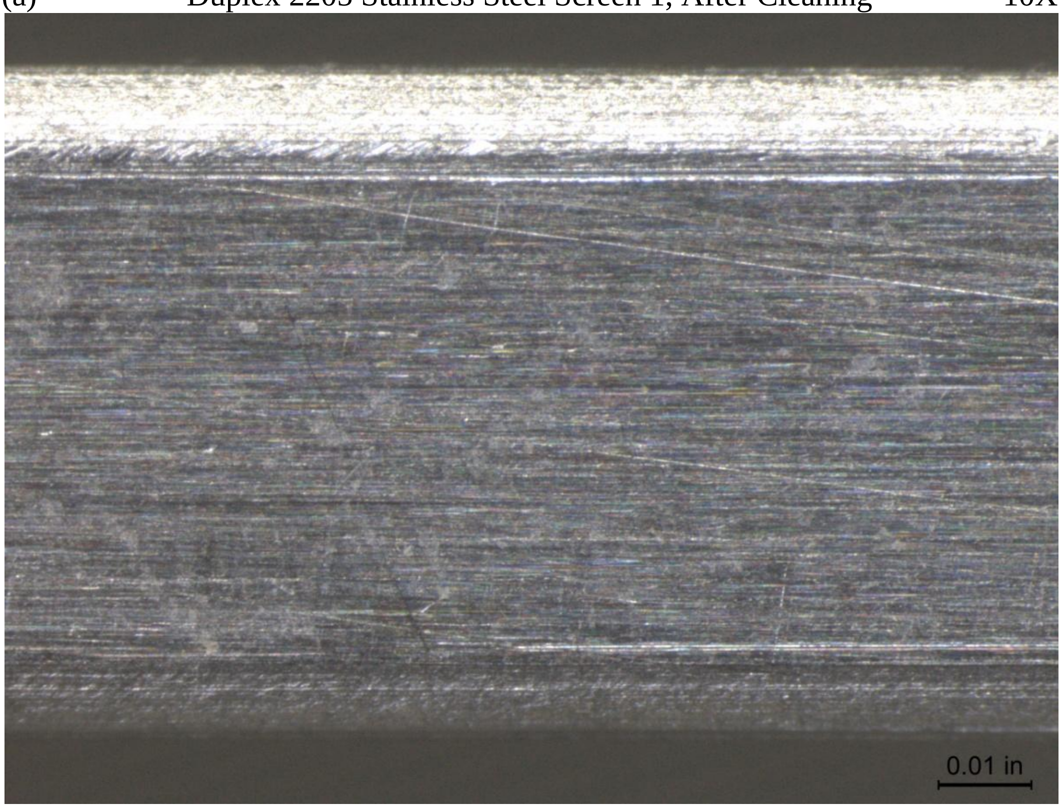


(b) Duplex 2205 Stainless Steel Screen 1, Before Cleaning 50X

Figure 9 Optical macrographs of duplex 2205 stainless steel screen 1 after a 3 month corrosion test, before cleaning.

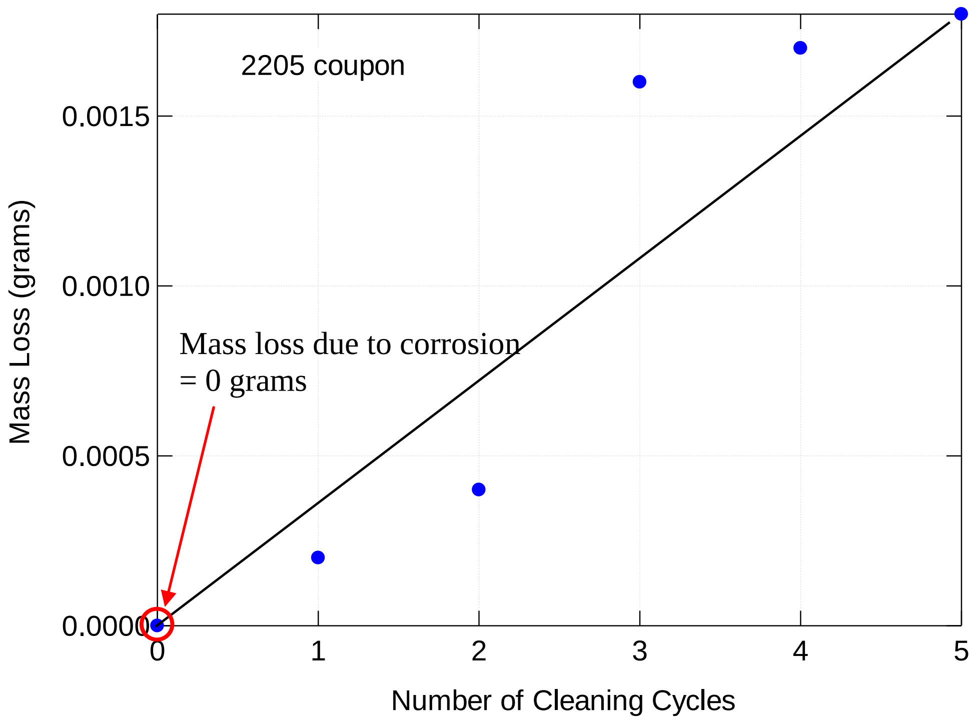


(a) Duplex 2205 Stainless Steel Screen 1, After Cleaning 10X

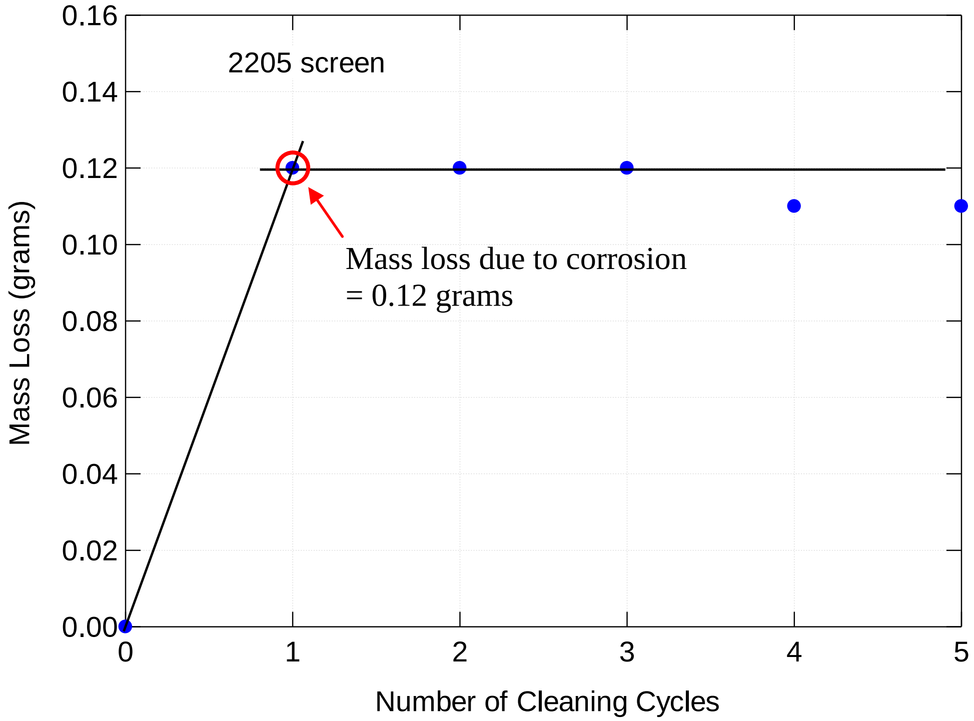


(b) Duplex 2205 Stainless Steel Screen 1, After Cleaning 50X

Figure 10 Optical macrographs of duplex 2205 stainless steel screen 1 after a 3 month corrosion test, after cleaning.

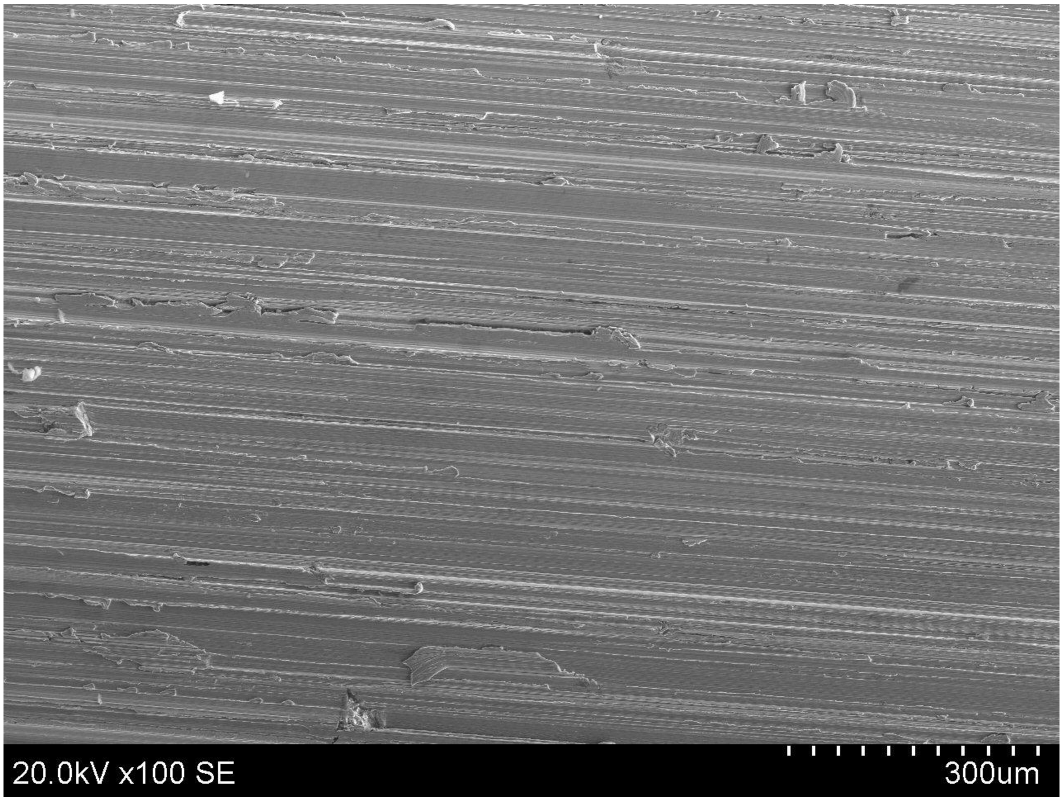


(a)

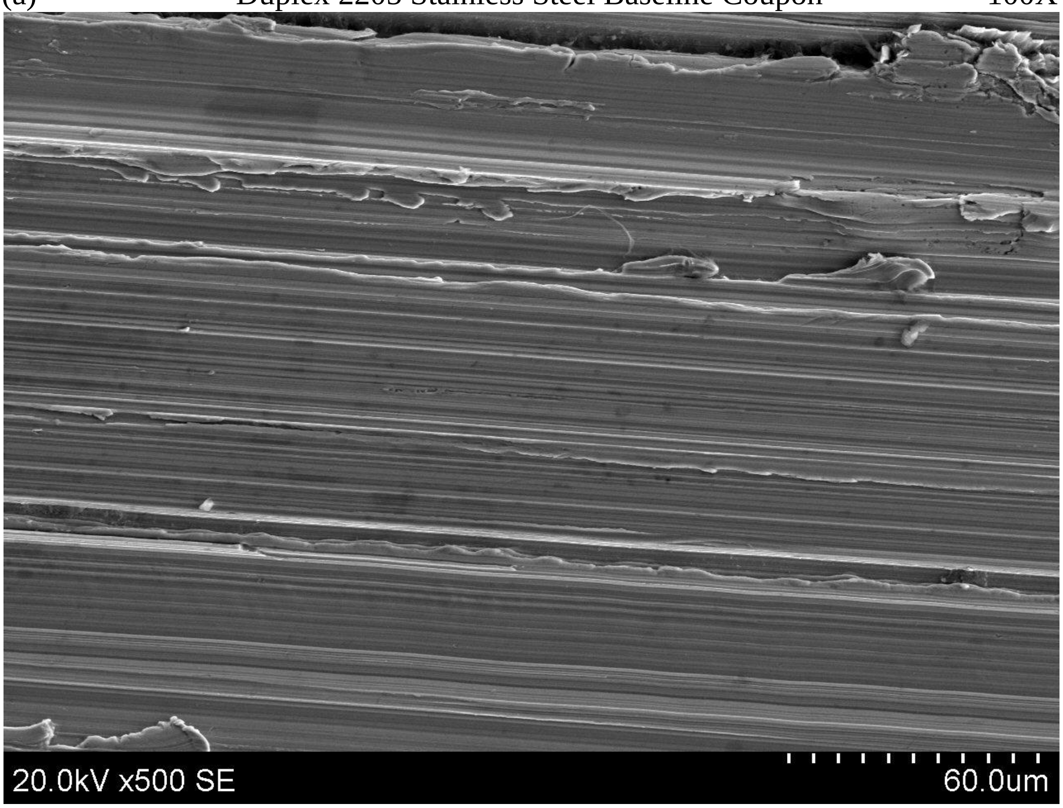


(b)

Figure 11 Mass loss of the duplex 2205 stainless steel (a) coupon 6 and (b) screen 1 during cleaning.

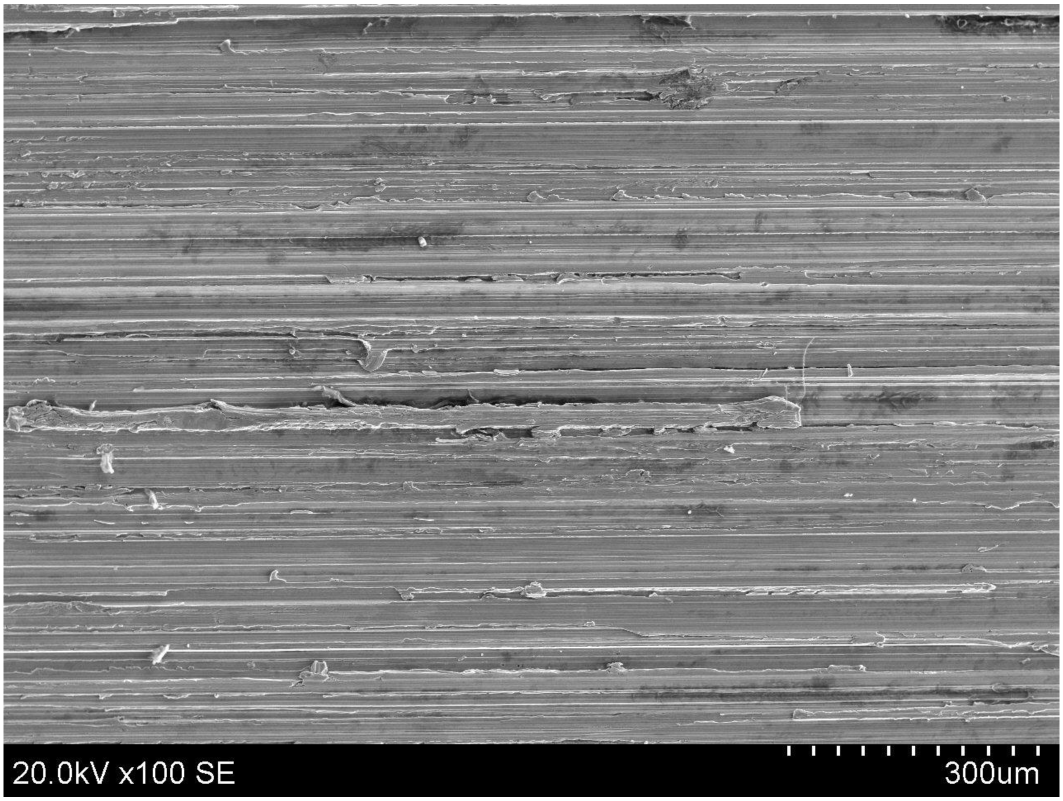


(a) Duplex 2205 Stainless Steel Baseline Coupon 100X

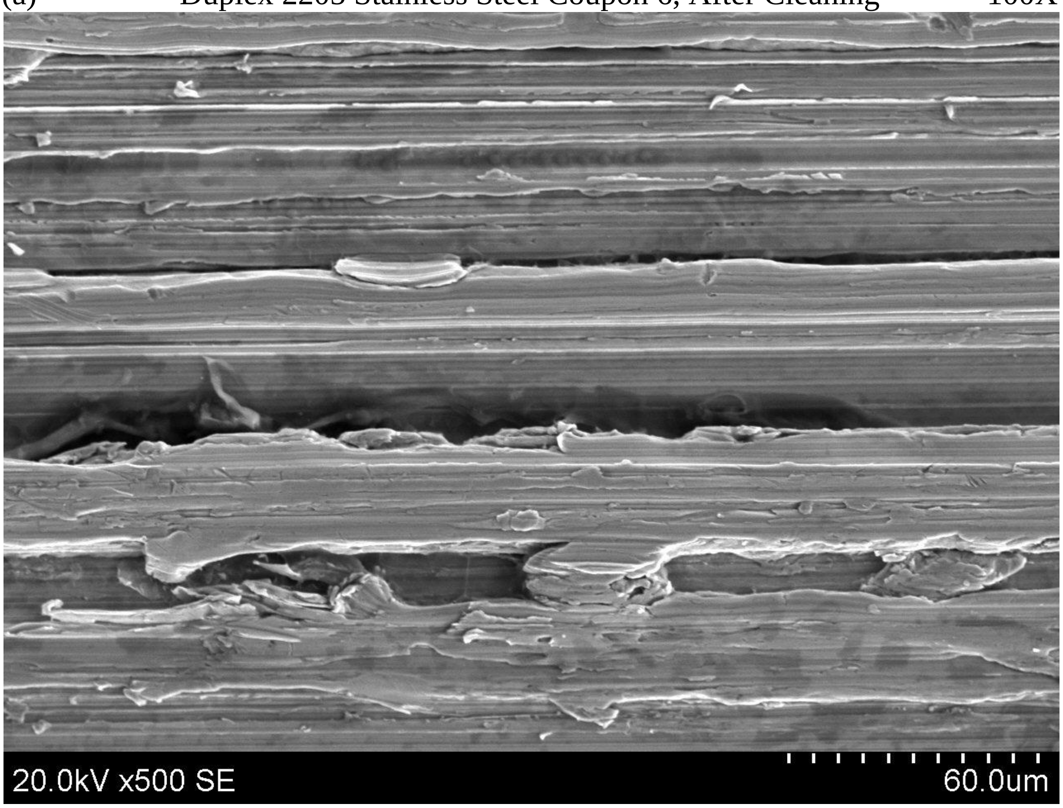


(b) Duplex 2205 Stainless Steel Baseline Coupon 500X

Figure 12 Scanning electron micrographs of the duplex 2205 stainless steel baseline coupon.

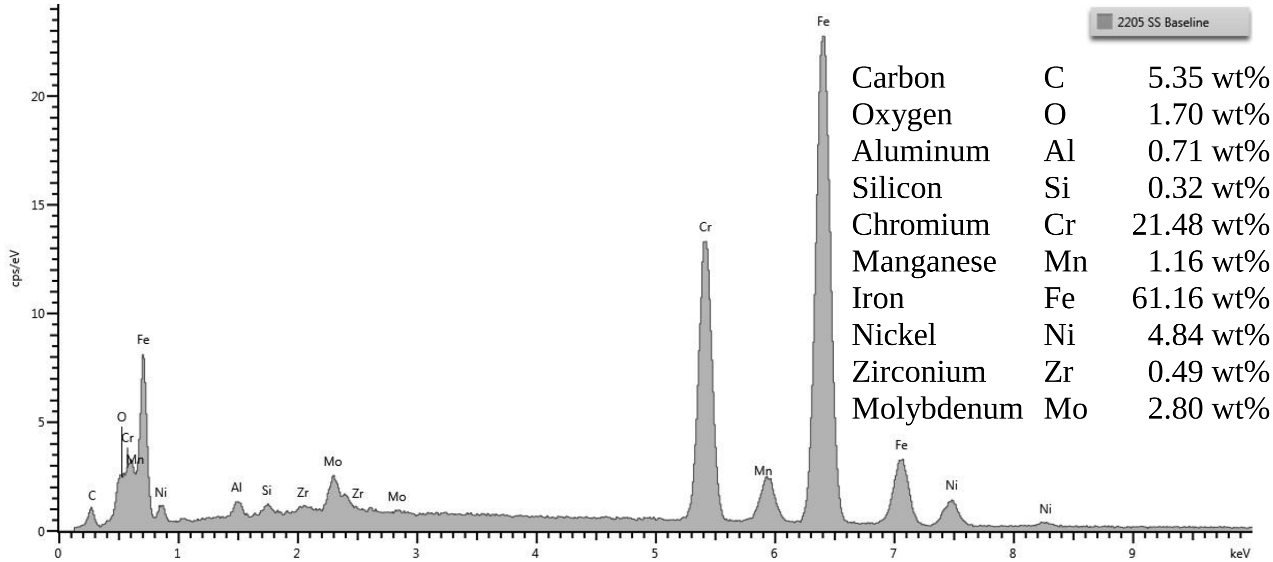


(a) Duplex 2205 Stainless Steel Coupon 6, After Cleaning 100X

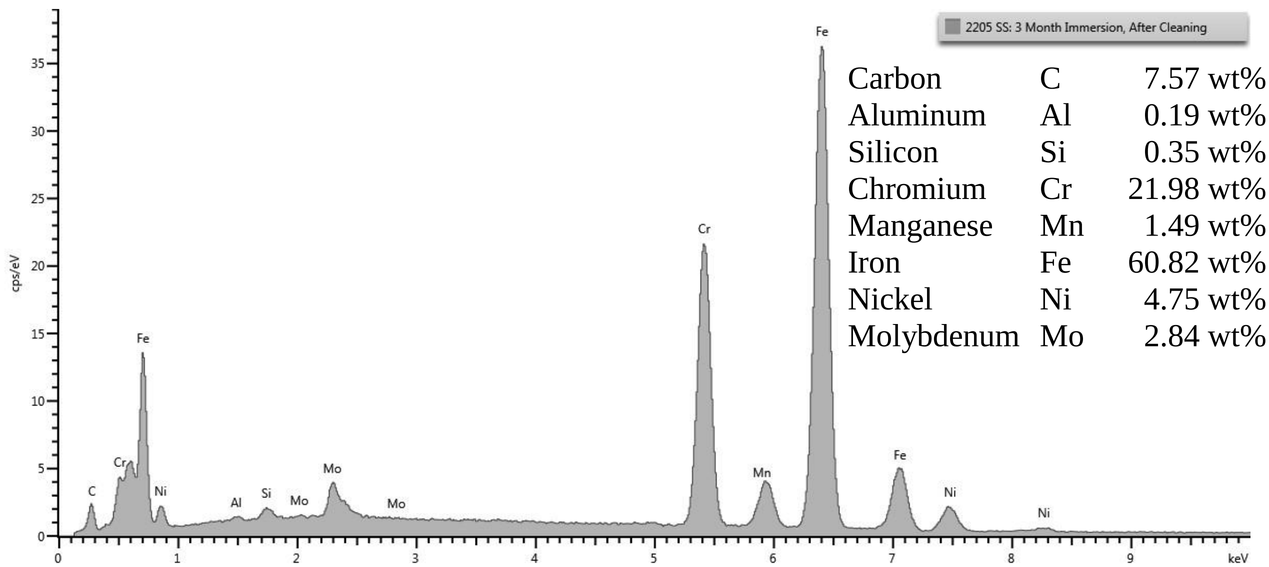


(b) Duplex 2205 Stainless Steel Coupon 6, After Cleaning 500X

Figure 13 Scanning electron micrographs of duplex stainless steel coupon 6 after a 3 month corrosion test, after cleaning.

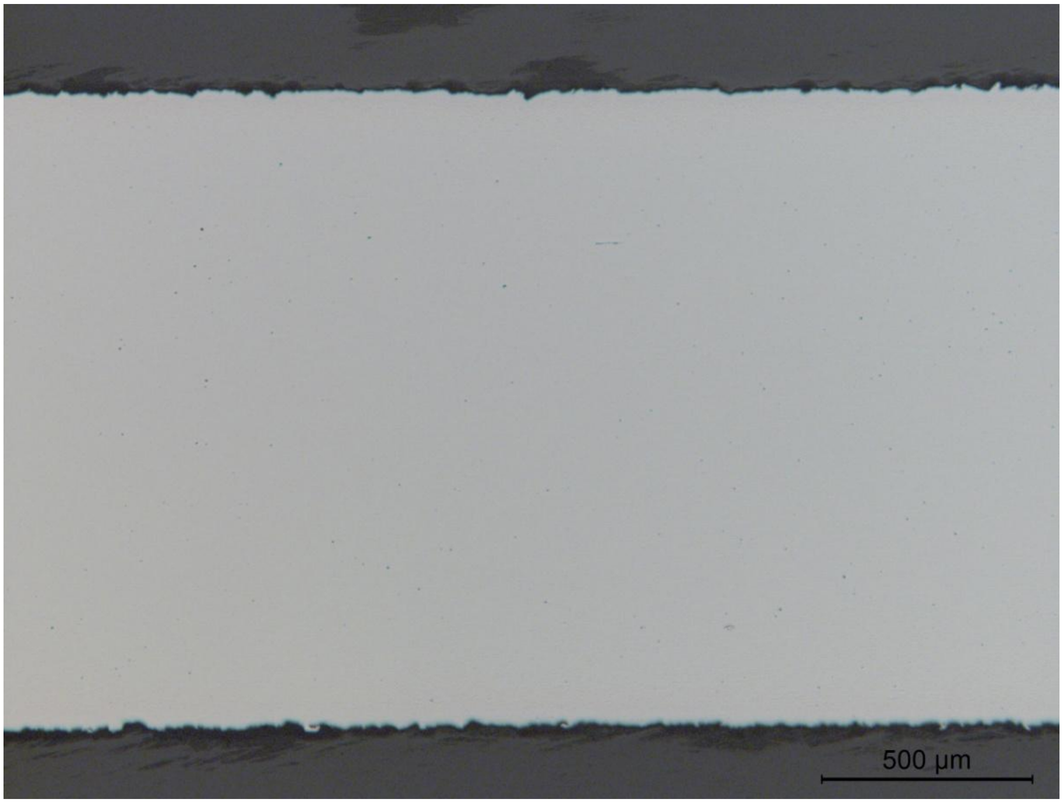


(a) Duplex 2205 Stainless Steel Baseline Coupon



(b) Duplex 2205 Stainless Steel Coupon 6, After Cleaning

Figure 14 Energy dispersive x-ray spectra of (a) the duplex 2205 stainless steel baseline coupon and (b) coupon 6 after a 3 month corrosion test, after cleaning. Coupon 6 before cleaning was not analyzed by energy dispersive x-ray spectroscopy due to the marine life on the surface of the coupon.



(a) Duplex 2205 Stainless Steel Coupon 6 50X

(b) Duplex 2205 Stainless Steel Coupon 6 200X

Figure 15 Optical micrographs of duplex stainless steel coupon 6.

Report No. 5005.0361 **November 7, 2014**

CORROSION EVALUATION OF 2205 DUPLEX STAINLESS STEEL COUPONS AND SCREENS WITH ANTI-BIOFOULING COATING

Customer Authorization: Verbal

Report To: V & A Engineering
Attn: Manuel Najar
155 Grand Avenue, Suite 700
Oakland, CA 94612

1.0 INTRODUCTION

Five coupons, five wedge wire screens, and one plate were submitted by V&A Engineering for corrosion evaluation. The coupons were 1-inch by 3-inches by ¼-inch thick. The wedge wire screens were 4-inches by 4-inches by 1-inch tall with 2 mm spacing. The plate was 4-inches by 4-inches by 1/8-inch thick. The sample was reportedly a 2205 duplex stainless steel alloy with an anti-biofouling coating.

Four coupons and four screens were to be placed in seawater for a period up to one year. After every 3 month interval, one coupon and one screen were to be removed from the test system and examined for corrosion. The purpose of this evaluation was to document the samples in the baseline as-received condition, then again after 3, 6, 9, and 12 months of water exposure, record any loss in mass, examine for any pitting corrosion, and estimate the corrosion rate.

The samples were evaluated by the following laboratory procedures:

1) Visual examination and weighing
2) Cleaning per ASTM G1[1]
3) Scanning electron microscopy
4) Metallography

The results of the evaluation showed minimal mass loss and corrosion for the coupon and screen after 3 months of corrosion testing. Both the coupon and screen had a corrosion rate of approximately 0.002 millimeters per year.

[1] G1: Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

2.0 EVALUATION[2]

2.1 Visual Examination

The sample identifications for the coupons and wedge wire screens and their corresponding immersion times are shown in Table 1. The coupons had identification numbers stamped on the front face by V&A Engineering. A number of notches, corresponding to the sample number, were sawed at the edge of each screen for identification after the corrosion test. The weights of the samples were recorded. Coupons 6 – 9 and screens 1 – 5 were sent back to V&A for corrosion testing. Coupon 10 was the baseline sample and documented by photography, optical stereoscopy and scanning electron microscopy for comparison to the tested samples. Screen 5 was documented as a baseline by photography and optical stereoscopy, and then sent to V&A for testing.

Photographs of the baseline coupon are shown in Figure 1. Photographs of coupon 1, after 3 months of corrosion testing, are shown in Figure 2. A photograph of the baseline screen is shown in Figure 3. A photograph of screen 1, after 3 months of corrosion testing, is shown in Figure 4.

2.2 Cleaning

The coupon and screen were cleaned with solution C.7.1 per ASTM G1.[3] One cleaning cycle was approximately 5 minutes. After each cleaning cycle, the samples were rinsed in water, dried, and weighed. The cleaning and weighing cycle was completed four times for the coupon and screen. The weights of the samples as-received, after corrosion testing but before cleaning, and after each cleaning cycle are presented in Table 2.

Optical macrographs of the baseline coupon and screen are shown in Figures 5 and 8, respectively. Representative optical macrographs of the samples before and after cleaning are shown in Figures 6 – 7 and 9 – 10. The mass loss versus the number of cleaning cycles was plotted, shown in Figure 11. The equations for best fit lines AB and BC, calculated using IGOR Pro, are listed in Table 3. Point B, indicated by the red circle in each plot, corresponds to the mass loss due to corrosion during the cleaning process for each sample. This mass loss was subtracted from the weight of the sample before cleaning and from the weight of the sample as-received to determine the total mass loss from corrosion. The corrosion rate of each sample was determined by the formula specified in Section 8.1 of ASTM G1:

$$Corrosion\ Rate = \frac{K\ x\ W}{A\ x\ T\ x\ D}$$

where K = 8.76×10^4, T = time of exposure in hours, A = area in cm^2, W = mass loss in grams, and D = density in g/cm^3. The total mass loss from corrosion and the calculated corrosion rate of each sample is shown in Table 4.

2.3 Scanning Electron Microscopy

[2] The magnifications of the optical and scanning electron micrographs in this report are approximate and should not be used as a basis for dimensional analyses unless otherwise indicated.
[3] 100 mL nitric acid + 900 ml reagent water.

The baseline coupon and coupon 1 were examined with a scanning electron microscope. Representative scanning electron micrographs of the baseline coupon are shown in Figure 12. Representative scanning electron micrographs of coupon 1 before and after cleaning are shown in Figures 13 – 14. Energy dispersive x-ray spectra of the baseline coupon and coupon before and after cleaning are shown in Figures 15 – 16.

2.4 Metallography

Cross sections were taken from the coupon and prepared for a metallographic examination. Optical micrographs of the surface for coupon 1 are shown in Figure 17. Small, shallow pits were observed in coupon 1, measuring 20 µm in depth.

3.0 DISCUSSION

The coupon and screen showed minimal mass loss and pitting after 3 months of corrosion testing. The coupon had lost 0.023 grams of material and had a corrosion rate of 0.002 millimeters per year. The screen had lost 0.25 grams of material and had a corrosion rate of 0.002 millimeters per year.

4.0 CONCLUSIONS[4]

The following conclusions are based upon the submitted samples and the evidence gathered:

1. The coupon, after 3 months of corrosion testing, had a mass loss of 0.023 grams and a corrosion rate of 0.002 mm / year.

2. The screen, after 3 months of corrosion testing, had a mass loss of 0.25 grams and a corrosion rate of 0.002 mm / year.

Prepared by:	Reviewed by:
Norman Yuen (signature)	*Audrey A. Fasching* (signature)
Norman Yuen Materials Engineer	Audrey A. Fasching, Ph.D., P.E. Senior Materials Engineer

[4] The conclusions in this report are based upon the available information and evidence provided by the client and gathered by Anamet, within the scope of work authorized by the client, and they are hereby presented by Anamet to a reasonable degree of engineering and scientific certainty. Anamet reserves the right to amend or supplement its conclusions or opinions presented in this report should additional data or information become available, or further work be approved by the client.

Table 1
Sample Identifications

Description		V&A Engineering Identification (As-Received)	Anamet Identification (in report)	Notes
Alloy	Part			
2205 Duplex Stainless Steel with anti-biofouling coating	**Flat Plate** 4-inch x 4-inch x 1/8-inch	None	Plate	None
	Coupon 1-inch x 3-inch x 1/8-inch with autogenous weld bead	2205 SS 1	Coupon 1*	3 Month Immersion
		2205 SS 2	Coupon 2*	6 Month Immersion
		2205 SS 3	Coupon 3*	9 Month Immersion
		2205 SS 4	Coupon 4*	12 Month Immersion
		2205 SS 5	Coupon 5	Baseline Sample (no exposure)
	Wedge Wire Screen 4-inch x 4-inch x 1-inch with 2 mm spacing	None	Screen 1*	3 Month Immersion
		None	Screen 2*	6 Month Immersion
		None	Screen 3*	9 Month Immersion
		None	Screen 4*	12 Month Immersion
		None	Screen 5*	12 Month Immersion

* Cable ties were attached to each sample to designate sample identification. The number of cable ties per sample corresponded to the sample number.

Table 2
Sample Weights

Sample	Baseline Measurement	Measurements after 3 Months Corrosion Testing				
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)
Coupon 1	24.1892	24.1683	24.1668	24.1666	24.1665	-
Screen 1	339.91	340.03	339.70	339.66	339.63	339.63

Table 3
Equations of Lines AB and BC for Corrosion Testing Samples

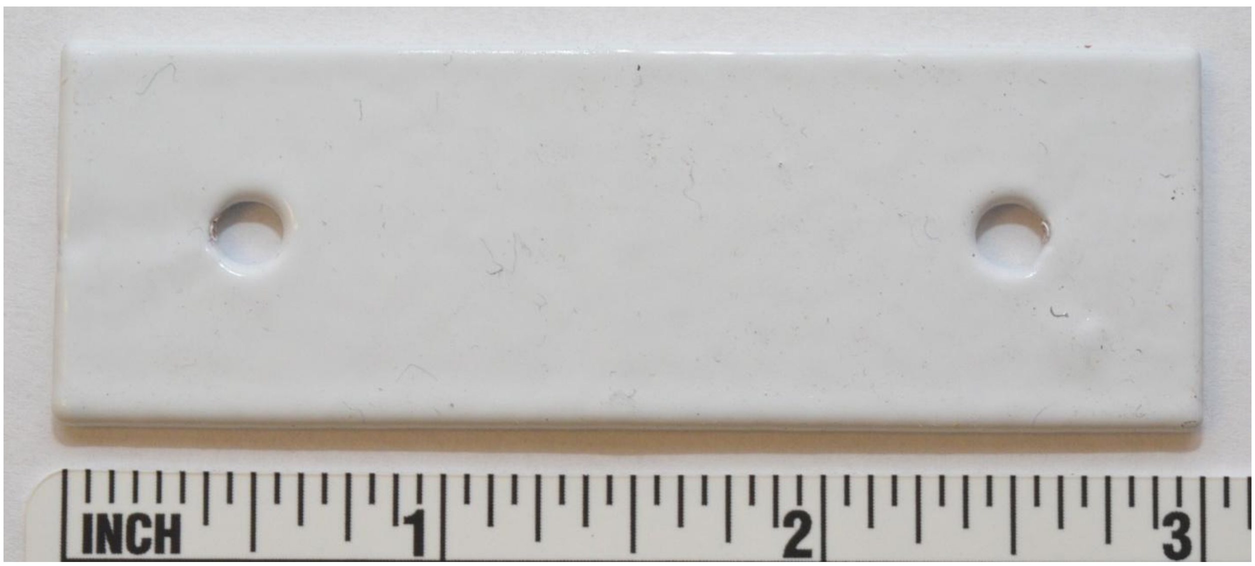
Sample	Line AB	Line BC	Point B (Approximate Mass Loss from Corrosion During Cleaning)
Coupon 1	y = 0.0015x	y = 0.0001x + 0.0015	0.0016 grams
Screen 1	y = 0.33x	y = 0.02x + 0.35	0.37 grams

Table 4
Total Mass Loss from Corrosion and Corrosion Rate

Sample	Total Mass Loss from Corrosion*	Corrosion Rate
Coupon 1	0.023 grams	0.002 mm / year
Screen 1	0.25 grams	0.002 mm / year

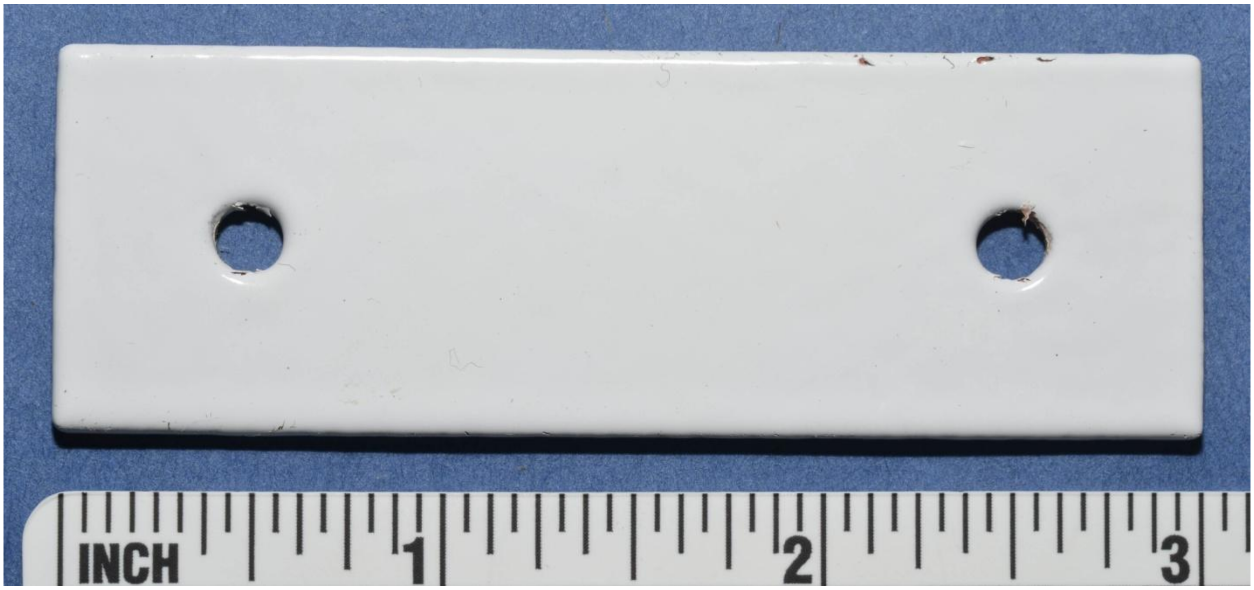
* Weight As-Received – (Weight Before Cleaning – Mass Loss from Corrosion During Cleaning)

(a) Coated Duplex 2205 Stainless Steel Baseline Coupon, Front Side

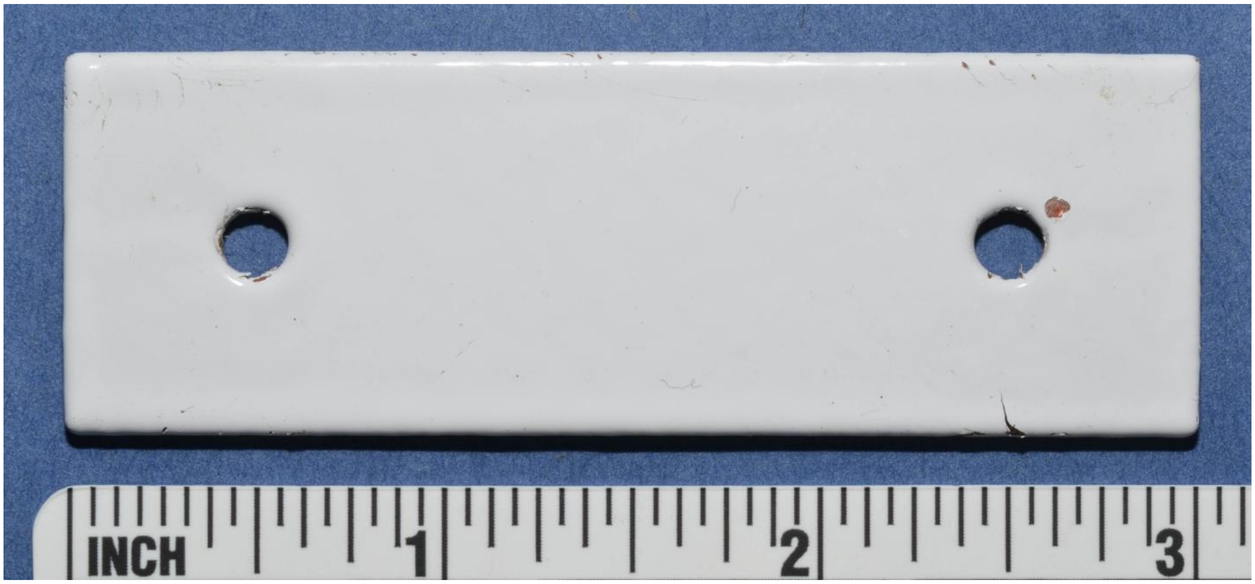


(b) Coated Duplex 2205 Stainless Steel Baseline Coupon, Back Side

Figure 1 Photographs of the duplex 2205 stainless steel with anti-biofouling coating baseline coupon (a) front and (b) back side.



(a) Coated Duplex 2205 Stainless Steel Coupon 1, Front Side



(b) Coated Duplex 2205 Stainless Steel Coupon 1, Back Side

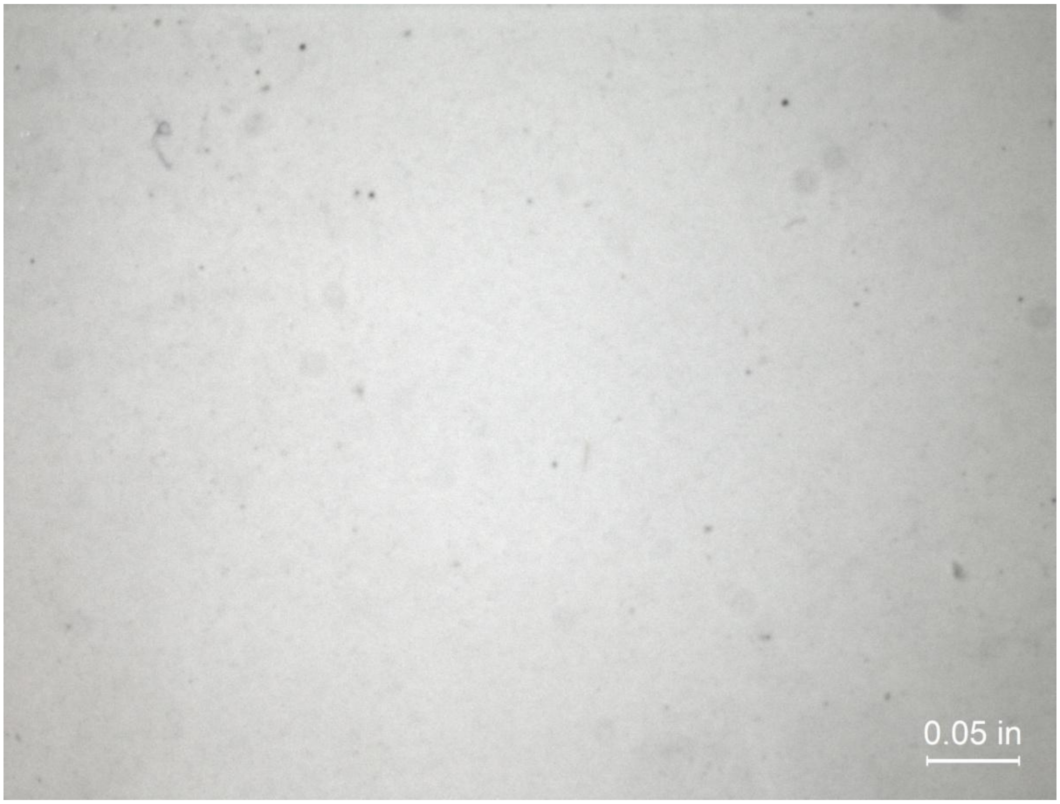
Figure 2 Photographs of duplex 2205 stainless steel with anti-biofouling coating coupon 1 (a) front and (b) back side after a 3 month corrosion test.

(a) Coated Duplex 2205 Stainless Steel Baseline Screen

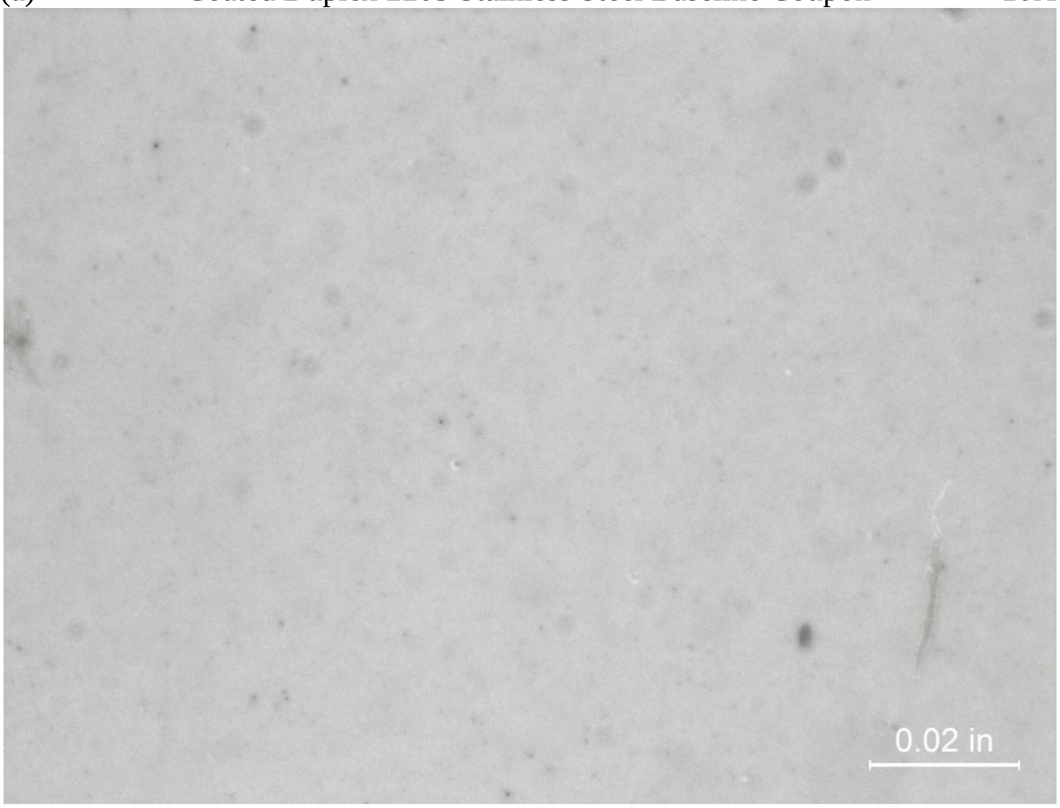
Figure 3 Photograph of the duplex 2205 stainless steel with anti-biofouling coating baseline screen.

(a) Coated Duplex 2205 Stainless Steel Screen 1

Figure 4 Photograph of duplex 2205 stainless steel with anti-biofouling coating screen 1 after a 3 month corrosion test.

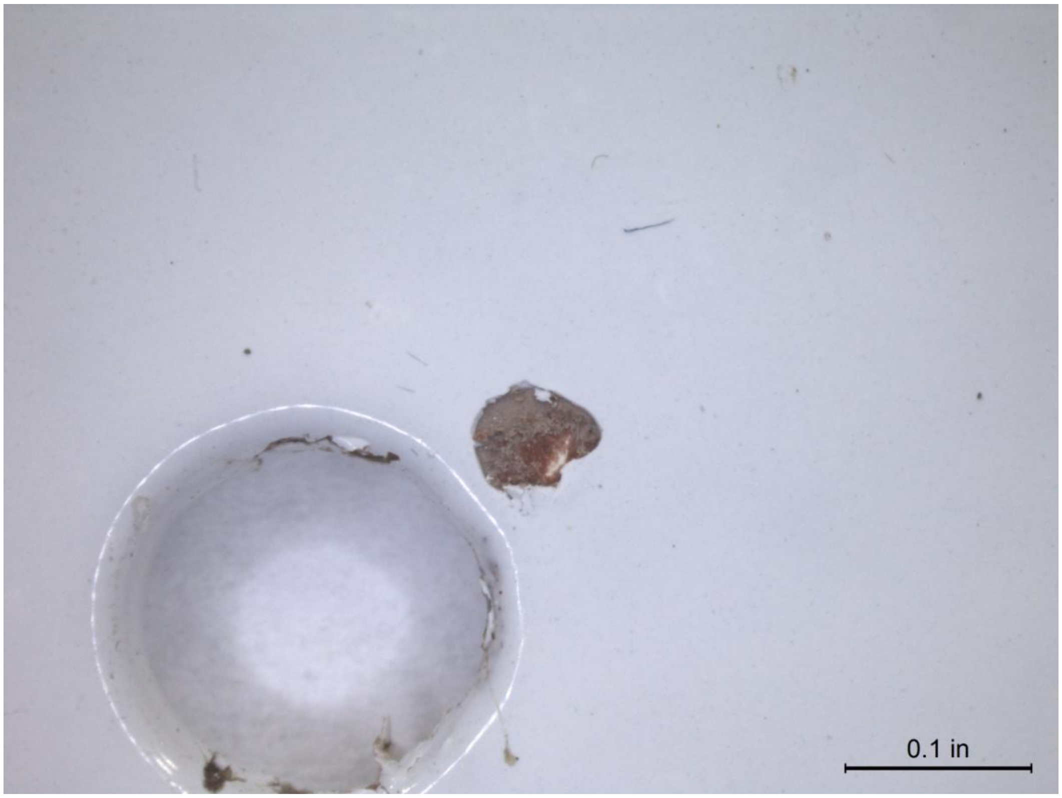


(a) Coated Duplex 2205 Stainless Steel Baseline Coupon 10X

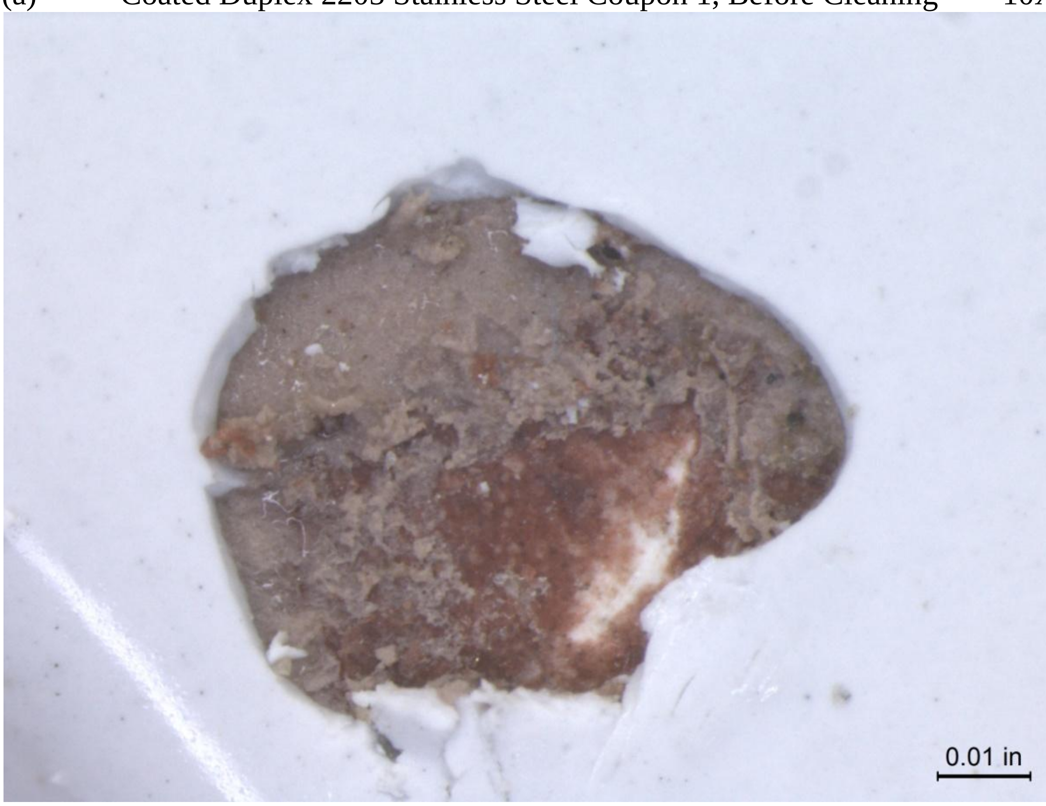


(b) Coated Duplex 2205 Stainless Steel Baseline Coupon 40X

Figure 5 Optical macrographs of the duplex 2205 stainless steel with anti-biofouling coating baseline coupon.

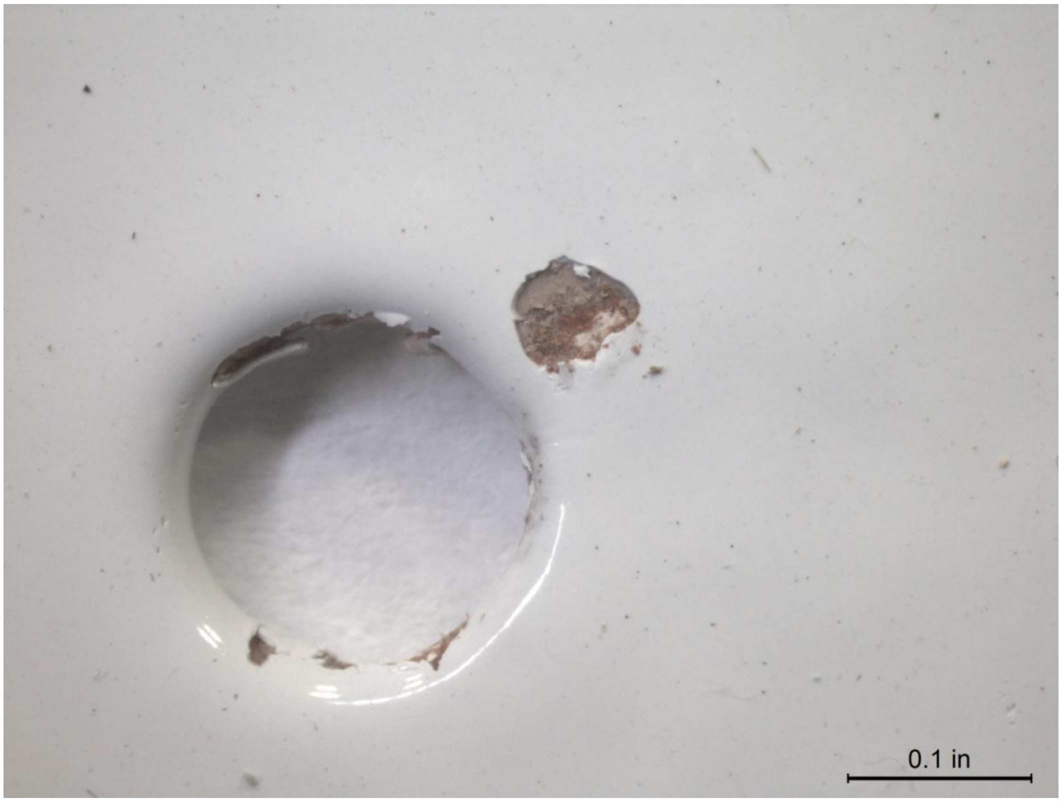


(a) Coated Duplex 2205 Stainless Steel Coupon 1, Before Cleaning 10X

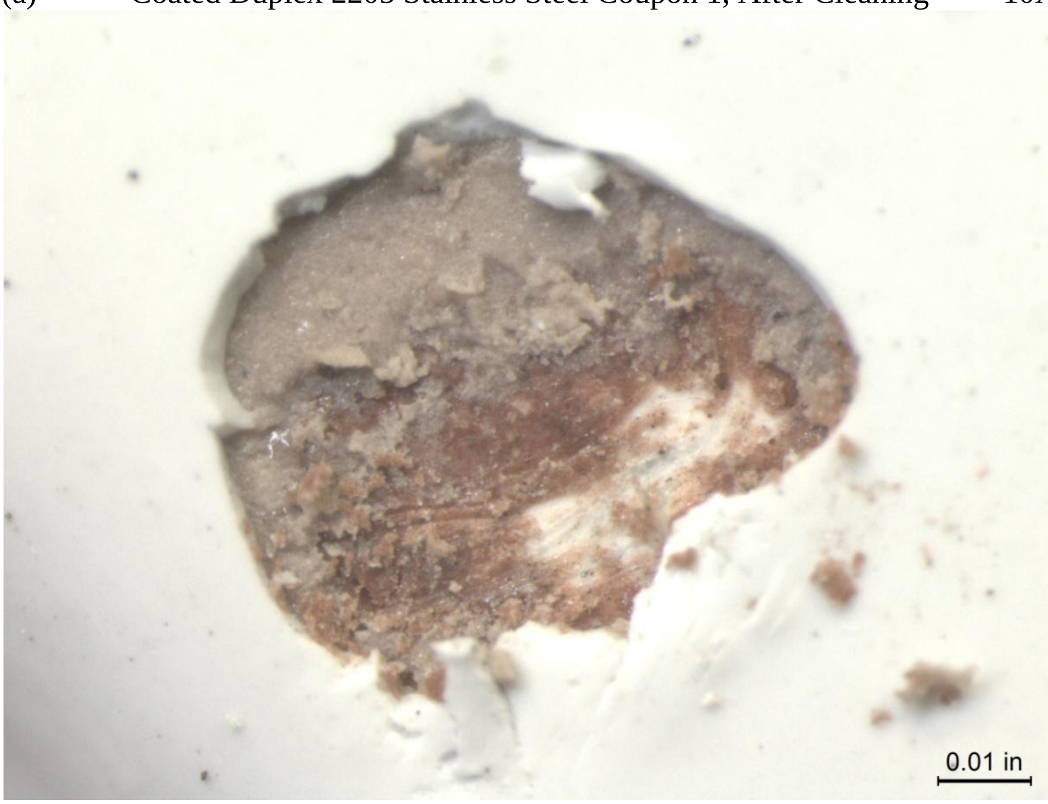


(b) Coated Duplex 2205 Stainless Steel Coupon 1, Before Cleaning 50X

Figure 6 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 1 after a 3 month corrosion test, before cleaning.

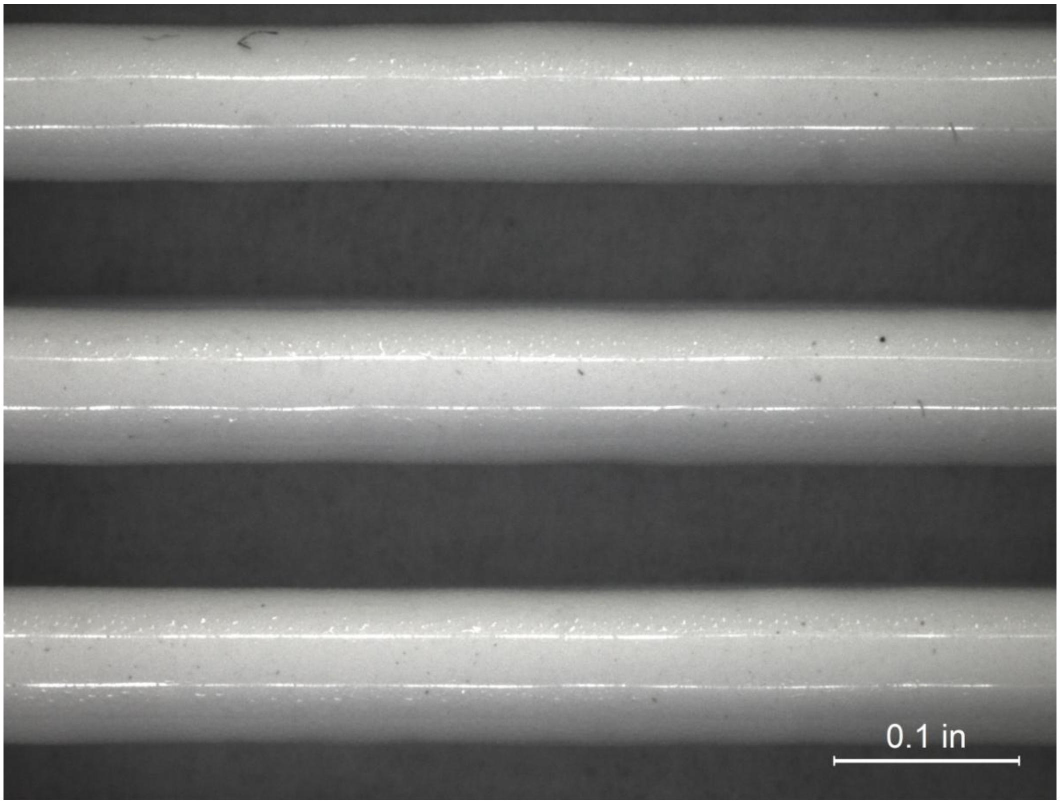


(a) Coated Duplex 2205 Stainless Steel Coupon 1, After Cleaning 10X



(b) Coated Duplex 2205 Stainless Steel Coupon 1, After Cleaning 50X

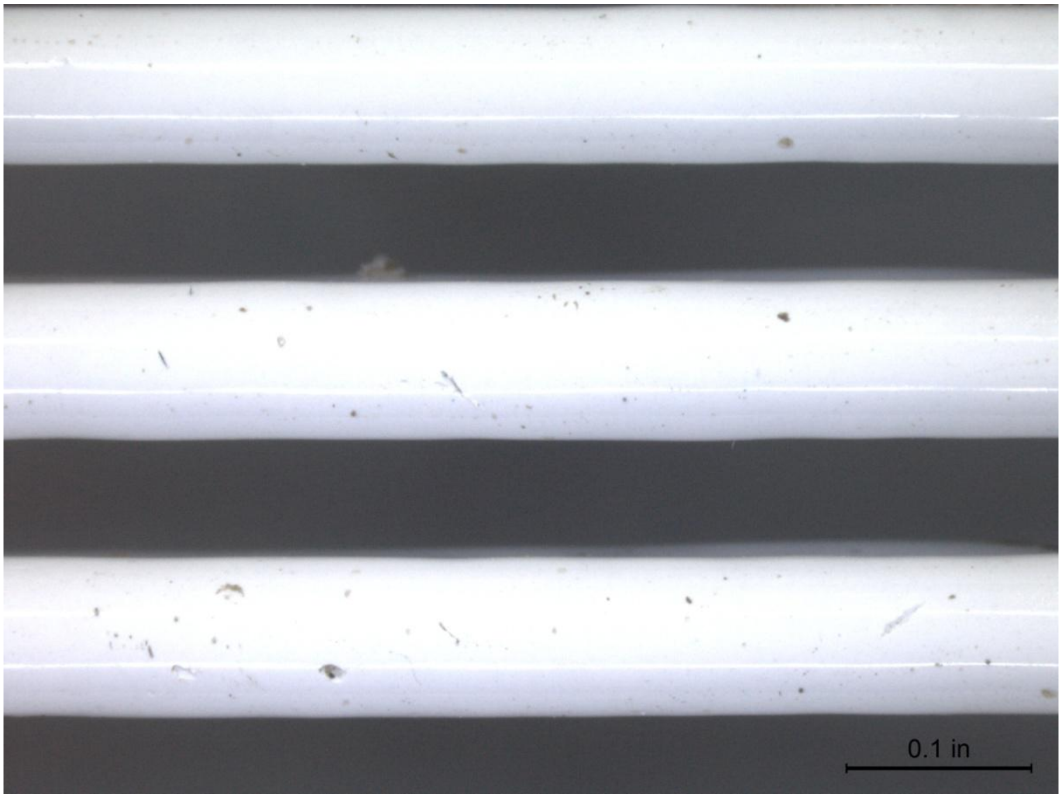
Figure 7 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 1 after a 3 month corrosion test, after cleaning.



(a) Coated Duplex 2205 Stainless Steel Baseline Screen 10X

(b) Coated Duplex 2205 Stainless Steel Baseline Screen 50X

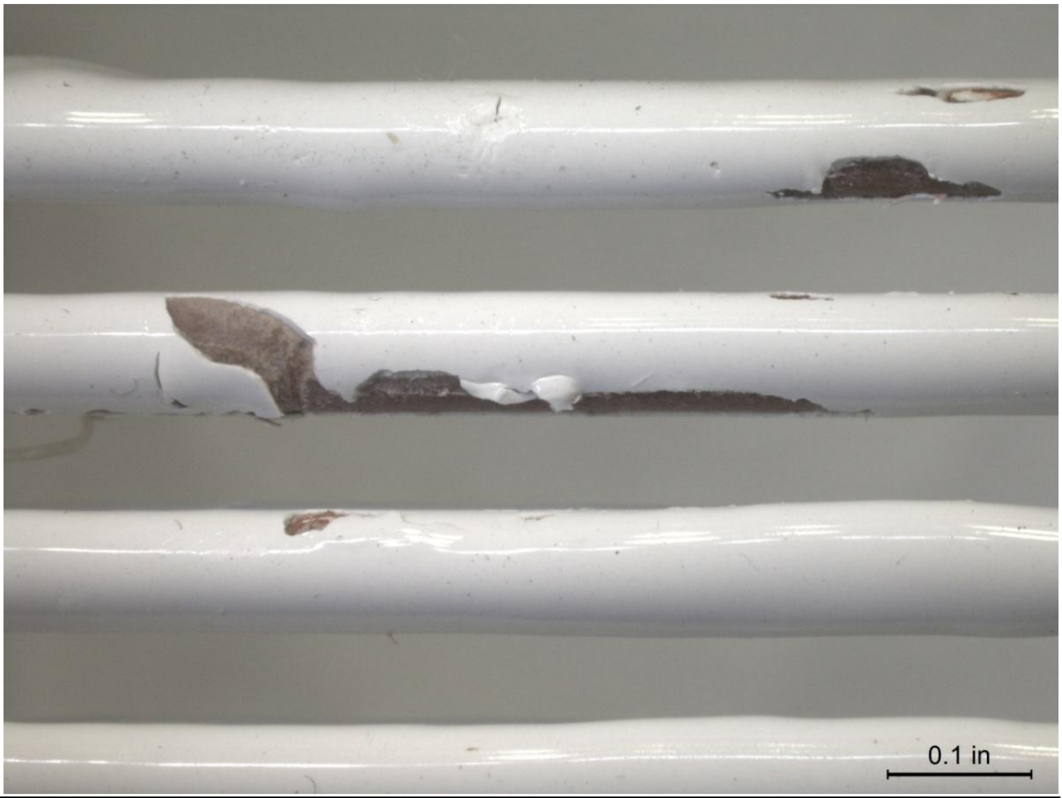
Figure 8 Optical macrographs of the duplex 2205 stainless steel with anti-biofouling coating baseline screen.



(a) Coated Duplex 2205 Stainless Steel Screen 1, Before Cleaning 10X

(b) Coated Duplex 2205 Stainless Steel Screen 1, Before Cleaning 50X

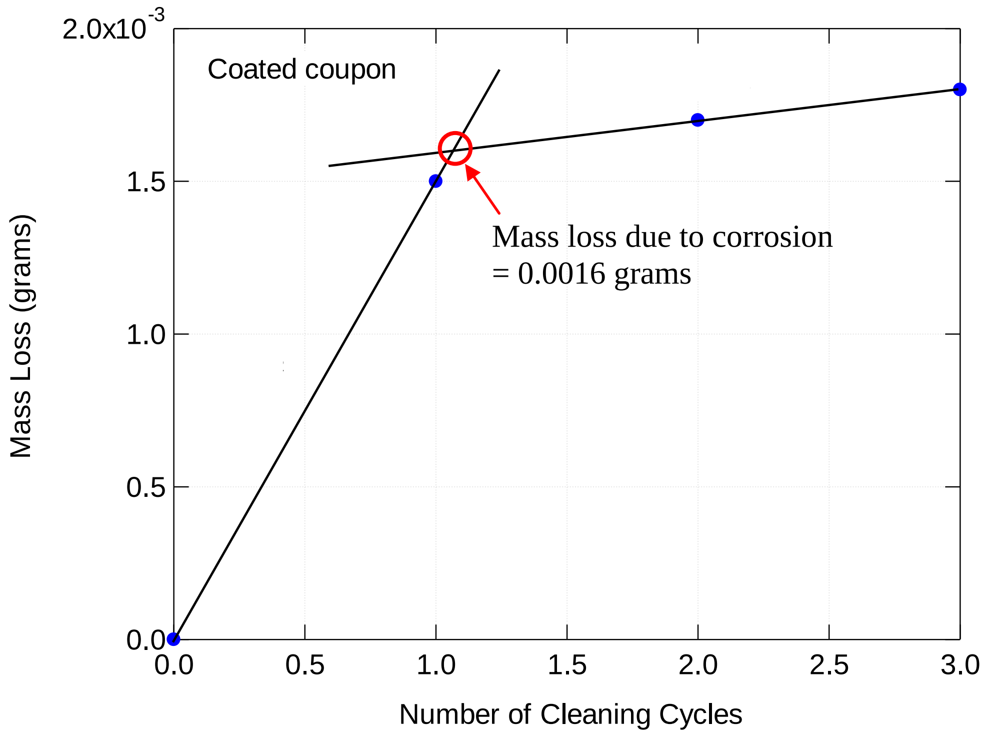
Figure 9 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating screen 1 after a 3 month corrosion test, before cleaning.



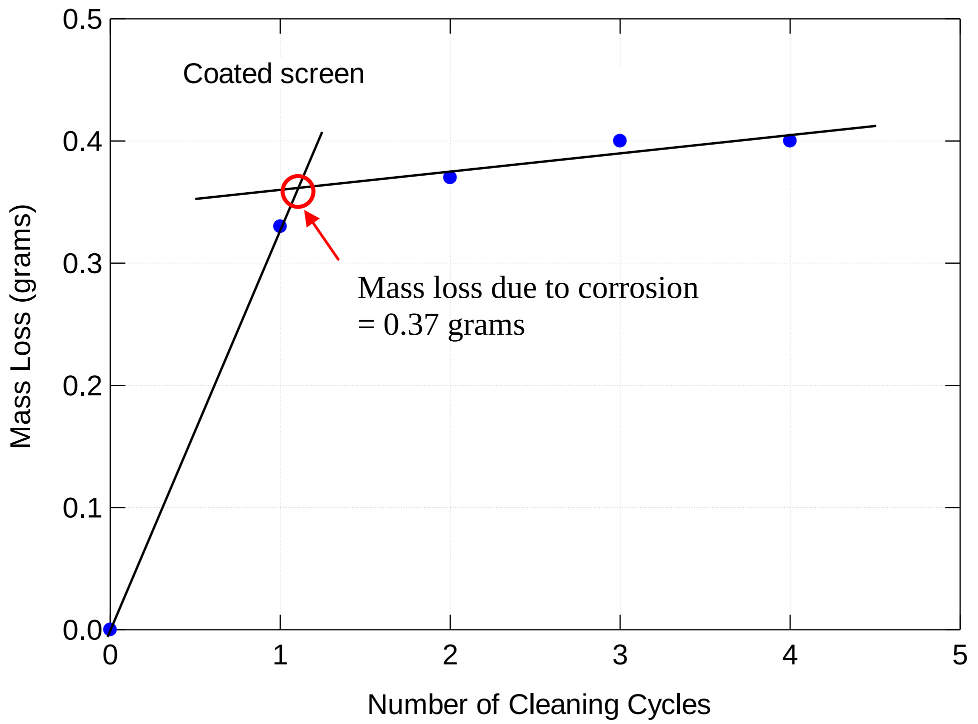
(a) Coated Duplex 2205 Stainless Steel Screen 1, After Cleaning 10X

(b) Coated Duplex 2205 Stainless Steel Screen 1, After Cleaning 50X

Figure 10 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating screen 1 after a 3 month corrosion test, after cleaning.

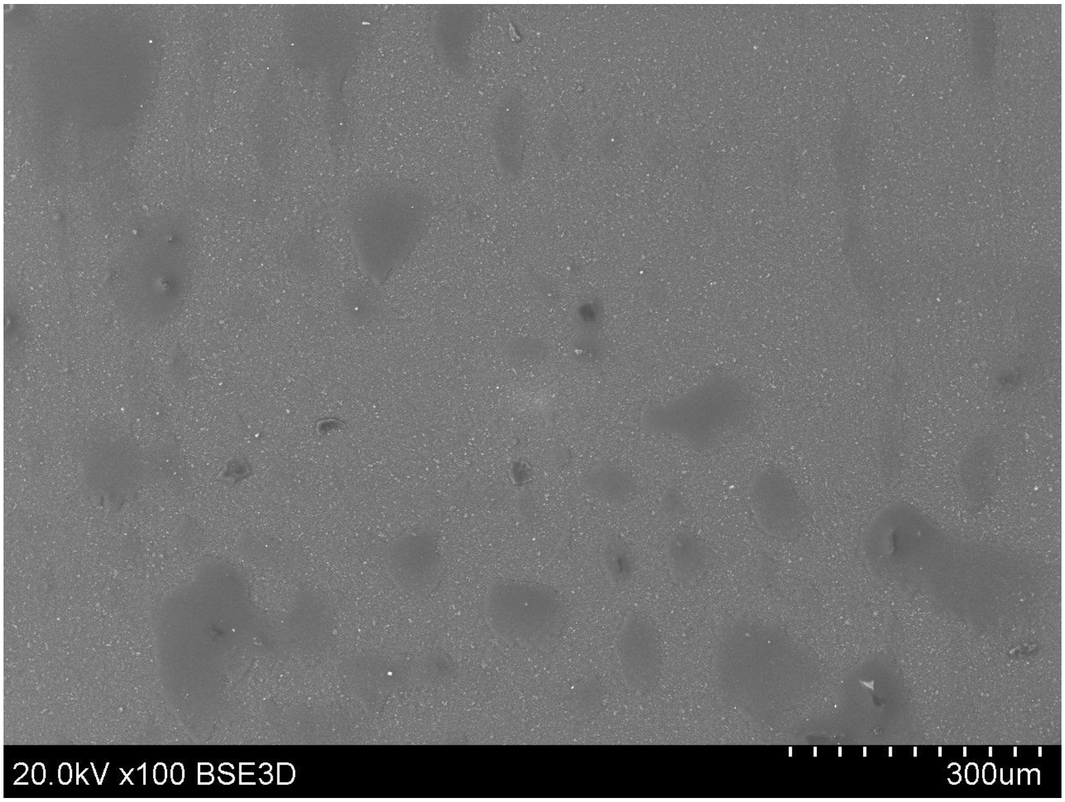


(a)

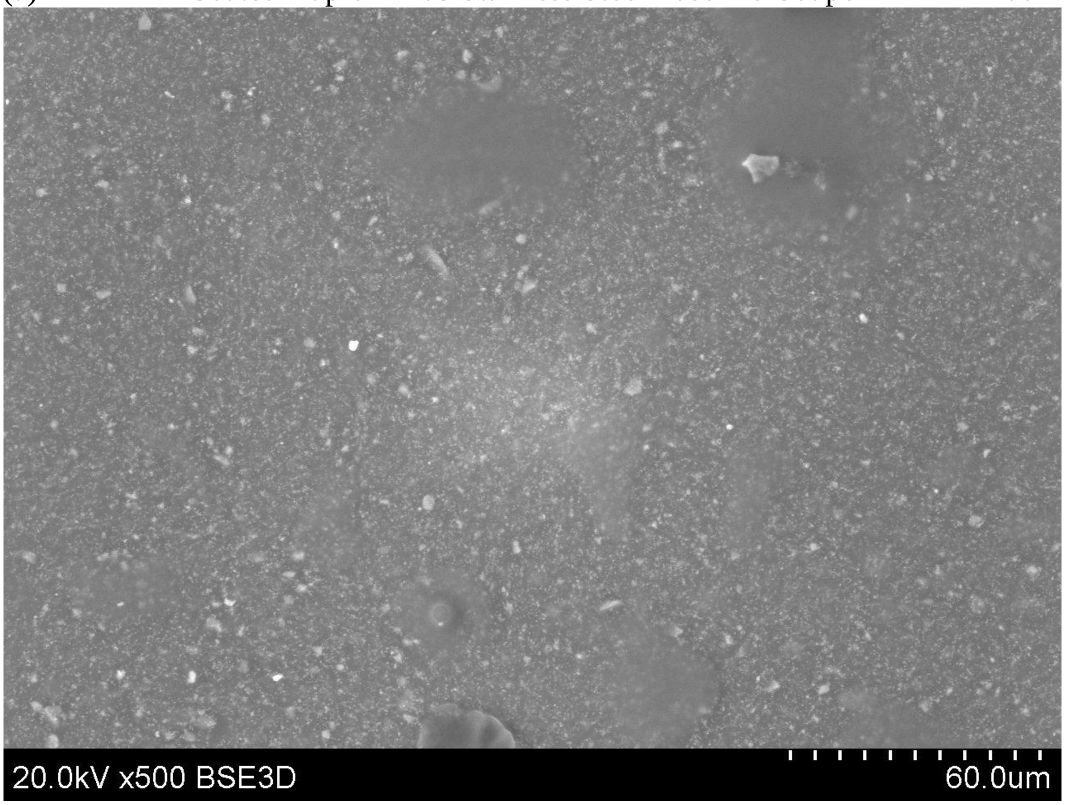


(b)

Figure 11 Mass loss of the duplex 2205 stainless steel with anti-biofouling coating (a) coupon 1 and (b) screen 1 during cleaning.

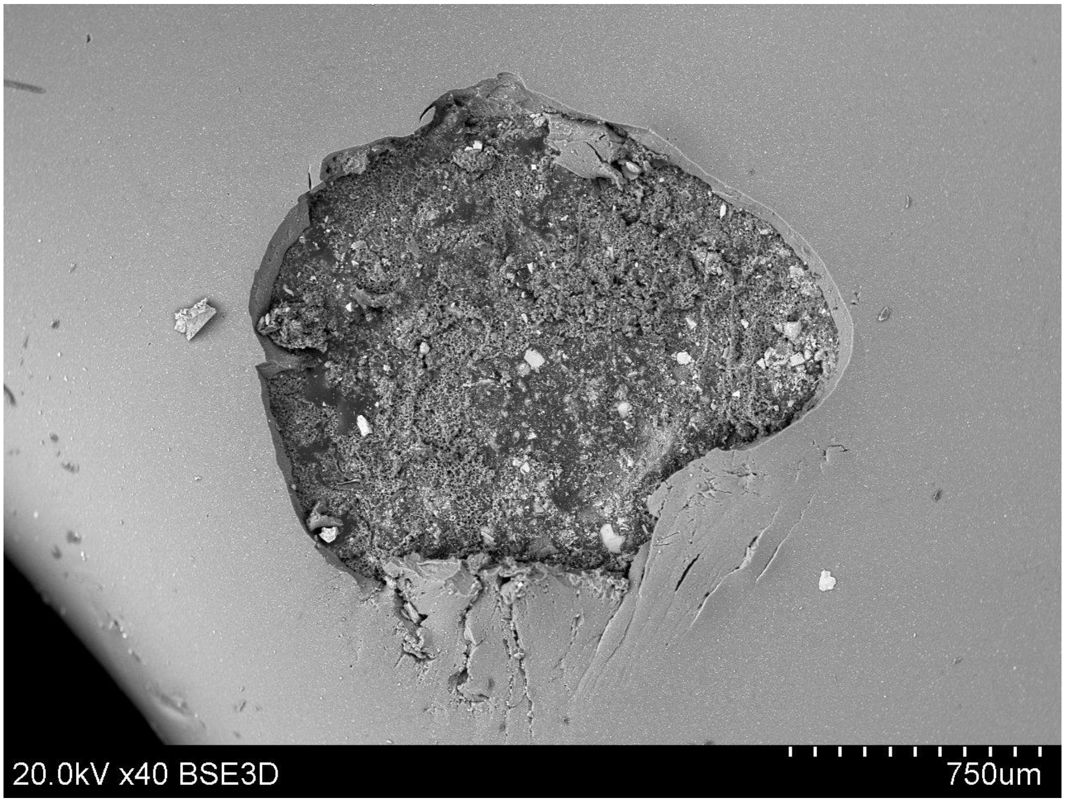


(a) Coated Duplex 2205 Stainless Steel Baseline Coupon 100X

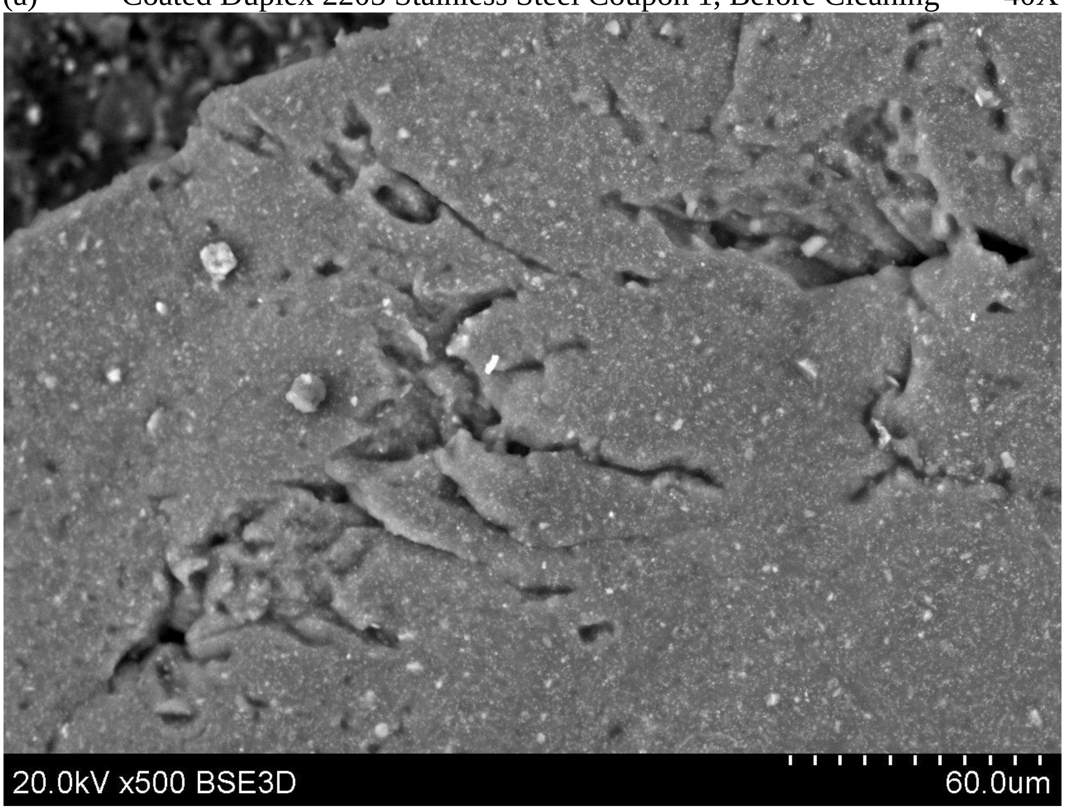


(b) Coated Duplex 2205 Stainless Steel Baseline Coupon 500X

Figure 12 Scanning electron micrographs of the duplex 2205 stainless steel with anti-biofouling coating baseline coupon.

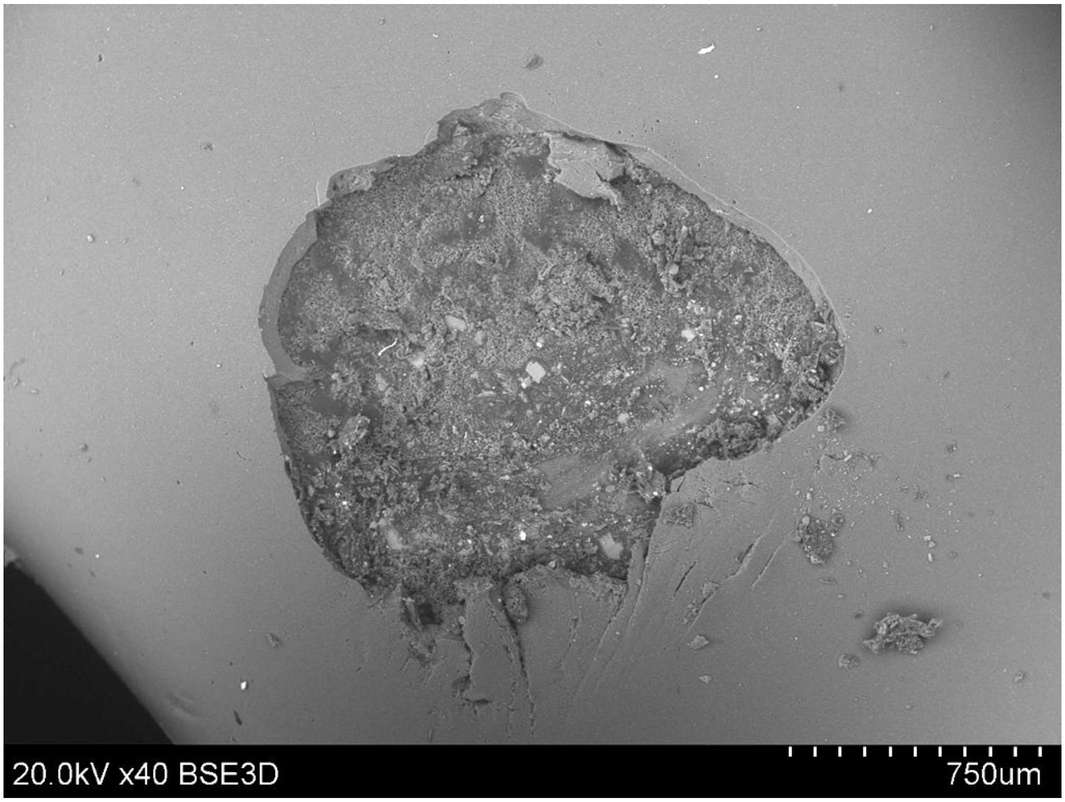


(a) Coated Duplex 2205 Stainless Steel Coupon 1, Before Cleaning 40X

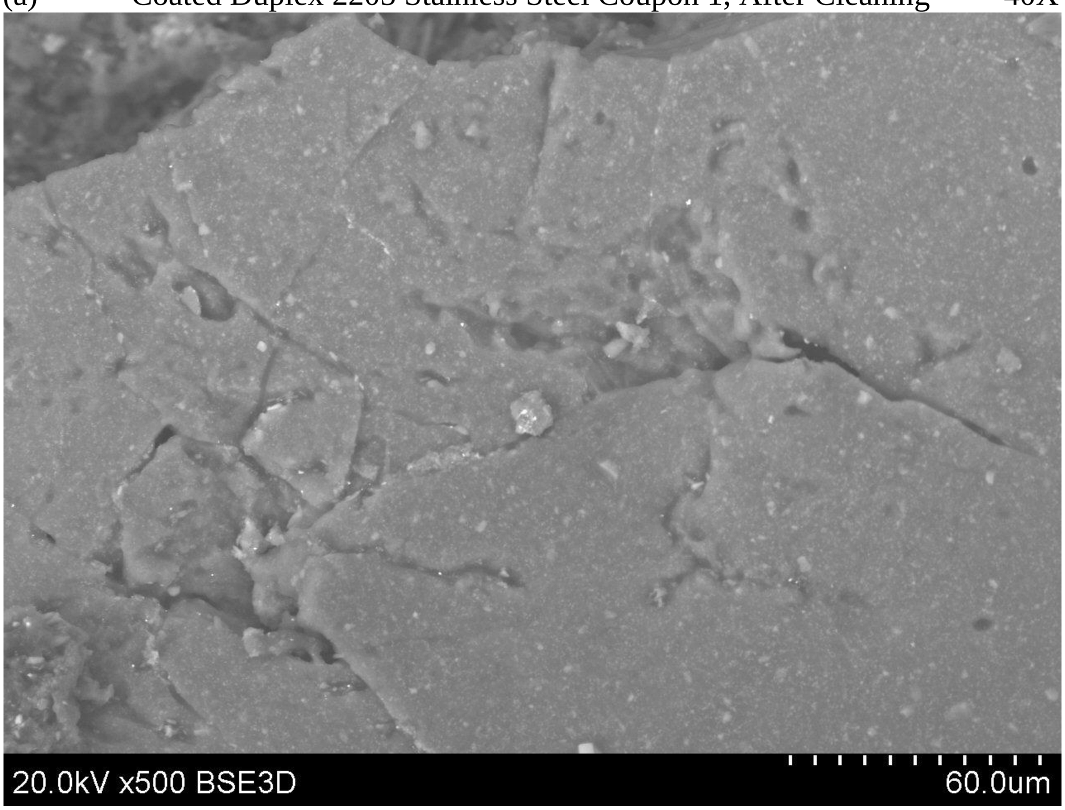


(b) Coated Duplex 2205 Stainless Steel Coupon 1, Before Cleaning 500X

Figure 13 Scanning electron micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 1 after a 3 month corrosion test, before cleaning.

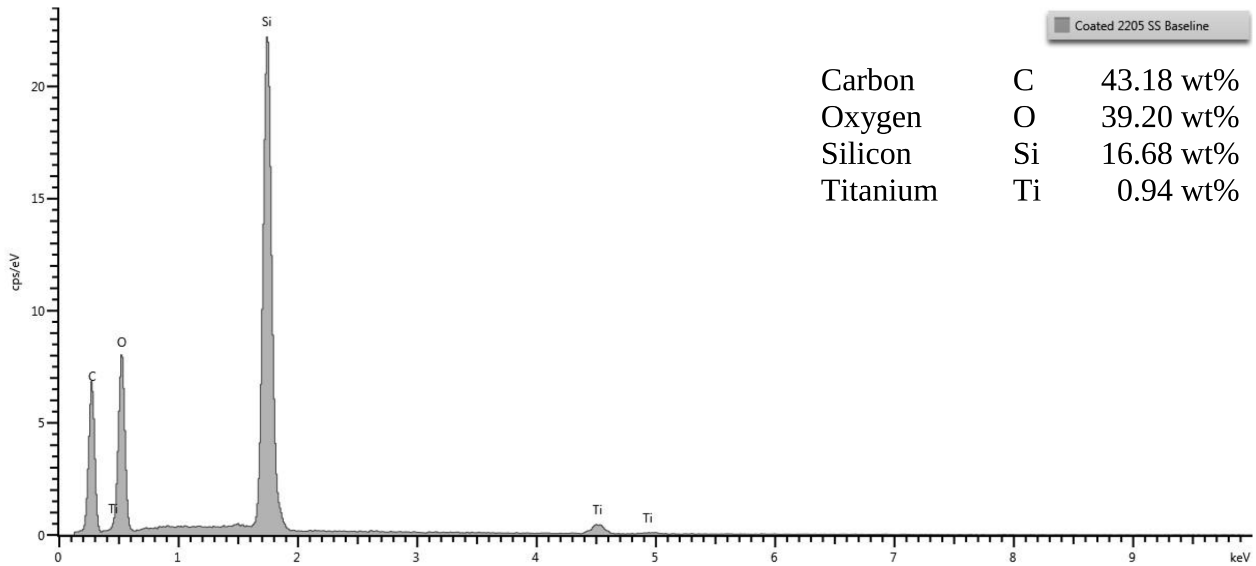


(a) Coated Duplex 2205 Stainless Steel Coupon 1, After Cleaning 40X



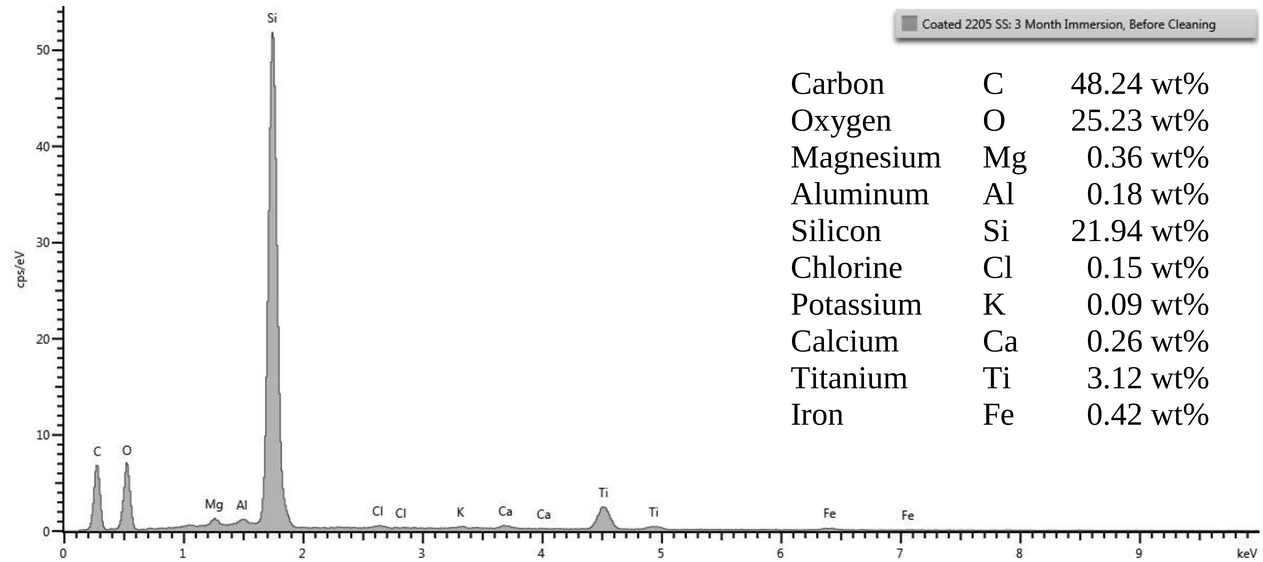
(b) Coated Duplex 2205 Stainless Steel Coupon 1, After Cleaning 500X

Figure 14 Scanning electron micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 1 after a 3 month corrosion test, after cleaning.

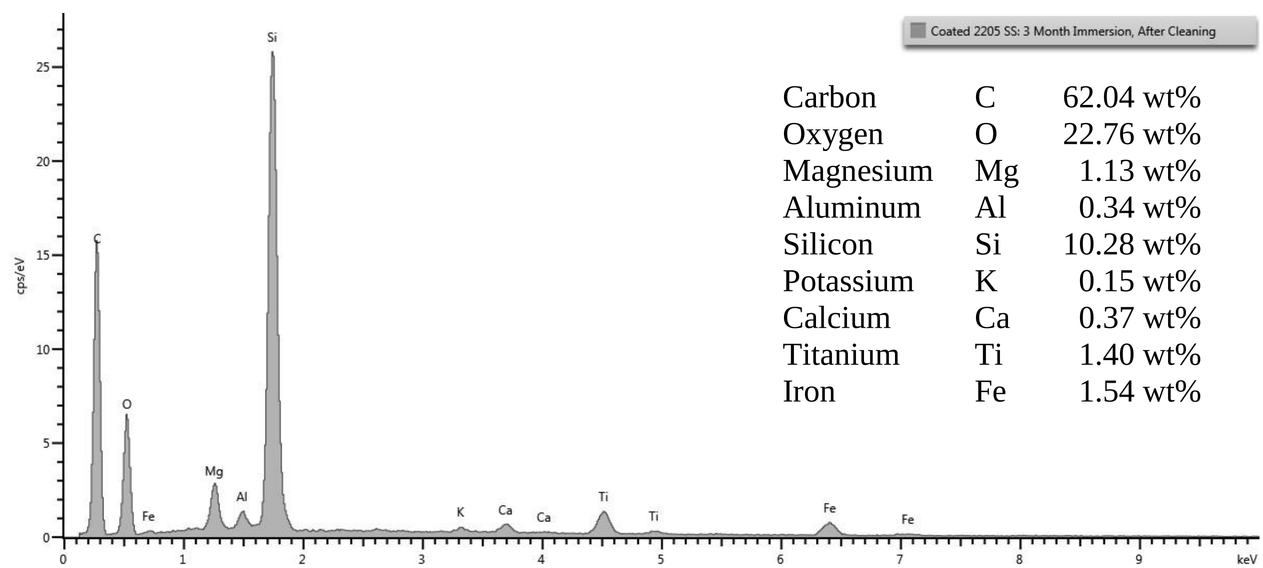


(a) Coated Duplex 2205 Stainless Steel Baseline Coupon

Figure 15 Energy dispersive x-ray spectra of the duplex 2205 stainless steel with anti-biofouling coating baseline coupon.

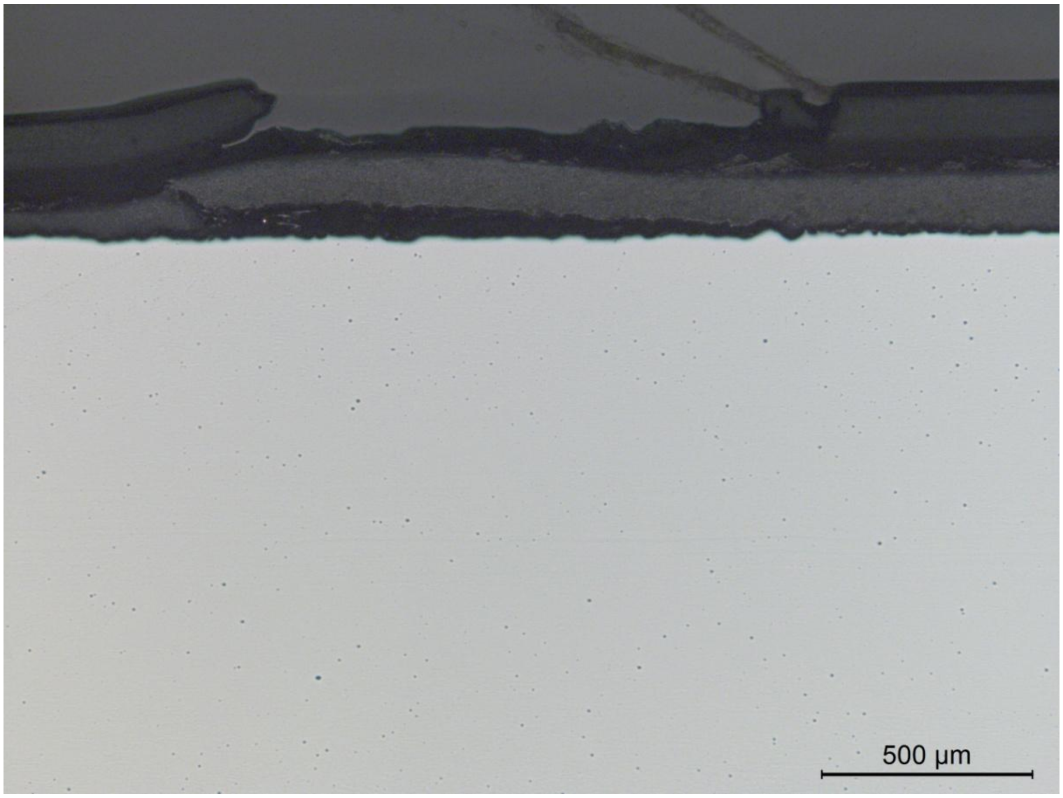


(a) Coated Duplex 2205 Stainless Steel Coupon 1, Before Cleaning

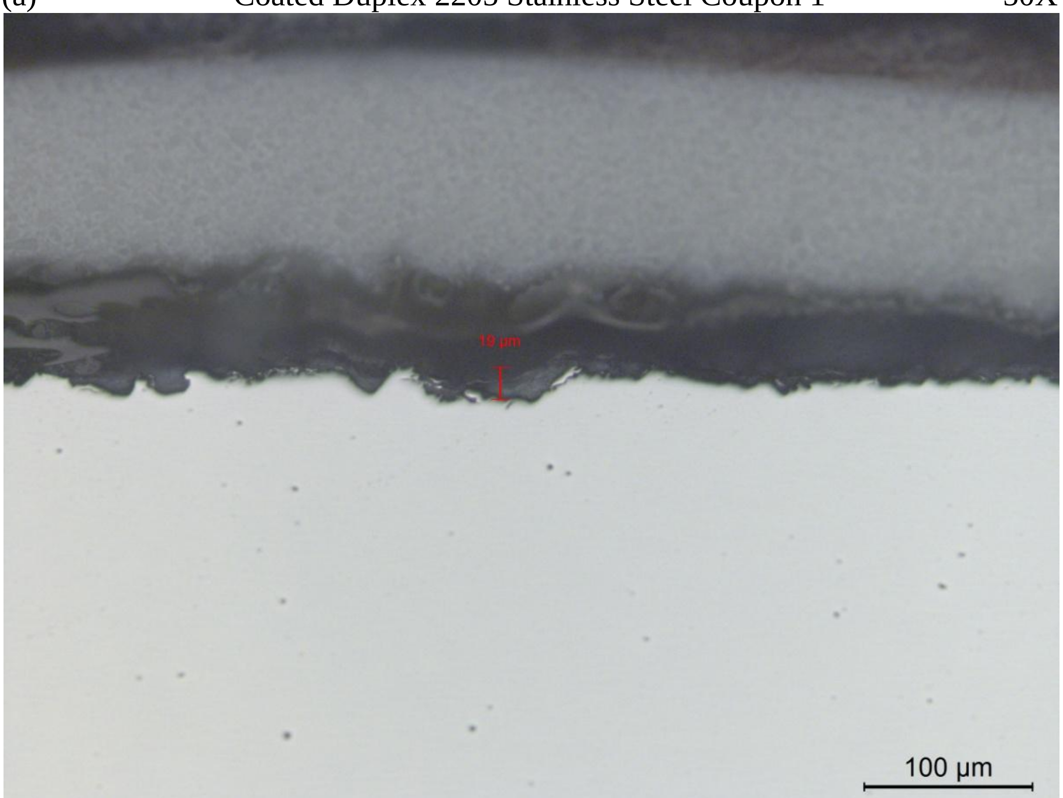


(b) Coated Duplex 2205 Stainless Steel Coupon 1, After Cleaning

Figure 16 Energy dispersive x-ray spectra of duplex 2205 stainless steel with anti-biofouling coating coupon 1 after a 3 month corrosion test (a) before cleaning and (b) after cleaning.



(a) Coated Duplex 2205 Stainless Steel Coupon 1 50X



(b) Coated Duplex 2205 Stainless Steel Coupon 1 200X

Figure 17 Optical micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 1.

Report No. 5005.0361 **November 7, 2014**

CORROSION EVALUATION OF CDA 715 COUPONS AND SCREENS

Customer Authorization: Verbal

Report To: V & A Engineering
Attn: Manuel Najar
155 Grand Avenue, Suite 700
Oakland, CA 94612

1.0 INTRODUCTION

Five coupons, five wedge wire screens, and one plate were submitted by V&A Engineering for corrosion evaluation. The coupons were 1-inch by 3-inches by ¼-inch thick. The wedge wire screens were 4-inches by 4-inches by 1/4-inch tall with 2 mm spacing. The plate was 4-inches by 4-inches by 1/8-inch thick. The sample was reportedly CDA 715, a 70 wt% copper, 30 wt% nickel alloy.

Four coupons and four screens were to be placed in seawater for a period up to one year. After every 3 month interval, one coupon and one screen were to be removed from the test system and examined for corrosion. The purpose of this evaluation was to document the samples in the baseline as-received condition, then again after 3, 6, 9, and 12 months of water exposure, record any loss in mass, examine for any pitting corrosion, and estimate the corrosion rate.

The samples were evaluated by the following laboratory procedures:

1) Visual examination and weighing
2) Cleaning per ASTM G1[1]
3) Scanning electron microscopy
4) Metallography

The results of the evaluation showed minimal mass loss and corrosion for the coupon and screen after 3 months of corrosion testing. The coupon and screen had a corrosion rate of approximately 0.021 millimeters per year and 0.022 millimeters per year, respectively.

[1] G1: Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

2.0 EVALUATION[2]

2.1 Visual Examination

The sample identifications for the coupons and wedge wire screens and their corresponding immersion times are shown in Table 1. The coupons had identification numbers stamped on the front face by V&A Engineering. A number of notches, corresponding to the sample number, were sawed at the edge of each screen for identification after the corrosion test. The weights of the samples were recorded. Coupons 1 – 4 and screens 1 – 5 were sent back to V&A for corrosion testing. Coupon 5 was the baseline sample and documented by photography, optical stereoscopy and scanning electron microscopy for comparison to the tested samples. Screen 5 was documented as a baseline by photography and optical stereoscopy, and then sent to V&A for testing.

Photographs of the baseline coupon are shown in Figure 1. Photographs of coupon 1, after 3 months of corrosion testing, are shown in Figure 2. A photograph of the baseline screen is shown in Figure 3. A photograph of screen 1, after 3 months of corrosion testing, is shown in Figure 4.

2.2 Cleaning

The coupon and screen were cleaned with solution C.2.1 per ASTM G1.[3] One cleaning cycle was approximately 1 minute. After each cleaning cycle, the samples were rinsed in water, dried, and weighed. The cleaning and weighing cycle was completed five times for the coupon and four times for the screen. The weights of the samples as-received, after corrosion testing but before cleaning, and after each cleaning cycle are presented in Table 2.

Optical macrographs of the baseline coupon and screen are shown in Figures 5 and 8, respectively. Representative optical macrographs of the samples before and after cleaning are shown in Figures 6 – 7 and 9 – 10. The mass loss versus the number of cleaning cycles was plotted, shown in Figure 11. The equations for best fit lines AB and BC, calculated using IGOR Pro, are listed in Table 3. Point B, indicated by the red circle in each plot, corresponds to the mass loss due to corrosion during the cleaning process for each sample. This mass loss was subtracted from the weight of the sample before cleaning and from the weight of the sample as-received to determine the total mass loss from corrosion. The corrosion rate of each sample was determined by the formula specified in Section 8.1 of ASTM G1:

$$Corrosion\ Rate = \frac{K\ x\ W}{A\ x\ T\ x\ D}$$

where K = 8.76×10^4, T = time of exposure in hours, A = area in cm^2, W = mass loss in grams, and D = density in g/cm^3. The total mass loss from corrosion and the calculated corrosion rate of each sample is shown in Table 4.

[2] The magnifications of the optical and scanning electron micrographs in this report are approximate and should not be used as a basis for dimensional analyses unless otherwise indicated.
[3] 500 mL hydrochloric acid + 500 ml reagent water.

2.3 Scanning Electron Microscopy

The baseline coupon and coupon 1 were examined with a scanning electron microscope. Representative scanning electron micrographs of the baseline coupon are shown in Figure 12. Representative scanning electron micrographs of coupon 1 before and after cleaning are shown in Figures 13 – 14. Energy dispersive x-ray spectra of the baseline coupon and the coupon before and after cleaning are shown in Figures 15 – 16.

2.4 Metallography

A cross section was taken from the coupon and prepared for a metallographic examination. Optical micrographs of the surface for coupon 1 are shown in Figure 17. An elliptical pit was observed in coupon 1, measuring 50 μm deep.

3.0 DISCUSSION

The coupon and screen showed minimal mass loss and pitting after 3 months of corrosion testing. The coupon had lost 0.248 grams of material and had a corrosion rate of 0.021 millimeters per year. The screen had lost 2.04 grams of material and had a corrosion rate of 0.022 millimeters per year.

4.0 CONCLUSIONS[4]

The following conclusions are based upon the submitted samples and the evidence gathered:

1. The coupon, after 3 months of corrosion testing, had a mass loss of 0.248 grams and a corrosion rate of 0.021 mm / year.

2. The screen, after 3 months of corrosion testing, had a mass loss of 2.04 grams and a corrosion rate of 0.022 mm / year.

Prepared by:	Reviewed by:
Norman Yuen	Audrey A. Fasching
Norman Yuen Materials Engineer	Audrey A. Fasching, Ph.D., P.E. Senior Materials Engineer

[4] The conclusions in this report are based upon the available information and evidence provided by the client and gathered by Anamet, within the scope of work authorized by the client, and they are hereby presented by Anamet to a reasonable degree of engineering and scientific certainty. Anamet reserves the right to amend or supplement its conclusions or opinions presented in this report should additional data or information become available, or further work be approved by the client.

Table 1
Sample Identifications

Description		V&A Engineering Identification (As-Received)	Anamet Identification (in report)	Notes
Alloy	Part			
CDA 715 (Cu 70 – Ni 30)	**Flat Plate** 4-inch x 4-inch x 1/8-inch	CDA 715 1	Plate	None
	Coupon 1-inch x 3-inch x 1/8-inch with autogenous weld bead	CDA 715W 1	Coupon 1	3 Month Immersion
		CDA 715W 2	Coupon 2	6 Month Immersion
		CDA 715W 3	Coupon 3	9 Month Immersion
		CDA 715W 4	Coupon 4	12 Month Immersion
		CDA 715W 5	Coupon 5	Baseline Sample (no exposure)
	Wedge Wire Screen 4-inch x 4-inch x 1-inch with 2 mm spacing	None	Screen 1	3 Month Immersion
		None	Screen 2	6 Month Immersion
		None	Screen 3	9 Month Immersion
		None	Screen 4	12 Month Immersion
		None	Screen 5	12 Month Immersion

Table 2
Sample Weights

Sample	Baseline Measurement	Measurements after 3 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 1	23.3284	23.1538	23.0863	32.0802	23.0795	23.0782	23.0770
Screen 1	210.45	209.34	208.52	208.42	208.41	208.41	-

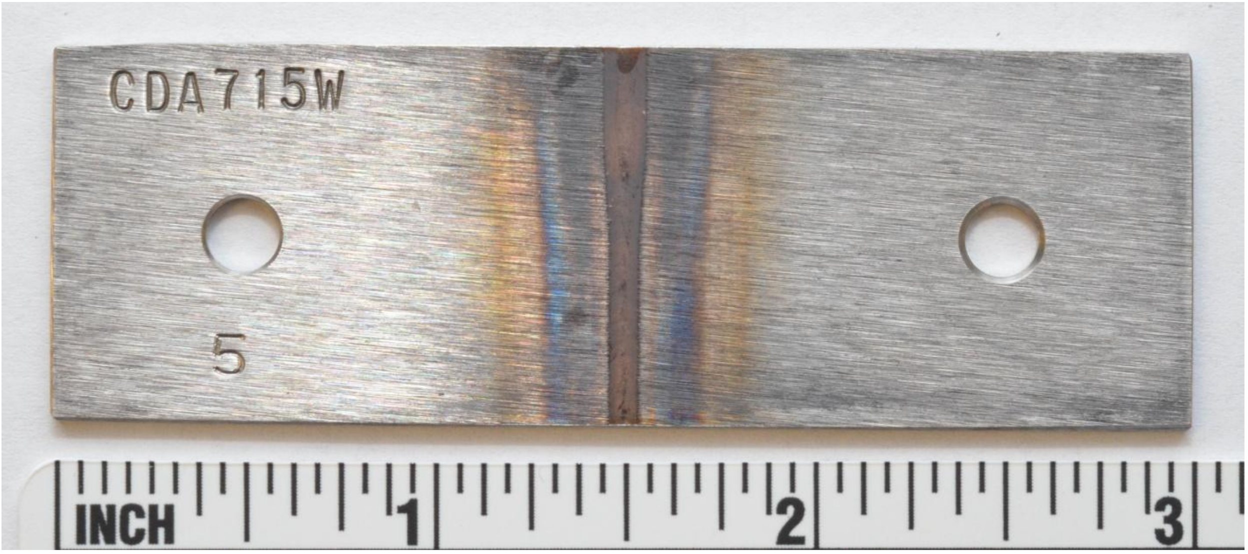
Table 3
Equations of Lines AB and BC for Corrosion Testing Samples

Sample	Line AB	Line BC	Point B (Approximate Mass Loss from Corrosion During Cleaning)
Coupon 1	y = 0.068x	y = 0.001x + 0.072	0.073 grams
Screen 1	y = 0.83x	y = 0.01x + 0.92	0.93 grams

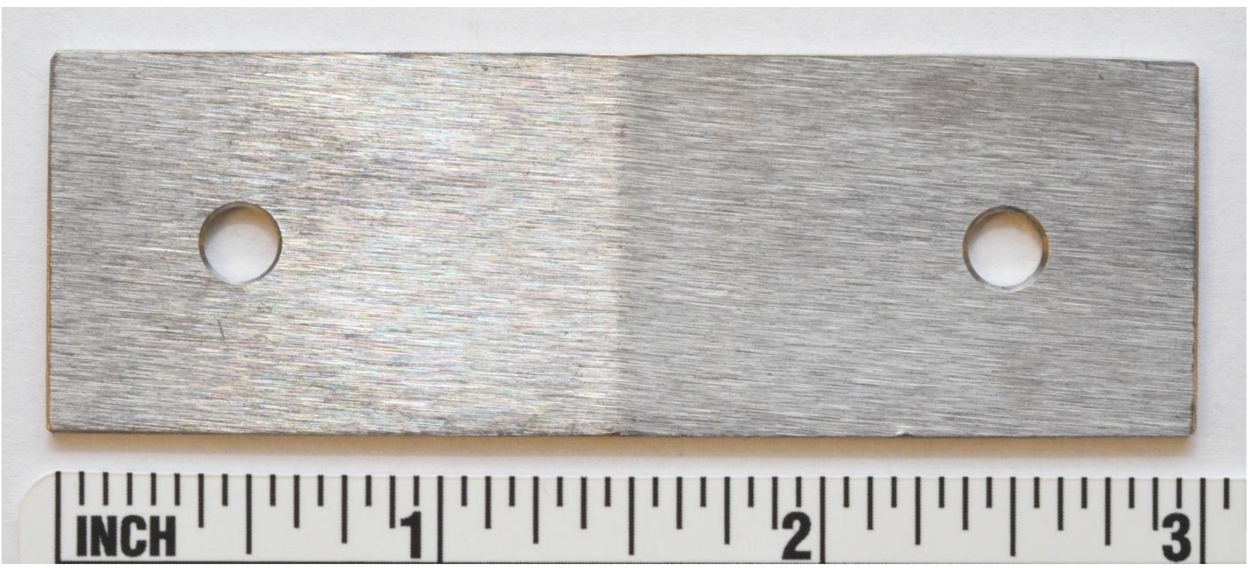
Table 4
Total Mass Loss from Corrosion and Corrosion Rates

Sample	Total Mass Loss from Corrosion*	Corrosion Rate
Coupon 1	0.248 grams	0.021 mm / year
Screen 1	2.04 grams	0.022 mm / year

* Weight As-Received – (Weight Before Cleaning – Mass Loss from Corrosion During Cleaning)

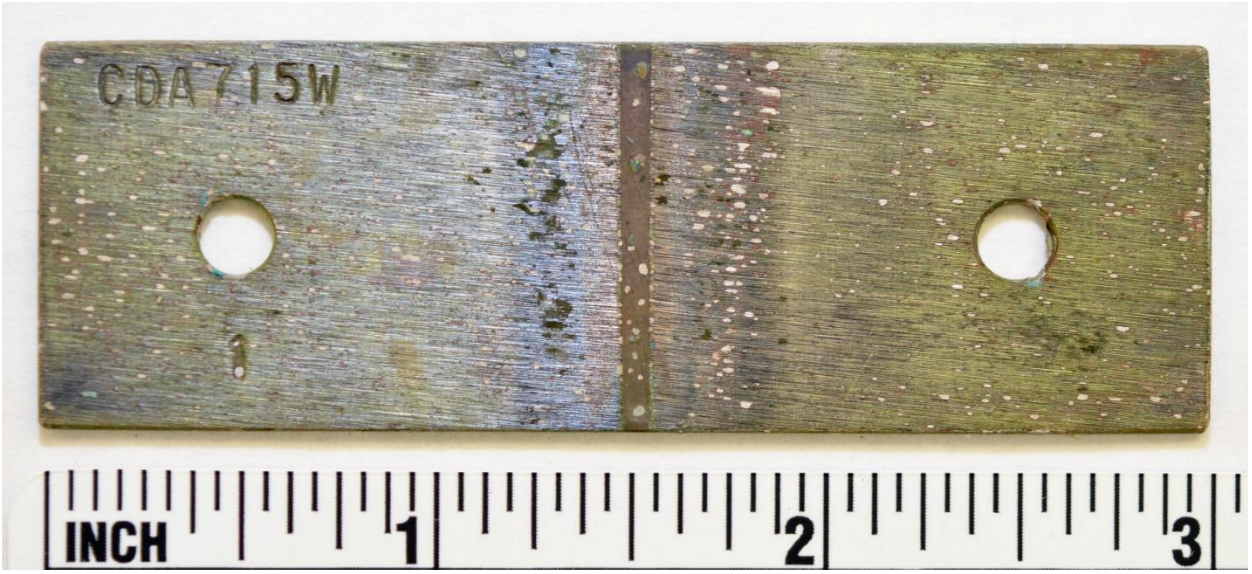


(a) CDA 715 Baseline Coupon, Front Side

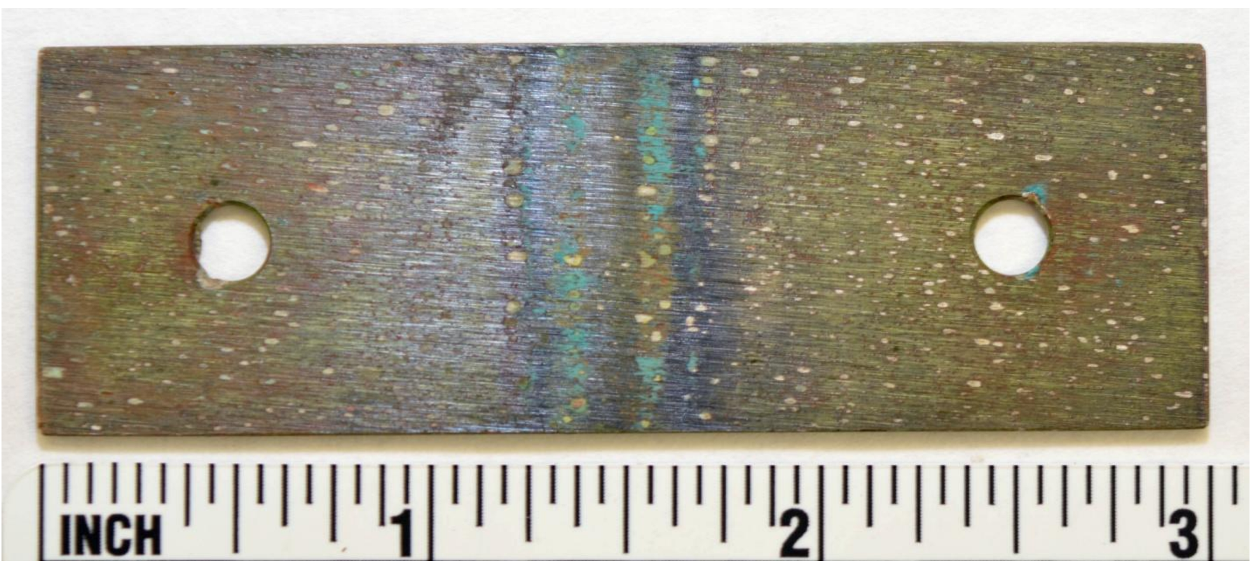


(b) CDA 715 Baseline Coupon, Back Side

Figure 1 Photographs of the CDA 715 baseline coupon (a) front and (b) back side.

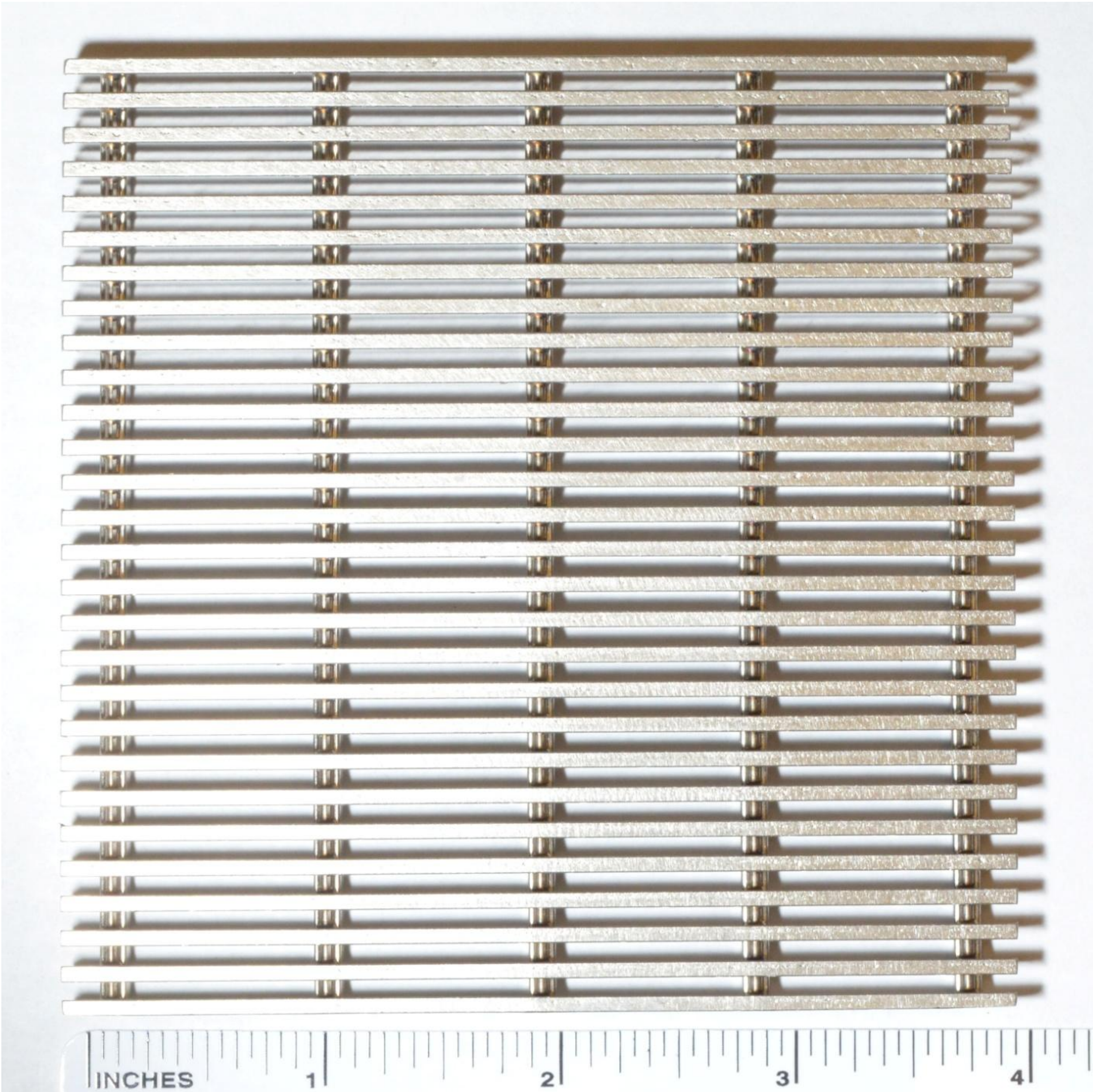


(a) CDA 715 Coupon 1, Front Side



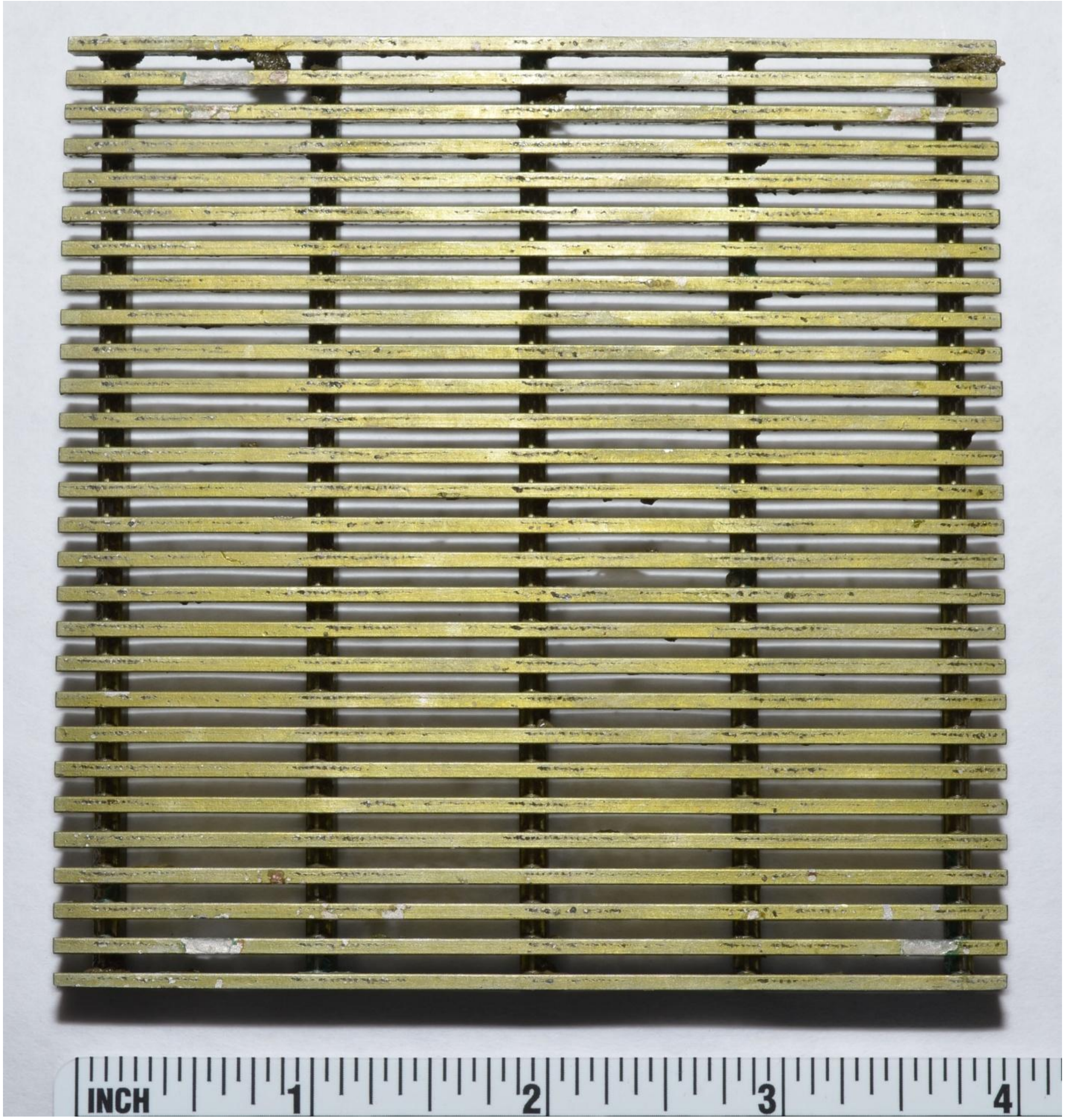
(b) CDA 715 Coupon 1, Back Side

Figure 2 Photographs of CDA 715 coupon 1 (a) front and (b) back side after a 3 month corrosion test.



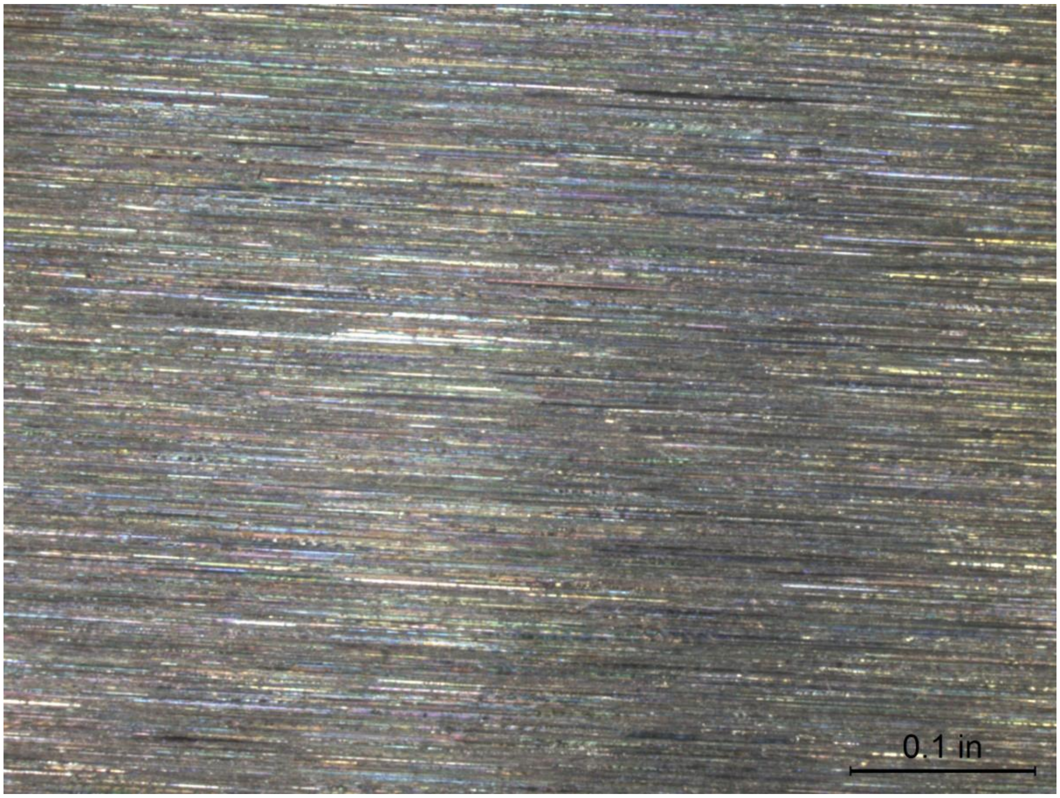
(a) CDA 715 Baseline Screen

Figure 3 Photograph of the CDA 715 baseline screen.

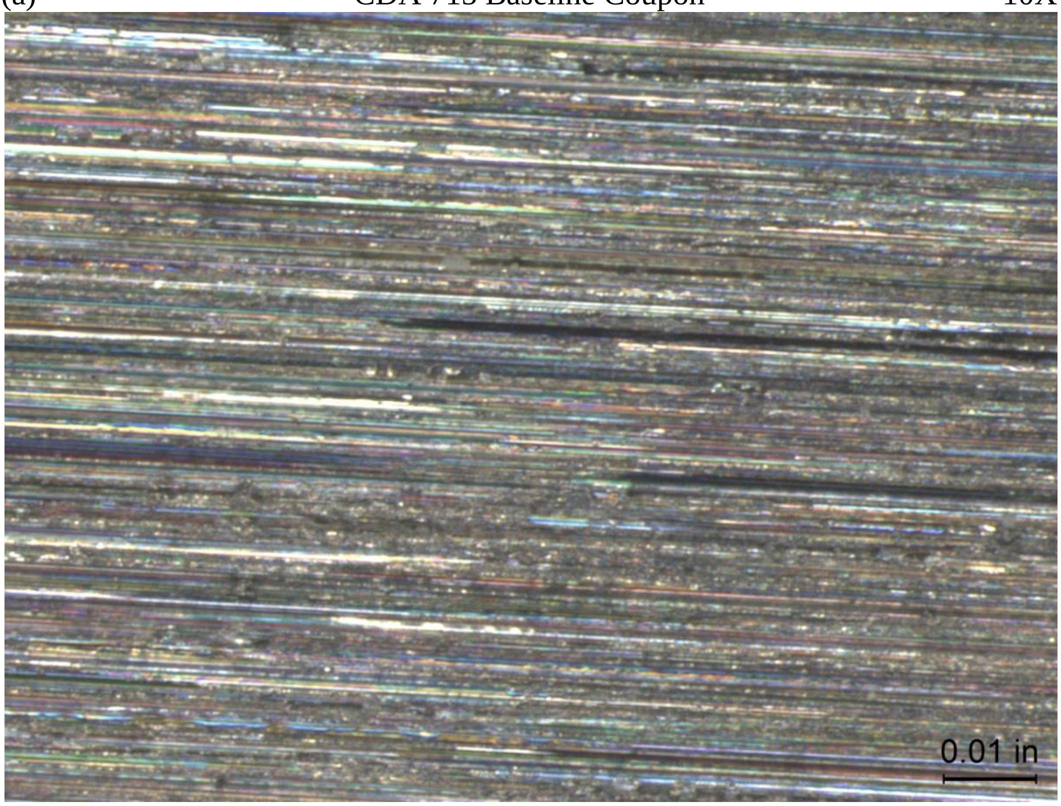


(a) CDA 715 Screen 1

Figure 4 Photograph of CDA 715 screen 1 after a 3 month corrosion test.



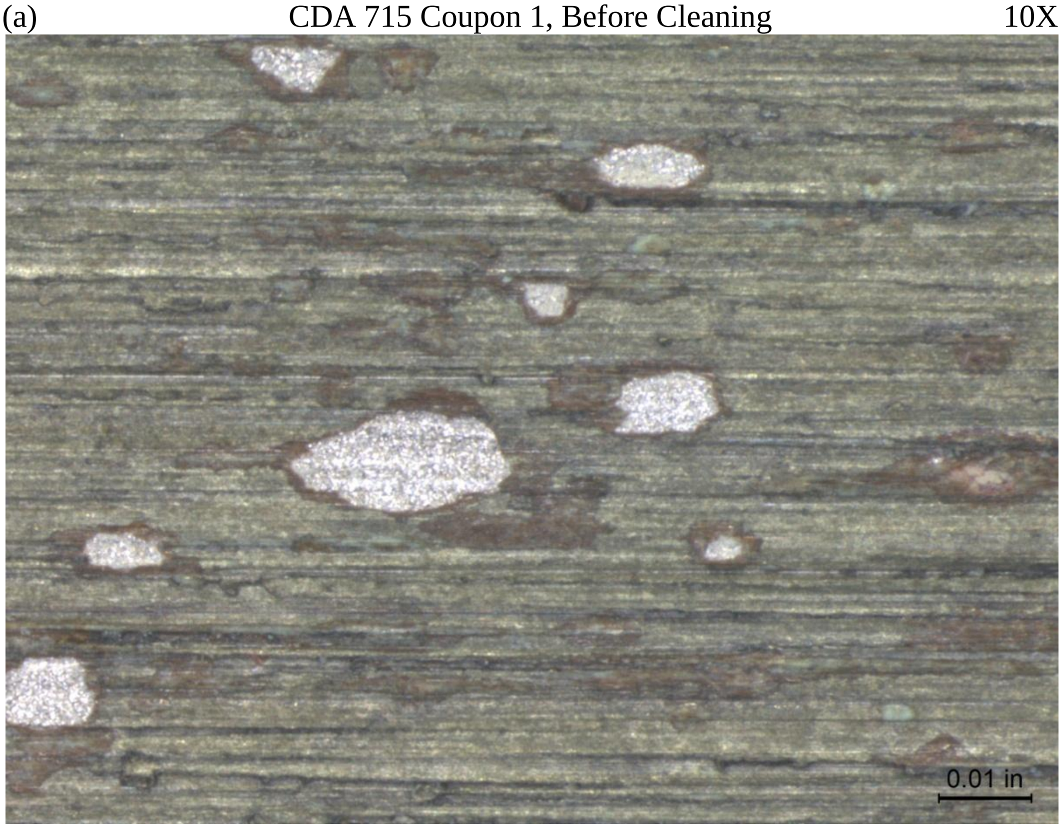
(a) CDA 715 Baseline Coupon 10X



(b) CDA 715 Baseline Coupon 50X

Figure 5 Optical macrographs of the CDA 715 baseline coupon.

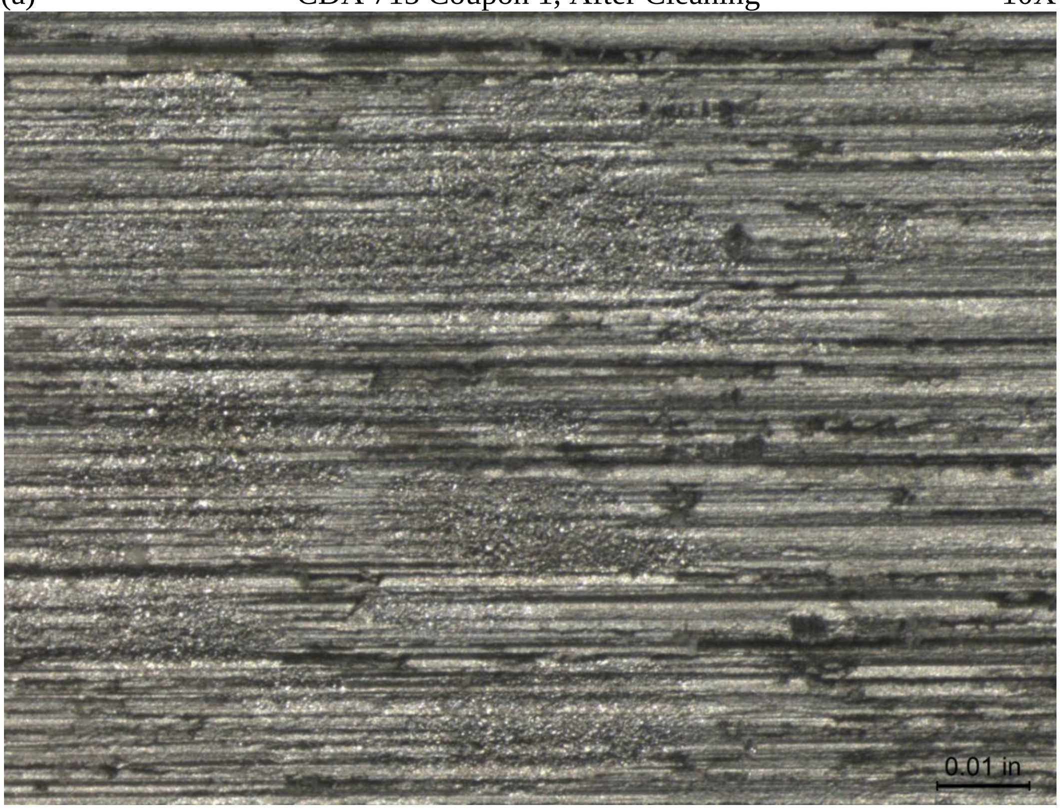
(a) CDA 715 Coupon 1, Before Cleaning 10X



(b) CDA 715 Coupon 1, Before Cleaning 50X

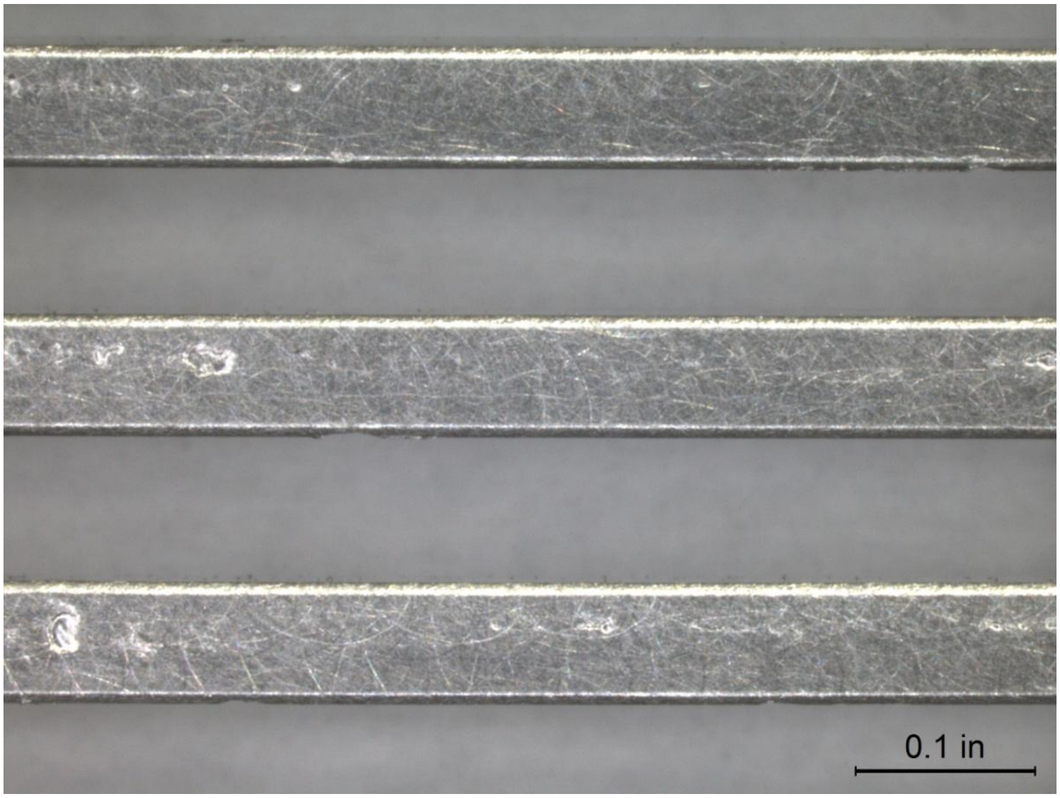
Figure 6 Optical macrographs of CDA 715 coupon 1 after a 3 month corrosion test, before cleaning.

(a) CDA 715 Coupon 1, After Cleaning 10X

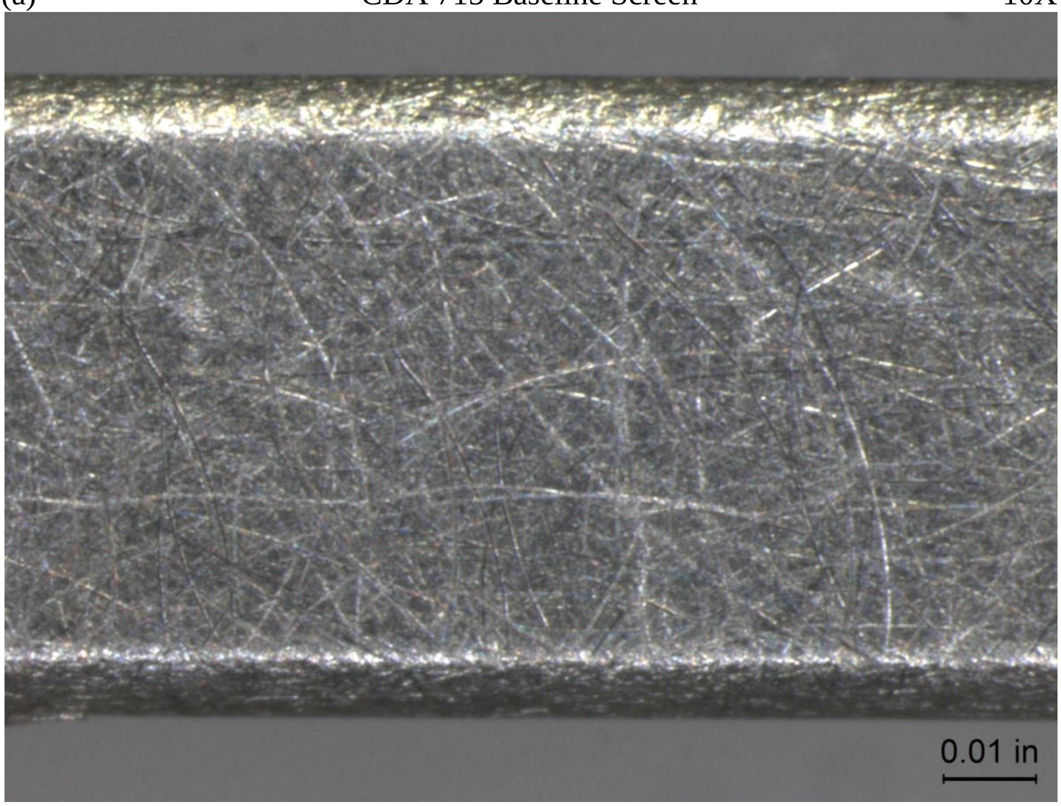


(b) CDA 715 Coupon 1, After Cleaning 50X

Figure 7 Optical macrographs of CDA 715 coupon 1 after a 3 month corrosion test, after cleaning.

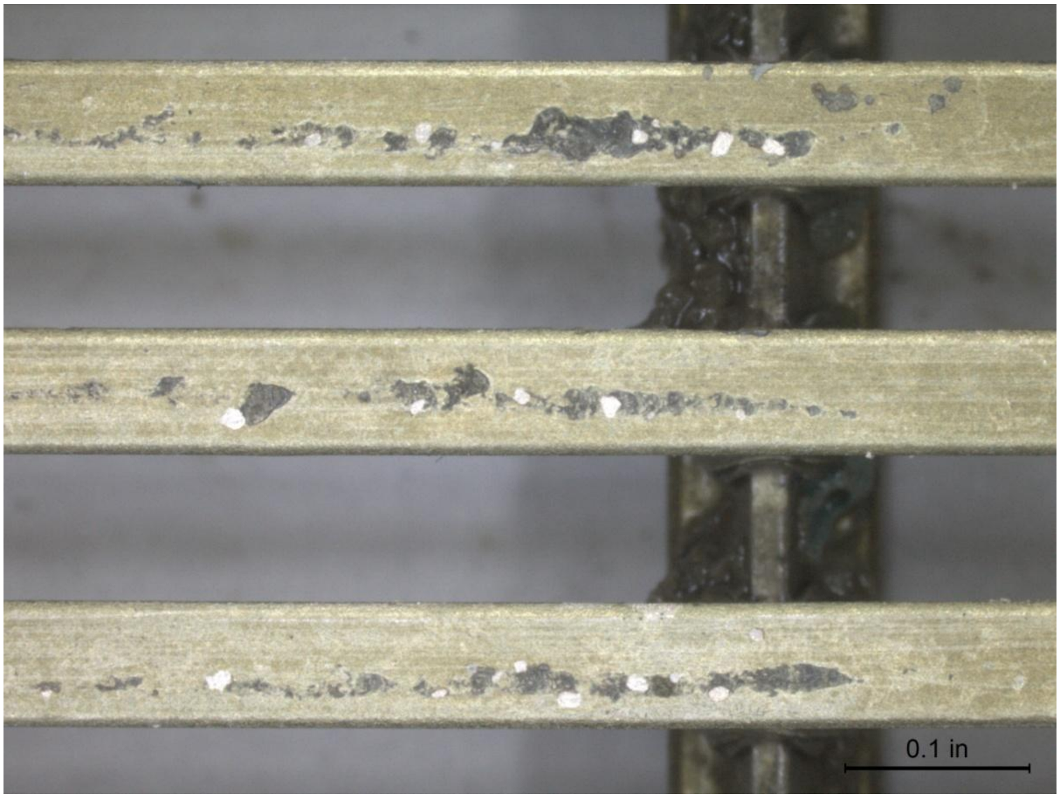


(a) CDA 715 Baseline Screen 10X

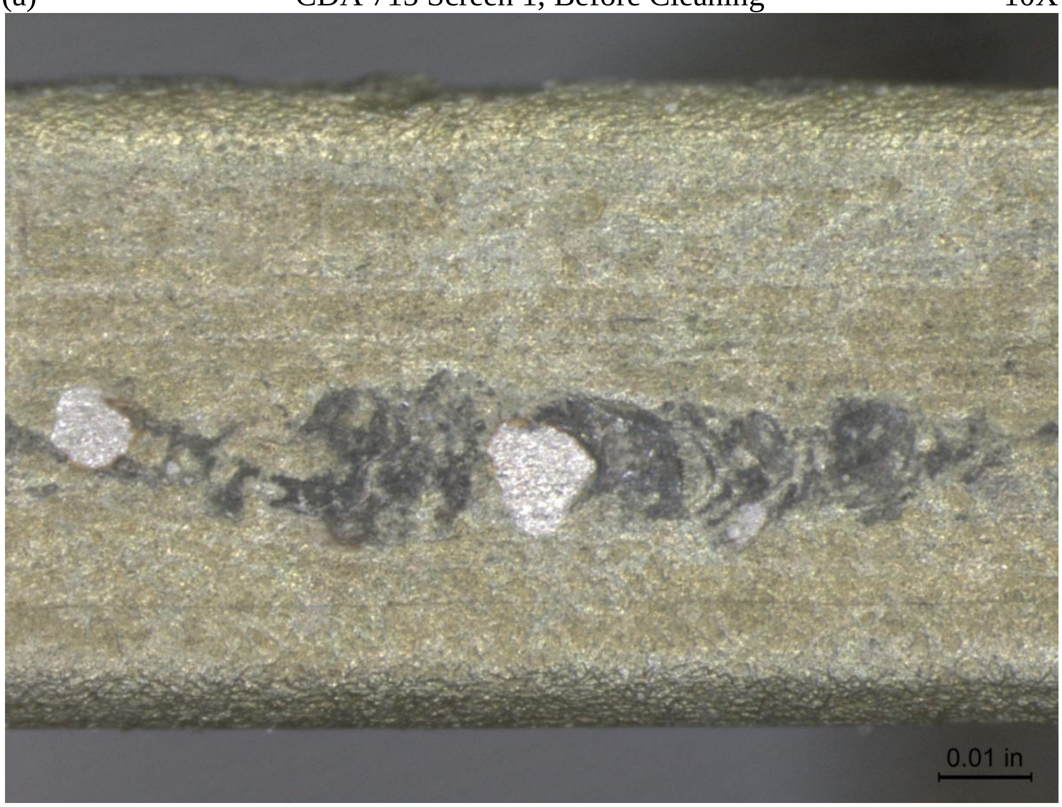


(b) CDA 715 Baseline Screen 50X

Figure 8 Optical macrographs of the CDA 715 baseline screen.

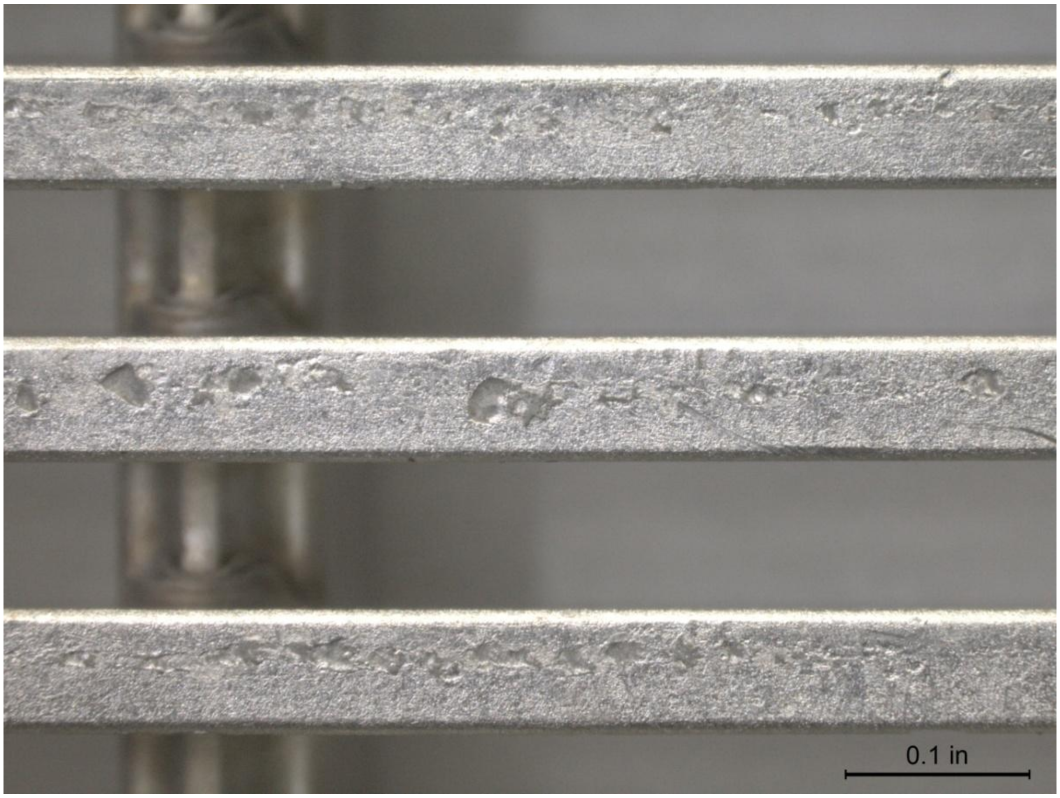


(a) CDA 715 Screen 1, Before Cleaning 10X

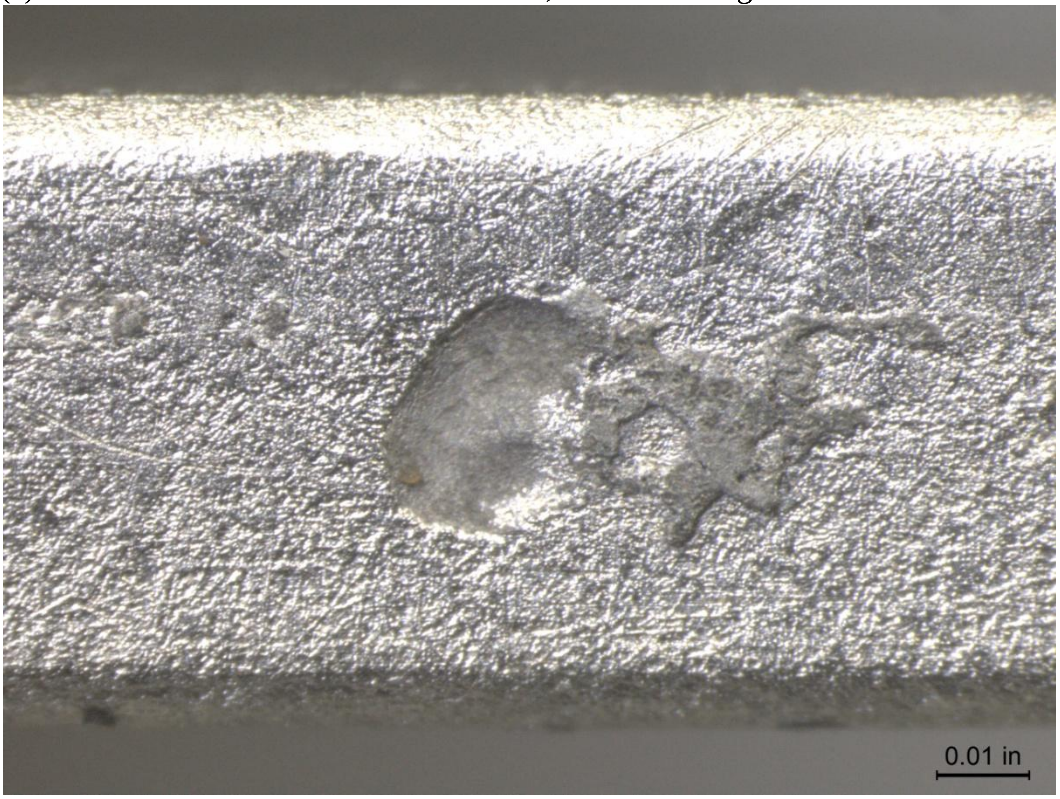


(b) CDA 715 Screen 1, Before Cleaning 50X

Figure 9 Optical macrographs of CDA 715 screen 1 after a 3 month corrosion test, before cleaning.

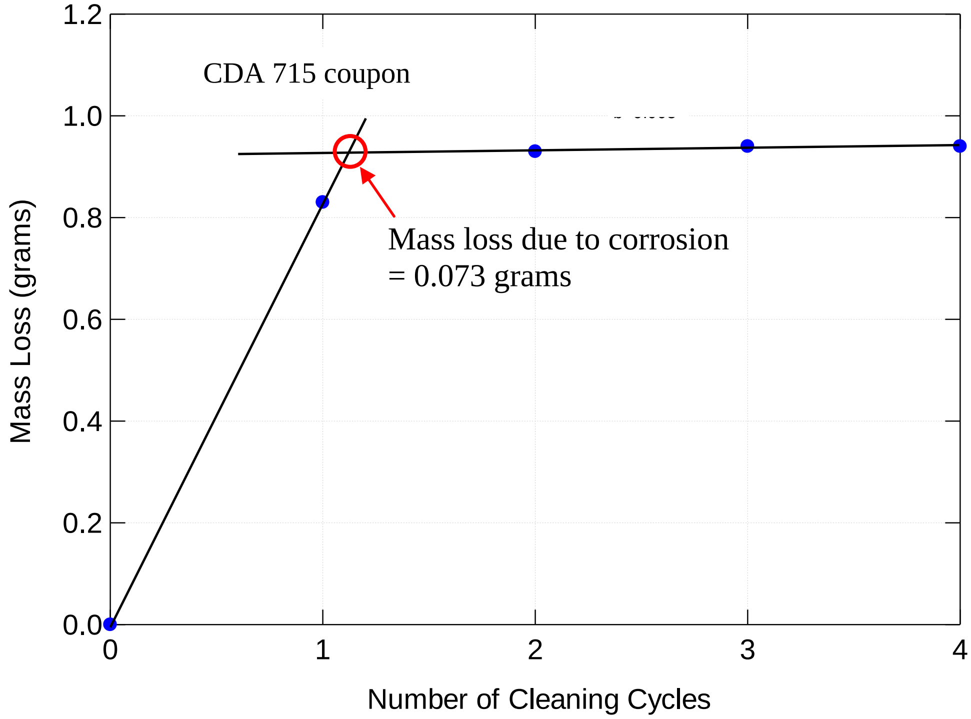


(a) CDA 715 Screen 1, After Cleaning 10X

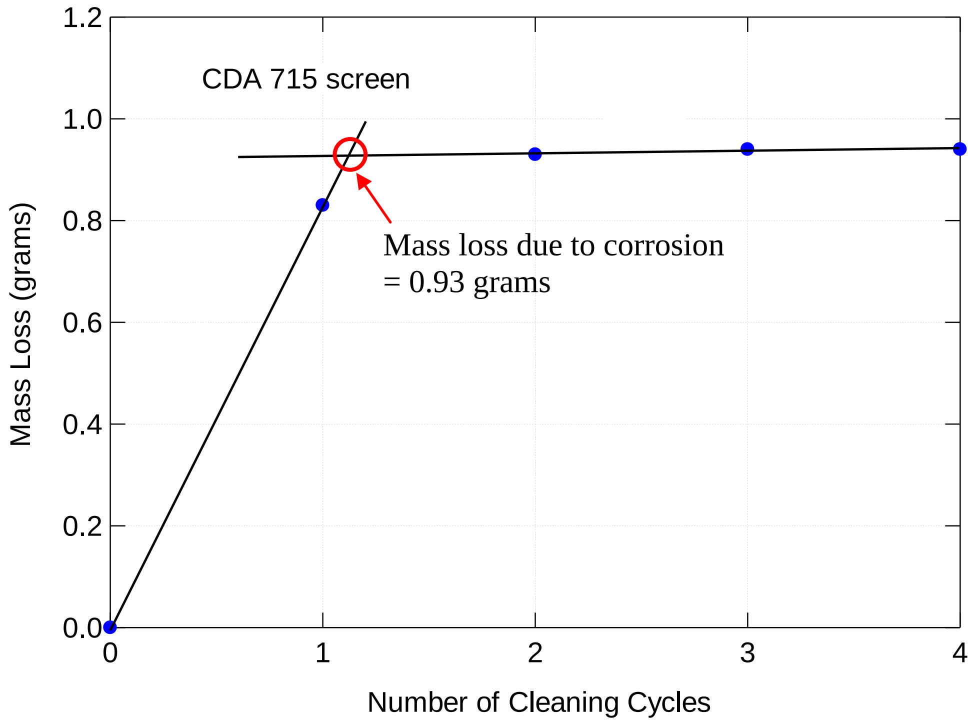


(b) CDA 715 Screen 1, After Cleaning 50X

Figure 10 Optical macrographs of CDA 715 screen 1 after a 3 month corrosion test, after cleaning.

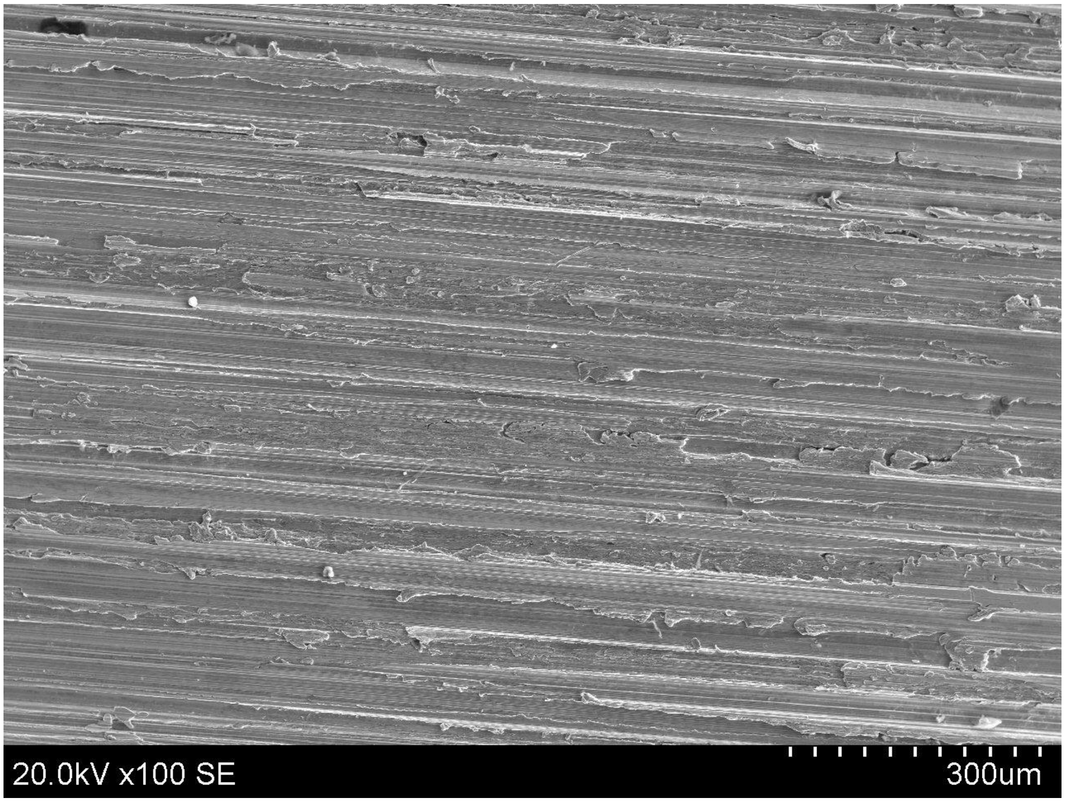


(a)

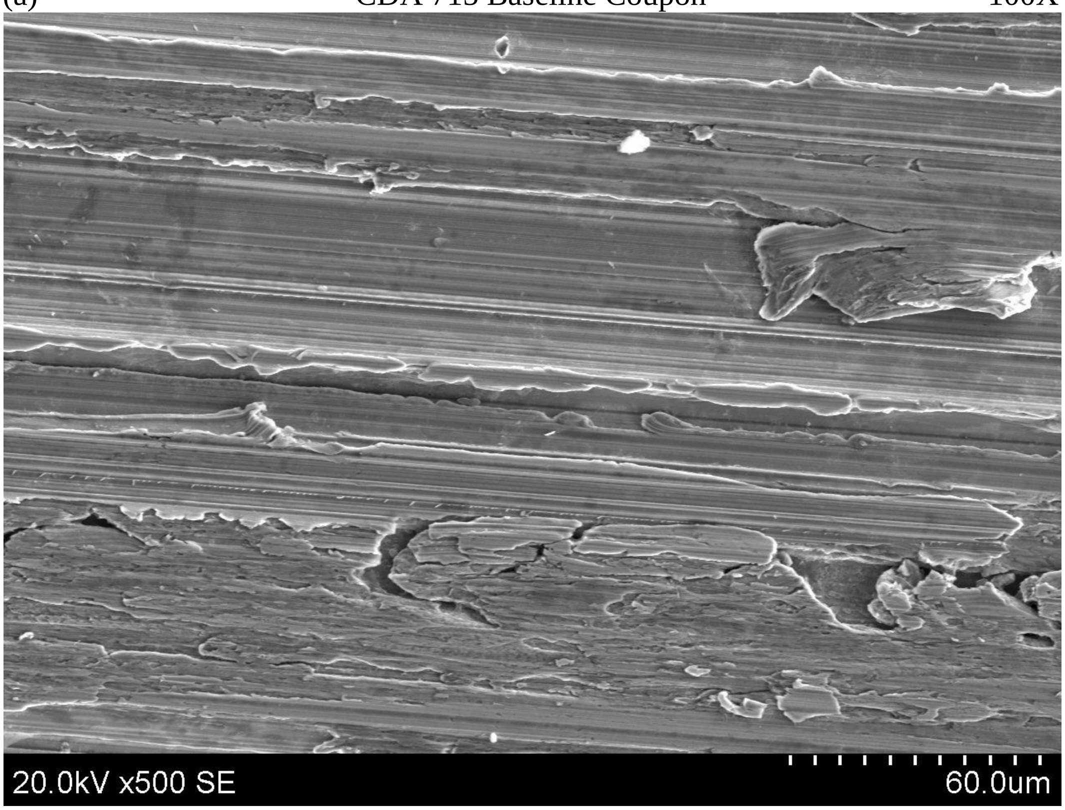


(b)

Figure 11 Mass loss of CDA 715 (a) coupon 1 and (b) screen 1 during cleaning.

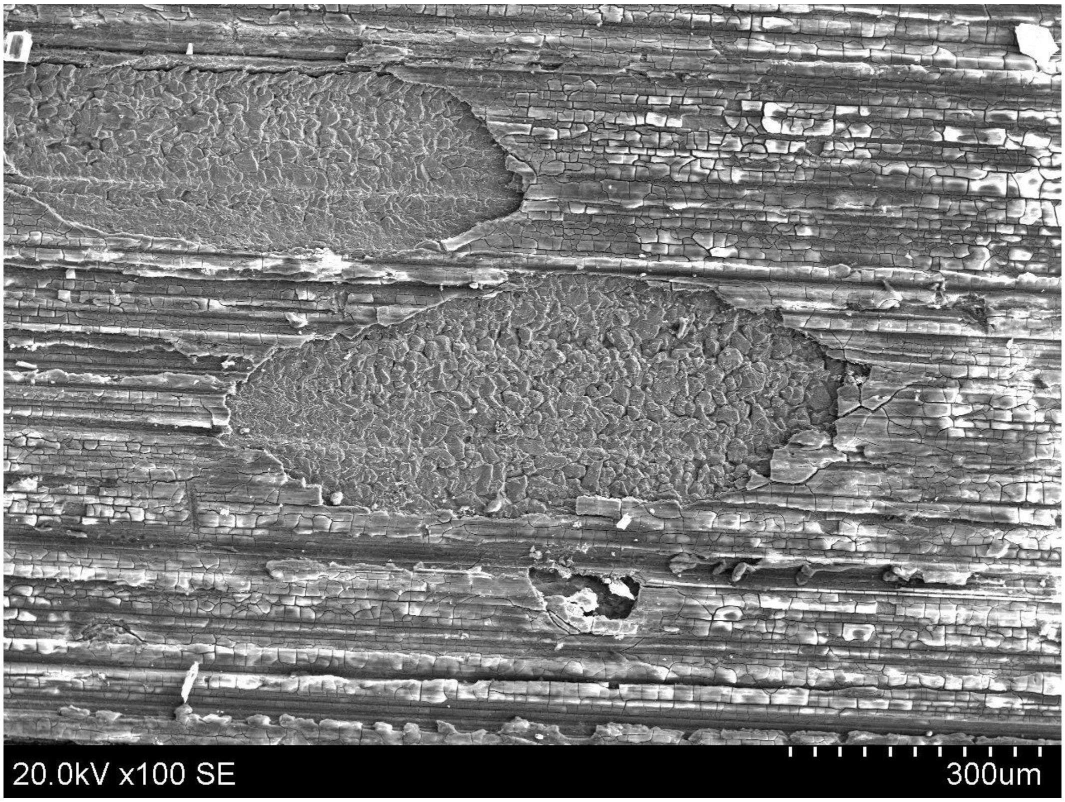


(a) CDA 715 Baseline Coupon 100X

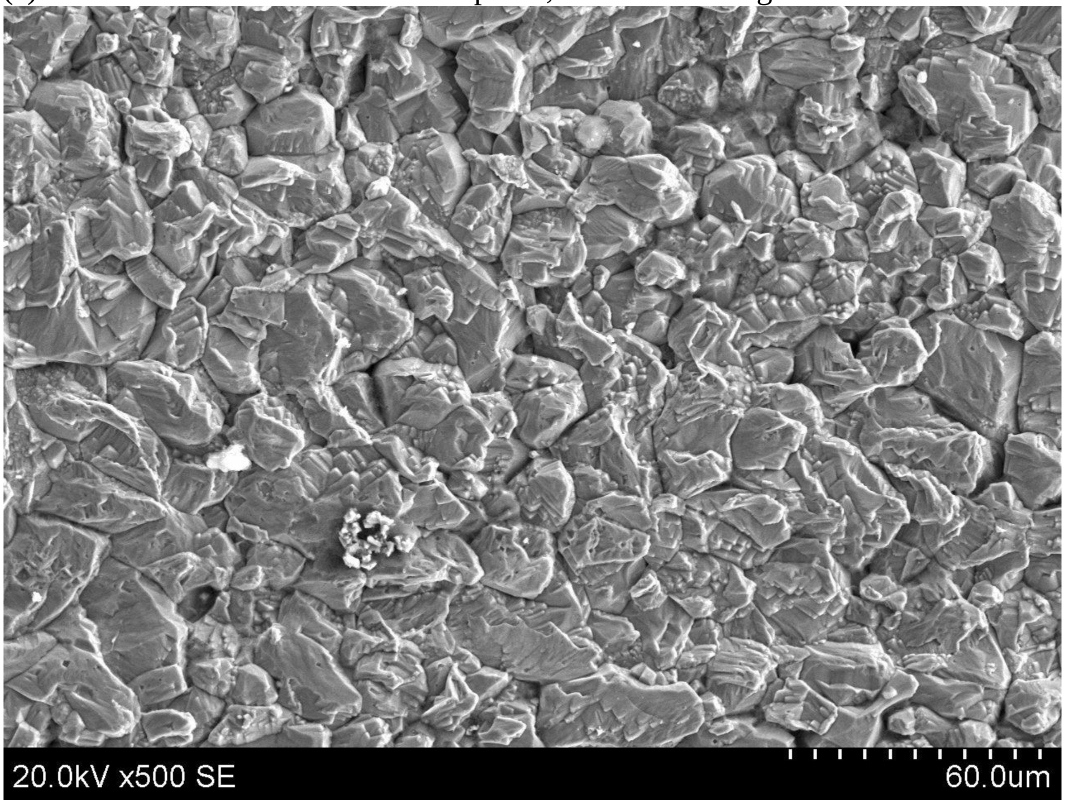


(b) CDA 715 Baseline Coupon 500X

Figure 12 Scanning electron micrographs of the CDA 715 baseline coupon.

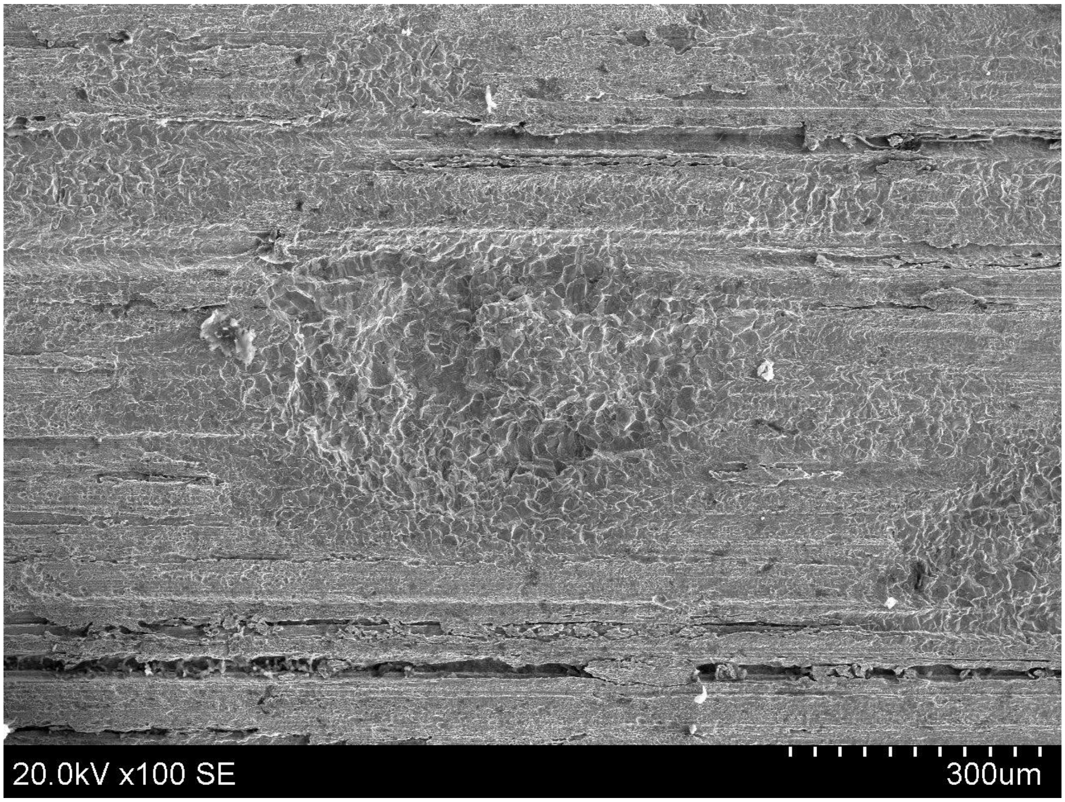


(a) CDA 715 Coupon 1, Before Cleaning 100X

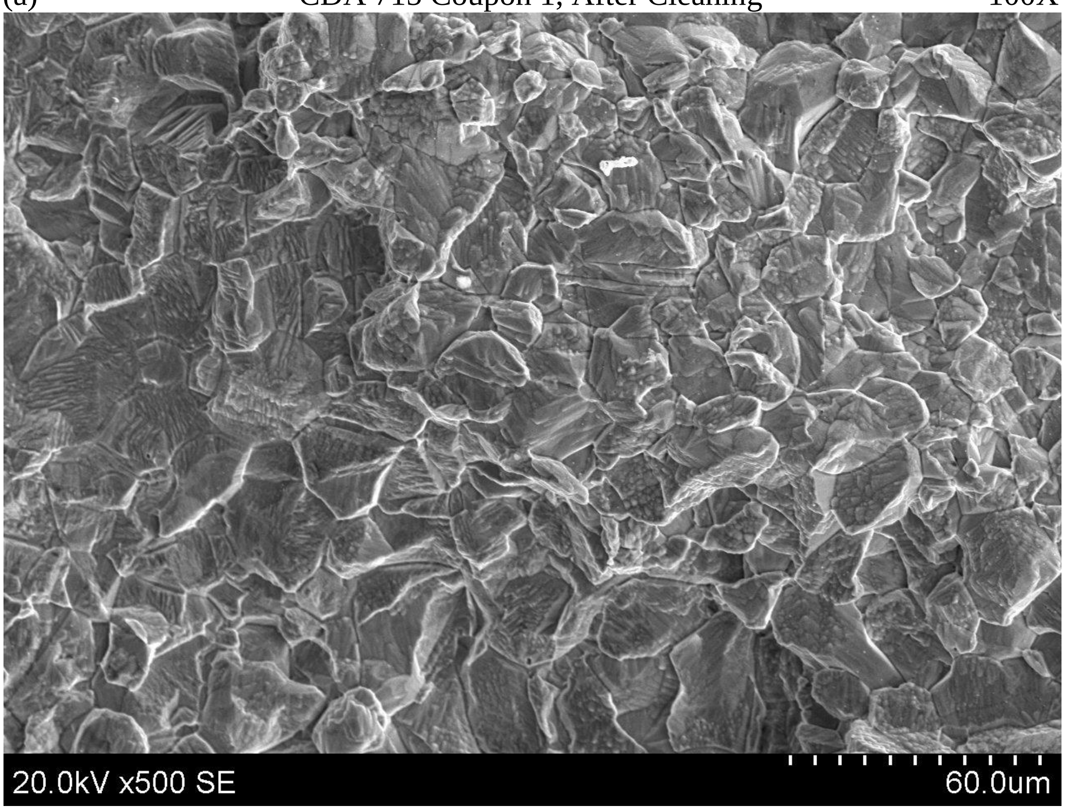


(b) CDA 715 Coupon 1, Before Cleaning 500X

Figure 13 Scanning electron micrographs of CDA 715 coupon 1 after a 3 month immersion test, before cleaning.

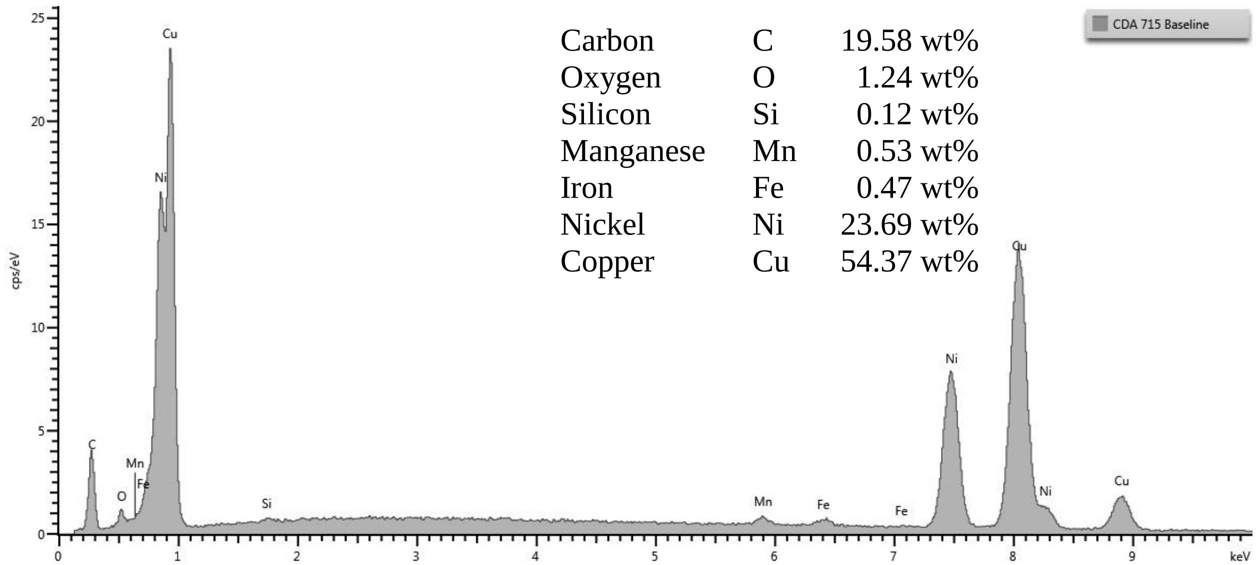


(a) CDA 715 Coupon 1, After Cleaning 100X



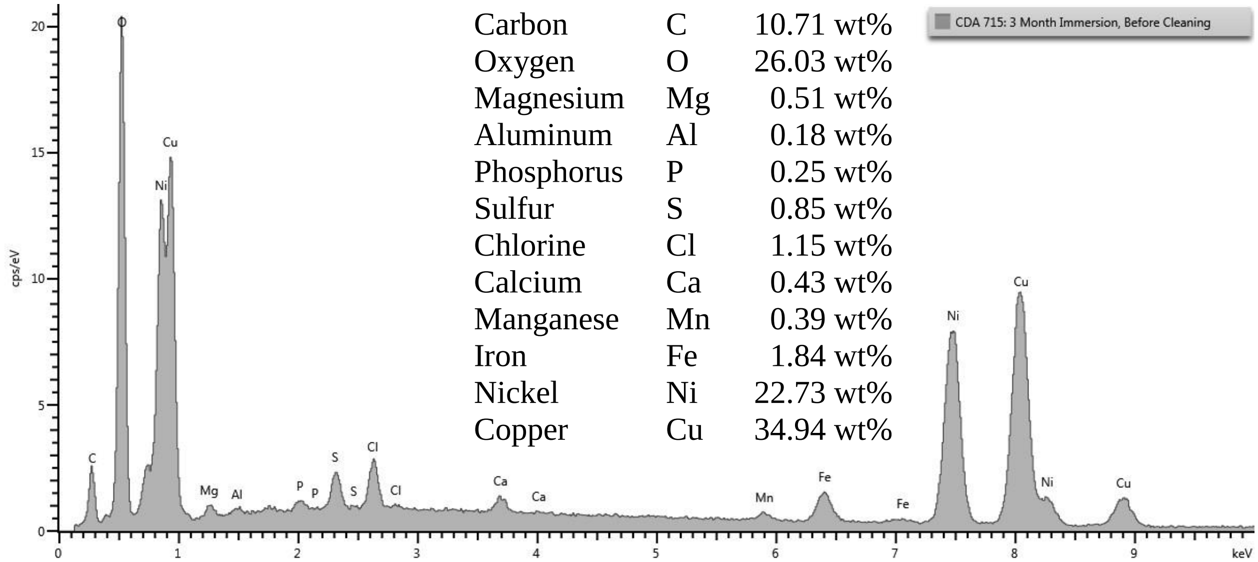
(b) CDA 715 Coupon 1, After Cleaning 500X

Figure 14 Scanning electron micrographs of CDA 715 coupon 1 after a 3 month immersion test, after cleaning.

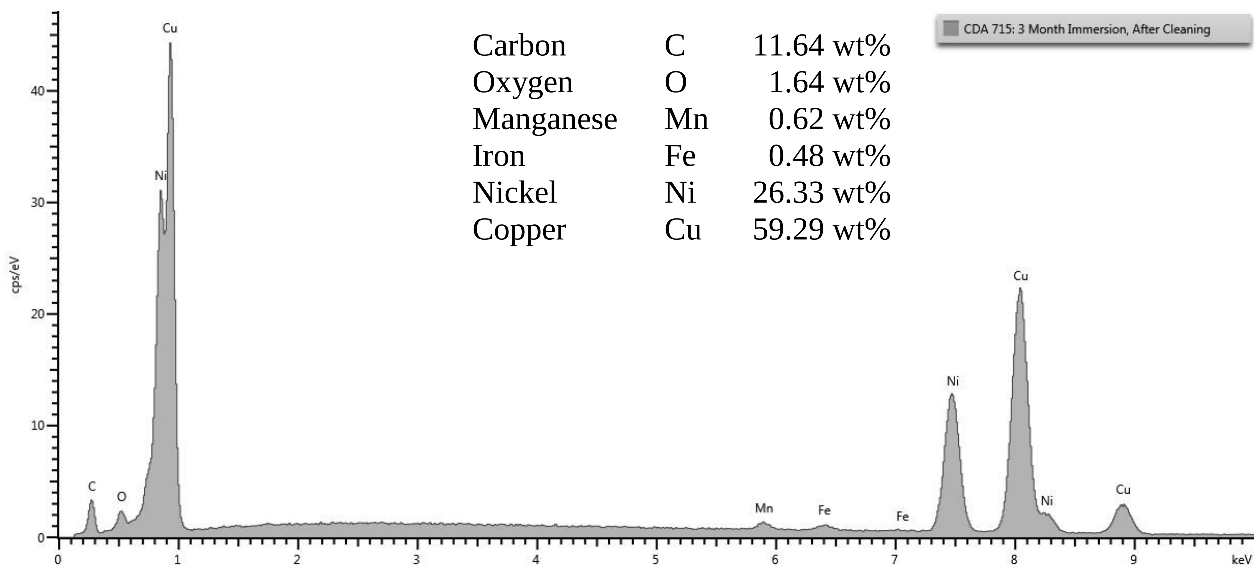


(a) CDA 715 Baseline Coupon

Figure 15 Energy dispersive x-ray spectra of the CDA 715 baseline coupon.

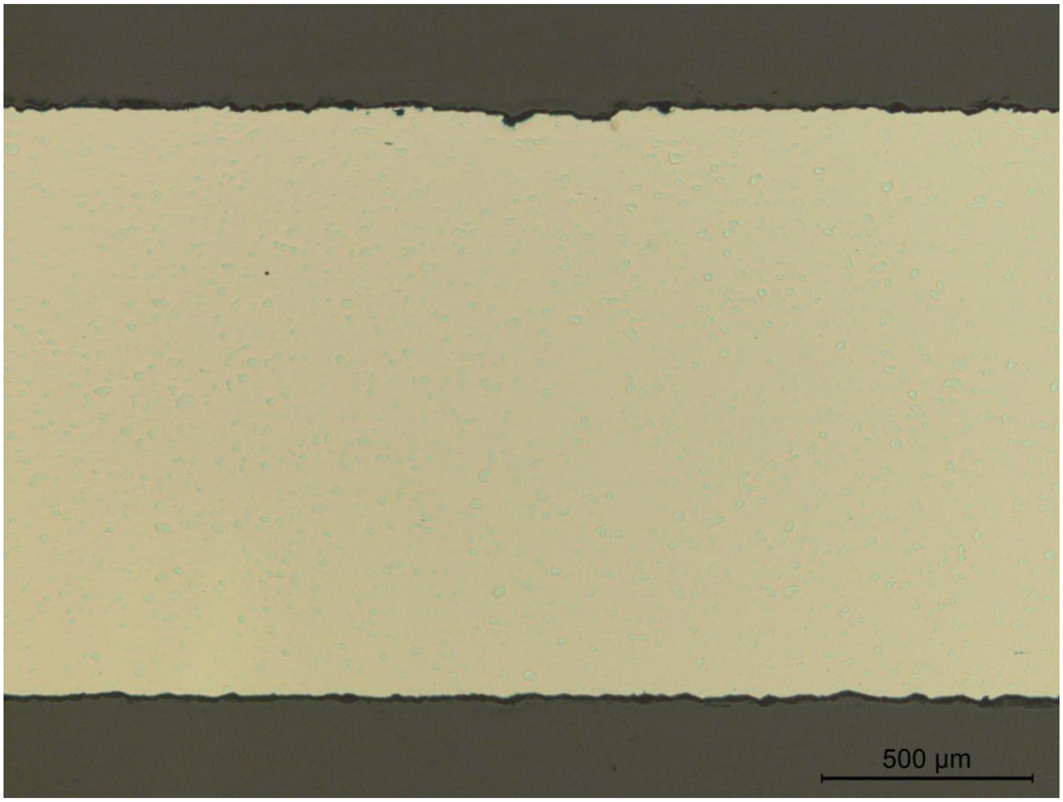


(a) CDA 715 Coupon 1, Before Cleaning

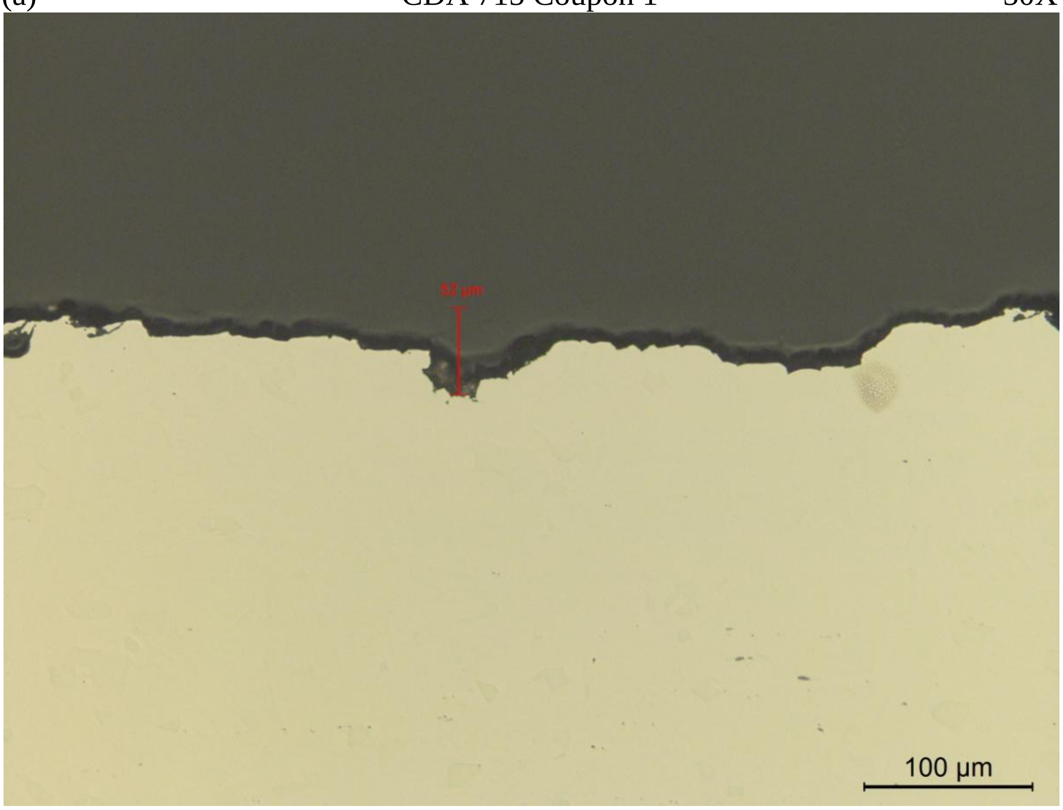


(b) CDA 715 Coupon 1, After Cleaning

Figure 16 Energy dispersive x-ray spectra of CDA 715 coupon 1 after a 3 month corrosion test (a) before cleaning and (b) after cleaning.



(a) CDA 715 Coupon 1 50X



(b) CDA 715 Coupon 1 200X

Figure 17 Optical micrographs of CDA 715 coupon 1.

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Report No. 5005.0361 **November 7, 2014**

CORROSION EVALUATION OF CDA 706 COUPONS AND SCREENS

Customer Authorization: Verbal

Report To: V & A Engineering
Attn: Manuel Najar
155 Grand Avenue, Suite 700
Oakland, CA 94612

1.0 INTRODUCTION

Five coupons, five wedge wire screens, and one plate were submitted by V&A Engineering for corrosion evaluation. The coupons were 1-inch by 3-inches by ¼-inch thick. The wedge wire screens were 4-inches by 4-inches by 1-inch tall with 4 mm spacing. The plate was 4-inches by 4-inches by 1/8-inch thick. The sample was reportedly CDA 706, a 90 wt% copper, 10 wt% nickel alloy.

Four coupons and four screens were to be placed in seawater for a period up to one year. After every 3 month interval, one coupon and one screen were to be removed from the test system and examined for corrosion. The purpose of this evaluation was to document the samples in the baseline as-received condition, then again after 3, 6, 9, and 12 months of water exposure, record any loss in mass, and examine for any pitting corrosion.

The samples were evaluated by the following laboratory procedures:

1) Visual examination and weighing
2) Cleaning per ASTM G1[1]
3) Scanning electron microscopy
4) Metallography

The results of the evaluation showed minimal mass loss and corrosion for the coupon and screen after 3 months of corrosion testing. The coupon and screen had a corrosion rate of approximately 0.022 millimeters per year and 0.129 millimeters per year, respectively.

[1] G1: Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

2.0 EVALUATION[2]

2.1 Visual Examination

The sample identifications for the coupons and wedge wire screens and their corresponding immersion times are shown in Table 1. The coupons had identification numbers stamped on the front face by V&A Engineering. A number of notches, corresponding to the sample number, were sawed at the edge of each screen for identification after the corrosion test. The weights of the samples were recorded. Coupons 1 – 4 and screens 1 – 5 were sent back to V&A for corrosion testing. Coupon 5 was the baseline sample and documented by photography, optical stereoscopy and scanning electron microscopy for comparison to the tested samples. Screen 5 was documented as a baseline by photography and optical stereoscopy, and then sent to V&A for testing.

Photographs of the baseline coupon are shown in Figure 1. Photographs of coupon 1, after 3 months of corrosion testing, are shown in Figure 2. A photograph of the baseline screen is shown in Figure 3. A photograph of screen 1, after 3 months of corrosion testing, is shown in Figure 4.

2.2 Cleaning

The coupon and screen were cleaned with solution C.2.1 per ASTM G1.[3] One cleaning cycle was approximately 1 minute. After each cleaning cycle, the samples were rinsed in water, dried, and weighed. The cleaning and weighing cycle was completed five times for the coupon and screen. The weights of the samples as-received, after corrosion testing but before cleaning, and after each cleaning cycle are presented in Table 2.

Optical macrographs of the baseline coupon and screen are shown in Figures 5 and 8, respectively. Representative optical macrographs of the samples before and after cleaning are shown in Figures 6 – 7 and 9 – 10. The mass loss versus the number of cleaning cycles was plotted, shown in Figure 11. The equations for best fit lines AB and BC, calculated using IGOR Pro, are listed in Table 3. Point B, indicated by the red circle in each plot, corresponds to the mass loss due to corrosion during the cleaning process for each sample. This mass loss was subtracted from the weight of the sample before cleaning and from the weight of the sample as-received to determine the total mass loss from corrosion. The corrosion rate of each sample was determined by the formula specified in Section 8.1 of ASTM G1:

$$Corrosion\ Rate = \frac{K\ x\ W}{A\ x\ T\ x\ D}$$

where K = 8.76×10^4, T = time of exposure in hours, A = area in cm^2, W = mass loss in grams, and D = density in g/cm^3. The total mass loss from corrosion and the calculated corrosion rate of each sample is shown in Table 4.

2.3 Scanning Electron Microscopy

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[2] The magnifications of the optical and scanning electron micrographs in this report are approximate and should not be used as a basis for dimensional analyses unless otherwise indicated.
[3] 500 mL hydrochloric acid + 500 ml reagent water.

The baseline coupon and coupon 1 were examined with a scanning electron microscope. Representative scanning electron micrographs of the baseline coupon are shown in Figure 12. Representative scanning electron micrographs of coupon 1 before and after cleaning are shown in Figures 13 – 14. Energy dispersive x-ray spectra of the baseline coupon and coupon before and after cleaning are shown in Figures 15 – 16.

2.4 Metallography

Cross sections were taken from the coupon and prepared for a metallographic examination. Optical micrographs of the surface for coupon 1 are shown in Figure 17. A wide, shallow pit was observed in coupon 1, measuring 80 μm deep.

3.0 DISCUSSION

The coupon and screen showed minimal mass loss and pitting after 3 months of corrosion testing. The coupon had lost 0.256 grams of material and had a corrosion rate of 0.022 millimeters per year. The screen had lost 14.48 grams of material and had a corrosion rate of 0.129 millimeters per year.

4.0 CONCLUSIONS[4]

The following conclusions are based upon the submitted samples and the evidence gathered:

1. The coupon, after 3 months of corrosion testing, had a mass loss of 0.256 grams and a corrosion rate of 0.022 mm / year.

2. The screen, after 3 months of corrosion testing, had a mass loss of 14.48 grams and a corrosion rate of 0.129 mm / year.

Prepared by:	Reviewed by:
Norman Yuen (signature)	Audrey A Fasching (signature)
Norman Yuen Materials Engineer	Audrey A. Fasching, Ph.D., P.E. Senior Materials Engineer

[4] The conclusions in this report are based upon the available information and evidence provided by the client and gathered by Anamet, within the scope of work authorized by the client, and they are hereby presented by Anamet to a reasonable degree of engineering and scientific certainty. Anamet reserves the right to amend or supplement its conclusions or opinions presented in this report should additional data or information become available, or further work be approved by the client.

Table 1
Sample Identifications

Description		V&A Engineering Identification (As-Received)	Anamet Identification (in report)	Notes
Alloy	Part			
CDA 706 (Cu 90 – Ni 10)	**Flat Plate** 4-inch x 4-inch x 1/8-inch	CDA 706 1	Plate	None
	Coupon 1-inch x 3-inch x 1/8-inch with autogenous weld bead	CDA 706W 1	Coupon 1	3 Month Immersion
		CDA 706W 2	Coupon 2	6 Month Immersion
		CDA 706W 3	Coupon 3	9 Month Immersion
		CDA 706W 4	Coupon 4	12 Month Immersion
		CDA 706W 5	Coupon 5	Baseline Sample (no exposure)
	Wedge Wire Screen 4-inch x 4-inch x 1-inch with 2 mm spacing	None	Screen 1	3 Month Immersion
		None	Screen 2	6 Month Immersion
		None	Screen 3	9 Month Immersion
		None	Screen 4	12 Month Immersion
		None	Screen 5	12 Month Immersion

Table 2
Sample Weights

Sample	Baseline Measurement	Measurements after 3 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 1	25.8560	25.6429	25.6003	25.5972	25.5954	25.5930	25.5915
Screen 1	310.59	301.27	298.54	296.15	295.97	295.80	295.78

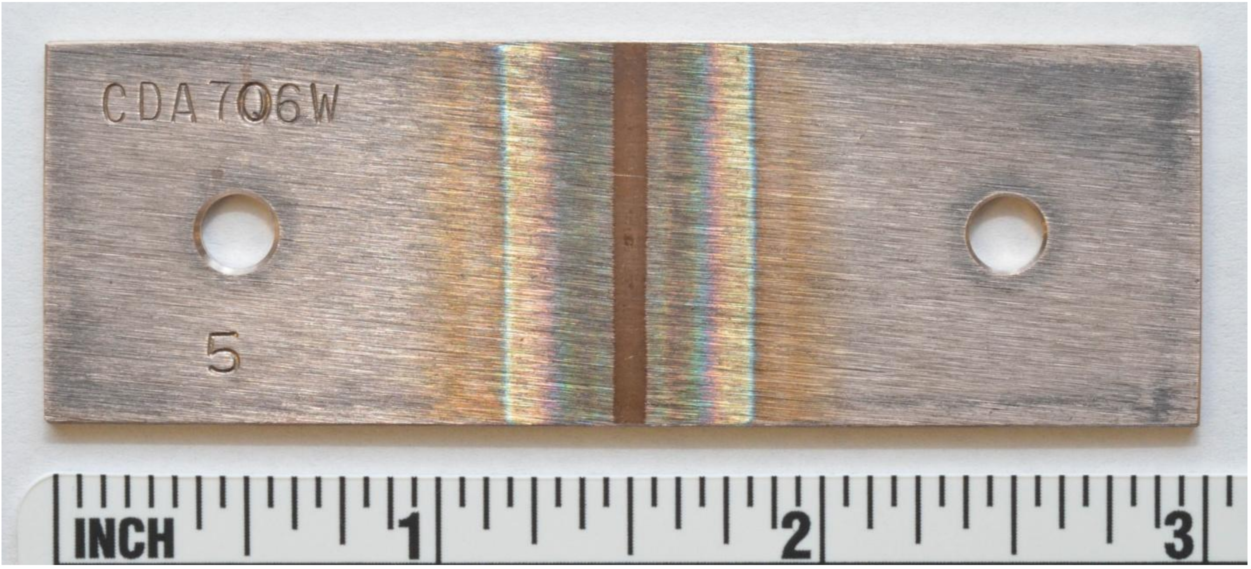
Table 3
Equations of Lines AB and BC for Corrosion Testing Samples

Sample	Line AB	Line BC	Point B (Approximate Mass Loss from Corrosion)
Coupon 1	y = 0.043x	y = 0.002x + 0.041	0.043 grams
Screen 1	y = 2.59x	y = 0.13x + 4.90	5.16 grams

Table 4
Total Mass Loss from Corrosion and Corrosion Rate

Sample	Total Mass Loss from Corrosion*	Corrosion Rate
Coupon 1	0.256 grams	0.022 mm / year
Screen 1	14.48 grams	0.129 mm / year

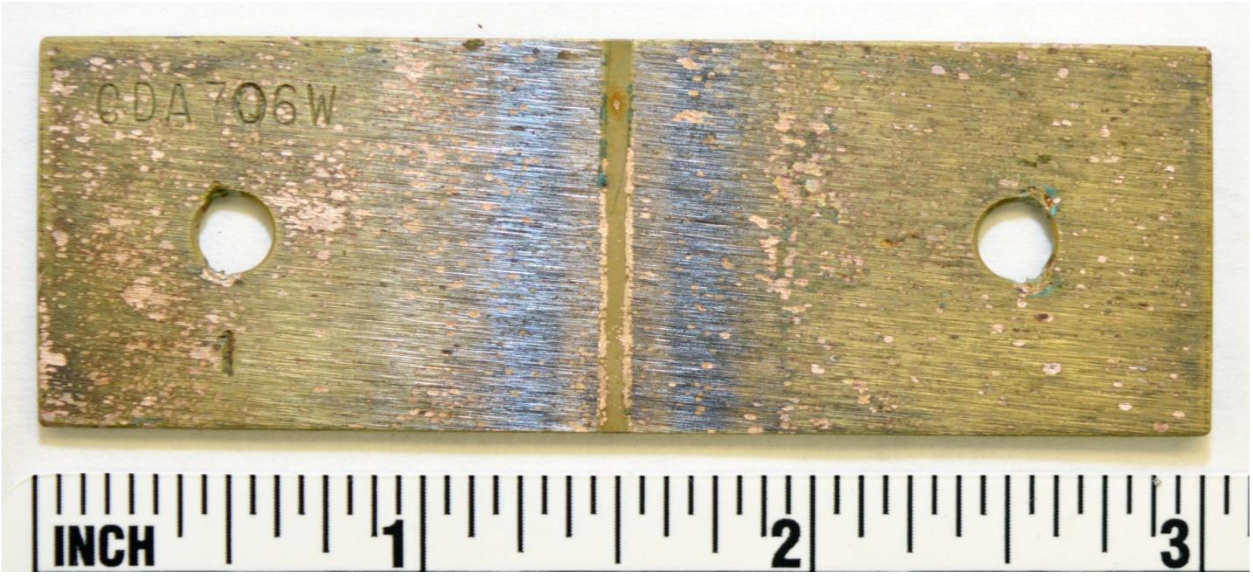
* Weight As-Received – (Weight Before Cleaning – Mass Loss from Corrosion During Cleaning)



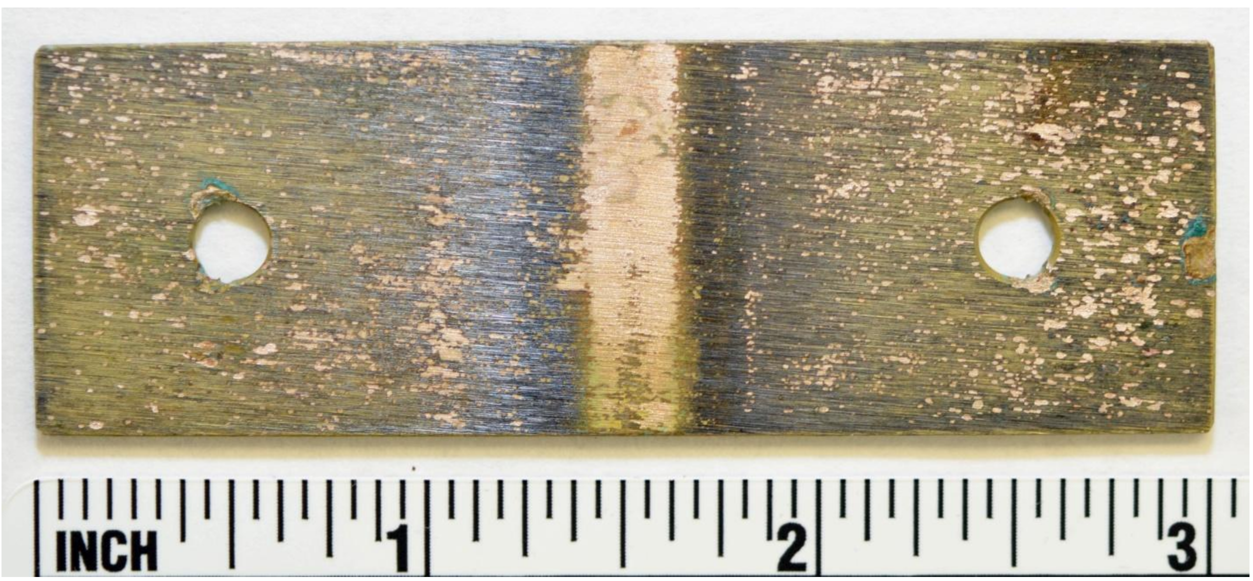
(a) CDA 706 Baseline Coupon, Front Side

(b) CDA 706 Baseline Coupon, Back Side

Figure 1 Photographs of the CDA 706 baseline coupon (a) front and (b) back side.

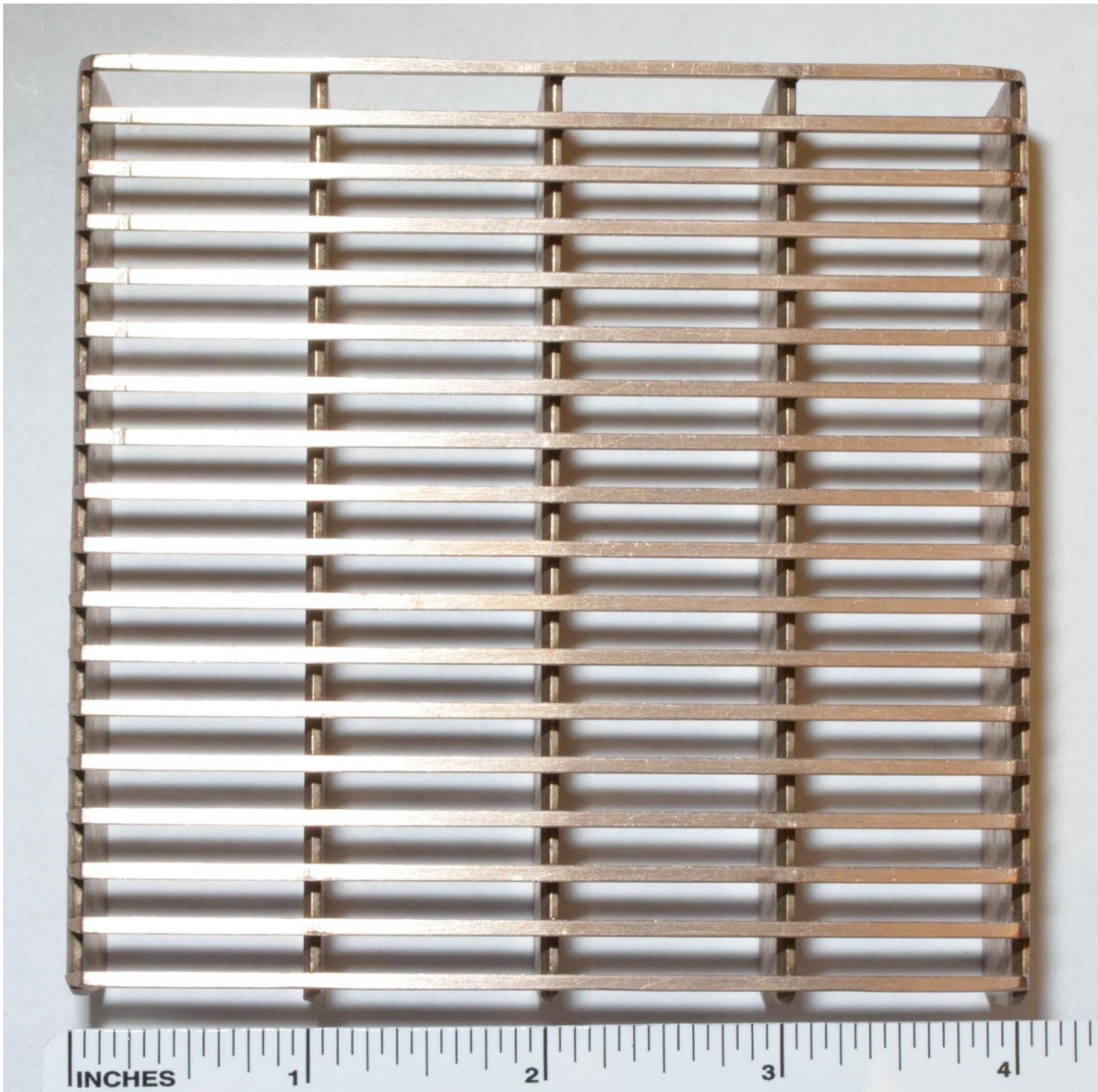


(a) CDA 706 Coupon 1, Front Side



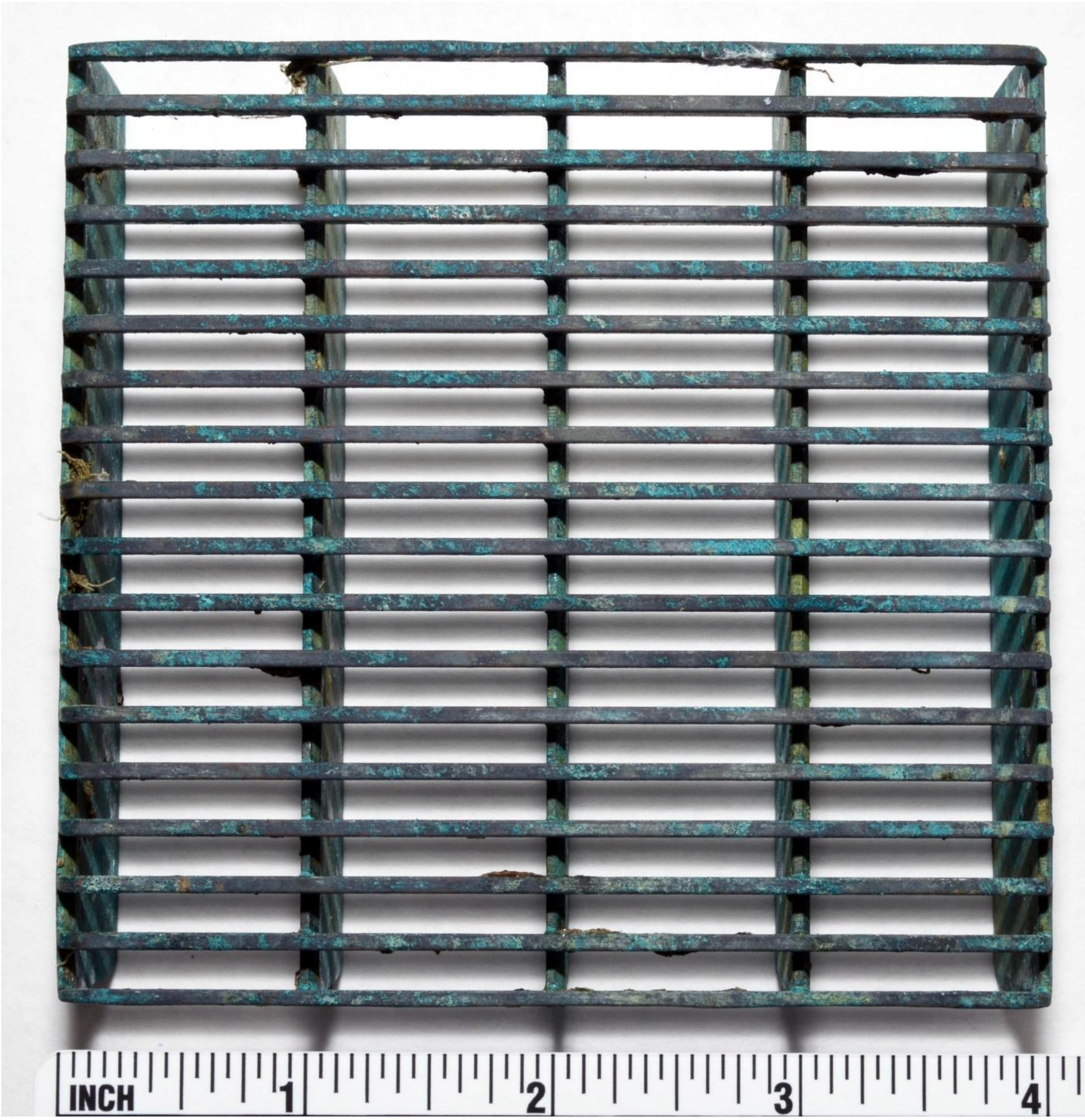
(b) CDA 706 Coupon 1, Back Side

Figure 2 Photographs of CDA 706 coupon 1 (a) front and (b) back side after a 3 month corrosion test.



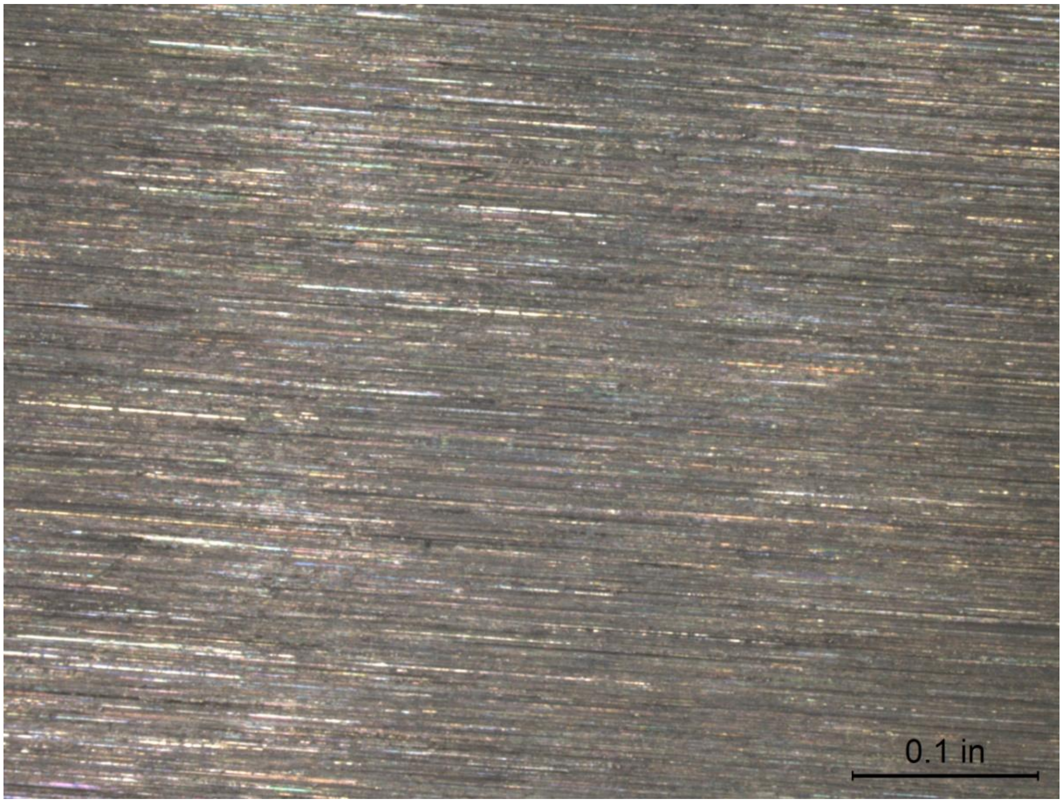
(a) CDA 706 Baseline Screen

Figure 3 Photograph of the CDA 706 baseline screen.

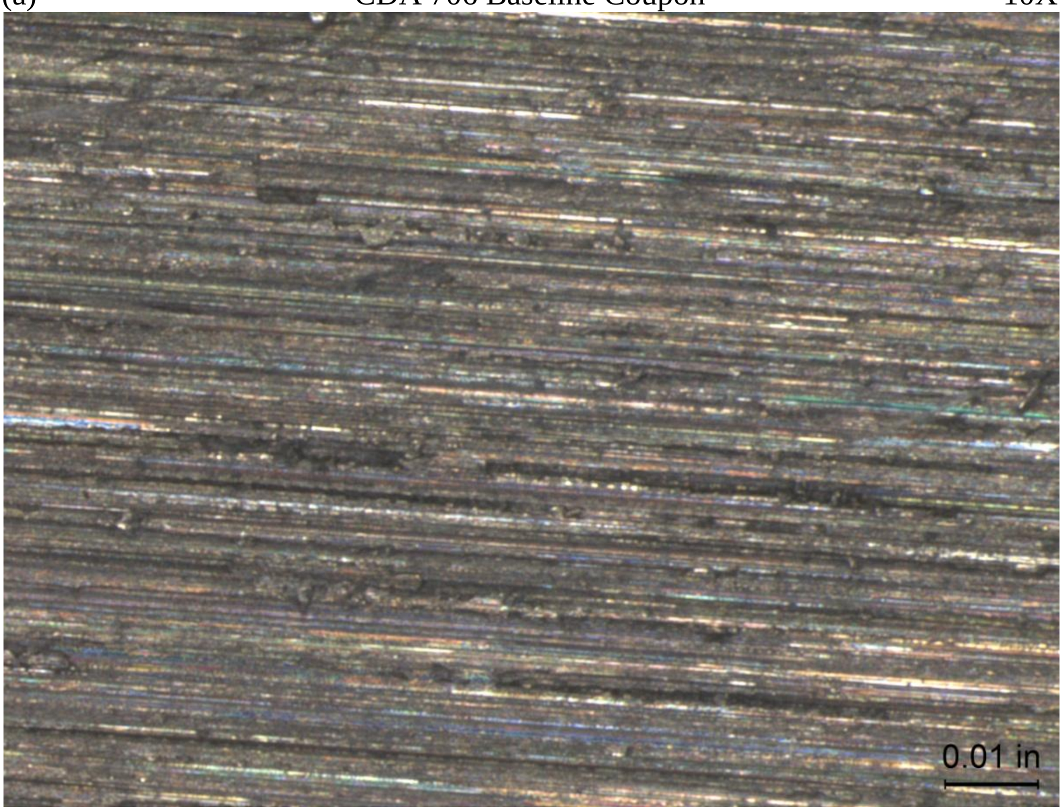


(a) CDA 706 Screen 1

Figure 4 Photograph of CDA 706 screen 1 after a 3 month corrosion test.

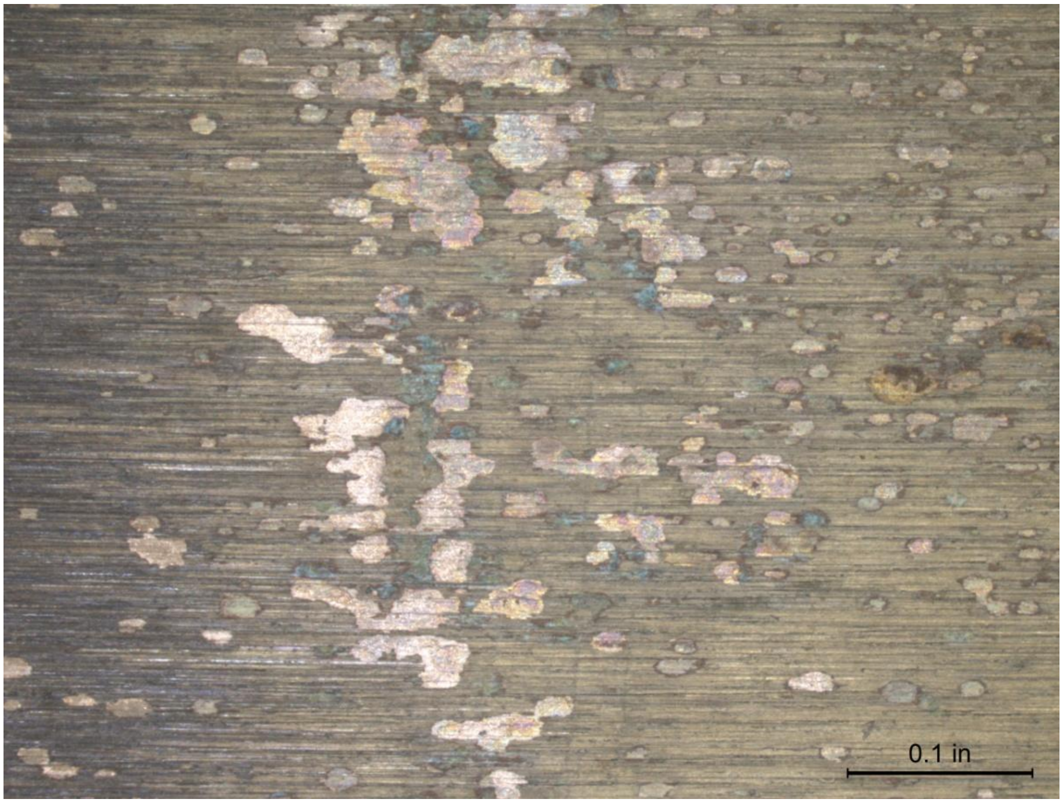


(a) CDA 706 Baseline Coupon 10X

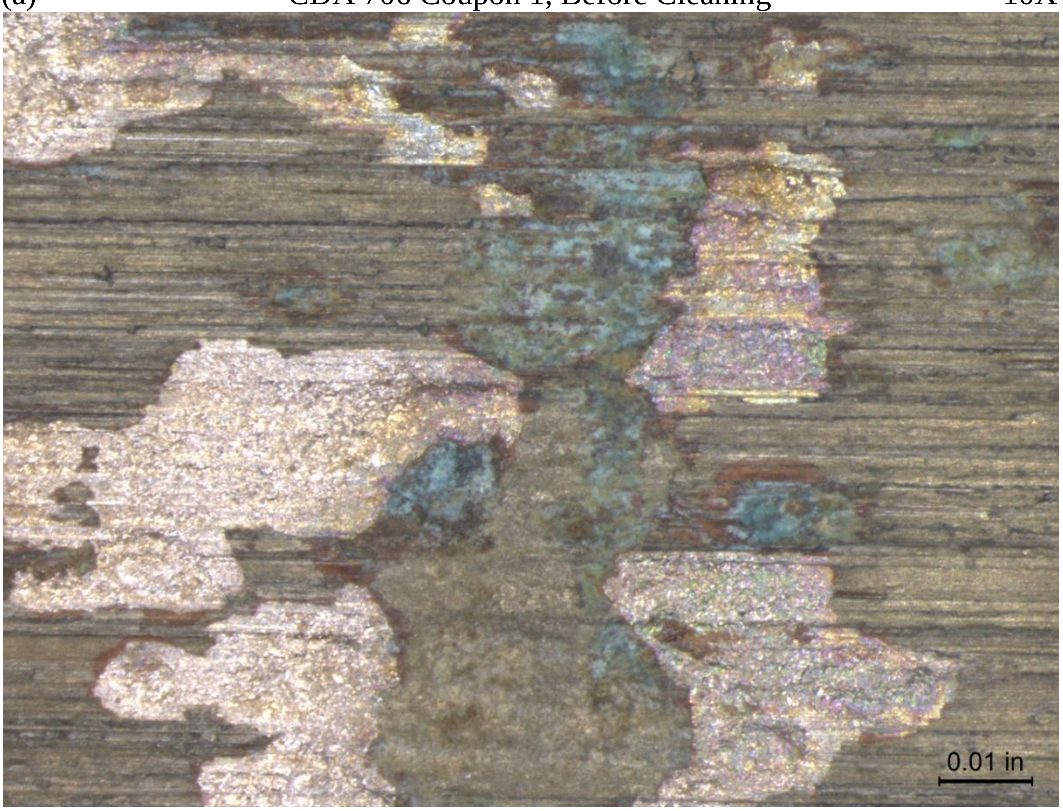


(b) CDA 706 Baseline Coupon 50X

Figure 5 Optical macrographs of the CDA 706 baseline coupon.



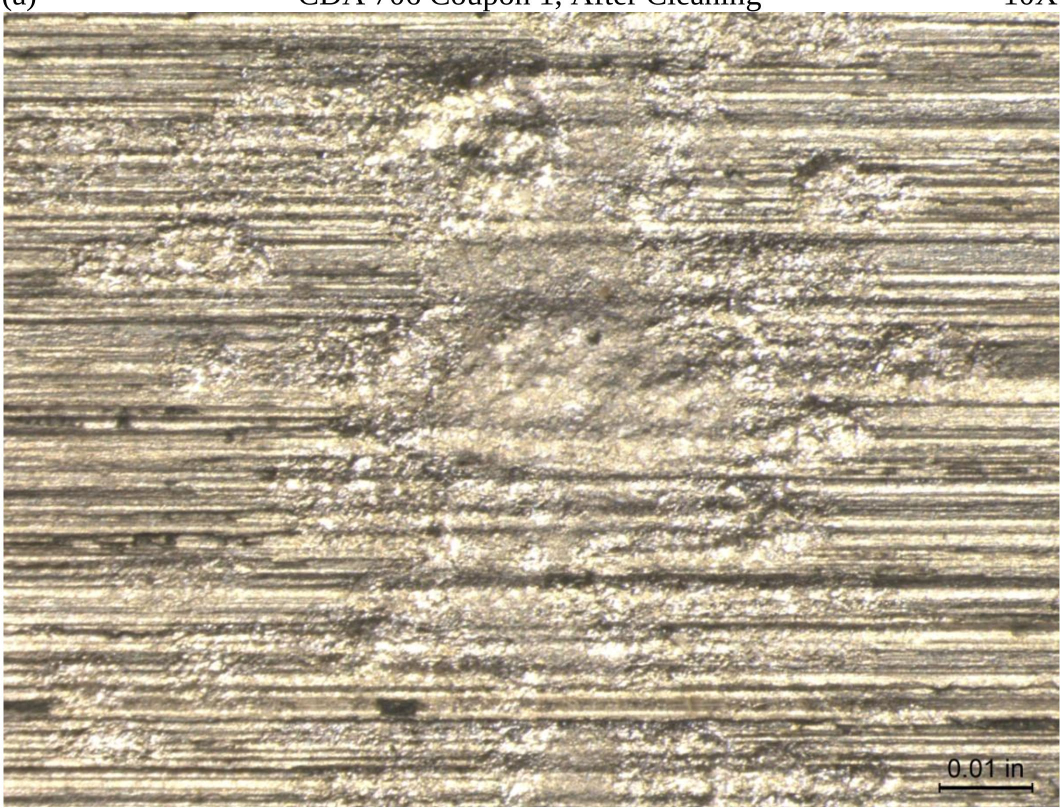
(a) CDA 706 Coupon 1, Before Cleaning 10X



(b) CDA 706 Coupon 1, Before Cleaning 50X

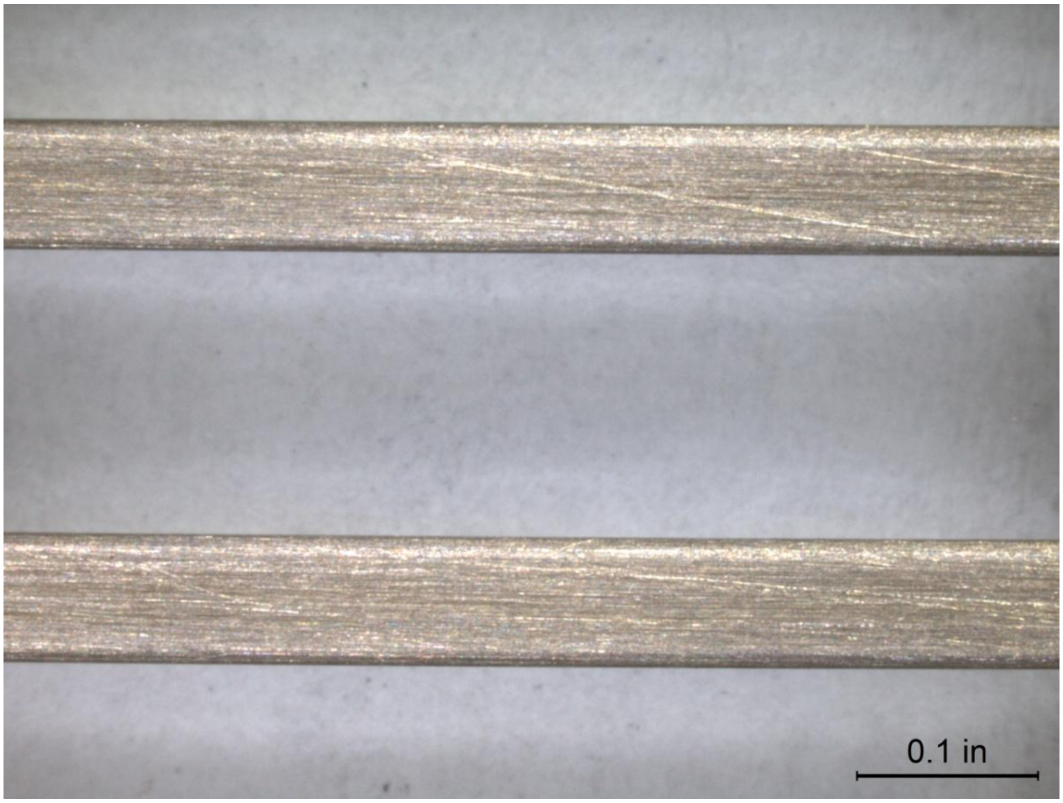
Figure 6 Optical macrographs of CDA 706 coupon 1 after a 3 month corrosion test, before cleaning.

(a) CDA 706 Coupon 1, After Cleaning 10X

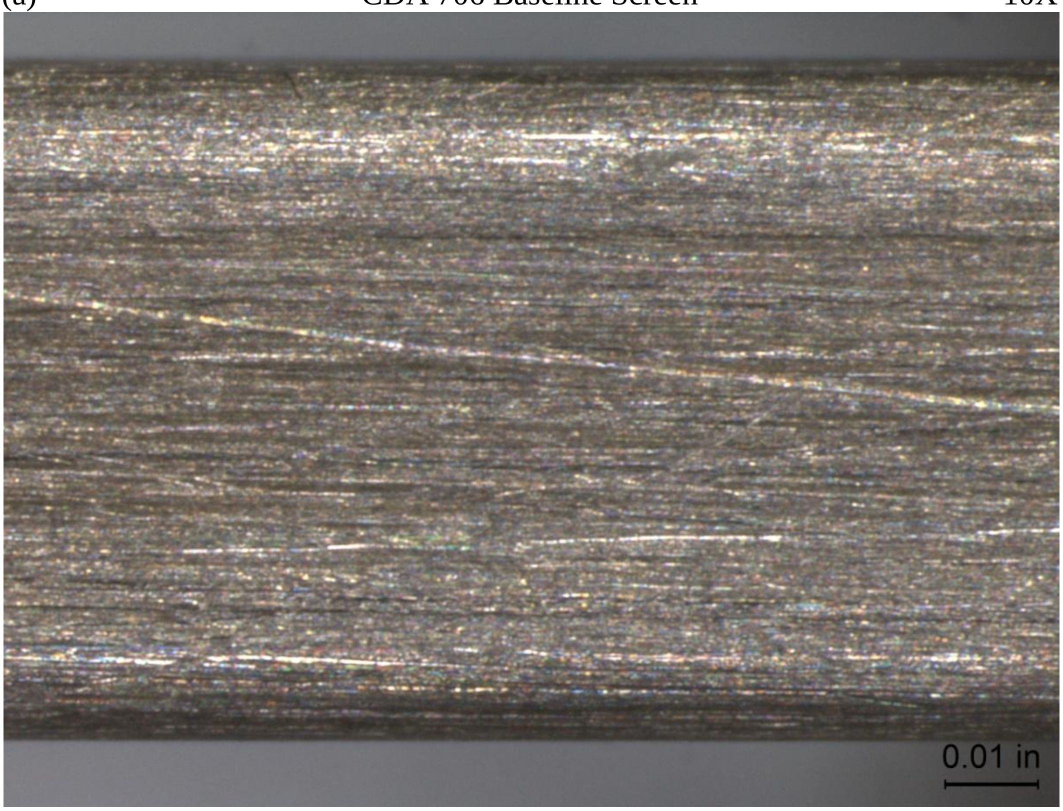


(b) CDA 706 Coupon 1, After Cleaning 50X

Figure 7 Optical macrographs of CDA 706 coupon 1 after a 3 month corrosion test, before cleaning.

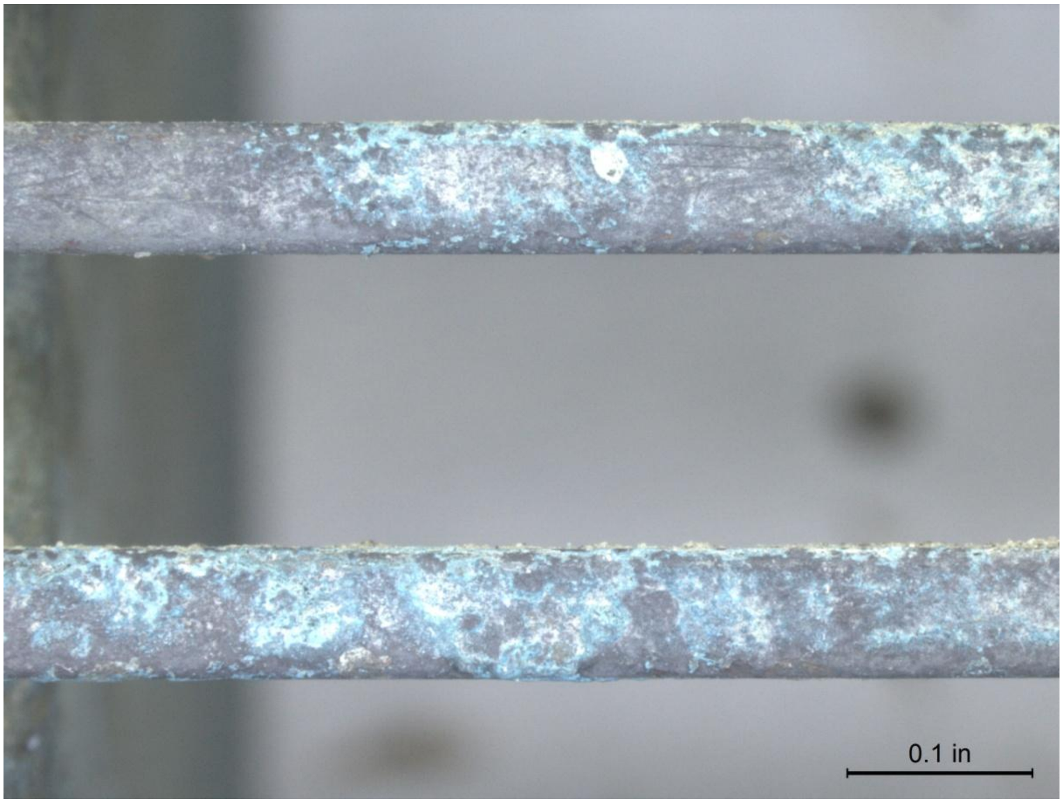


(a) CDA 706 Baseline Screen 10X

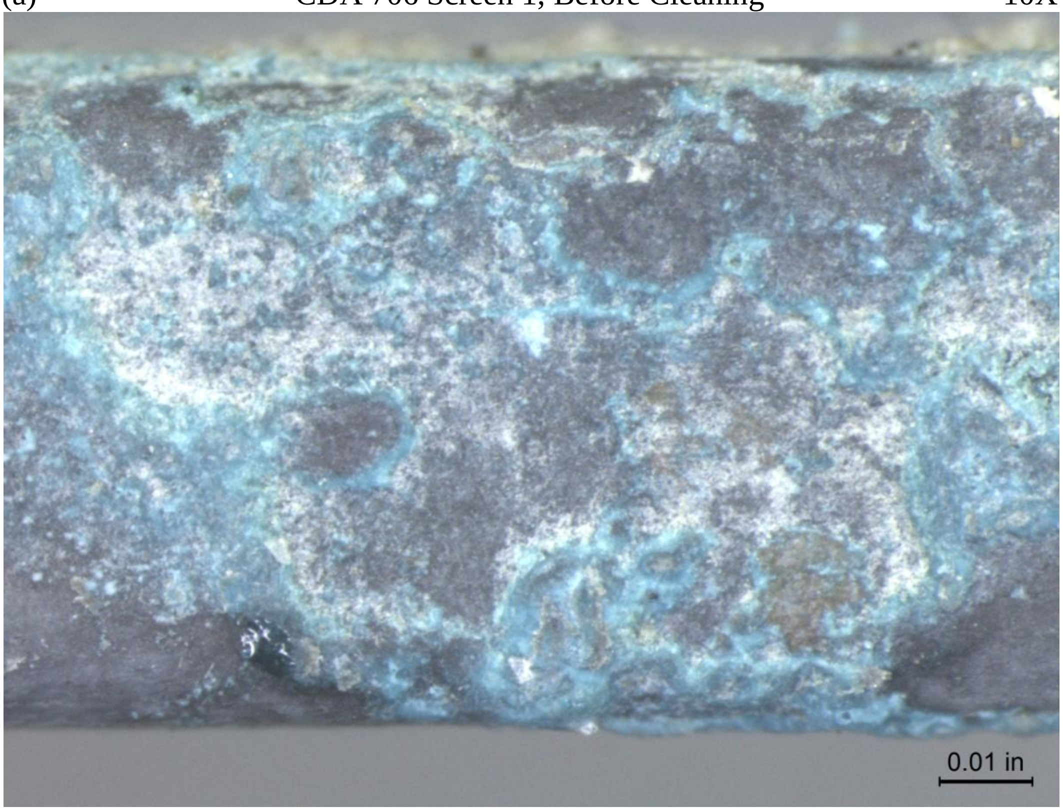


(b) CDA 706 Baseline Screen 50X

Figure 8 Optical macrographs of the CDA 706 baseline screen.

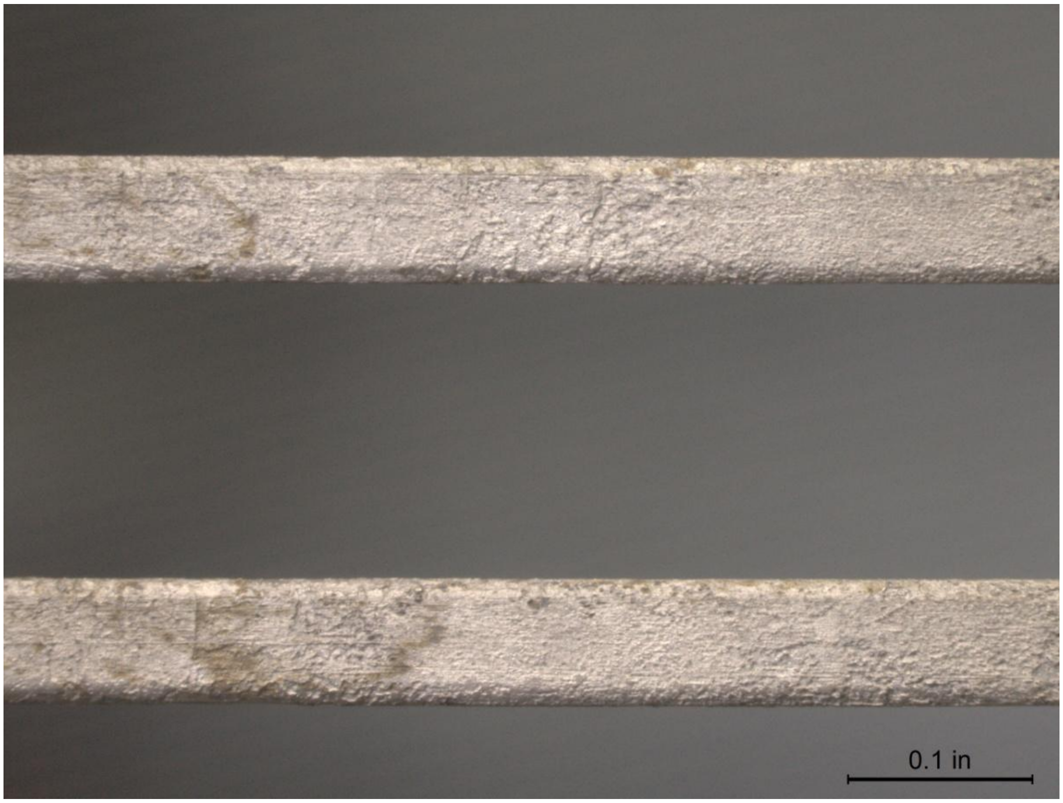


(a) CDA 706 Screen 1, Before Cleaning 10X

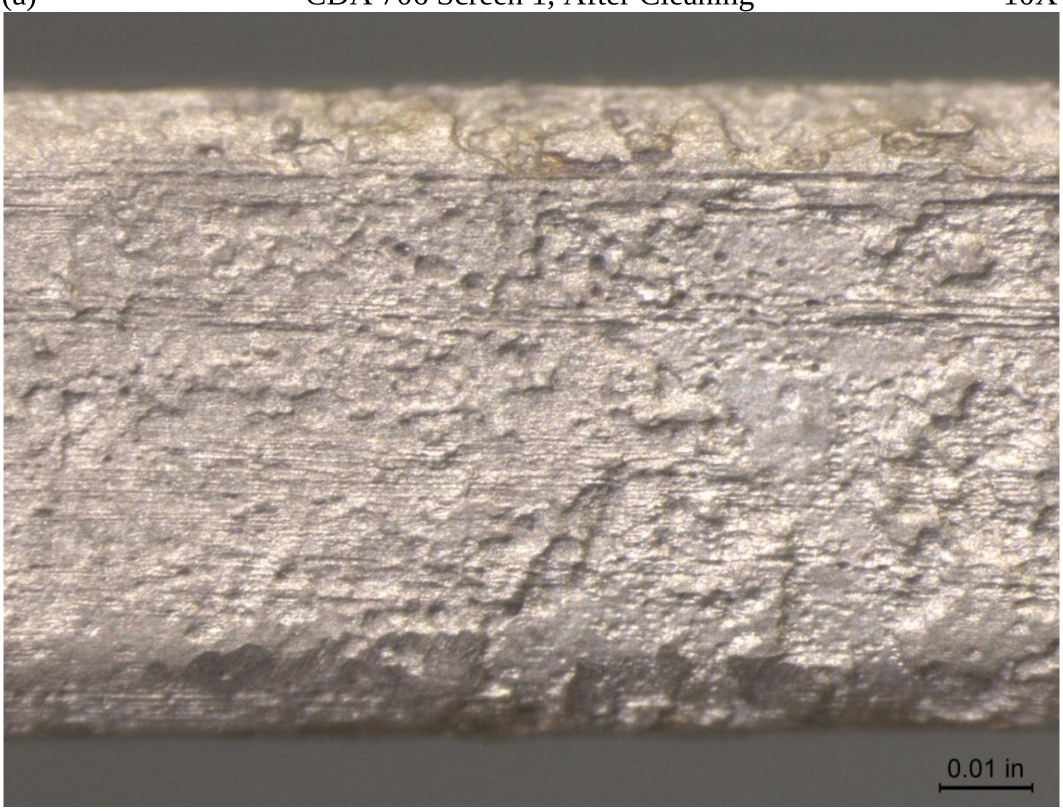


(b) CDA 706 Screen 1, Before Cleaning 50X

Figure 9 Optical macrographs of CDA 706 screen 1 after a 3 month corrosion test, before cleaning.



(a) CDA 706 Screen 1, After Cleaning 10X



(b) CDA 706 Screen 1, After Cleaning 50X

Figure 10 Optical macrographs of CDA 706 screen 1 after a 3 month corrosion test, after cleaning.

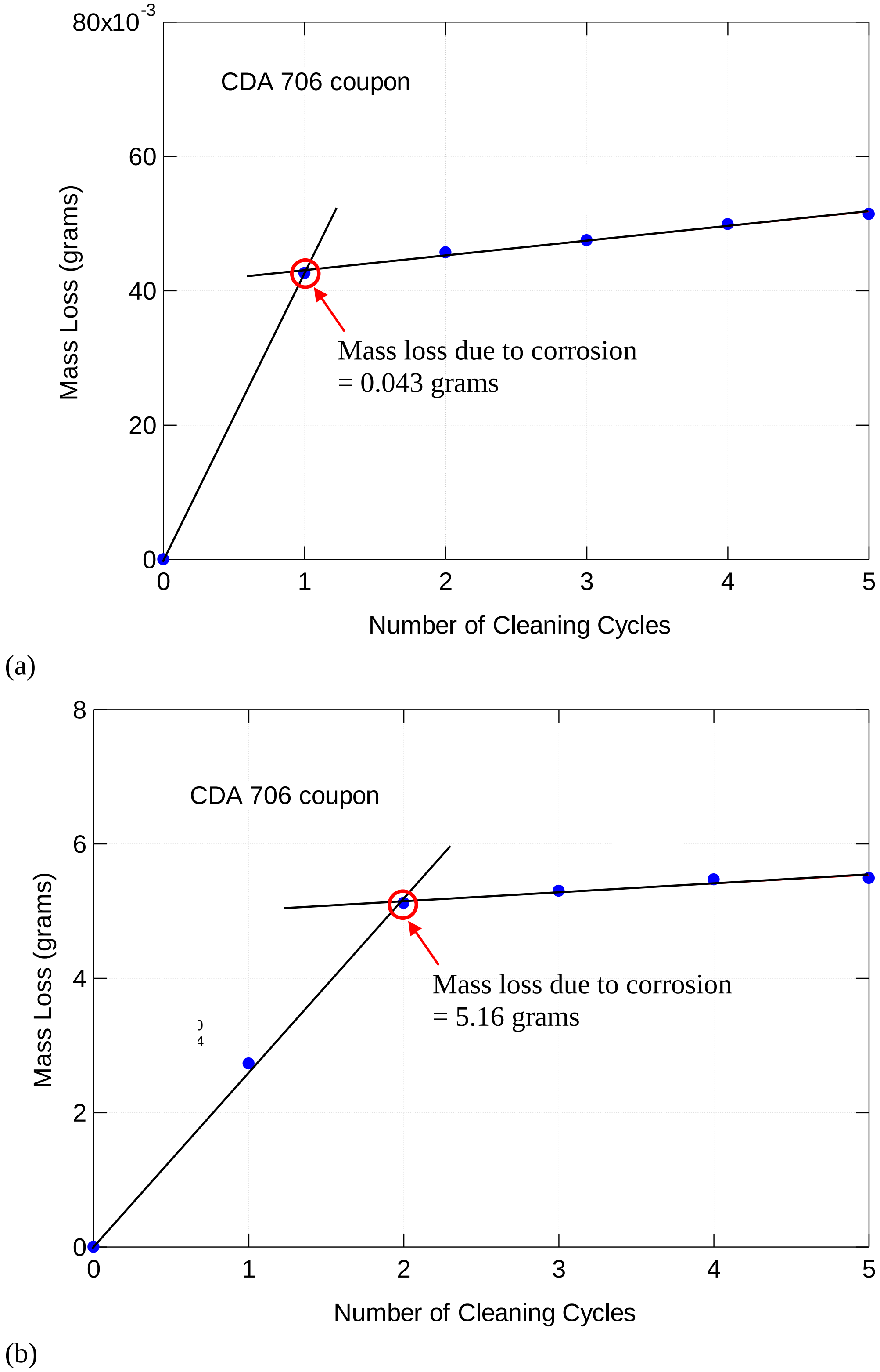
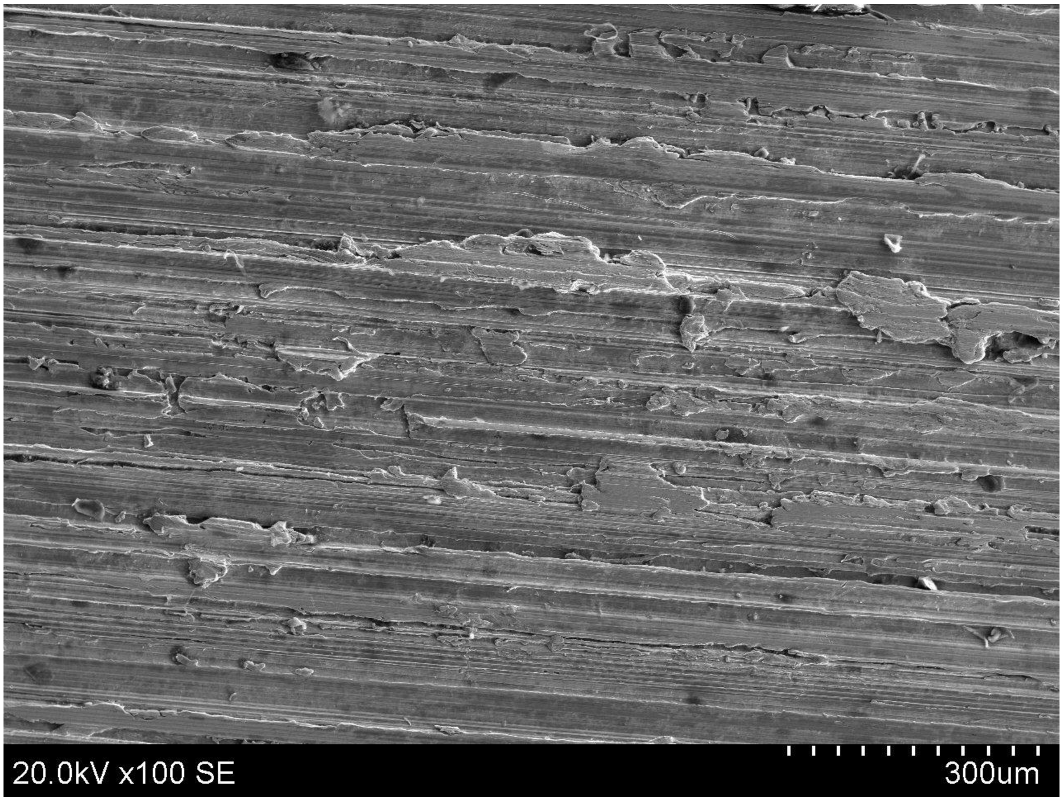
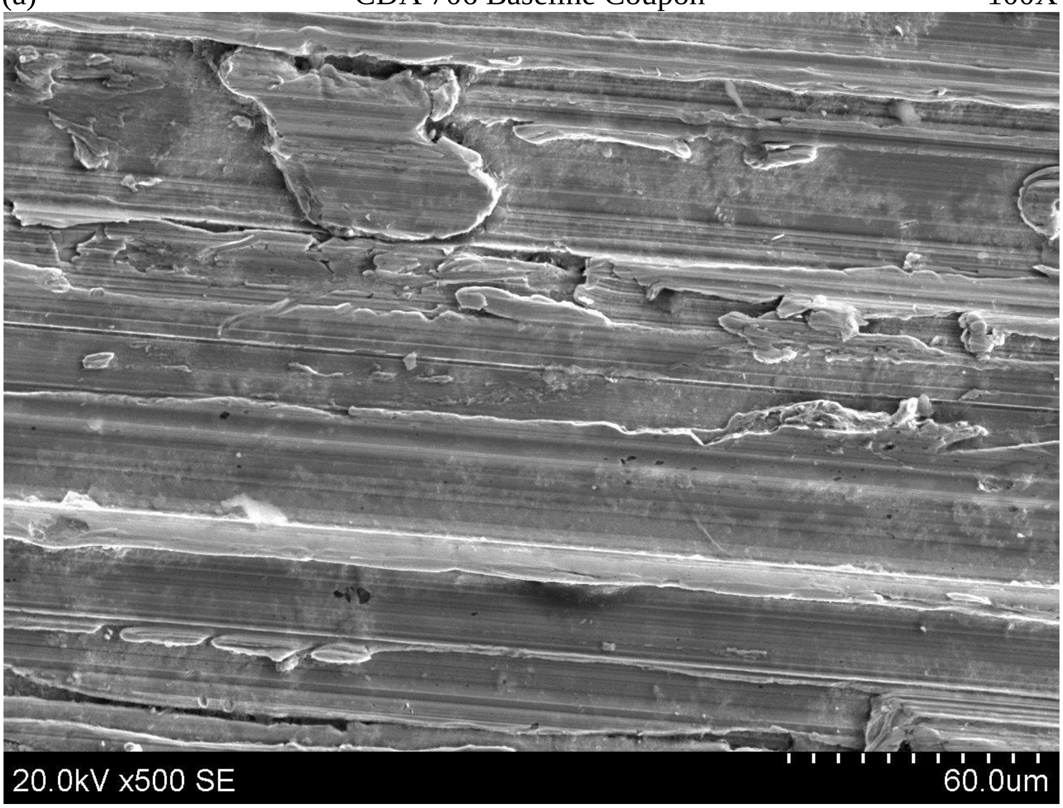


Figure 11 Mass loss of CDA 706 (a) coupon 1 and (b) screen 1 during cleaning.

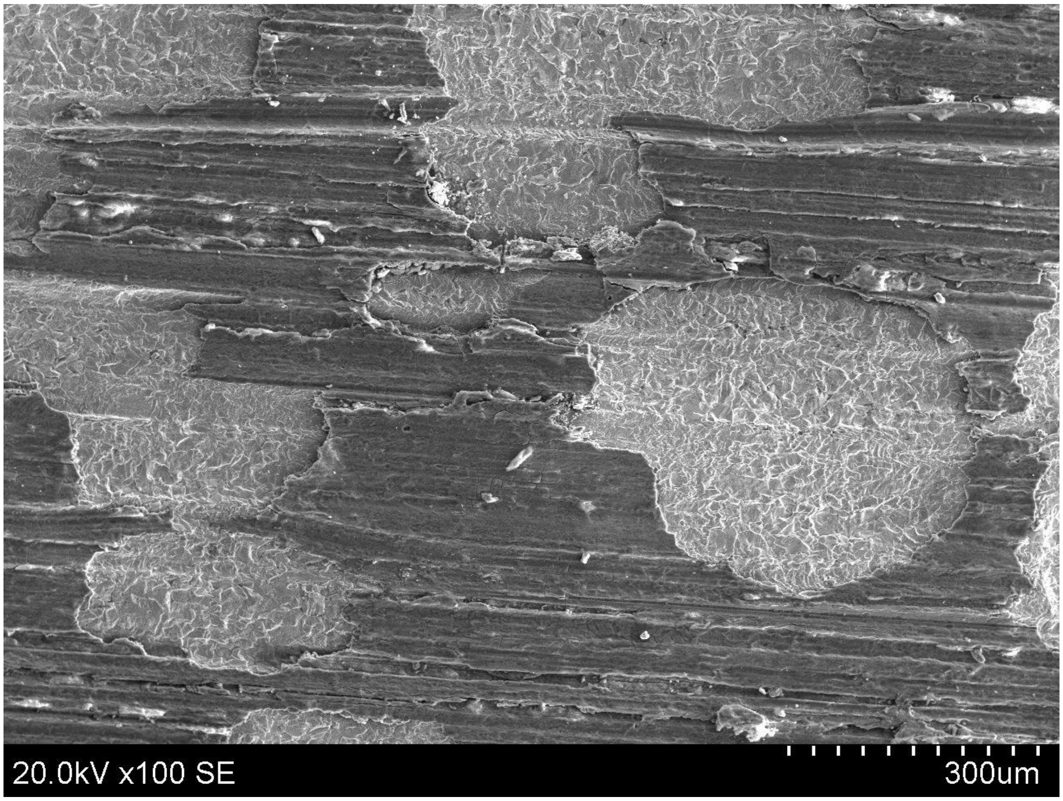


(a) CDA 706 Baseline Coupon 100X

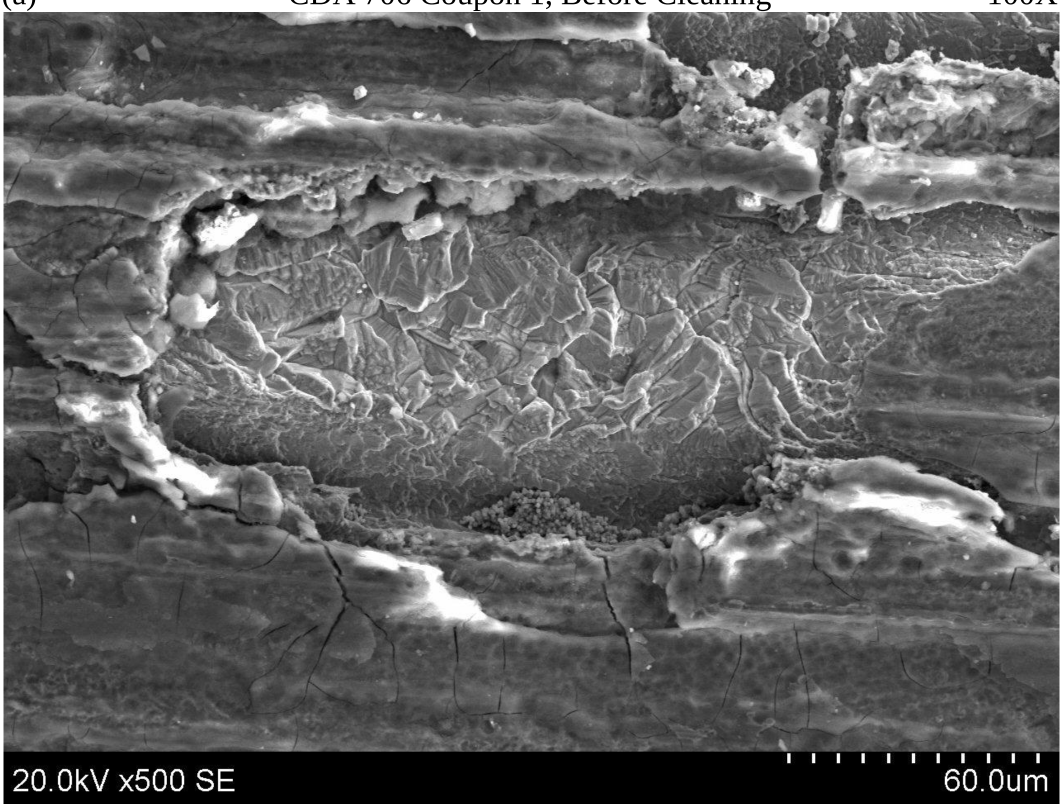


(b) CDA 706 Baseline Coupon 500X

Figure 12 Scanning electron micrographs of the CDA 706 baseline coupon.

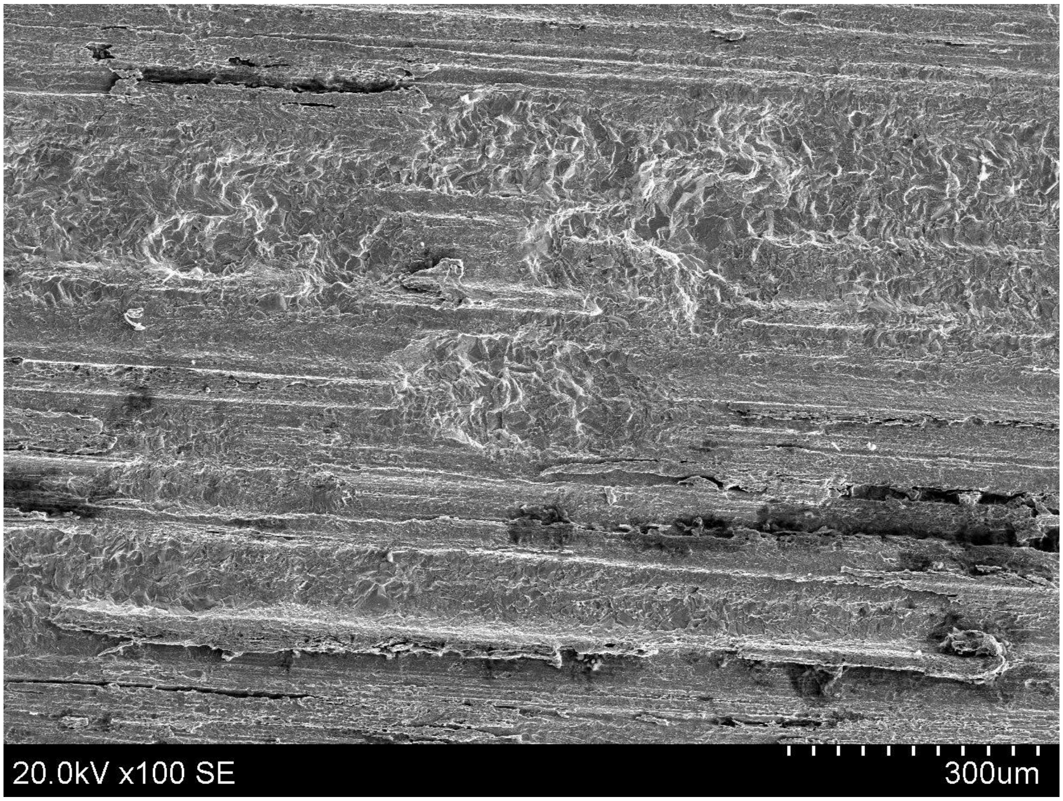


(a) CDA 706 Coupon 1, Before Cleaning 100X

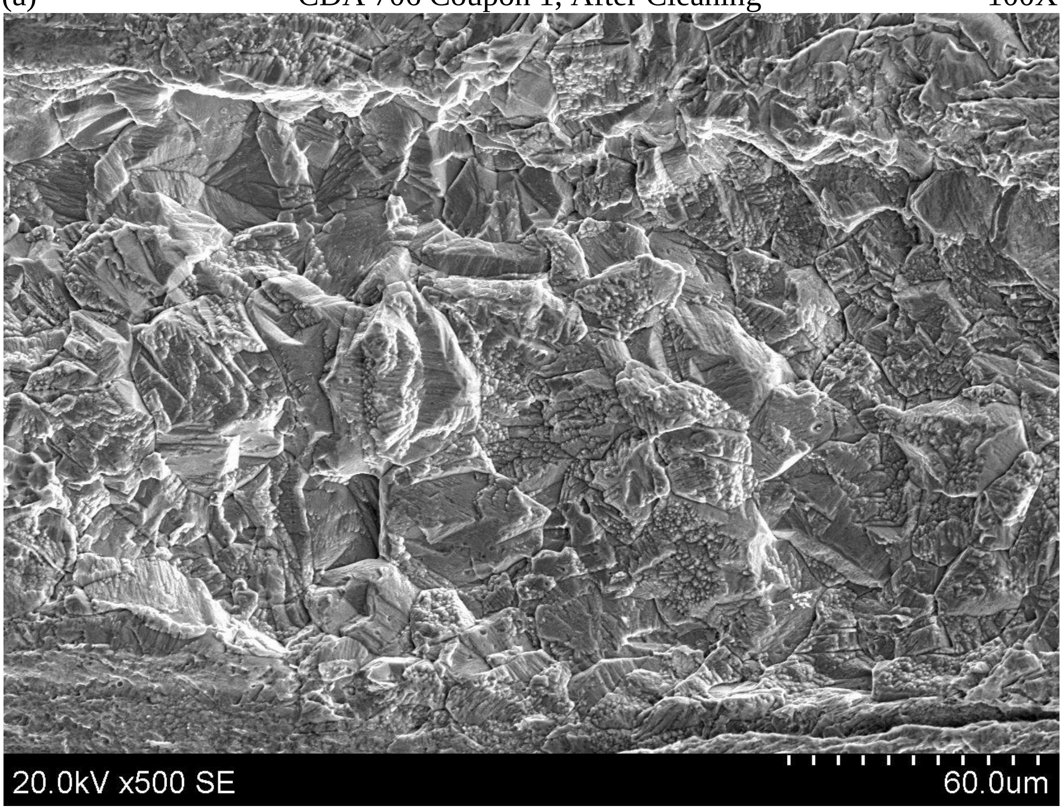


(b) CDA 706 Coupon 1, Before Cleaning 500X

Figure 13 Scanning electron micrographs of CDA 706 coupon 1 after a 3 month corrosion test, before cleaning.

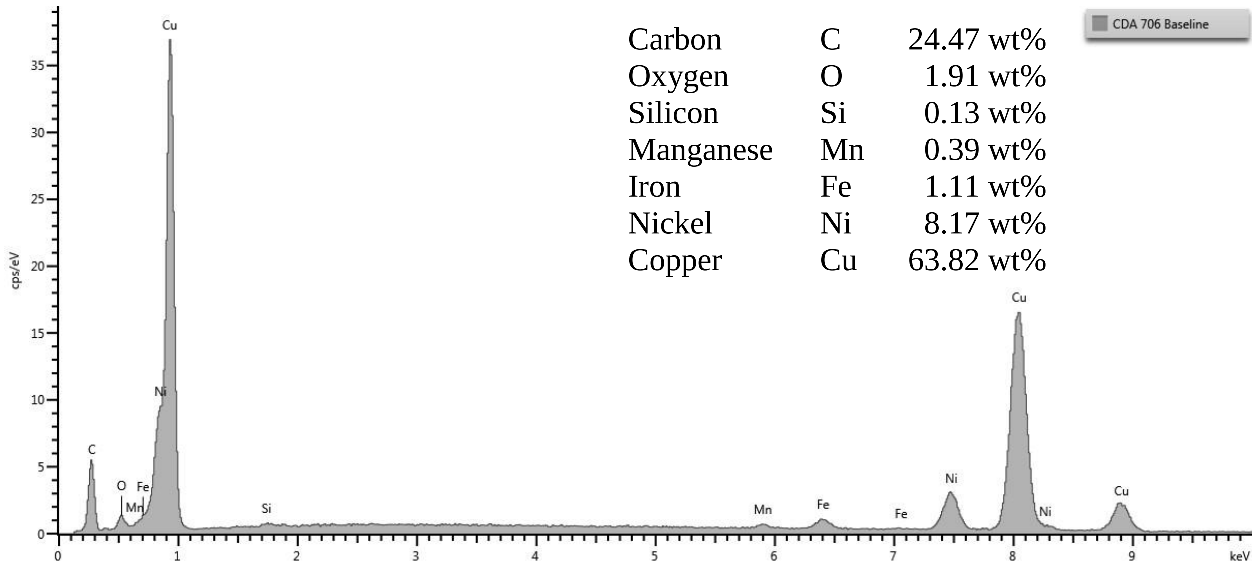


(a) CDA 706 Coupon 1, After Cleaning 100X



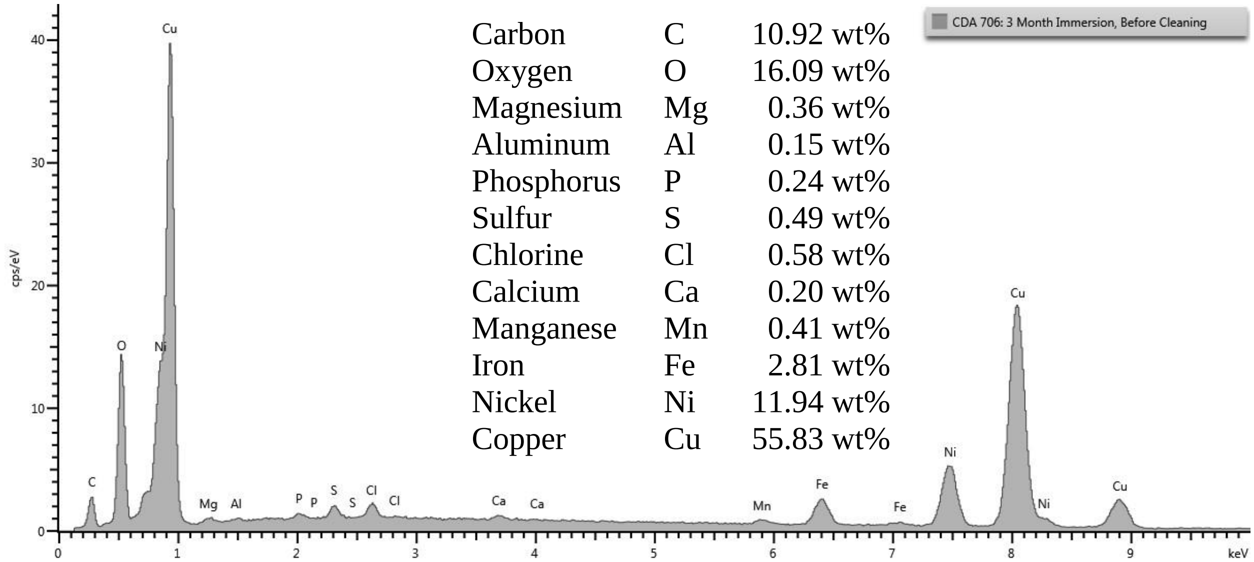
(b) CDA 706 Coupon 1, After Cleaning 500X

Figure 14 Scanning electron micrographs of CDA 706 coupon 1 after a 3 month corrosion test, after cleaning.

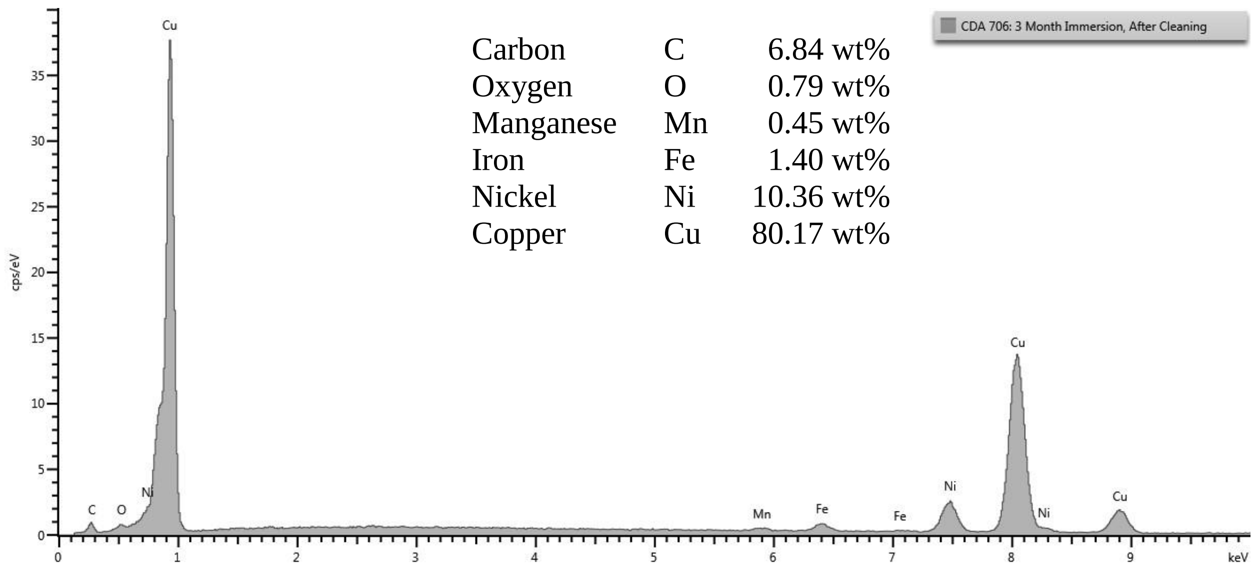


(b) CDA 706 Baseline Coupon

Figure 15 Energy dispersive x-ray spectra of the CDA 706 baseline coupon.



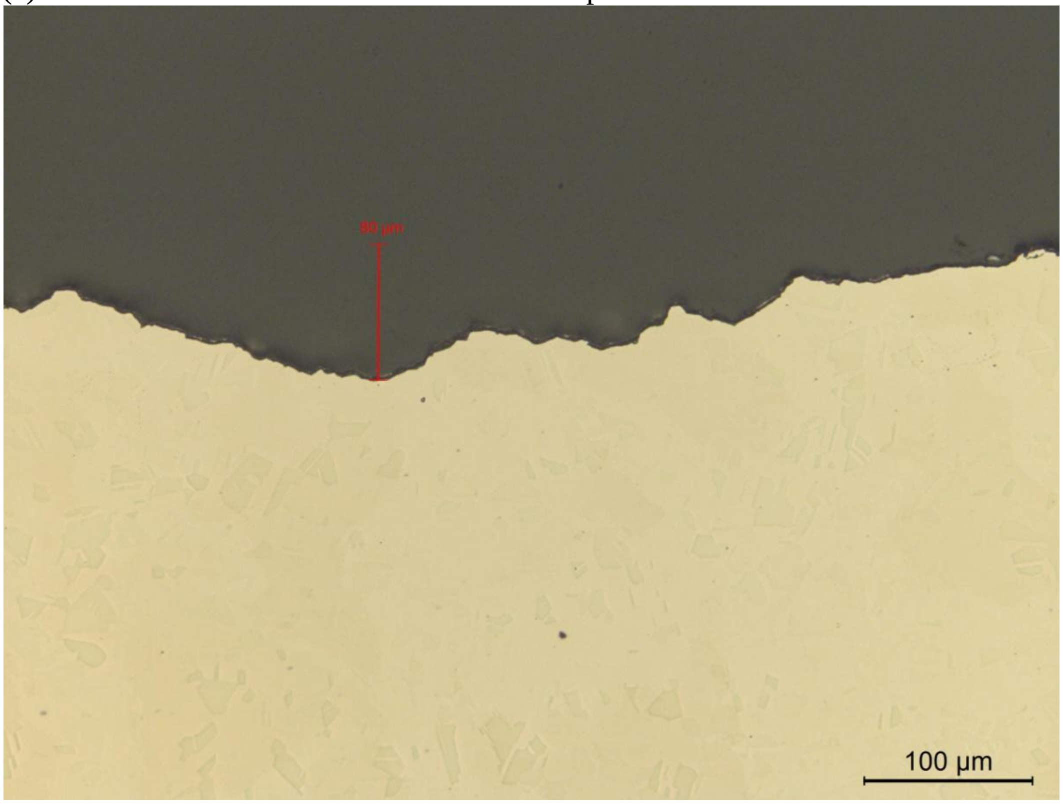
(a) CDA 706 Coupon 1, Before Cleaning



(b) CDA 706 Coupon 1, After Cleaning

Figure 16 Energy dispersive x-ray spectra of CDA 706 coupon 1 after a 3 month corrosion test (a) before cleaning and (b) after cleaning.

(a) CDA 706 Coupon 1 50X



(b) CDA 706 Coupon 1 200X

Figure 17 Optical micrographs of CDA 706 coupon 1. The pit was approximately 80 µm deep.

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Report No. 5005.0361 **November 7, 2014**

CORROSION EVALUATION OF Z-ALLOY COUPONS AND SCREENS

Customer Authorization: Verbal

Report To: V & A Engineering
Attn: Manuel Najar
155 Grand Avenue, Suite 700
Oakland, CA 94612

1.0 INTRODUCTION

Five coupons, five wedge wire screens, and one plate were submitted by V&A Engineering for corrosion evaluation. The coupons were 1-inch by 3-inches by ¼-inch thick. The wedge wire screens were 4-inches by 4-inches by 1-inch tall with 2 mm spacing. The plate was 4-inches by 4-inches by 1/8-inch thick. The sample was reportedly a Z-Alloy, a proprietary material from Johnson Screens.

Four coupons and four screens were to be placed in seawater for a period up to one year. After every 3 month interval, one coupon and one screen were to be removed from the test system and examined for corrosion. The purpose of this evaluation was to document the samples in the baseline as-received condition, then again after 3, 6, 9, and 12 months of water exposure, record any loss in mass, examine for any pitting corrosion, and estimate the corrosion rate.

The samples were evaluated by the following laboratory procedures:

1) Visual examination and weighing
2) Cleaning per ASTM G1[1]
3) Scanning electron microscopy
4) Metallography

The results of the evaluation showed moderate mass loss and corrosion for the coupon and screen after 3 months of corrosion testing. The coupon and screen had a corrosion rate of approximately 0.015 millimeters per year and 0.113 millimeters per year, respectively.

[1] G1: Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

2.0 EVALUATION[2]

2.1 Visual Examination

The sample identifications for the coupons and wedge wire screens and their corresponding immersion times are shown in Table 1. The coupons had identification numbers stamped on the front face by V&A Engineering. A number of notches, corresponding to the sample number, were sawed at the edge of each screen for identification after the corrosion test. The weights of the samples were recorded. Coupons 1 – 4 and screens 1 – 5 were sent back to V&A for corrosion testing. Coupons 5 and 6 were the baseline samples and documented by photography, optical stereoscopy and scanning electron microscopy for comparison to the tested samples. Screen 5 was documented as a baseline by photography and optical stereoscopy, and then sent to V&A for testing.

Photographs of the baseline coupon are shown in Figure 1. Photographs of coupon 1, after 3 months of corrosion testing, are shown in Figure 2.

A photograph of the baseline screen is shown in Figure 3. A photograph of screen 1, after 3 months of corrosion testing, is shown in Figure 4.

2.2 Cleaning

The coupon and screen were cleaned with solution C.2.1 per ASTM G1.[3] One cleaning cycle was approximately 1 minute. After each cleaning cycle, the samples were rinsed in water, dried, and weighed. The cleaning and weighing cycle was completed five times for the coupon and screen. The weights of the samples as-received, after corrosion testing but before cleaning, and after each cleaning cycle are presented in Table 2.

Optical macrographs of the baseline coupon and screen are shown in Figures 5 and 8, respectively. Representative optical macrographs of the samples before and after cleaning are shown in Figures 6 – 7 and 9 – 10. The mass loss versus the number of cleaning cycles was plotted, shown in Figure 11. The equations for best fit lines AB and BC, calculated using IGOR Pro, are listed in Table 3. Point B, indicated by the red circle in each plot, corresponds to the mass loss due to corrosion during the cleaning process for each sample. This mass loss was subtracted from the weight of the sample before cleaning and from the weight of the sample as-received to determine the total mass loss from corrosion. The corrosion rate of each sample was determined by the formula specified in Section 8.1 of ASTM G1:

$$Corrosion\ Rate = \frac{K\ x\ W}{A\ x\ T\ x\ D}$$

where $K = 8.76 \times 10^4$, T = time of exposure in hours, A = area in cm^2, W = mass loss in grams, and D = density in g/cm^3. The density of the Z-Alloy was determined by cutting a section out of the baseline coupon, measuring the length, width, and thickness, and weighing the section with a

[2] The magnifications of the optical and scanning electron micrographs in this report are approximate and should not be used as a basis for dimensional analyses unless otherwise indicated.
[3] 500 mL hydrochloric acid + 500 ml reagent water.

balance. The total mass loss from corrosion and the calculated corrosion rate of each sample is shown in Table 4.

2.3 Scanning Electron Microscopy

The baseline coupon and coupon 1 were examined with a scanning electron microscope. Representative scanning electron micrographs of the baseline coupon are shown in Figure 12. Representative scanning electron micrographs of coupon 1 before and after cleaning are shown in Figures 13 – 14. Energy dispersive x-ray spectra of the baseline coupon and coupon before and after cleaning are shown in Figure 15 – 16.

2.4 Metallography

Cross sections were taken from the coupon and prepared for a metallographic examination. Optical micrographs of the surface for coupon 1 are shown in Figure 17. A wide, shallow pit was observed in coupon 1, measuring 0.2 mm in depth.

3.0 DISCUSSION

The coupon and screen showed moderate mass loss and pitting after 3 months of corrosion testing. The coupon had lost 0.172 grams of material and had a corrosion rate of 0.015 millimeters per year. The screen had lost 14.96 grams of material and had a corrosion rate of 0.113 millimeters per year.

4.0 CONCLUSIONS[4]

The following conclusions are based upon the submitted samples and the evidence gathered:

1. The coupon, after 3 months of corrosion testing, had a mass loss of 0.172 grams and a corrosion rate of 0.015 mm / year.

2. The screen, after 3 months of corrosion testing, had a mass loss of 14.96 grams and a corrosion rate of 0.113 mm / year.

[4] The conclusions in this report are based upon the available information and evidence provided by the client and gathered by Anamet, within the scope of work authorized by the client, and they are hereby presented by Anamet to a reasonable degree of engineering and scientific certainty. Anamet reserves the right to amend or supplement its conclusions or opinions presented in this report should additional data or information become available, or further work be approved by the client.

Prepared by:

Norman Yuen
Materials Engineer

Reviewed by:

Audrey A. Fasching, Ph.D., P.E.
Senior Materials Engineer

Table 1
Sample Identifications

Description		V&A Engineering Identification (As-Received)	Anamet Identification (in report)	Notes
Alloy	Part			
Z Alloy	**Flat Plate** 4-inch x 4-inch x 1/8-inch	Z	Plate	None
	Coupon 1-inch x 3-inch x 1/8-inch with autogenous weld bead	1	Coupon 1	3 Month Immersion
		2	Coupon 2	6 Month Immersion
		3	Coupon 3	9 Month Immersion
		4	Coupon 4	12 Month Immersion
		5	Coupon 5	Baseline Sample (no exposure)
		6	Coupon 6	Baseline Sample (no exposure)
	Wedge Wire Screen 4-inch x 4-inch x 1-inch with 2 mm spacing	None	Screen 1	3 Month Immersion
		None	Screen 2	6 Month Immersion
		None	Screen 3	9 Month Immersion
		None	Screen 4	12 Month Immersion
		None	Screen 5	12 Month Immersion

Table 2
Sample Weights

Sample	Baseline Measurement	Measurements after 3 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 1	26.8665	26.7135	26.6958	26.6926	26.6911	26.6887	26.6872
Screen 1	361.74	352.24	348.56	346.76	346.62	346.50	346.48

Table 3
Equations of Line AB and BC for Corrosion Testing Samples

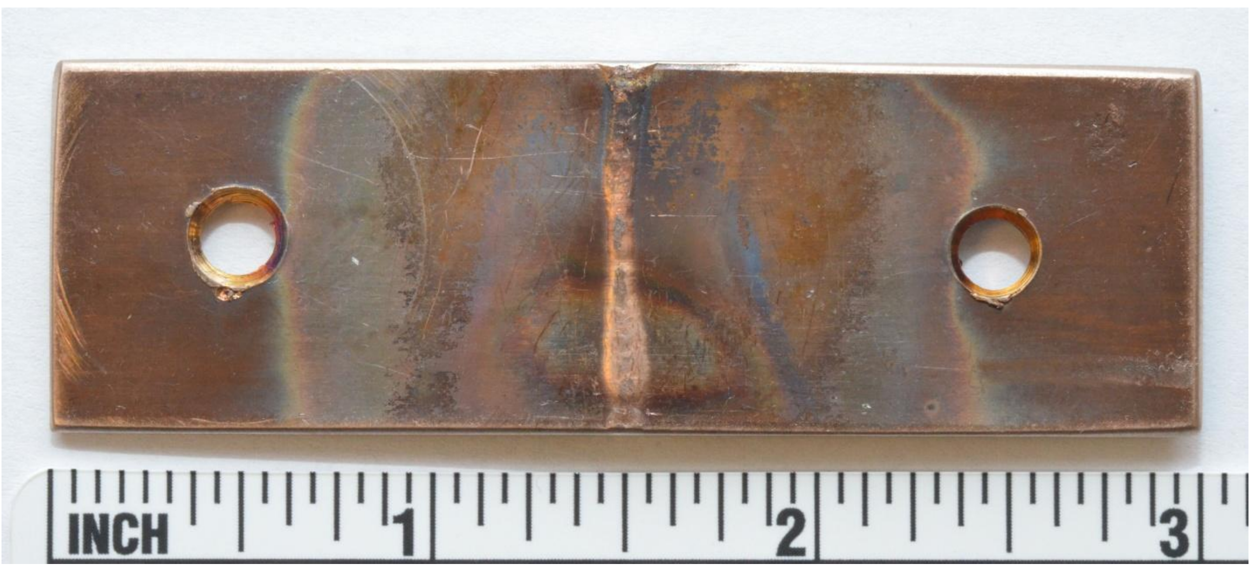
Sample	Line AB	Line BC	Point B (Approximate Mass Loss from Corrosion During Cleaning)
Coupon 1	y = 0.018x	y = 0.002x + 0.017	0.019 grams
Screen 1	y = 3.68x	y = 0.10x + 5.31	5.46 grams

Table 4
Total Mass Loss from Corrosion and Corrosion Rate

Sample	Total Mass Loss from Corrosion*	Corrosion Rate
Coupon 1	0.172 grams	0.015 mm / year
Screen 1	14.96 grams	0.113 mm / year

* Weight As-Received – (Weight Before Cleaning – Mass Loss from Corrosion During Cleaning)

(a) Z-Alloy Baseline Coupon, Front Side



(b) Z-Alloy Baseline Coupon, Back Side

Figure 1 Photographs of the Z-Alloy baseline coupon (a) front and (b) back side.

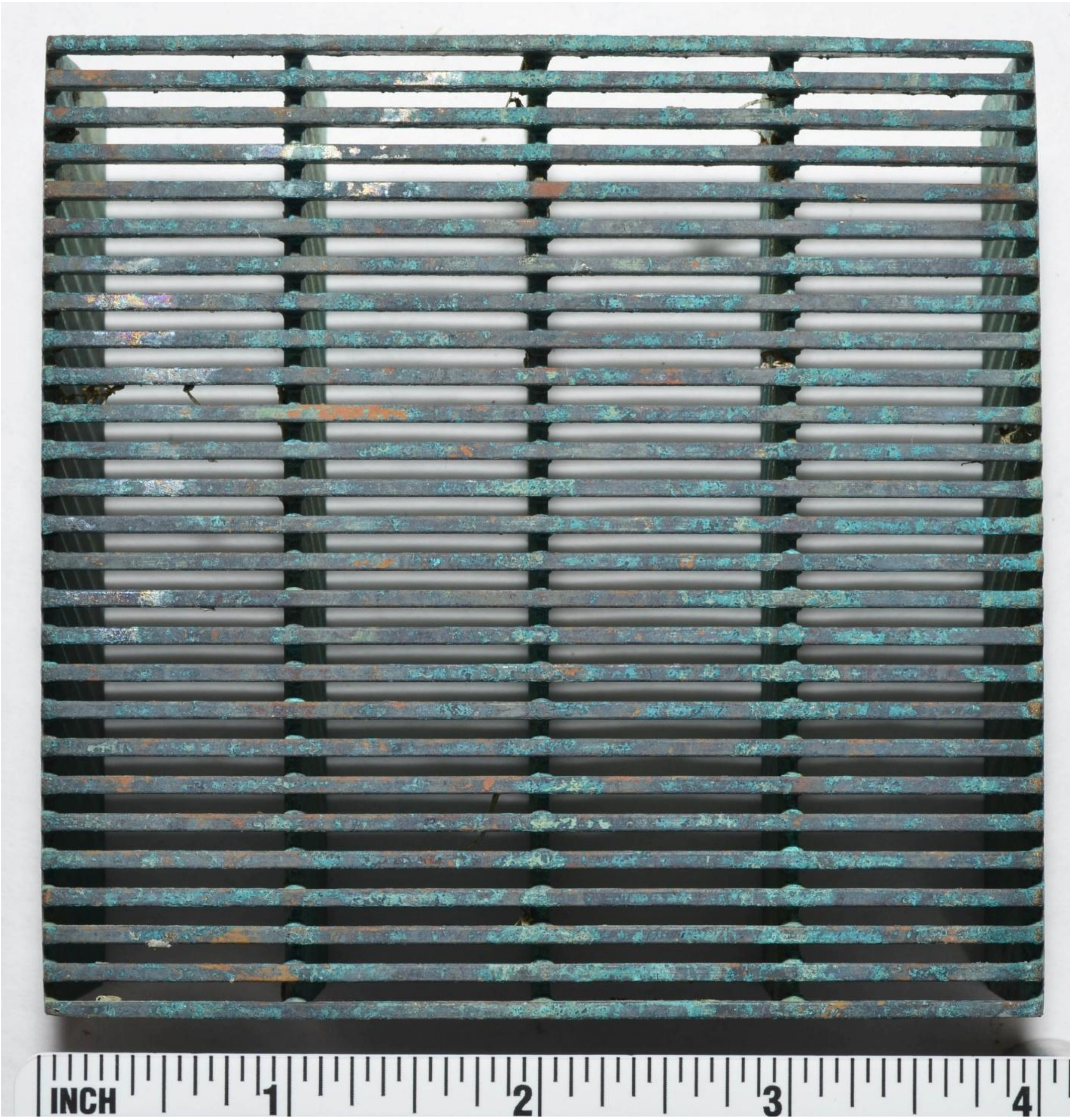
(a) Z-Alloy Coupon 1 Front Side

(b) Z-Alloy Coupon 1 Back Side

Figure 2 Photographs of Z-Alloy coupon 1 (a) front and (b) back side after a 3 month corrosion test.

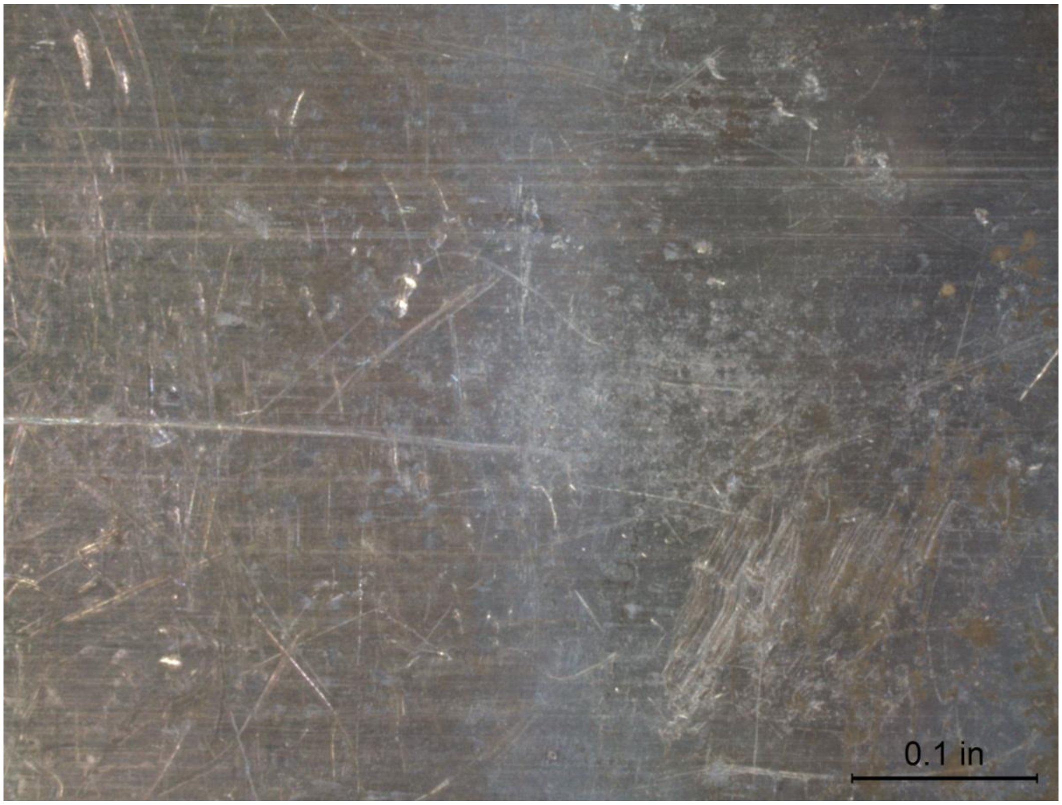
(a) Z-Alloy Baseline Screen

Figure 3 Photograph of the Z-Alloy baseline screen.



(a) Z-Alloy Screen 1

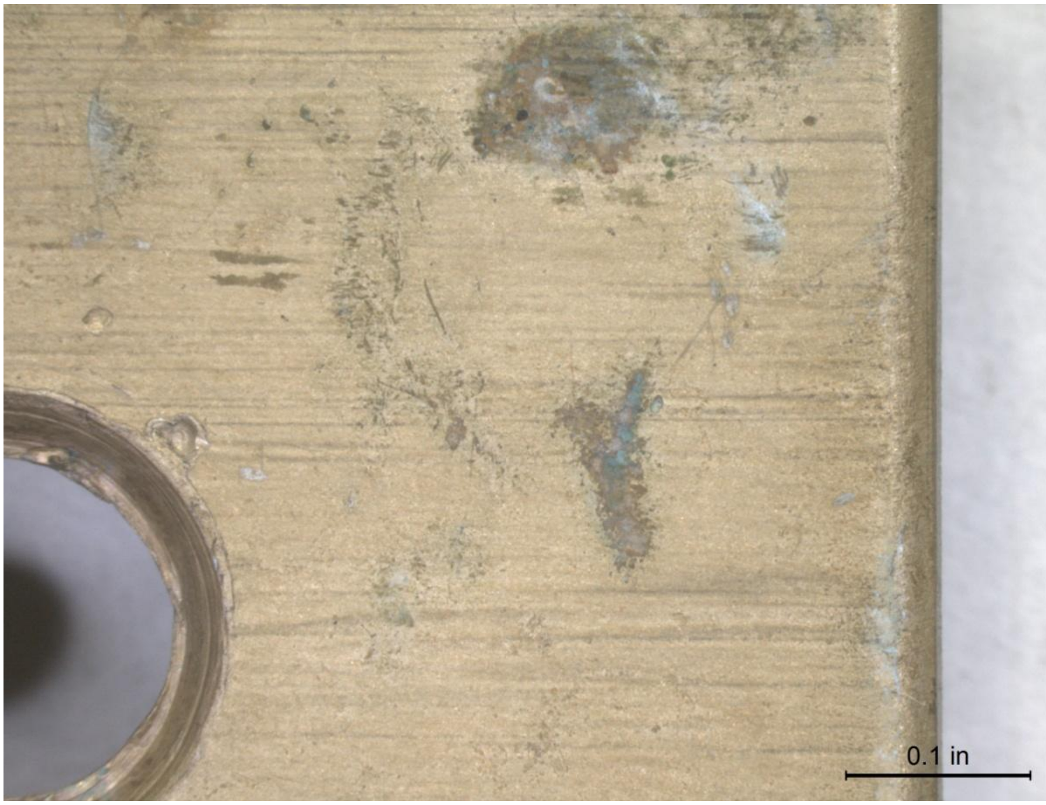
Figure 4 Photograph of Z-Alloy screen 1 after a 3 month corrosion test.



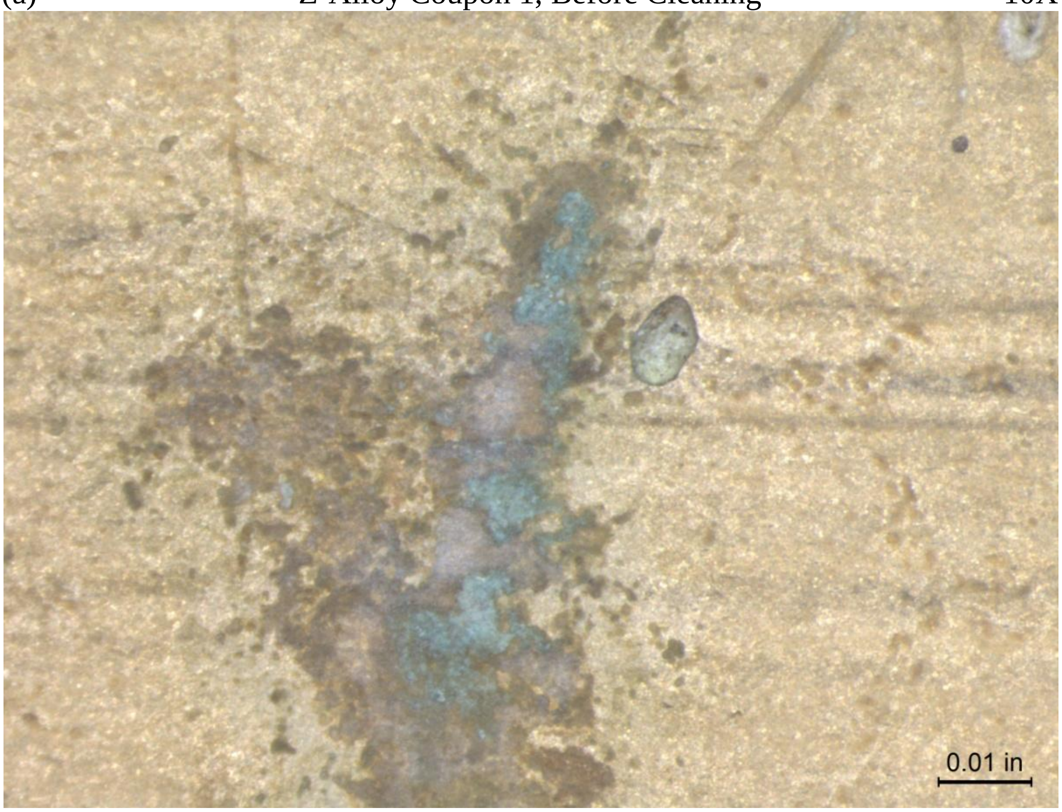
(a) Z-Alloy Baseline Coupon 10X

(b) Z-Alloy Baseline Coupon 50X

Figure 5 Optical macrographs of the Z-Alloy baseline coupon.

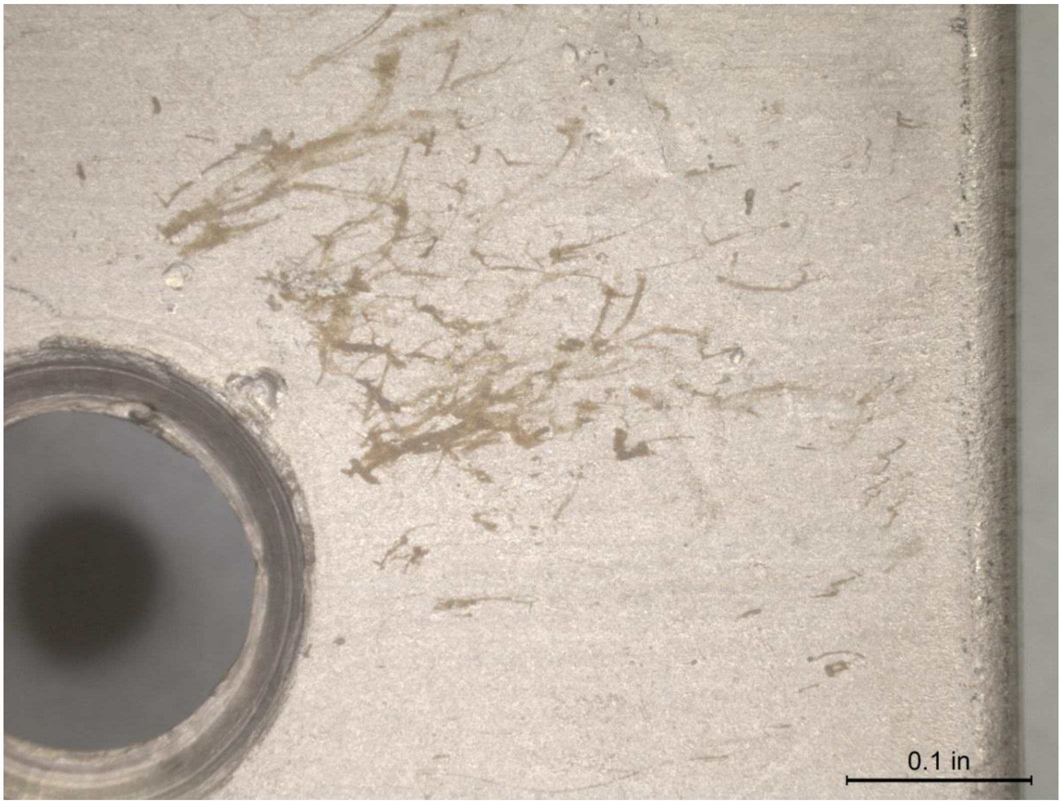


(a) Z-Alloy Coupon 1, Before Cleaning 10X



(b) Z-Alloy Coupon 1, Before Cleaning 50X

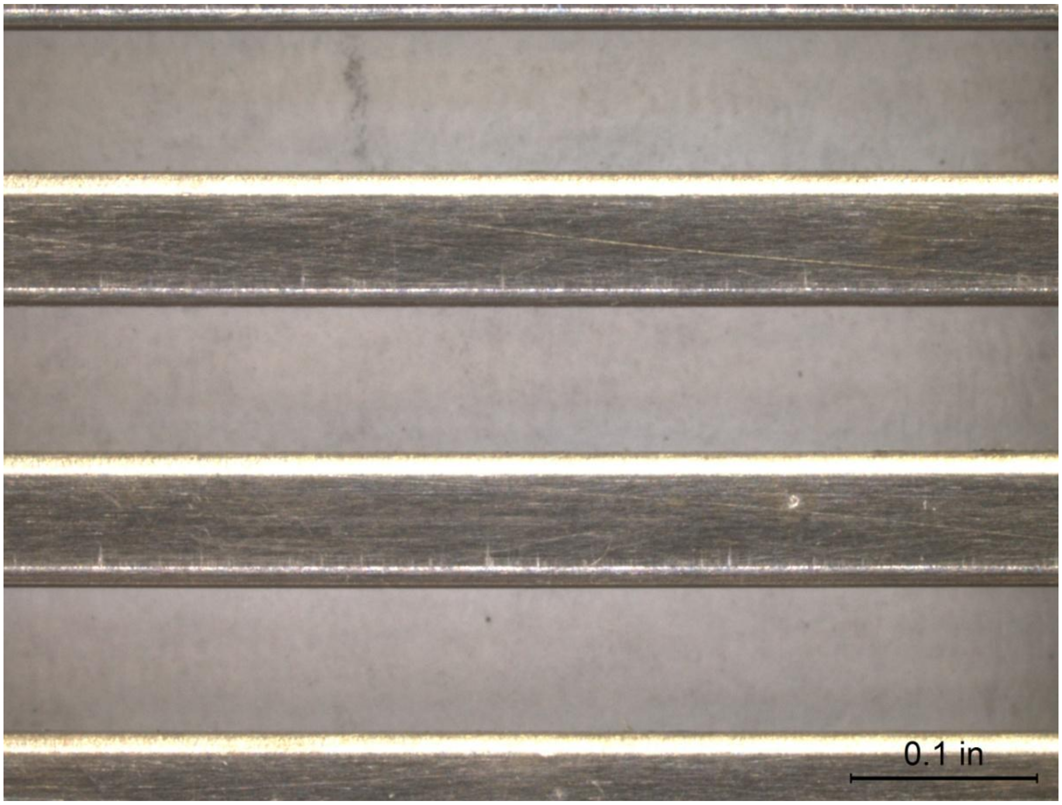
Figure 6 Optical macrographs of Z-Alloy coupon 1 after a 3 month corrosion test, before cleaning.



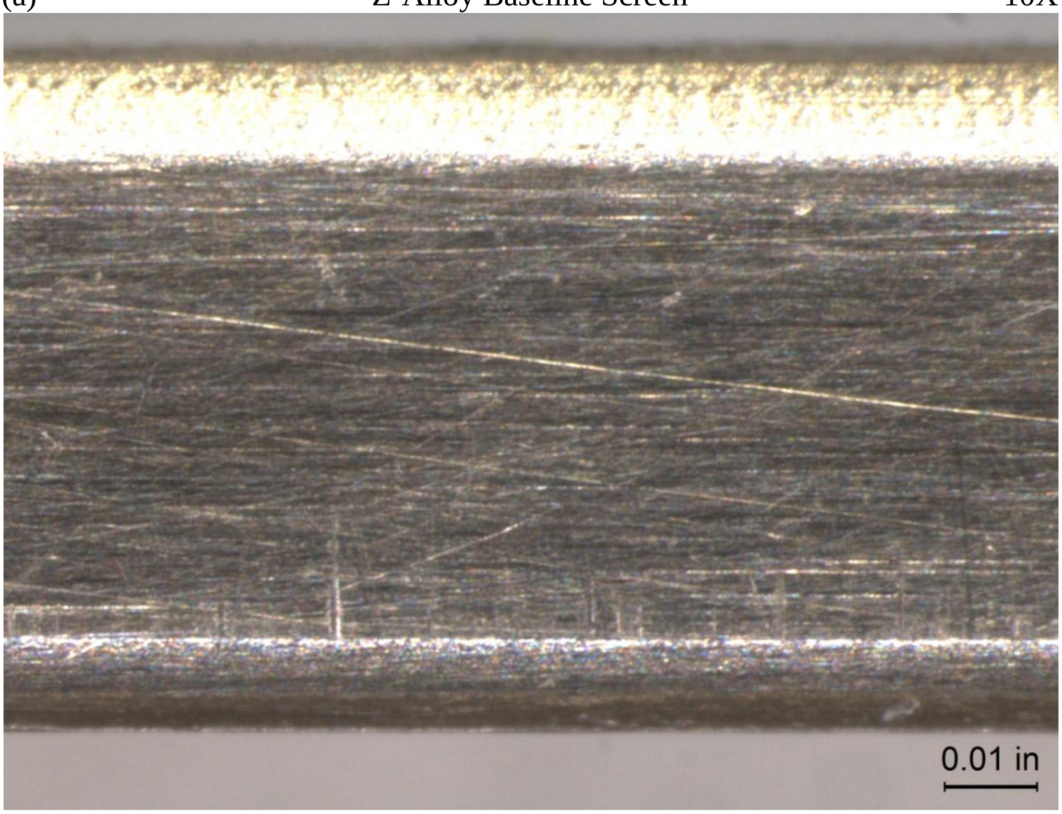
(a) Z-Alloy Coupon 1, After Cleaning 10X

(b) Z-Alloy Coupon 1, After Cleaning 50X

Figure 7 Optical macrographs of Z-Alloy coupon 1 after a 3 month corrosion test, after cleaning.

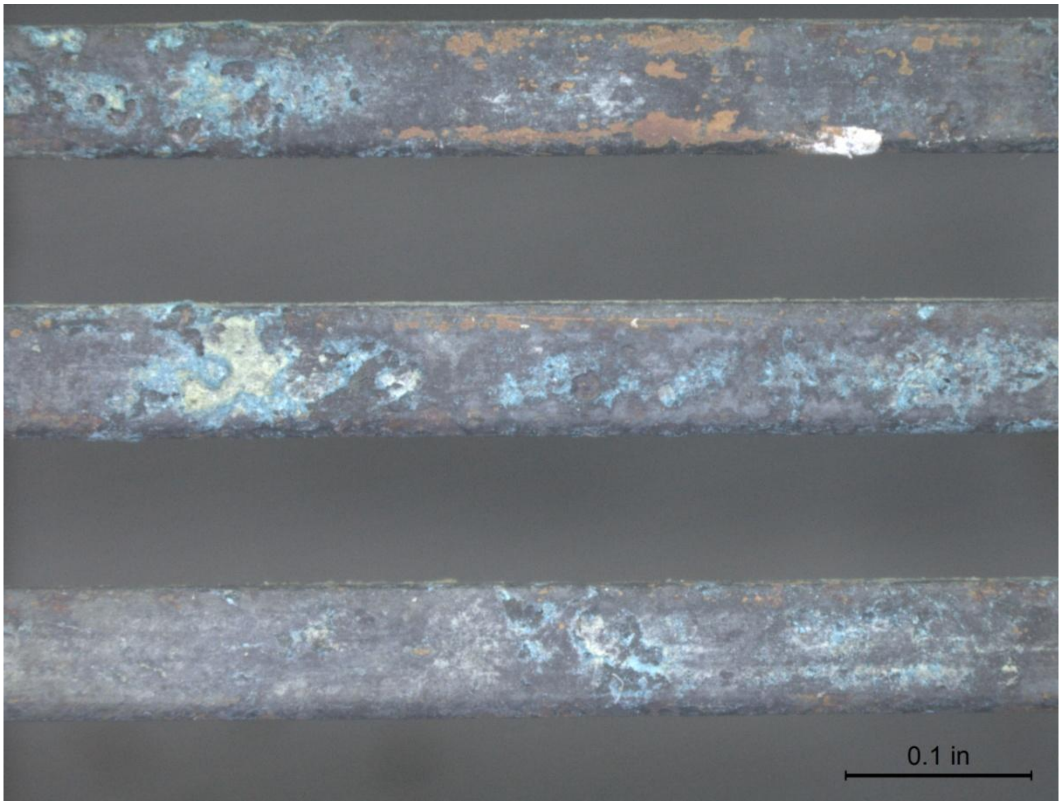


(a) Z-Alloy Baseline Screen 10X

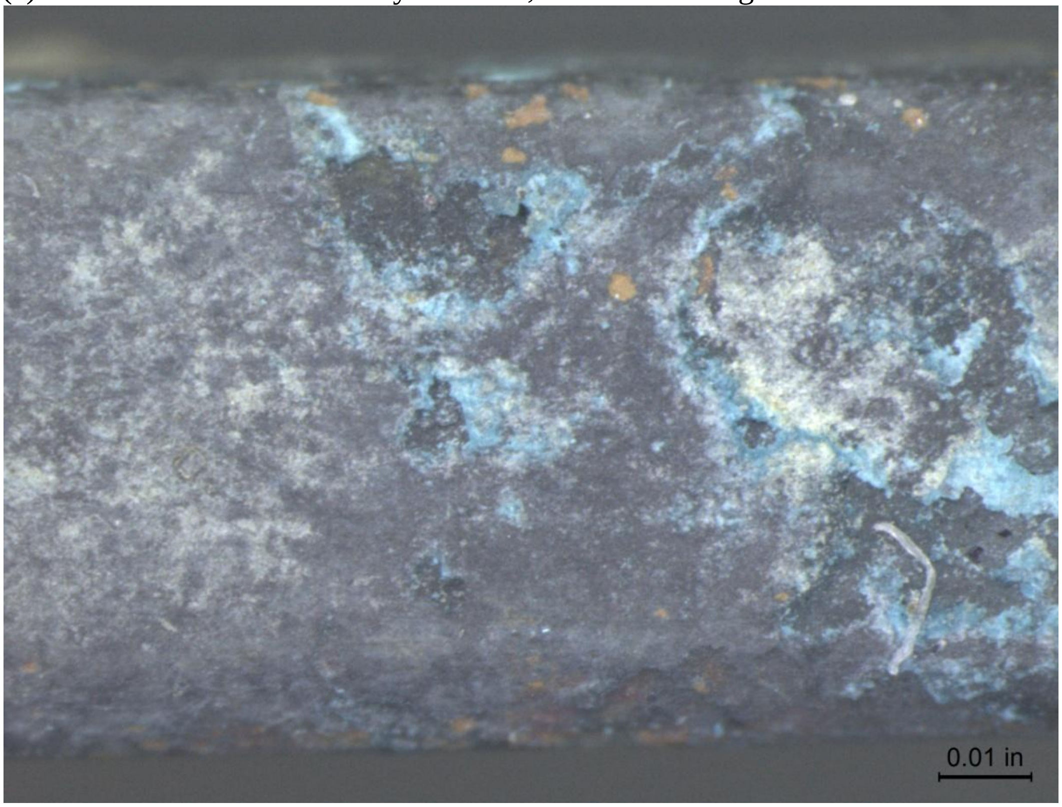


(b) Z-Alloy Baseline Screen 50X

Figure 8 Optical macrographs of the Z-Alloy baseline screen.

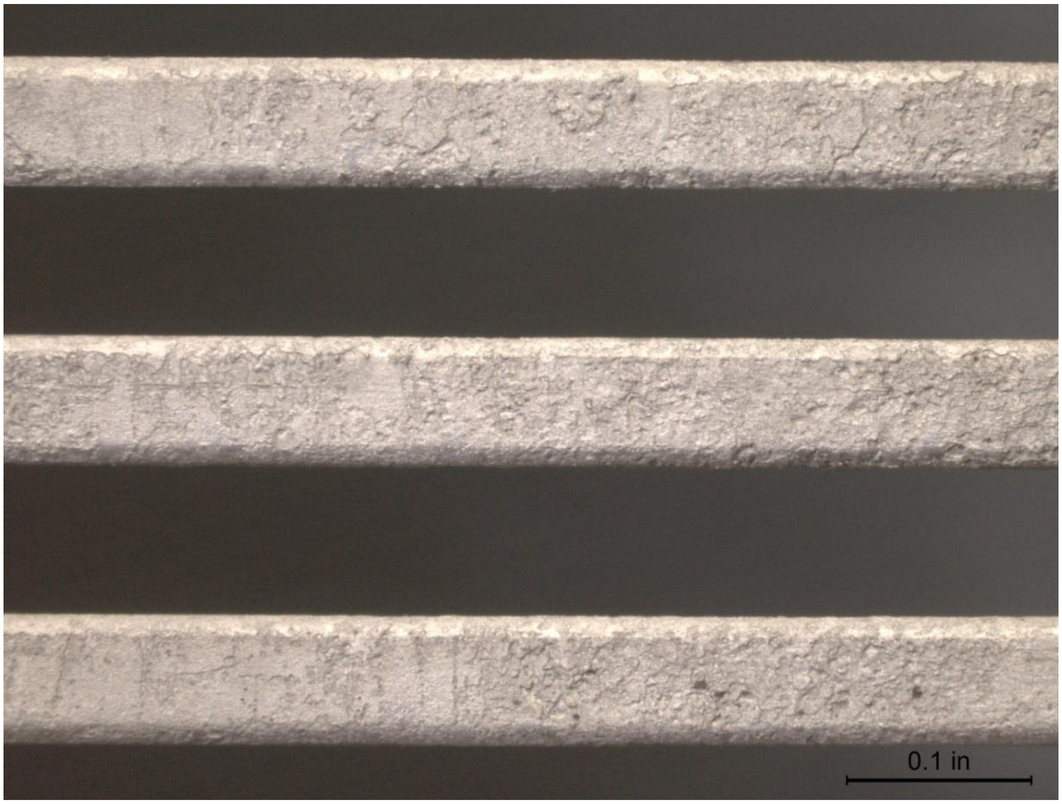


(a) Z-Alloy Screen 1, Before Cleaning 10X

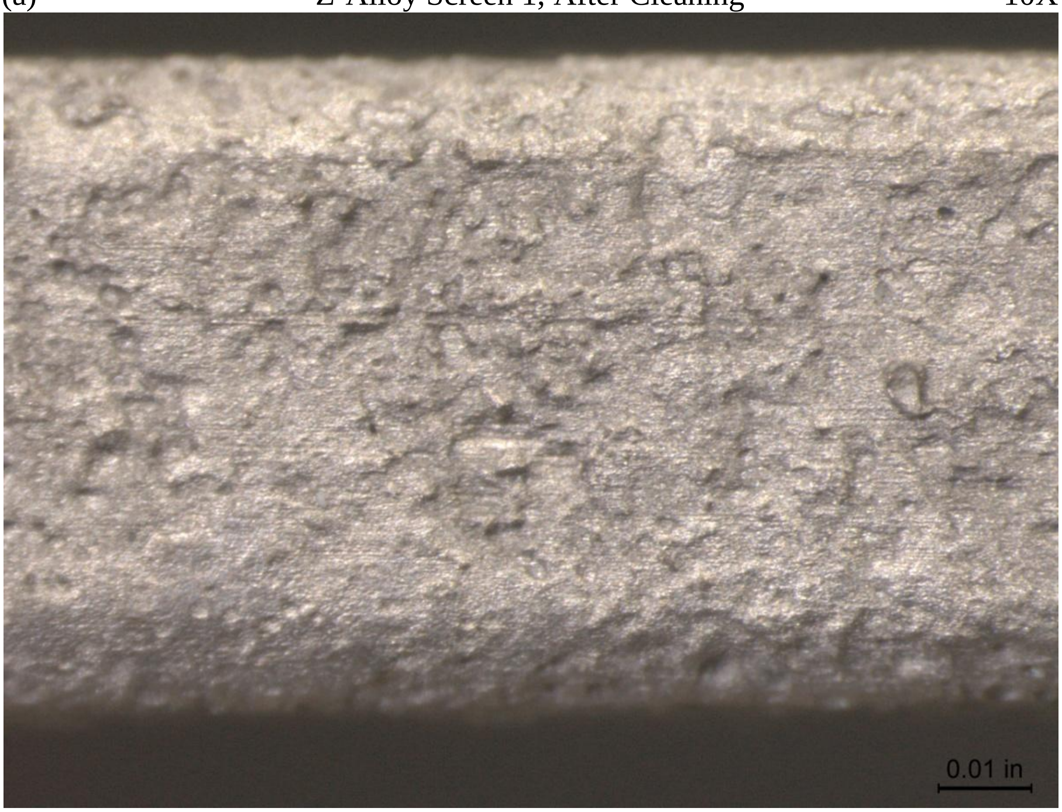


(b) Z-Alloy Screen 1, Before Cleaning 50X

Figure 9 Optical macrographs of Z-Alloy screen 1 after a 3 month corrosion test, before cleaning.

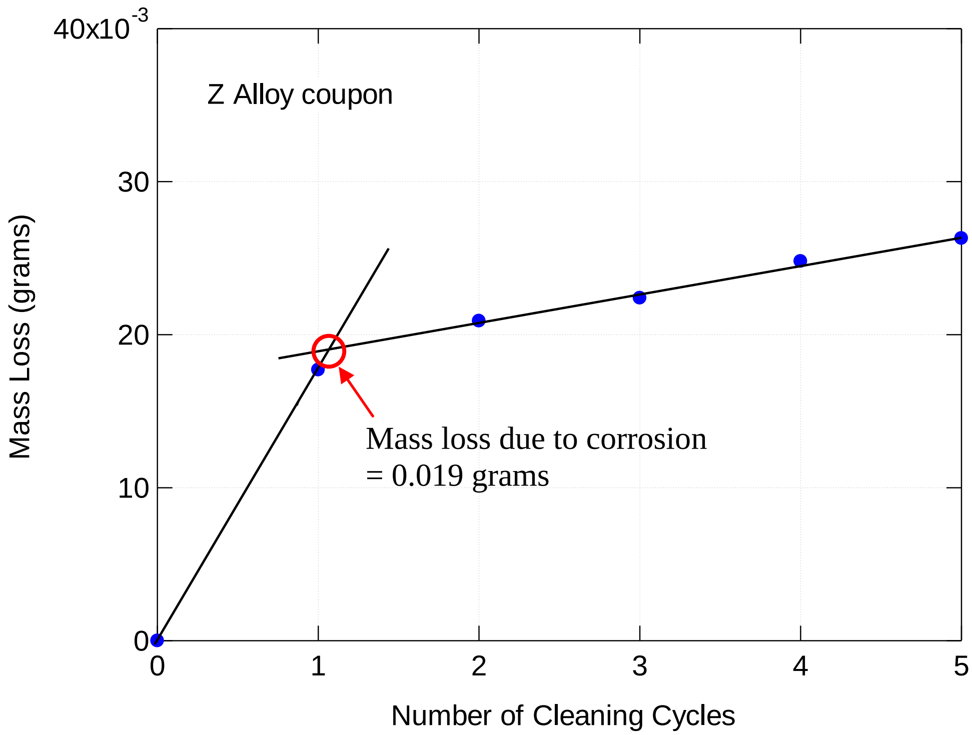


(a) Z-Alloy Screen 1, After Cleaning 10X

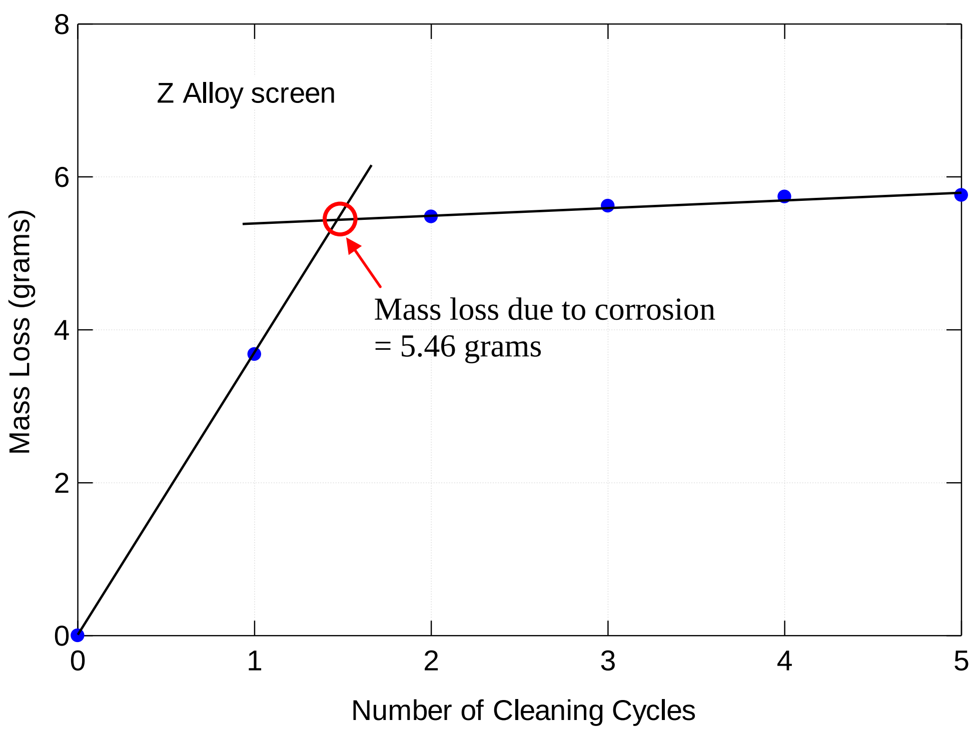


(b) Z-Alloy Screen 1, After Cleaning 50X

Figure 10 Optical macrographs of Z-Alloy screen 1 after a 3 month corrosion test, after cleaning.

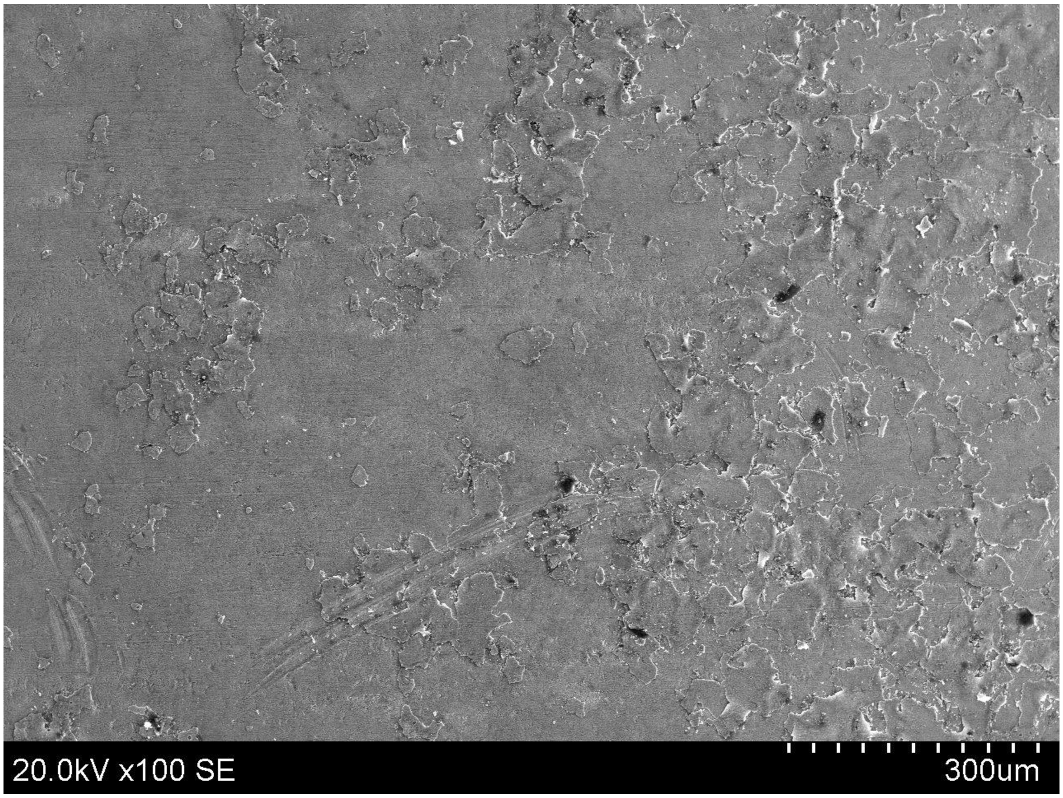


(a)

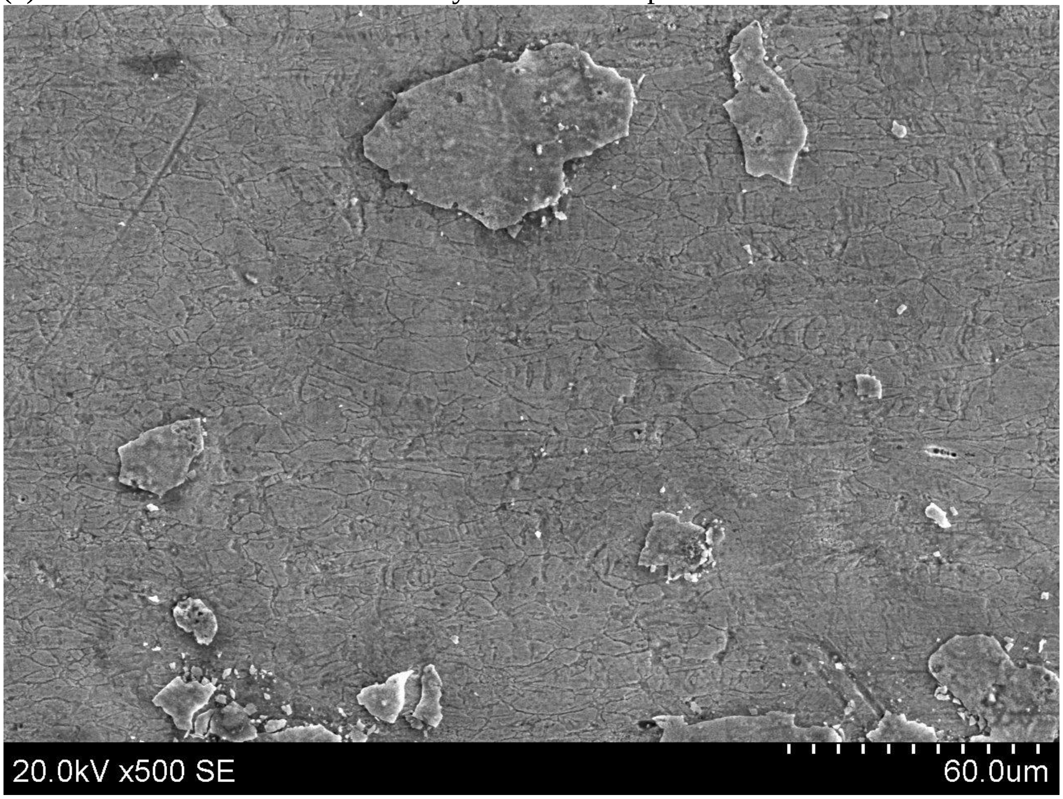


(b)

Figure 11 Mass loss of the Z-Alloy (a) coupon 1 and (b) screen 1 during cleaning.

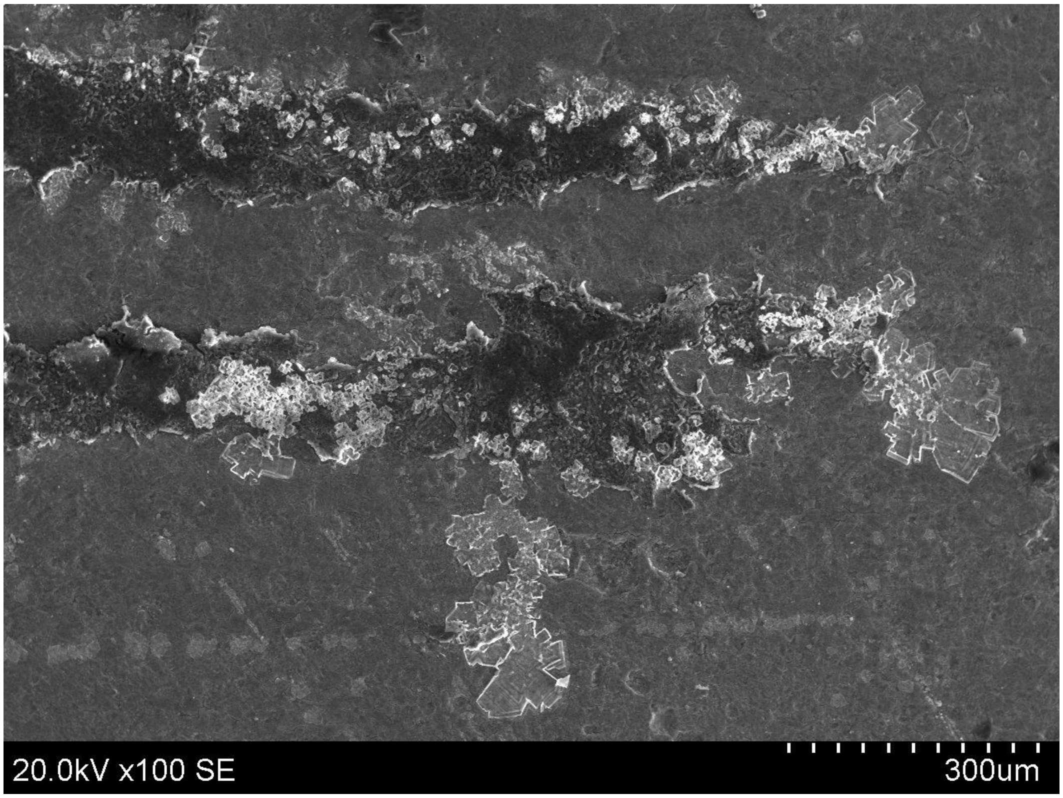


(a) Z-Alloy Baseline Coupon 100X

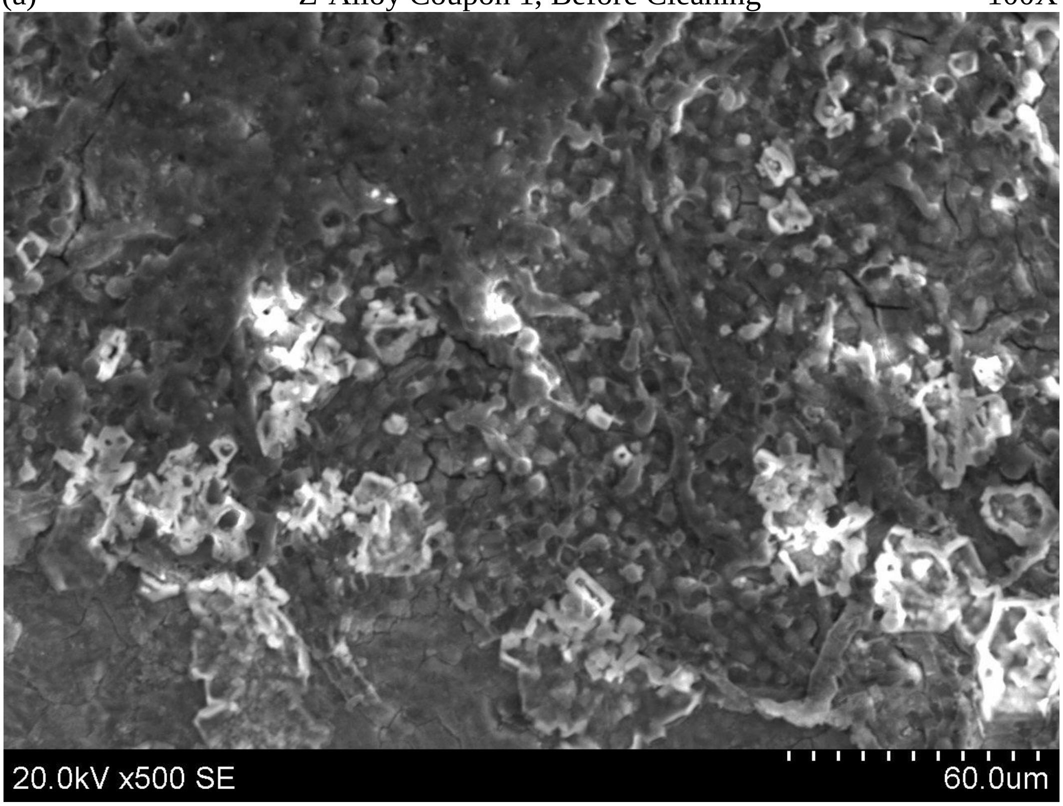


(b) Z-Alloy Baseline Coupon 500X

Figure 12 Scanning electron micrographs of Z-Alloy baseline coupon.



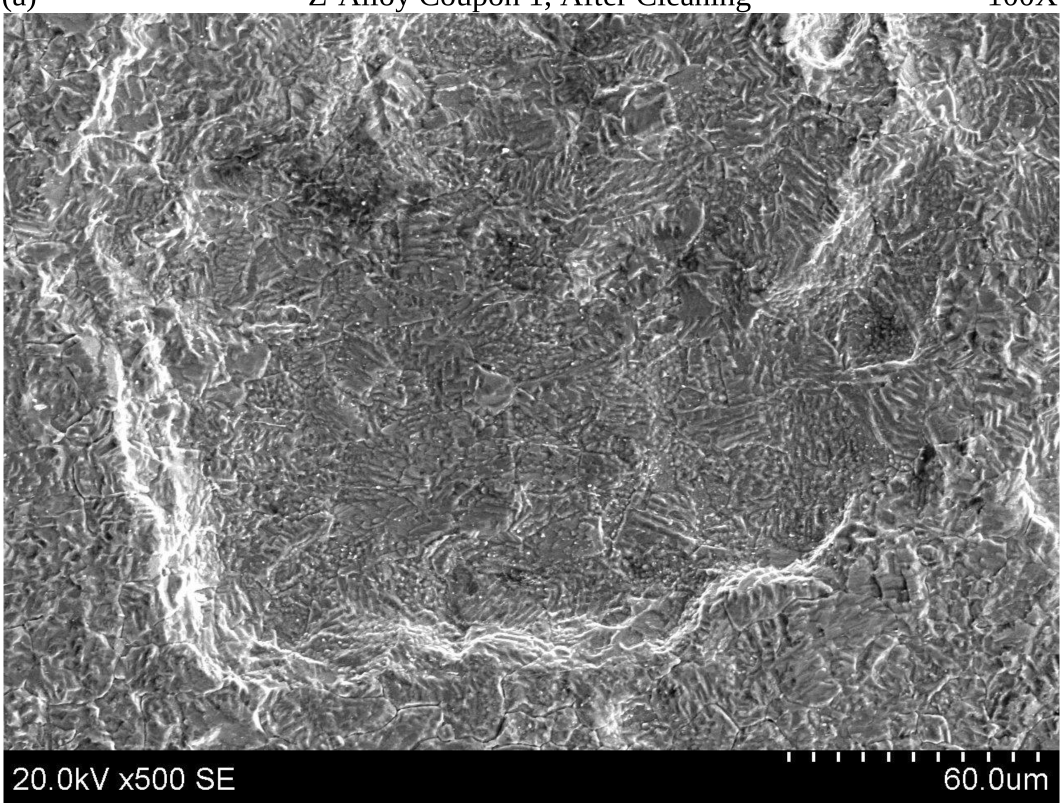
(a) Z-Alloy Coupon 1, Before Cleaning 100X



(b) Z-Alloy Coupon 1, Before Cleaning 500X

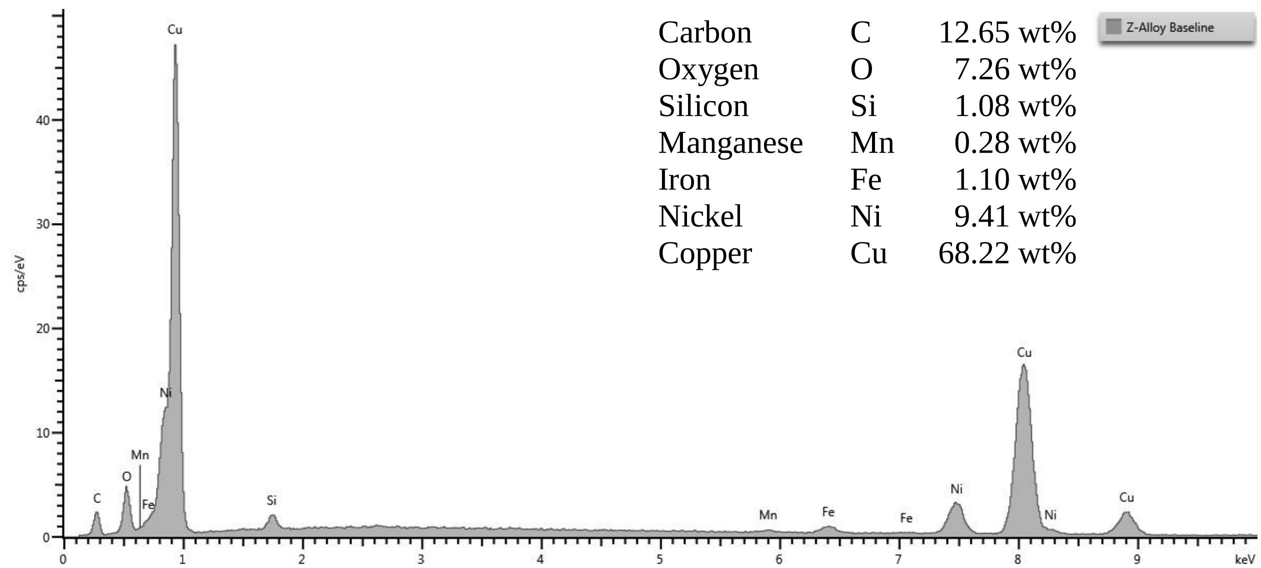
Figure 13 Scanning electron micrographs of Z-Alloy coupon 1 after a 3 month corrosion test, before cleaning.

(a) Z-Alloy Coupon 1, After Cleaning 100X



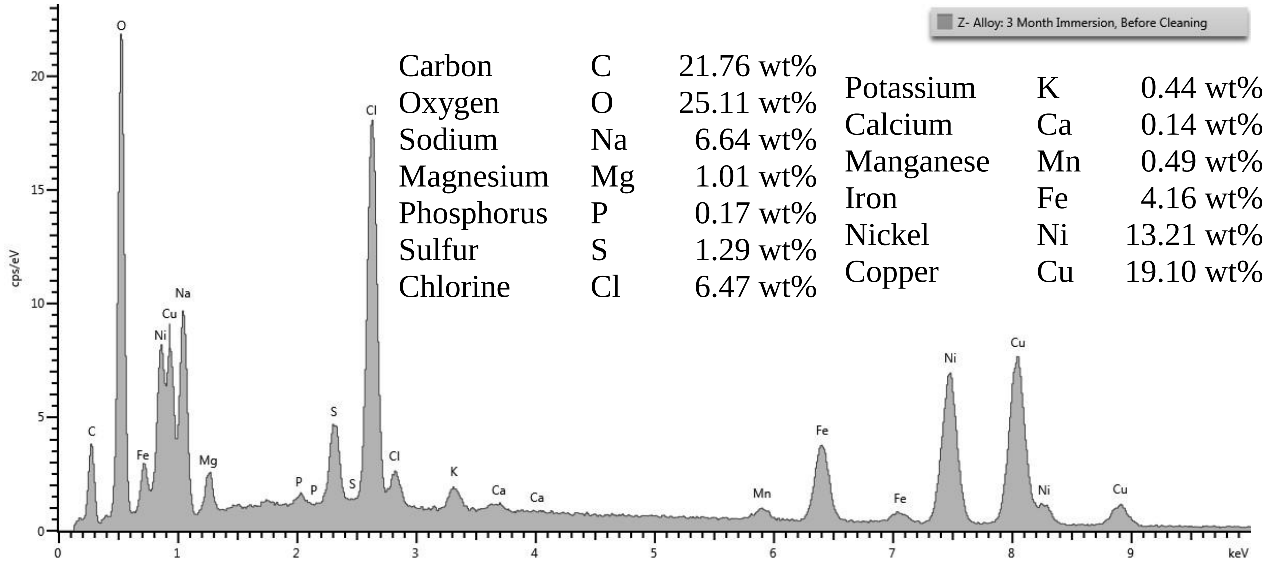
(b) Z-Alloy Coupon 1, After Cleaning 500X

Figure 14 Scanning electron micrographs of Z-Alloy coupon 1 after a 3 month corrosion test, after cleaning.



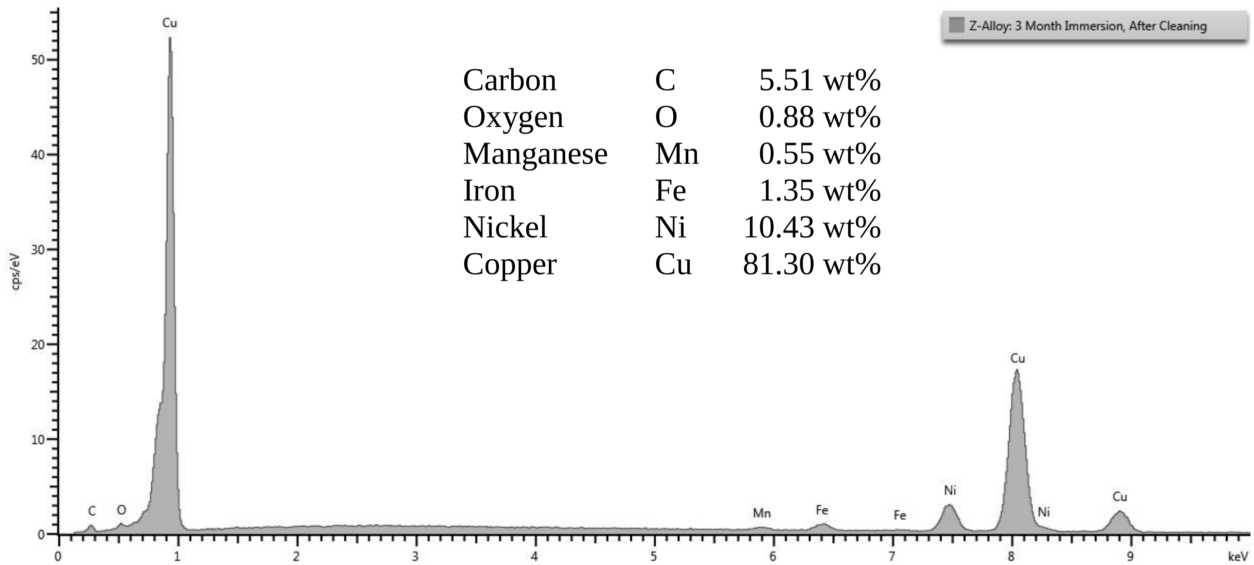
(a) Z-Alloy Baseline Coupon

Figure 15 Energy dispersive x-ray spectra of Z-Alloy baseline coupon 1.



Carbon	C	21.76 wt%
Oxygen	O	25.11 wt%
Sodium	Na	6.64 wt%
Magnesium	Mg	1.01 wt%
Phosphorus	P	0.17 wt%
Sulfur	S	1.29 wt%
Chlorine	Cl	6.47 wt%
Potassium	K	0.44 wt%
Calcium	Ca	0.14 wt%
Manganese	Mn	0.49 wt%
Iron	Fe	4.16 wt%
Nickel	Ni	13.21 wt%
Copper	Cu	19.10 wt%

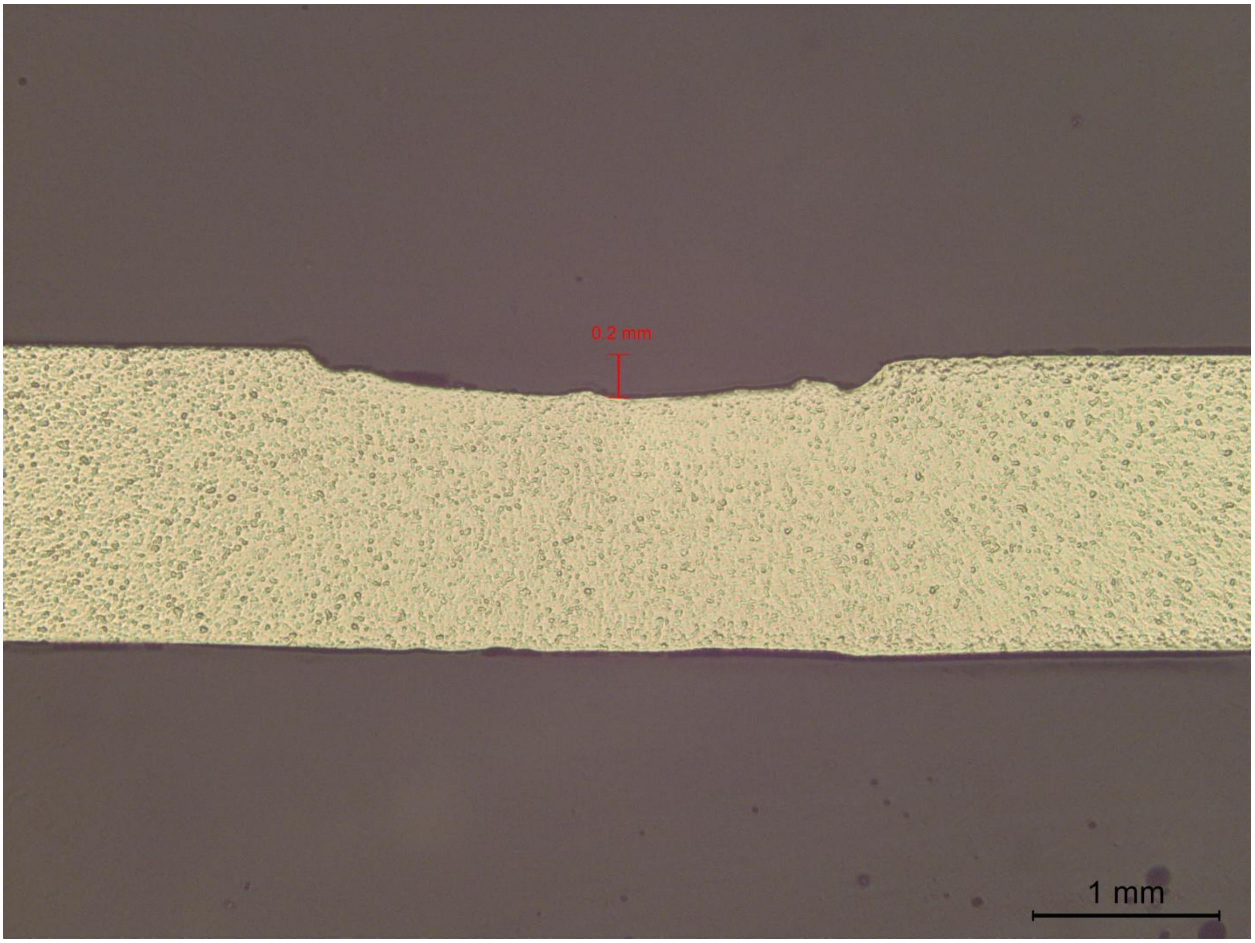
(a) Z-Alloy Coupon 1, Before Cleaning



Carbon	C	5.51 wt%
Oxygen	O	0.88 wt%
Manganese	Mn	0.55 wt%
Iron	Fe	1.35 wt%
Nickel	Ni	10.43 wt%
Copper	Cu	81.30 wt%

(b) Z-Alloy Coupon 1, After Cleaning

Figure 16 Energy dispersive x-ray spectra of Z-Alloy coupon 1 after a 3 month corrosion test (a) before cleaning and (b) after cleaning.



(a) Z-Alloy Coupon 1, After Cleaning 18.75X

Figure 17 Optical micrographs of Z-Alloy coupon 1.

West Basin Municipal Water District Ocean Water Desalination Intake Corrosion Study

Prepared for: TETRA TECH

Date: February 2015

Prepared by: V&A

V&A Project No.: 13-0376

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ES EXECUTIVE SUMMARY

West Basin Municipal Water District (West Basin) is pursuing ocean water desalination as an added source of water for its clients. The intent of the study is to measure the extent of corrosion and biofouling on bare and coated metal coupons. Twenty four samples made from four different alloys were identified and installed on a testing apparatus at the West Basin Ocean Water Desalination Intake location near El Segundo, CA. One coupon from each alloy will be removed after 3, 6, 9 and 11 months and will be sent to a laboratory for analysis. The purpose of the corrosion study is the following:

A. To determine the corrosion rates and modes of anticipated corrosion that will occur on the selected materials.
B. To determine the effectiveness of several antifouling control strategies for future design, implementation and operation of intake facilities.
C. To determine the effect that a foul release protective coating will have on biological growth on the test samples.
D. To determine proper material selection, manufacturer quality control, and proper installation of screens.
E. To select materials that are readily available for manufacture of the wedge wire intake screen for use at the full scale West Basin Desalination Plant.
F. To present information with material selection options, showing overall capital cost, and O&M costs.

The purpose of this report is to provide the results of the on-site and in-situ testing of metal coupons and wedge wire screen samples after the first 195 days of immersion in the Pacific Ocean seawater. The samples were installed on June 17, 2014 and removed on December 29, 2014. Table ES-1 summarizes the corrosion rate results for four different alloys.

Pitting and general corrosion were the primary mechanisms of corrosion on the coupons. The average corrosion rates of the 3-month samples are higher than the 6-month samples except for the 90-10 Cu-Ni coupon. The lower average corrosion rates of the 6-month samples are likely due to the passivation of the surfaces after 6 months. The passivation layer helps protect the surface from corrosion.

Table ES-1 summarizes the results of the testing.

Table ES-1. Corrosion Rates of Four Alloys after 195 days in Seawater Exposure

Alloy	Sample Type	Surface Area (sq. in.)	Maximum Pitting Depth over 195 days (mils)	Overall Average Corrosion Rate (mils/year)
2205 Duplex SS Uncoated	1-inch by 3-inch coupon	8.2	1.06	0.002
	Wedge Wire Screen	96.7	1.06	0.003
2205 Duplex SS with Foul Release Coating	1-inch by 3-inch coupon	8.2	1.34*	0.079*
	Wedge Wire Screen	96.7	1.34*	0.079*
CDA 715 70-30 Cu-Ni	1-inch by 3-inch coupon	8.2	0.87	0.630
	Wedge Wire Screen	65.0	0.87	0.866
CDA 706 90-10 Cu-Ni	1-inch by 3-inch coupon	8.2	0.87	0.906
	Wedge Wire Screen	79.1	0.87	2.638
Z Alloy	1-inch by 3-inch coupon	8.2	0.51	0.394
	Wedge Wire Screen	96.3	0.51	2.441

*Mass loss and corrosion rate includes metal and coating material

Based on the data over 195 days, coated and uncoated 2205 Duplex Stainless Steel has the lowest overall average corrosion rates of the four metal alloys for both the coupons and screens tested in this study. However, the uncoated 2205 Duplex Stainless Steel samples were the most heavily fouled by marine life.

As can be seen in Table ES-1, the highest overall average corrosion rate was observed on the 90-10 Cu-Ni coupons and screens. The overall average corrosion rates of the 90-10Cu-Ni and Z Alloy screens were 3 to 6 times higher than the coupons of the same alloy. The 90-10 Cu-Ni coupons were provided from a different vendor than the screens and they may have a different chemical composition. However the same cannot be said for the Z Alloy samples because they were provided from the same vendor. Tenera Environmental indicated that the 70-30 Cu-Ni samples exhibited slightly more green marine life fouling on the coupons and screens than the 90-10 Cu-Ni and Z alloy metals. It is possible that the corrosion rate is reduced by the amount of marine life fouling present on the samples because it limits the exposure of the metal to the seawater. The ability of the metal to create a passivation layer on the surface of each alloy may also affect the corrosion rate.

The highest pitting rate was observed on the Foul Release-Coated 2205 Duplex Stainless Steel coupons. Pits on the small cross sectional areas of the wire screens were difficult to measure, but the pit measurements on the screens indicate the screens followed the same trend between the different alloys as the coupons.

1.0 INTRODUCTION

West Basin Municipal Water District (West Basin) is pursuing ocean water desalination as an added source of water for its clients. Five test samples made from four different alloys were identified, through review of the literature for similar studies, and installed on a testing apparatus at the West Basin Ocean Water Desalination Intake location near El Segundo, CA. The intent of the study is to measure the extent of corrosion and biofouling on bare and coated metal coupons. The samples were installed and ten coupons were removed after 195 days. Six additional coupons will be removed after 9 and 11 months until all 24 coupons are removed. Once removed, the samples will be sent to a lab for analysis. The overall objectives for the study are the following:

- To determine the corrosion rates and modes of anticipated corrosion that will occur on the selected materials.
- To determine the effectiveness of several antifouling control strategies for future design, implementation and operation of intake facilities.
- To determine the effect of a foul release that the protective coating will have on biological growth on the test samples. This will substantiate the ultimate selection of intake screen material and the benefit of providing an anti-fouling coating on the intake screen.
- To determine proper material selection, manufacturer quality control, and proper installation of screens.
- To select materials that are readily available for manufacture of the wedge wire intake screen for use at the full scale West Basin Desalination Plant.
- To present information with material selection options, showing overall capital cost, and O&M costs.

The purpose of this report is to provide the results of the on-site and in-situ testing of metal coupons and wedge wire screen samples after 195 days of immersion in the Pacific Ocean seawater.

2.0 METHODS

The purpose of this section is to describe the testing study procedures for on-site and in-situ testing of metal coupons and wedge wire screen samples in order to assess corrosion impact relative to material selection and operating practices. The results presented in this report are for the samples that were removed after 6 months of seawater exposure.

2.1 Procurement of Materials

Twenty-four (24) testing samples were obtained for testing of the corrosion coupons and 24 testing samples were obtained for the wedge wire screens (4 samples for each material type). The metal coupons are 1 inch wide by 3 inches long by 1/16 of an inch thick and the wedge wire screens are 4 inches by 4 inches with a 2 mm spacing. The 90-10 Cu-Ni screens have 4 mm spacing, between the screen wires.

V&A coordinated with the coupon vendors and screen manufacturers for the procurement of the testing samples. Metal Samples Company of Munford, Alabama, provided the 1-inch by 3-inch long by 1/16-inch thick coupons in 90-10 Copper-Nickel (Cu-Ni), 70-30 Cu-Ni, and the 2205 Duplex Stainless Steel. Metal Samples also provided the 4-inch by 4-inch by 1/8-inch thick flat plate in the same metal alloys. Holes were made on each 1-inch by 3-inch and 4-inch by 4-inch metal sample in order to secure it to the testing rack with plastic zip ties.

Johnson Screens/Bilfinger Water Technologies of New Brighton, Minnesota provided the 4-inch by 4-inch wedge wire screens in the 90-10 Cu-Ni, 2205 Duplex Stainless Steel, and Z alloys. They also provided the 1-inch by 3-inch by 1/16 inch thick coupons and the 4-inch by 4-inch flat plate in the Z alloy.

Hendrick Screen Company of Owensboro, Kentucky, provided the 4-inch by 4-inch wedge wire screens in 70-30 Cu-Ni.

2.2 Coating for Stainless Steel Screens and Coupons

V&A searched for a coating that would provide an NSF Standard 61-approved coating for drinking water contact and was known to prevent the attachment of marine life on hydraulic structures. V&A identified the following foul release coating system for the stainless steel samples from the literature review and discussions with manufacturers:

A. 1st coat - Sherwin Williams Macropoxy 646 PW immersion grade epoxy primer at 6 mils dry film thickness (dft)
B. 2nd coat - Sherwin Williams Seaguard Sher-Release beige silicone Tie Coat at 6 mils dft
C. 3rd coat - Sherwin Williams Seaguard Sher-Release white silicone Surface Coat at 6 mils dft

The coating was applied by Fuji Hunt Smart Surfaces in Davidsonville, Maryland.

2.3 Lab Analysis

2.3.1 Chemical Analysis by EDS

Anamet, Inc. of Hayward, California, performed a quantitative chemical analysis by Energy Dispersive x-ray Spectra (EDS) on a baseline control sample and on the samples after they were immersed in seawater. Anamet's report contains images of the spectra and is included as Appendix A.

2.3.2 Scanning Electron Microscopy

Anamet, Inc. of Hayward, California, performed Scanning Electron Microscopy (SEM) on the samples. The SEM uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. The signals that derive from electron-sample interactions reveal information about the sample including texture, chemical composition, and crystalline structure.

2.3.3 Metallography

Optical macrographs of the samples were also recorded by Anamet, Inc. before and after cleaning of the samples and are attached in Anamet's reports. A metallographic examination of a cross section of each sample was recorded.

2.3.4 Corrosion Rate Analysis

Samples were weighed by Anamet Laboratories in Hayward, CA before they were installed. The samples were analyzed by the lab after they were exposed to the seawater environment per ASTM G1 *Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens* and ASTM D2688 *Standard Test Method for Corrosivity of Water in the Absence of Heat Transfer (Weight Loss Method)*. The samples were cleaned with either nitric acid or hydrochloric acid. Plots of mass loss versus cleaning cycles for each sample are attached in Anamet's report. Pitting examination was performed per ASTM G46 *Standard Guide for Examination and Evaluation of Pitting Corrosion*.

2.4 Procedures

After the initial baseline parameters were obtained, the samples were shipped to Tenera Environmental for installation at the project site. Tenera Environmental assembled the testing rack

and affixed the coupons and wedge wire screens prior to immersion in the ocean source water. The wedge wire screens were secured to the testing rack with plastic zip ties. There was one test rack for each set of samples to be removed at each specified interval.

The testing samples consisted of metal coupons, wedge wire screens and flat plates (coated and uncoated) for installation on the in-situ testing apparatus installed by Tenera Environmental divers. Samples and cleaning were performed per ASTM G-1 *Preparing, Cleaning, and Evaluating Corrosion Test Specimens* and ASTM D2688 *Standard Test Method for Corrosivity of Water in the Absence of Heat Transfer (Weight Loss Method)*. ASTM G-1 includes procedures in Sections 14.10 through 14.14 that involve weighing and classifying the types of pits. This test method covers the determination of the corrosivity of water by evaluating pitting and by measuring the weight loss of metal specimens. Pitting is a form of localized corrosion: weight loss is a measure of the average corrosion rate.

A metallographic examination was performed per ASTM E3 *Standard Guide for Preparation of Metallographic Specimens*. The primary objective of metallographic examinations is to reveal the constituents and structure of metals and their alloys by means of a light optical or scanning electron microscope.

Before installation the samples were examined for the following baseline parameters:

1. Weigh all samples per ASTM G1. Samples to be coated will be weighed before and after coating application.
2. Examine samples visually to 40X
3. Color photograph, one of each material type
4. Photomicrograph @ 10X, one of each material type
5. Photomicrograph @ 50X, one of each material type
6. Scanning Electron Micrograph (SEM) @ 100X, one of each material type
7. Energy Dispersive Spectroscopy (EDS), one of each material type

Samples removed after 3, 6, 9 and 11 months of exposure have been and will be examined for the following:

1. Sample cleaning and weighing per ASTM G1 and ASTM D2688
2. Pitting examination per ASTM G46
3. Dimensional inspection (micrometers or NOGO gauge): Wedge wire and gap dimensions.
4. Photomicrograph @ 10X, one of each material type After Cleaning (AC)
5. Photomicrograph @ 50X, one of each material type AC
6. Scanning Electron Micrograph @ 100X, one of each material type AC
7. Elemental analysis with EDS, one of each material type AC
8. Metallographic examination per ASTM E3, one of each material type

2.5 Corrosion Mechanisms

Corrosion is an electrochemical phenomenon that takes place at the interface of the metal and electrolyte, which in this case is seawater. When the metal is in contact with the electrolyte, a difference in potential develops at the electrolyte/metal interface. When corrosion reactions take place, they generate a current between the metal and the electrolyte. Factors that may impact the corrosion rate include the following:

- Presence of inclusions in the metal or a Heat Affected Zone due to welding
- Mechanical stresses caused by welding, forming or temperature
- Water velocity and tidal fluctuations at the surface of the coupon (not possible to simulate in a lab)
- Alloy resistance to corrosion due to high chloride concentrations in seawater
- Water temperature, dissolved oxygen, sulfates, and chlorides

The following sections explain some possible corrosion mechanisms for the metals based on V&A's research.

2.5.1 Uniform Corrosion

If all metal surfaces are attacked via corrosion at an equal rate, the corrosion is termed uniform. As far as failure rate, the uniform corrosion rate is expressed in terms of pipe penetrating rates (rate of pipe wall loss) in thousandths of inches (mils) per year (mpy).

2.5.2 Localized and Pitting Corrosion

When corrosion of the metal surface is localized, the surface under the most aggressive attack becomes recessed with respect to the rest of the pipe surface and visible pits are formed. In such instances, the attack is said to be nonuniform, localized, or pitting corrosion. Theoretically, corrosion pitting in metals is divided into two phases: pit initiation and propagation.

2.5.3 Stress Corrosion Cracking

The occurrence of stress corrosion cracking (SCC) depends on the simultaneous achievement of three requirements: 1) a susceptible material; 2) a chemical environment that causes SCC for that material and 3) sufficient tensile (mechanical) stress within the material. The mechanical stresses may be caused by welding, forming, applied loads, and temperature.

Photo 2-1 and Photo 2-2 show samples of the cracking that might occur for copper alloys and duplex stainless steel under mechanical and chemical stresses. These photos are not of the metal samples that are part of this study and are presented for demonstrative purposes only.

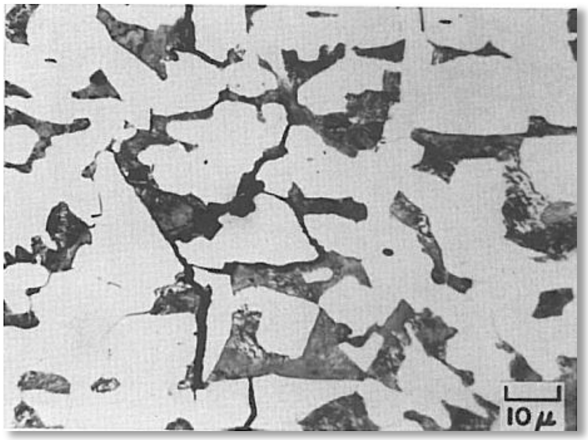


Photo 2-1. Intergranular Stress Corrosion Cracking in a Steel Pipe.[1]

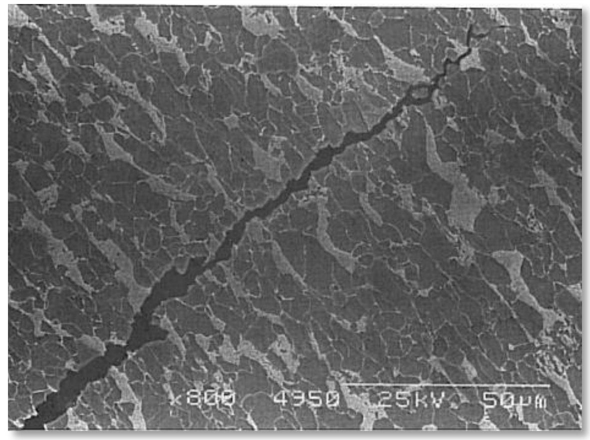


Photo 2-2. Transgranular Stress Corrosion Cracking in a Steel Pipe.[2]

2.6 Reference Corrosion Rates from Studies Performed by Others

V&A researched seawater corrosion rates for the alloys in this study to compare the corrosion rate of the alloys with the results of this study. Table 2-1 summarizes the information found in corrosion control literature.

Table 2-1. Average Corrosion Rates from Literature Review for Alloys in Seawater

Material	UNS	Corrosion Rate (mils/yr)	Reference
90-10 Cu-Ni	C70600	0.15	ASM Volume 13B p.140, Fig 13 (Efird & Anderson, Mater. Perform., 1975)
70 Cu-30Ni	C71500	0.13	ASM Volume 13B p. 140 Fig 14 (Efird & Anderson, Mater. Perform., 1975)
2205 duplex stainless steel	S32205	0.03	McGuire, Stainless Steels for Design Engineers, p. 101, 2008

[1] Revie, R. Winston. Uhlig's Corrosion Handbook. 2nd Edition, John Wiley and Sons, Inc. New York, 2000, p. 194.
[2] Ibid.

Figure 2-1 shows a graph of the average corrosion rates for several metal alloys in seawater. As seen in the graph, 70-30 Cu-Ni and 90-10 Cu-Ni have a corrosion rate of 0.15 to 0.5 mils per year.

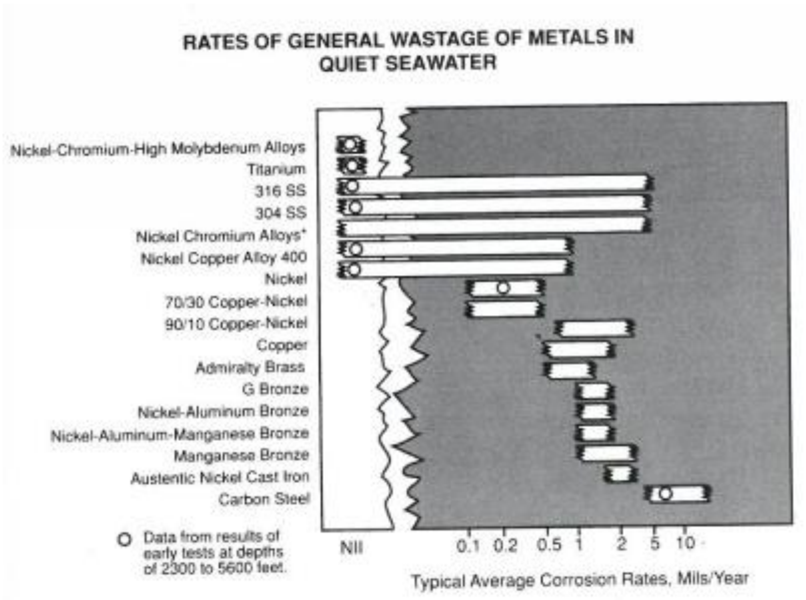


Figure 2-1. Graph of Average Corrosion Rates of Different Alloys in Seawater

3.0 FINDINGS

The second set of ten coupons and screens was installed on Tuesday, June 17, 2014, and retrieved after 195 days on Monday, December 29, 2014. Photographic documentation and lab results and analysis are presented below.

3.1 Photos of Samples After 6 Months of Exposure

Photo 3-1 through Photo 3-10 show the samples before they were cleaned or analyzed.

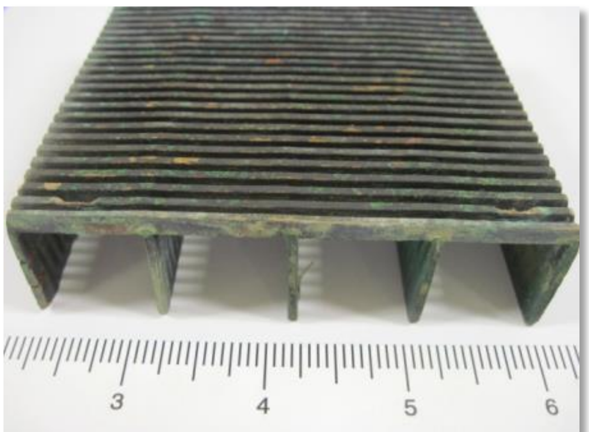


Photo 3-1. Z alloy 4-inch by 4-inch wedge wire screen.

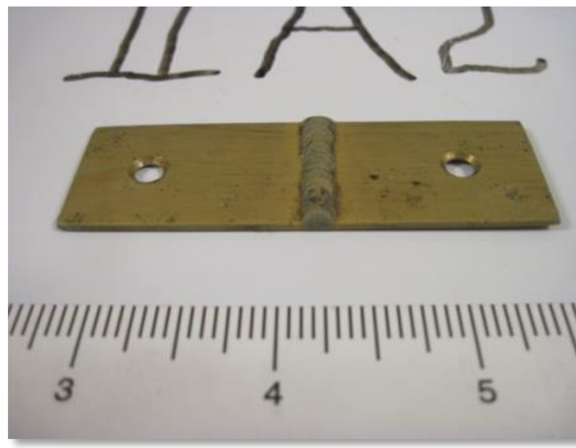


Photo 3-2. Z alloy 1-inch by 3-inch coupon with weld.

Photo 3-3. 70-30 Cu-Ni 4-inch by 4-inch wedge wire screen

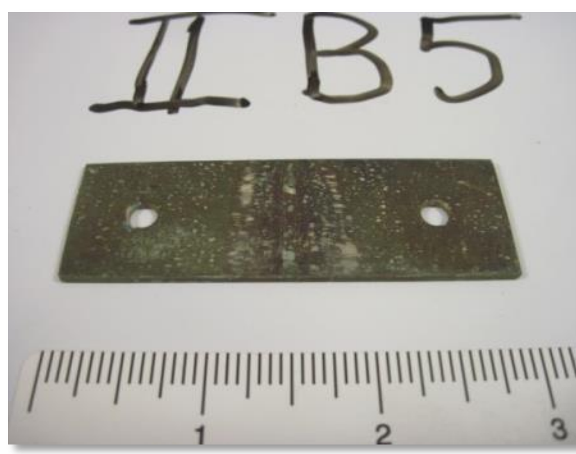


Photo 3-4. 70-30 Cu-Ni 1-inch by 3-inch coupon with weld

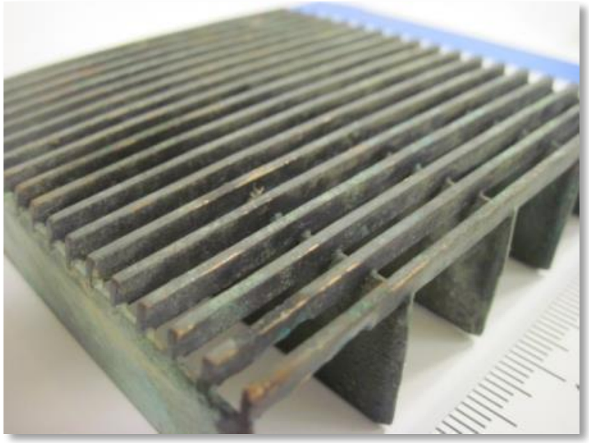


Photo 3-5. 90-10 Cu-Ni 4-inch by 4-inch wedge wire screen

Photo 3-6. 90-10 Cu-Ni 1-inch by 3-inch coupon with weld

Photo 3-7. 2205 Duplex stainless steel 4-inch by 4 inch wedge wire screen.

Photo 3-8. 2205 Duplex stainless Steel 1-inch by 3-inch coupon with a weld.

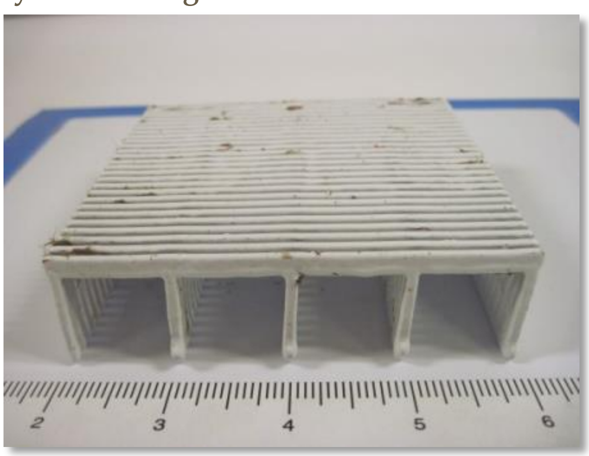


Photo 3-9. Coated 2205 Duplex Stainless Steel 4-inch by 4-inch wedge wire screen.

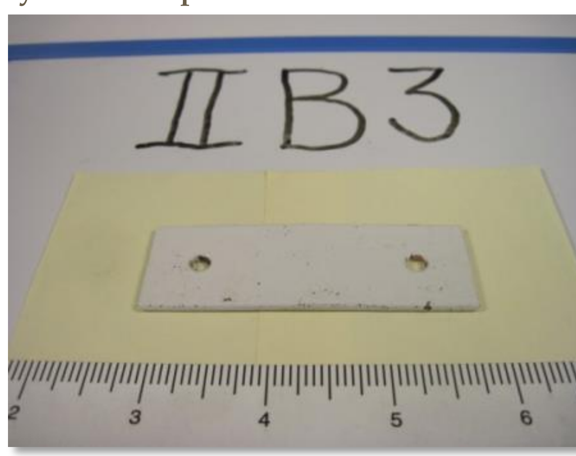


Photo 3-10. Coated 2205 Duplex stainless Steel 1-inch by 3-inch coupon with a weld.

3.2 Corrosion Rates After 195 Days

Table 3-1 summarizes the results of the corrosion rate analysis conducted by Anamet Inc. after the samples were exposed to seawater for 195 days starting on June 17, 2014.

Table 3-1. Corrosion Rates of Four Alloys After 195 days in Seawater Exposure

Alloy	Sample Type	Surface Area (sq. in.)	Maximum Pitting Depth over 195 days (mils)	Overall Average Corrosion Rate (mils/year)
2205 Duplex SS Uncoated	1-inch by 3-inch coupon	8.2	1.06	0.002
	Wedge Wire Screen	96.7	1.06	0.003
2205 Duplex SS with Foul Release Coating	1-inch by 3-inch coupon	8.2	1.34*	0.079*
	Wedge Wire Screen	96.7	1.34*	0.079*
CDA 715 70-30 Cu-Ni	1-inch by 3-inch coupon	8.2	0.87	0.630
	Wedge Wire Screen	65.0	0.87	0.866
CDA 706 90-10 Cu-Ni	1-inch by 3-inch coupon	8.2	0.87	0.906
	Wedge Wire Screen	79.1	0.87	2.638
Z Alloy	1-inch by 3-inch coupon	8.2	0.51	0.394
	Wedge Wire Screen	96.3	0.51	2.441

*Mass loss and corrosion rate includes metal and coating material

Based on the data over 195 days, coated and uncoated 2205 Duplex Stainless Steel has the lowest average corrosion rates of the four metal alloy coupons and screens tested in this study. However, the uncoated 2205 Duplex Stainless Steel samples were the most heavily fouled by marine life.

Of the copper alloy coupon samples, the Z alloy 1-inch by 3-inch coupon indicated the lowest overall average corrosion rate and the 90-10 Cu-Ni coupon had the highest corrosion rate. The 90-10 Cu-Ni screens had the highest corrosion rate of all of the screens after 195 days of exposure. The overall average corrosion rates of the 90-10Cu-Ni and Z Alloy screens were 3 to 6 times higher than the coupons of the same alloy. The 90-10 Cu-Ni coupons were provided from a different vendor than the screens and they may have a different chemical composition. However the same cannot be said for the Z Alloy samples because they were provided by the same vendor. Tenera Environmental indicated that the 70-30 Cu-Ni samples exhibited slightly more green marine life fouling on the coupons and screens than the 90-10 Cu-Ni and Z alloy metals. It is possible that the corrosion rate is reduced by the amount of marine life fouling present on the samples because it limits the exposure of the metal to the seawater. The ability of the metal to create a passivation layer on the surface of each alloy may also affect the corrosion rate.

The highest pitting rate was observed on the Foul Release-Coated 2205 Duplex Stainless Steel coupons. However, the mass loss was primarily due to the coating that was removed (see Photo 3-11 and Photo 3-12) from the samples and may not represent the metal loss. Pits on the small cross sectional areas of the wire screens were difficult to measure, but it is assumed that the screens have the same pitting rates as the coupons.

Photo 3-11 through Photo 3-20 show the surfaces of the samples under magnification. Photos are courtesy of Anamet Inc. and are included in the reports in Appendix A.

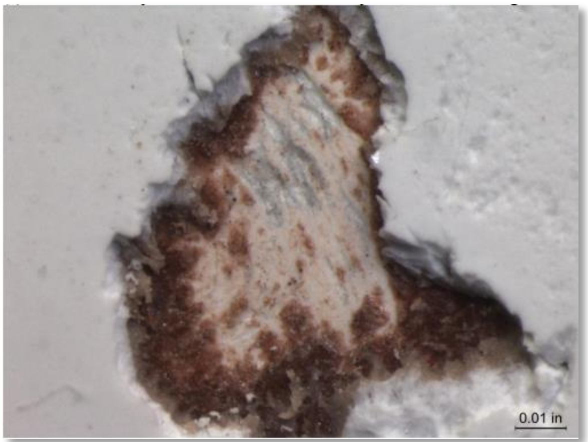


Photo 3-11. 2205 Duplex SS coupon surface exposed at an area of coating damage.

Photo 3-12. 2205 Duplex SS wedge wire screen surface at an area of coating damage.

Photo 3-13. 2205 Duplex SS coupon surface after cleaning under 50X magnification.

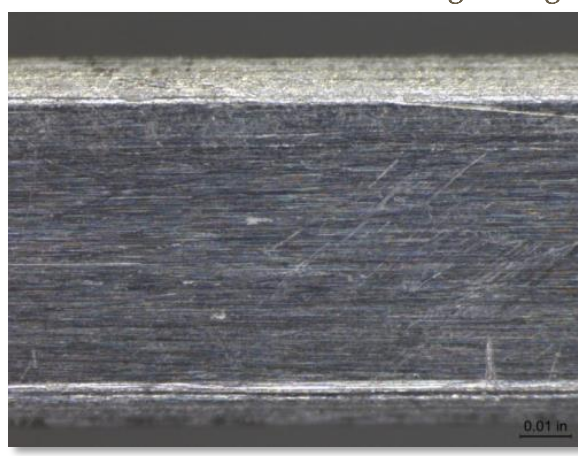


Photo 3-14. 2205 Duplex SS screen surface after cleaning under 50X magnification.

Photo 3-15. CDA 706 coupon 2 at 50x magnification after cleaning

Photo 3-16. CDA 706 Screen 2 at 50X magnification after cleaning.

Photo 3-17. CDA 715 coupon 2 at 50x magnification after cleaning.

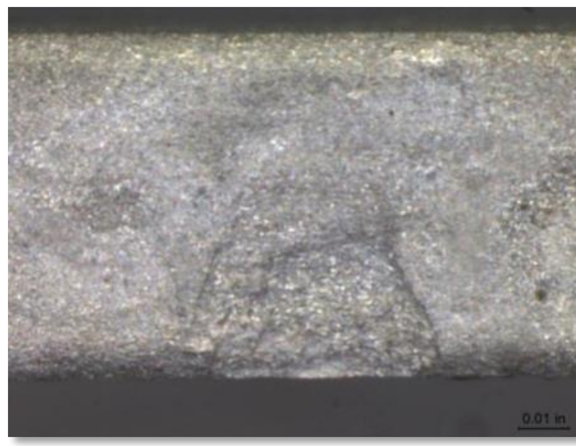


Photo 3-18. CDA 715 screen 2 at 50X magnification after cleaning.

Photo 3-19. Z Alloy Screen at 50X magnification after cleaning.

Photo 3-20. Z Alloy Screen at 50X magnification after cleaning.

4.0 CONCLUSIONS

Based on the literature research and the lab analysis, V&A presents the following conclusions.

4.1 Coupons

1. The average corrosion rates of the 3-month samples are higher than the 6-month samples except for the 90-10 Cu-Ni coupon. The 6 month samples have a protective passivation layer.
2. The average corrosion rate of the uncoated and coated 2205 Duplex Stainless Steel coupons was the lowest of the four alloys that were included in this study.
3. The average corrosion rate of the 90-10 Cu-Ni coupons was the highest of the four alloys that were included in this study.
4. The lowest coupon pitting depth was measured on the Z Alloy coupons after 195 days of exposure in seawater.
5. The highest pitting depth was measured on the Foul Release Coated 2205 Duplex Stainless Steel coupons after 195 days of exposure in seawater. However, this may be due to the loss of coating in addition to metal material.
6. Pitting and general corrosion were the primary modes of corrosion on the coupons.
7. There is a large difference in the overall corrosion rate between the coupons and screens for the 90-10Cu-Ni and Z Alloy samples.
8. The overall average corrosion rates of the 90-10Cu-Ni and Z Alloy screens were 3 to 6 times higher than the coupons of the same alloy.
9. The overall average corrosion rates were higher than the data found in the literature summarized in Table 2-1.

4.2 Screens

1. The average corrosion rate of the Uncoated 2205 Duplex Stainless Steel screens was the lowest of the four alloys after 195 days of exposure.
2. The average corrosion rate of the 90-10 Cu-Ni screens was the highest of the four alloys that were included in this study.
3. Pitting and general corrosion were the primary modes of corrosion on the screens.
4. The maximum pitting depth of the screens followed the same trend between the different alloys as the coupons.
5. The overall average corrosion rates of the 90-10Cu-Ni and Z Alloy screens were 3 to 6 times higher than the coupons of the same alloy.
6. The overall average corrosion rates were higher than the data found in the literature summarized in Table 2-1.

APPENDIX A. LAB ANALYSIS REPORTS

Anamet, inc Materials Engineering & Laboratory Testing
26102 EDEN LANDING ROAD, SUITE 3 • HAYWARD, CALIFORNIA 94545 • (510) 887-8811 • FAX (510) 887-8427

Report No. 5005.0361B **February 9, 2015**

CORROSION EVALUATION OF 2205 DUPLEX STAINLESS STEEL COUPONS AND SCREENS

Customer Authorization: Verbal

Report To: V & A Engineering
Attn: Manuel Najar
155 Grand Avenue, Suite 700
Oakland, CA 94612

1.0 INTRODUCTION

Five coupons, five wedge wire screens, and one plate were submitted by V&A Engineering for corrosion evaluation. The coupons were 1-inch by 3-inches by ¼-inch thick. The wedge wire screens were 4-inches by 4-inches by 1-inch tall with 4 mm spacing. The plate was 4-inches by 4-inches by 1/8-inch thick. The sample was reportedly a 2205 duplex stainless steel alloy.

Four coupons and four screens were to be placed in seawater for a period up to one year. After every 3 month interval, one coupon and one screen were to be removed from the test system and examined for corrosion. The purpose of this evaluation was to document the samples in the baseline as-received condition, then again after 3, 6, 9, and 12 months of water exposure, record any loss in mass, examine for any pitting corrosion, and estimate the corrosion rate.

The samples were evaluated by the following laboratory procedures:

1) Visual examination and weighing
2) Cleaning per ASTM G1[1]
3) Scanning electron microscopy
4) Metallography

The results of the evaluation showed minimal mass loss and corrosion for the coupon and screen after 3 months and 6 months of corrosion testing. Both the coupon and screen, after a 3 month corrosion test, had a corrosion rate less than 0.0005 millimeters per year. Both the coupon and screen, after a 6 month corrosion test, had a corrosion rate less than 0.0005 millimeters per year.

[1] G1: Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

2.0 EVALUATION[2]

2.1 Visual Examination

The sample identifications for the coupons and wedge wire screens and their corresponding immersion times are shown in Table 1. The coupons had identification numbers stamped on the front face by V&A Engineering. A number of notches, corresponding to the sample number, were sawed at the edge of each screen for identification after the corrosion test. The weights of the samples were recorded. Coupons 6 – 9 and screens 1 – 5 were sent back to V&A for corrosion testing. Coupon 10 was the baseline sample and documented by photography, optical stereoscopy and scanning electron microscopy for comparison to the tested samples. Screen 5 was documented as a baseline by photography and optical stereoscopy, and then sent to V&A for testing.

Photographs of the baseline coupon are shown in Figure 1. Photographs of coupon 1, after 3 months of corrosion testing, are shown in Figure 2. Photographs of coupon 2, after 6 months of corrosion testing, are shown in Figure 3.

A photograph of the baseline screen is shown in Figure 4. A photograph of screen 1, after 3 months of corrosion testing, is shown in Figure 5. A photograph of screen 2, after 6 months of corrosion testing, is shown in Figure 6.

2.2 Cleaning

The coupon and screen were cleaned with solution C.7.1 per ASTM G1.[3] One cleaning cycle was approximately 10 minutes. After each cleaning cycle, the samples were rinsed in water, dried, and weighed. The cleaning and weighing cycle was completed five times for the coupon and screen. The weights of the samples as-received, after corrosion testing but before cleaning, and after each cleaning cycle are presented in Table 2.

Optical macrographs of the baseline coupon and screen are shown in Figures 7 and 12, respectively. Representative optical macrographs of the samples after a 3 month corrosion test, before and after cleaning are shown in Figures 8 – 9 and 13 – 14. Representative optical macrographs of the samples after a 6 month corrosion test, before and after cleaning are shown in Figures 10 – 11 and 15 – 16.

The mass loss versus the number of cleaning cycles were plotted to determine the mass loss of the samples due to corrosion, shown in Figures 17 – 18. The equations for best fit lines AB and BC, calculated using IGOR Pro, are listed in Table 3. Point B, indicated by the red circle in each plot, corresponds to the mass loss due to corrosion for each sample. This mass loss was subtracted from the weight of the sample before cleaning and from the weight of the sample as-received to determine the total mass loss from corrosion. The corrosion rate of each sample was determined by the formula specified in Section 8.1 of ASTM G1:

[2] The magnifications of the optical and scanning electron micrographs in this report are approximate and should not be used as a basis for dimensional analyses unless otherwise indicated.
[3] 100 mL nitric acid + 900 ml reagent water.

$$Corrosion\ Rate = \frac{K\ x\ W}{A\ x\ T\ x\ D}$$

where K = 8.76 x 10^4, T = time of exposure in hours, A = area in cm^2, W = mass loss in grams, and D = density in g/cm^3. The density of the Z-Alloy was determined by cutting a section out of the baseline coupon, measuring the length, width, and thickness, and weighing the section with a balance. The total mass loss from corrosion and the calculated corrosion rate of each sample is shown in Table 4.

2.3 Scanning Electron Microscopy

The baseline coupon, coupon 6, and coupon 7 were examined with a scanning electron microscope. Representative scanning electron micrographs of the baseline coupon are shown in Figure 19. Representative scanning electron micrographs of coupon 1 after cleaning are shown in Figure 20. Representative scanning electron micrographs of coupon 2 after cleaning are shown in Figure 21.

An energy dispersive x-ray spectrum of the baseline coupon is shown in Figure 22. Energy dispersive x-ray spectra of the coupons after cleaning are shown in Figure 23. The coupon was not analyzed by scanning electron microscopy and energy dispersive x-ray spectroscopy before cleaning due to the amount of biological products on it.

2.4 Metallography

Cross sections were taken from the coupon and prepared for a metallographic examination. Optical micrographs of the surface for coupon 6 are shown in Figure 24. Small, narrow pits were observed in coupon 6, measuring 18 μm in depth. Optical micrographs of the surface for coupon 7 are shown in Figure 25. Small, narrow pits were observed in coupon 6, measuring 27 μm in depth.

3.0 DISCUSSION

The coupon and screen showed minimal mass loss and pitting after 3 and 6 months of corrosion testing.

After 3 months of corrosion testing, the coupon had lost less than 0.001 grams of material and had a corrosion rate less than 0.0005 millimeters per year. The weight loss is beyond the measurement capabilities of the balance. After 3 months of corrosion testing, the screen had lost 0.04 grams of material and had a corrosion rate less than 0.0005 millimeters per year.

After 6 months of corrosion testing, the coupon had lost less than 0.001 grams of material and had a corrosion rate less than 0.0005 millimeters per year. The weight loss is beyond the measurement capabilities of the balance. After 6 months of corrosion testing, the screen had lost 0.02 grams of material and had a corrosion rate less than 0.0005 millimeters per year.

4.0 CONCLUSIONS[4]

The following conclusions are based upon the submitted samples and the evidence gathered:

1. The coupon, after 3 months of corrosion testing, had a mass loss less than 0.001 grams and a corrosion rate less than 0.0005 mm / year.
2. The screen, after 3 months of corrosion testing, had a mass loss of 0.04 grams and a corrosion rate less than 0.0005 mm / year.
3. The coupon, after 6 months of corrosion testing, had a mass loss less than 0.001 grams and a corrosion rate less than 0.0005 mm / year.
4. The screen, after 6 months of corrosion testing, had a mass loss of 0.02 grams and a corrosion rate less than 0.0005 mm / year.

Prepared by:	Reviewed by:
Norman Yuen	Audrey A. Fasching
Norman Yuen Materials Engineer	Audrey A. Fasching, Ph.D., P.E. Senior Materials Engineer

[4] The conclusions in this report are based upon the available information and evidence provided by the client and gathered by Anamet, within the scope of work authorized by the client, and they are hereby presented by Anamet to a reasonable degree of engineering and scientific certainty. Anamet reserves the right to amend or supplement its conclusions or opinions presented in this report should additional data or information become available, or further work be approved by the client.

Table 1
Sample Identifications

Description		V&A Engineering Identification (As-Received)	Anamet Identification (in report)	Notes
Alloy	Part			
2205 Duplex Stainless Steel	**Flat Plate** 4-inch x 4-inch x 1/8-inch	2205 2	Plate	None
	Coupon 1-inch x 3-inch x 1/8-inch with autogenous weld bead	2205W 6	Coupon 6	3 Month Immersion
		2205W 7	Coupon 7	6 Month Immersion
		2205W 8	Coupon 8	9 Month Immersion
		2205W 9	Coupon 9	12 Month Immersion
		2205W 10	Coupon 10	Baseline Sample (no exposure)
	Wedge Wire Screen 4-inch x 4-inch x 1-inch with 2 mm spacing	None	Screen 1	3 Month Immersion
		None	Screen 2	6 Month Immersion
		None	Screen 3	9 Month Immersion
		None	Screen 4	12 Month Immersion
		None	Screen 5	12 Month Immersion

Table 2
Sample Weights

Sample	Baseline Measurement	Measurements after 3 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 6	22.1525	22.1531	22.1529	22.1527	22.1515	22.1514	22.1513
Screen 1	311.70	311.78	311.66	311.66	311.66	311.67	311.67

Sample	Baseline Measurement	Measurements after 6 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 7	22.0018	22.0018	22.0017	22.0015	22.0016	-	-
Screen 2	313.62	313.60	313.59	313.60	313.58	-	-

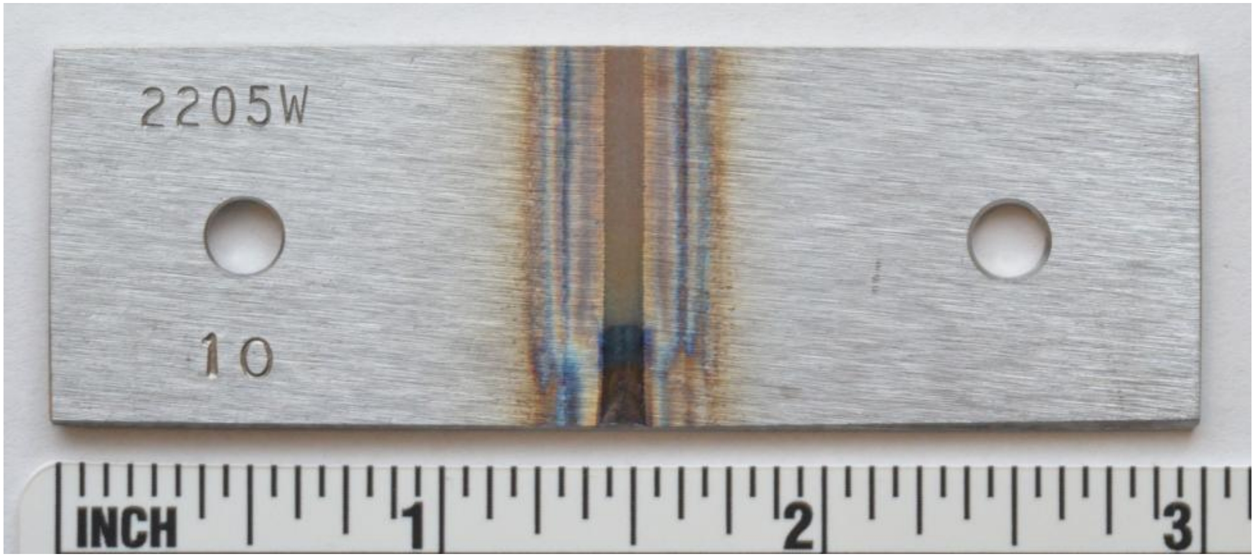
Table 3
Equations of Lines AB and BC for Corrosion Testing Samples

Sample	Line AB	Line BC	Point B (Approximate Mass Loss from Corrosion)
Coupon 6	y = 0.0004x	N/A	0 grams
Coupon 7	N/A	y = 0.0001x	0 grams
Screen 1	y = 0.12x	y = 0.120	0.12 grams
Screen 2	N/A	y = 0.007x	0 grams

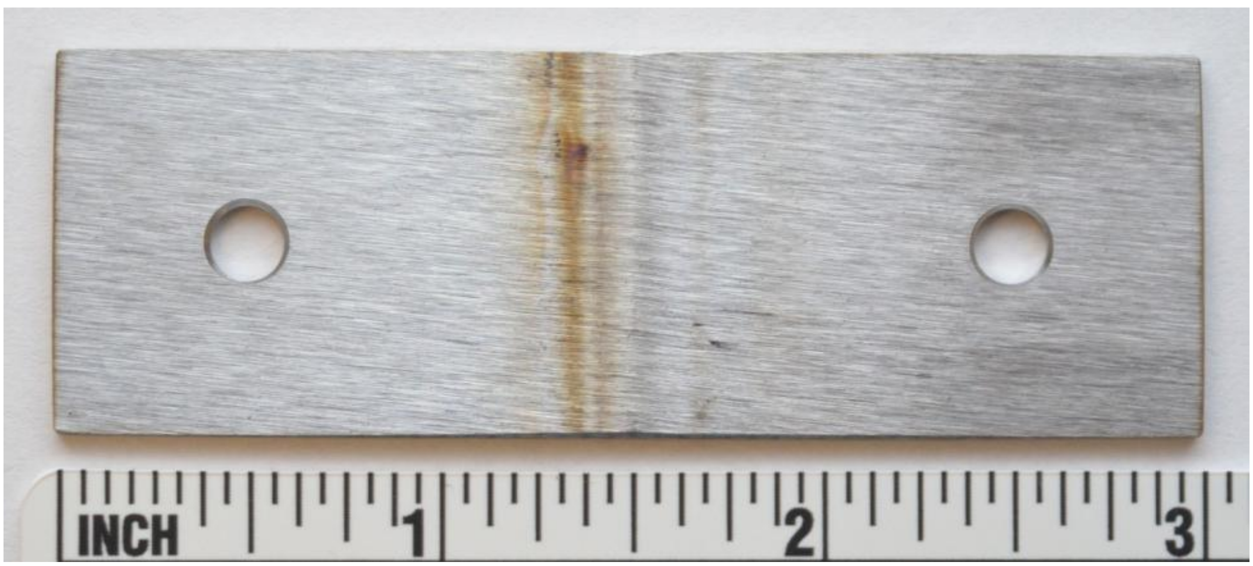
Table 4
Total Mass Loss from Corrosion and Corrosion Rate

Sample	Total Mass Loss from Corrosion*	Corrosion Rate
Coupon 6	< 0.001 grams	< 0.0005 mm / year
Coupon 7	< 0.001 grams	< 0.0005 mm / year
Screen 1	0.04 grams	< 0.0005 mm / year
Screen 2	0.02 grams	< 0.0005 mm / year

* Weight As-Received – (Weight Before Cleaning – Mass Loss from Corrosion During Cleaning)



(a) Duplex 2205 Stainless Steel Baseline Coupon, Front Side



(b) Duplex 2205 Stainless Steel Baseline Coupon, Back Side

Figure 1 Photographs of the duplex 2205 stainless steel baseline coupon (a) front and (b) back side.

(a) Duplex 2205 Stainless Steel Coupon 6, Front Side

(b) Duplex 2205 Stainless Steel Coupon 6, Back Side

Figure 2 Photographs of duplex 2205 stainless steel coupon 6 (a) front and (b) back side after a 3 month corrosion test.

(a) Duplex 2205 Stainless Steel Coupon 7, Front Side

(b) Duplex 2205 Stainless Steel Coupon 7, Back Side

Figure 3 Photographs of duplex 2205 stainless steel coupon 7 (a) front and (b) back side after a 6 month corrosion test.

(a) Duplex 2205 Stainless Steel Baseline Screen

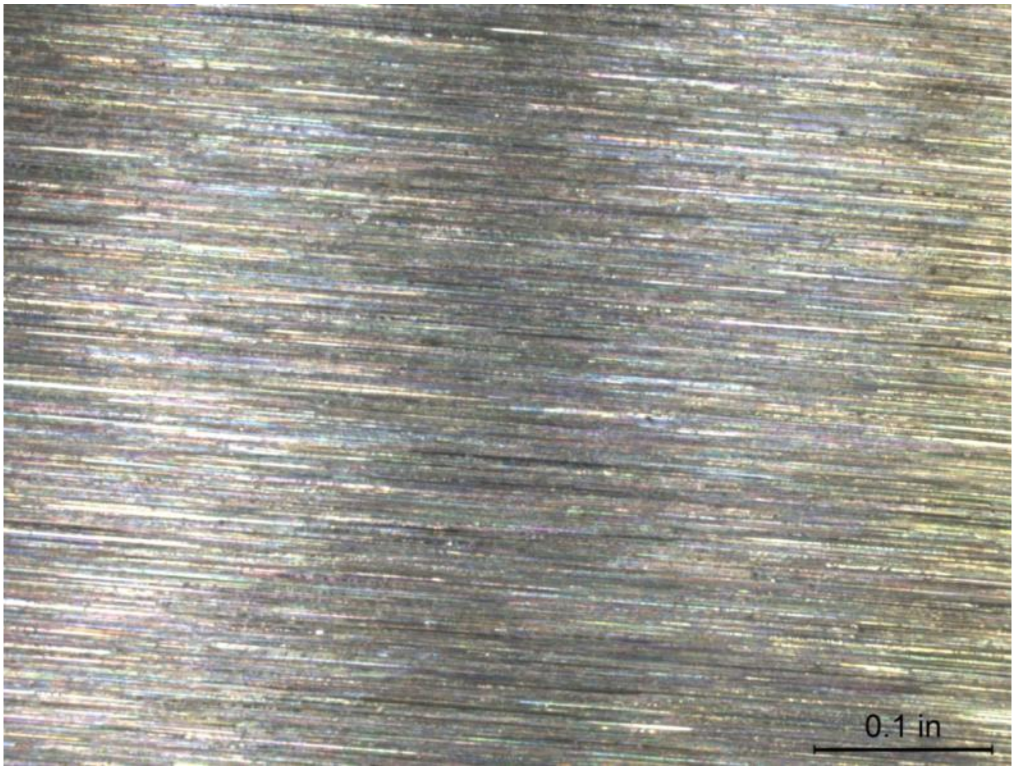
Figure 4 Photograph of the duplex 2205 stainless steel baseline screen.

(a) Duplex 2205 Stainless Steel Screen 1

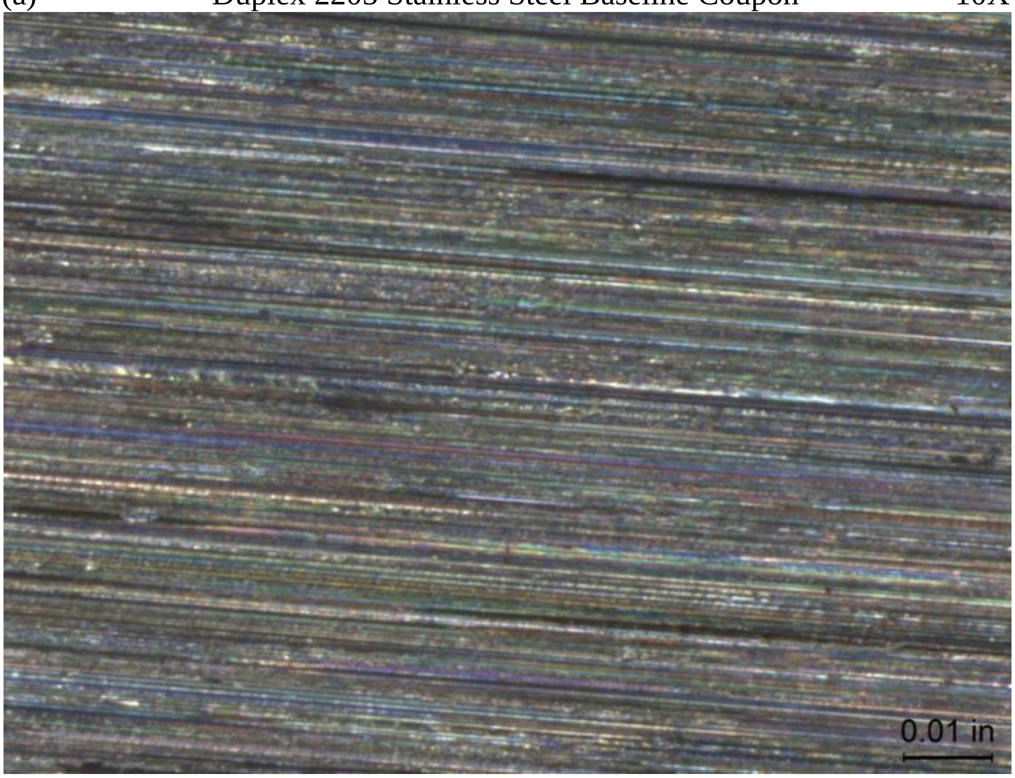
Figure 5 Photograph of duplex 2205 stainless steel screen 1 after a 3 month corrosion test.

(a) Duplex 2205 Stainless Steel Screen 2

Figure 6 Photograph of duplex 2205 stainless steel screen 2 after a 6 month corrosion test.



(a) Duplex 2205 Stainless Steel Baseline Coupon 10X



(b) Duplex 2205 Stainless Steel Baseline Coupon 50X

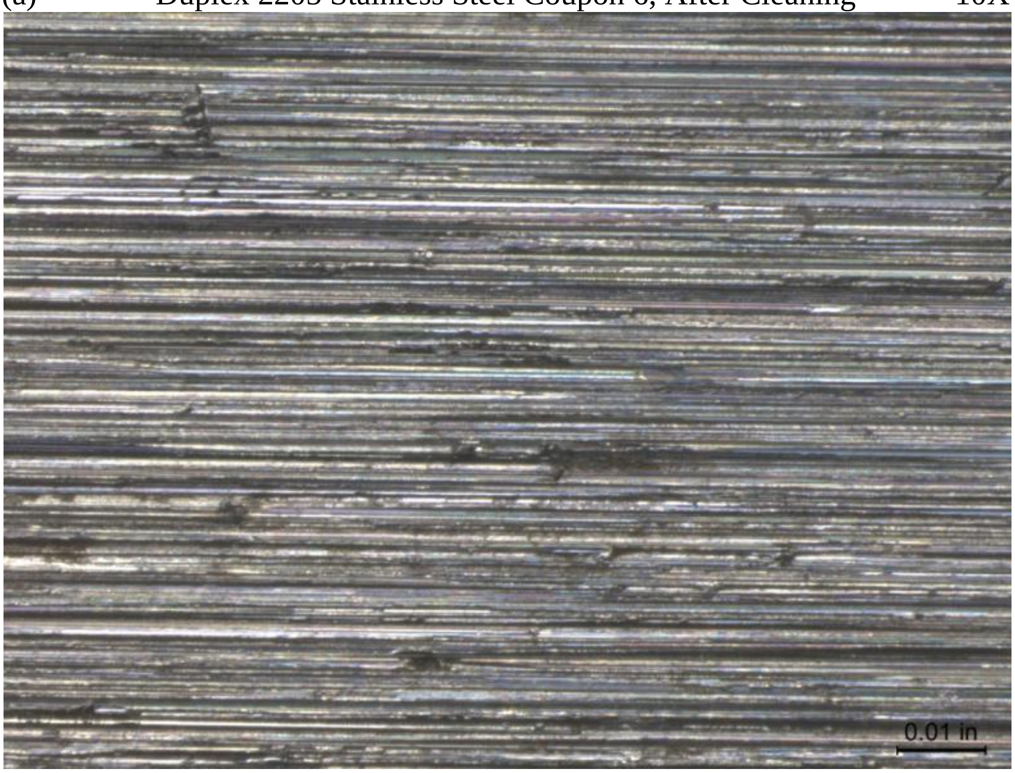
Figure 7 Optical macrographs of the duplex 2205 stainless steel baseline coupon.

(a) Duplex 2205 Stainless Steel Coupon 6, Before Cleaning 10X

(b) Duplex 2205 Stainless Steel Coupon 6, Before Cleaning 50X

Figure 8 Optical macrographs of duplex 2205 stainless steel coupon 6 after a 3 month corrosion test, before cleaning.

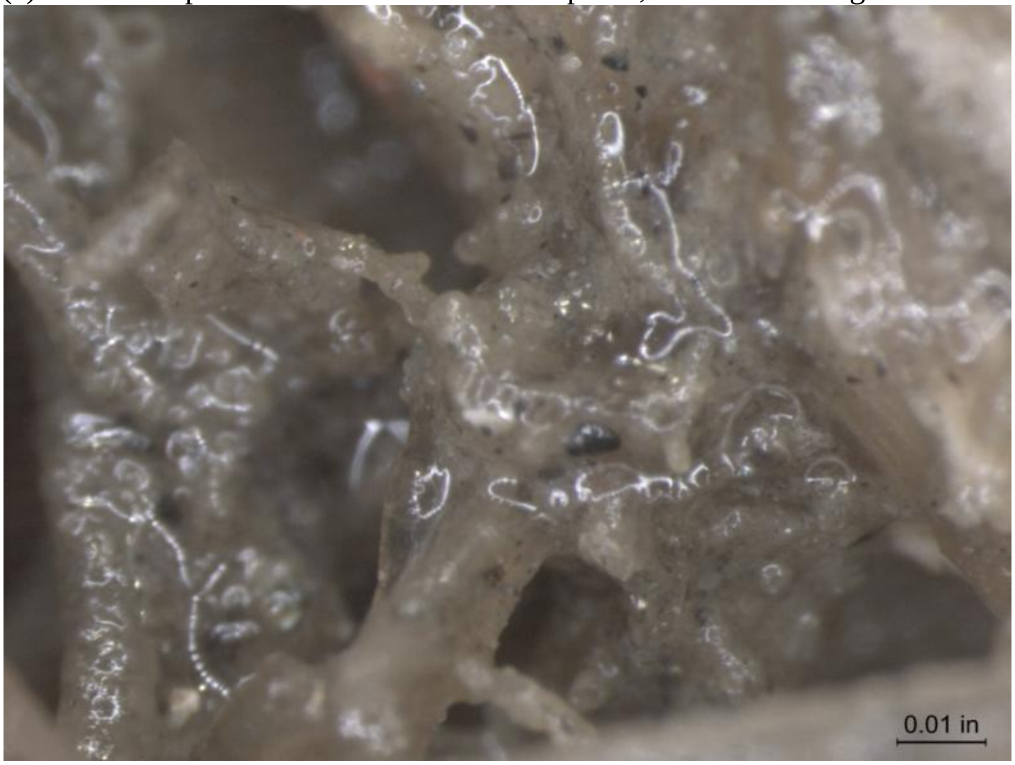
(a) Duplex 2205 Stainless Steel Coupon 6, After Cleaning 10X



(b) Duplex 2205 Stainless Steel Coupon 6, After Cleaning 50X

Figure 9 Optical macrographs of duplex 2205 stainless steel coupon 6 after a 3 month corrosion test, after cleaning.

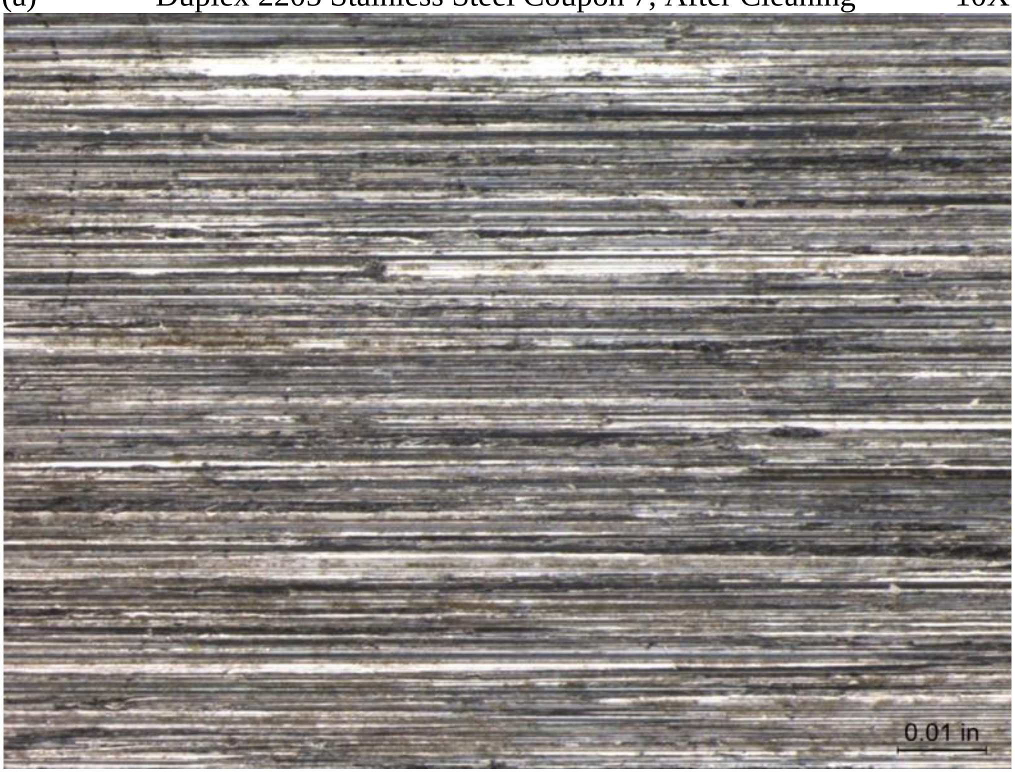
(a) Duplex 2205 Stainless Steel Coupon 7, Before Cleaning 10X



(b) Duplex 2205 Stainless Steel Coupon 7, Before Cleaning 50X

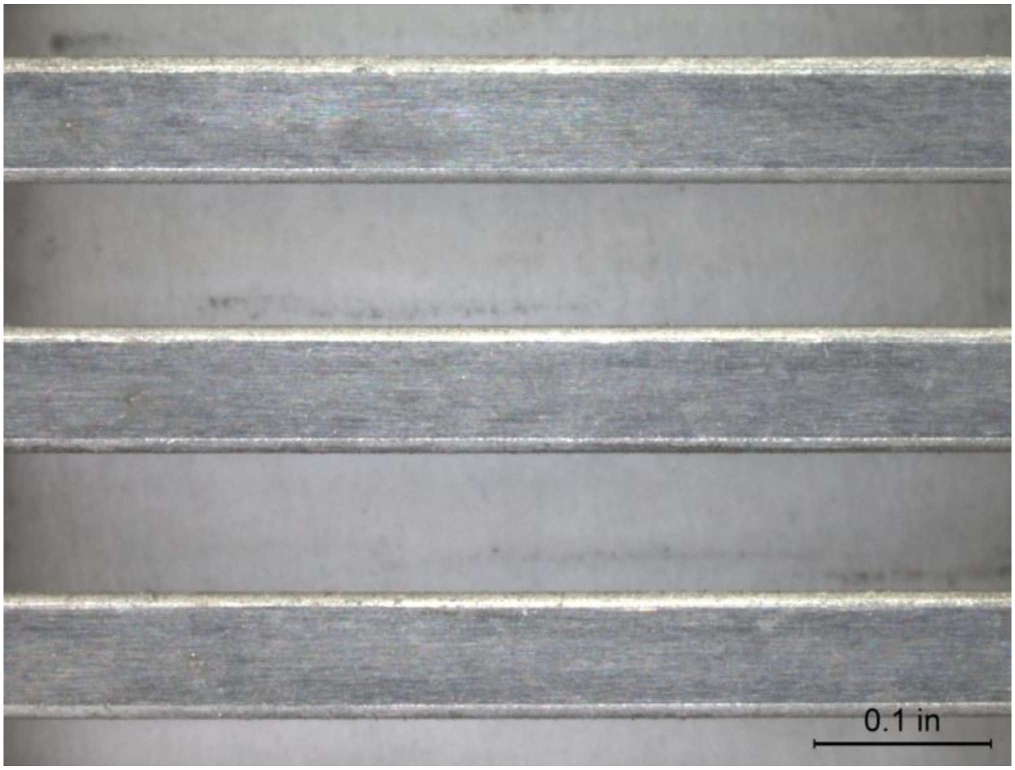
Figure 10 Optical macrographs of duplex 2205 stainless steel coupon 7 after a 6 month corrosion test, before cleaning.

(a) Duplex 2205 Stainless Steel Coupon 7, After Cleaning 10X

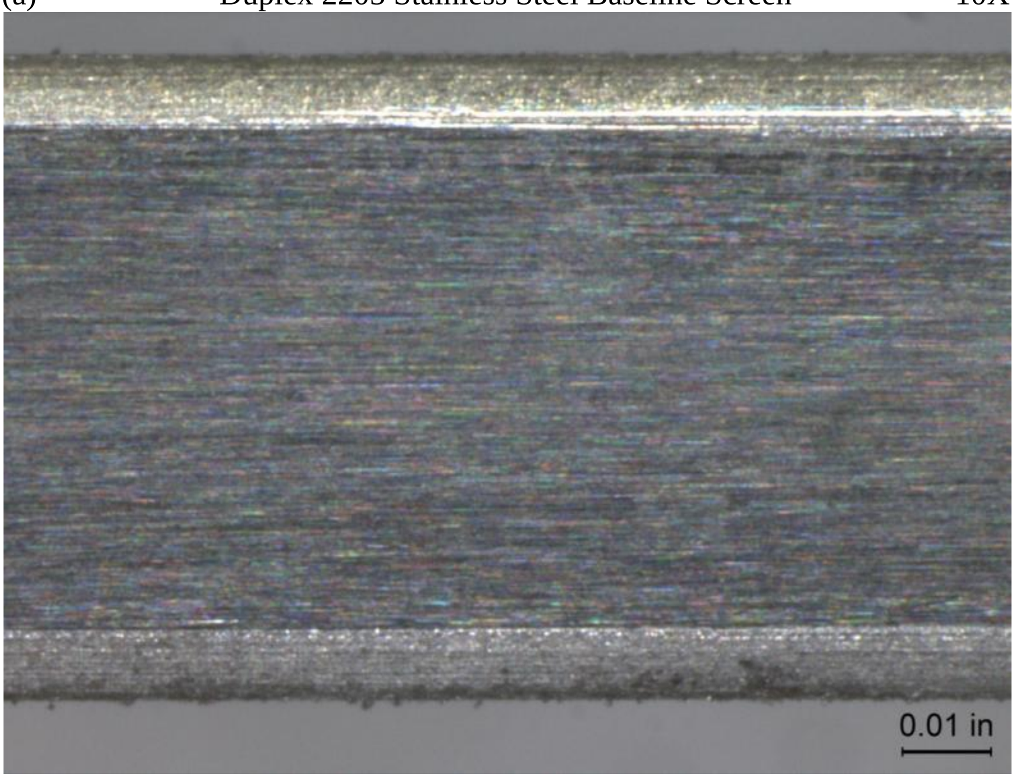


(b) Duplex 2205 Stainless Steel Coupon 7, After Cleaning 50X

Figure 11 Optical macrographs of duplex 2205 stainless steel coupon 7 after a 6 month corrosion test, after cleaning.

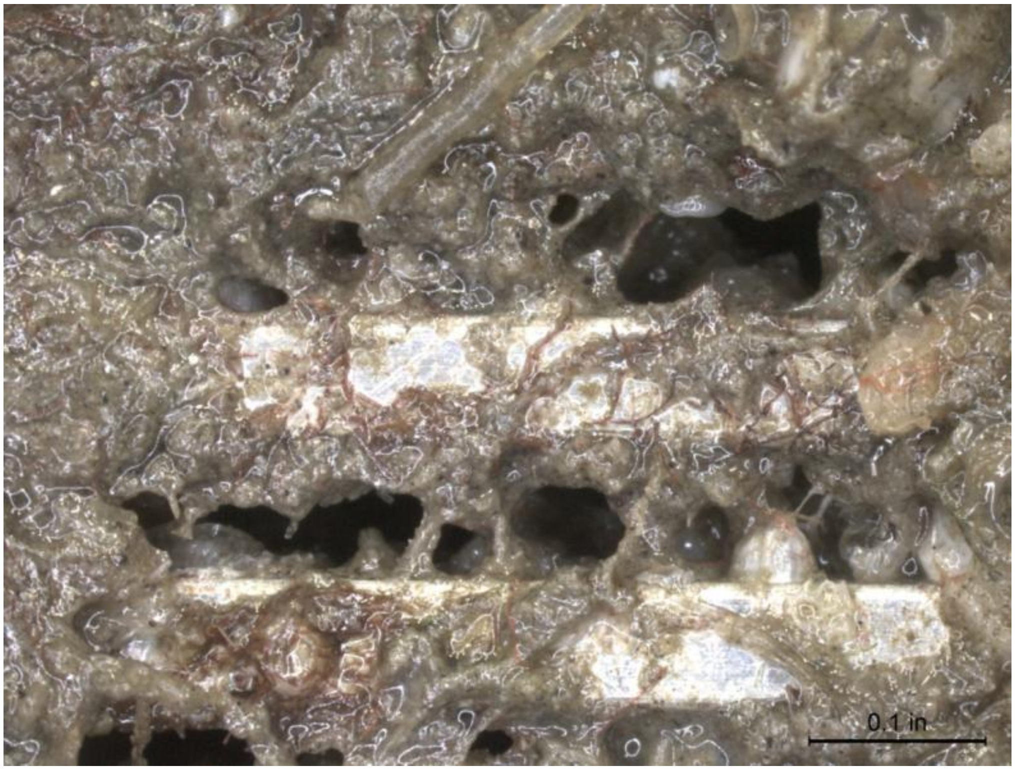


(a) Duplex 2205 Stainless Steel Baseline Screen 10X

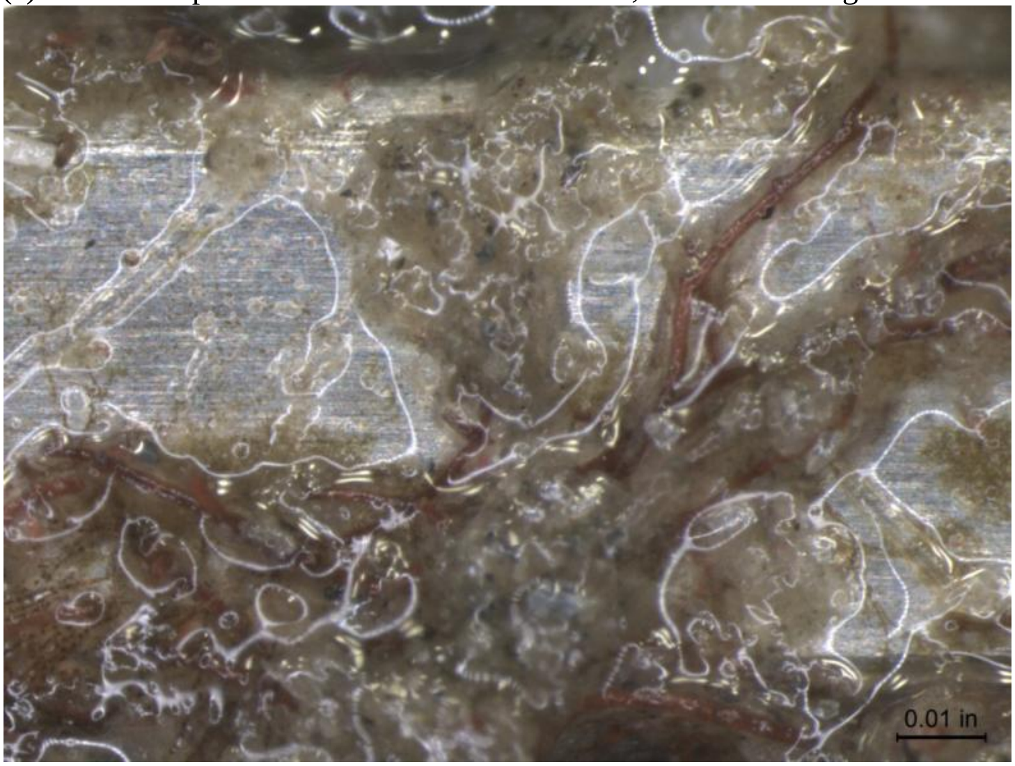


(b) Duplex 2205 Stainless Steel Baseline Screen 50X

Figure 12 Optical macrographs of the duplex 2205 stainless steel baseline screen.

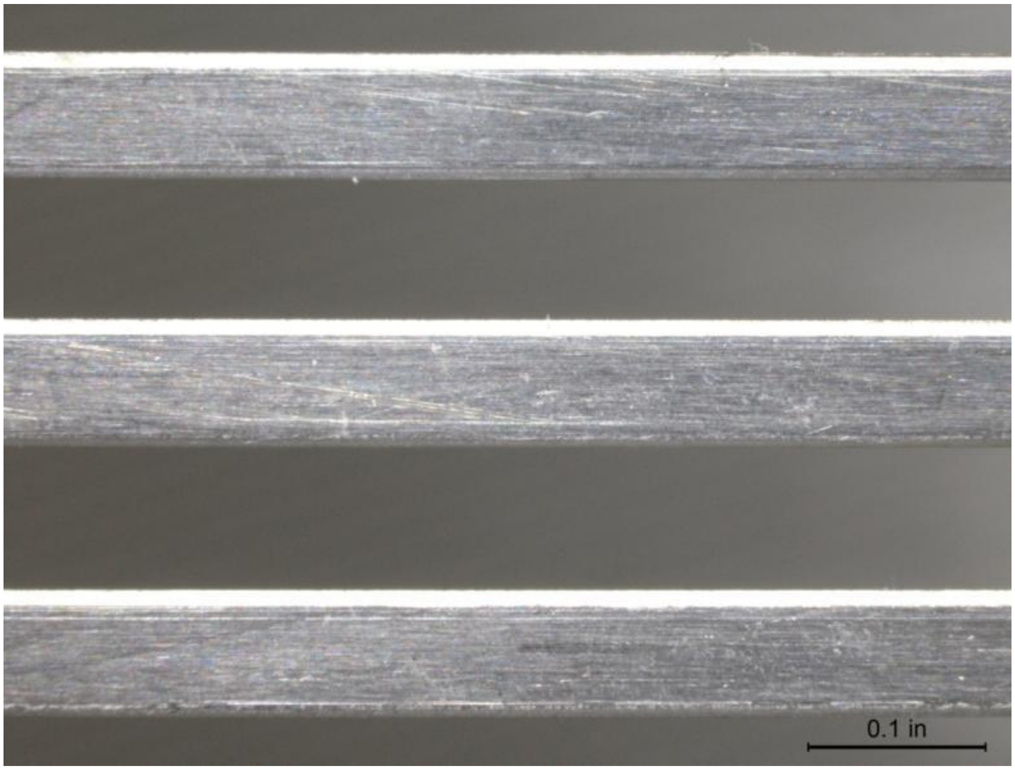


(a) Duplex 2205 Stainless Steel Screen 1, Before Cleaning 10X

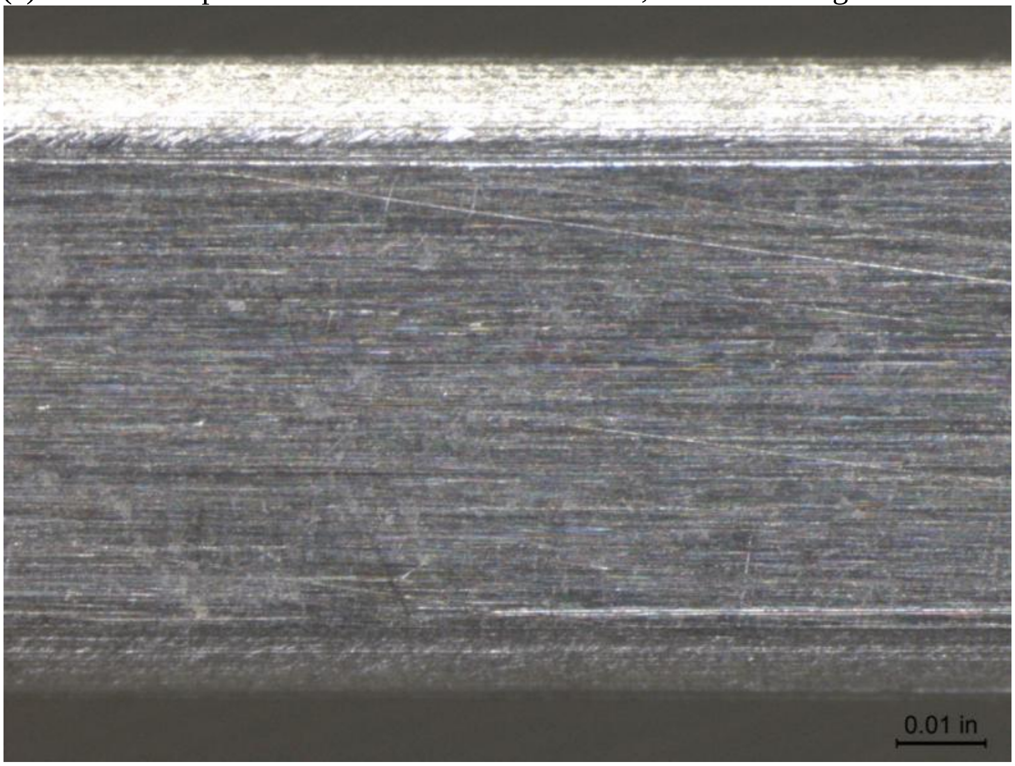


(b) Duplex 2205 Stainless Steel Screen 1, Before Cleaning 50X

Figure 13 Optical macrographs of duplex 2205 stainless steel screen 1 after a 3 month corrosion test, before cleaning.

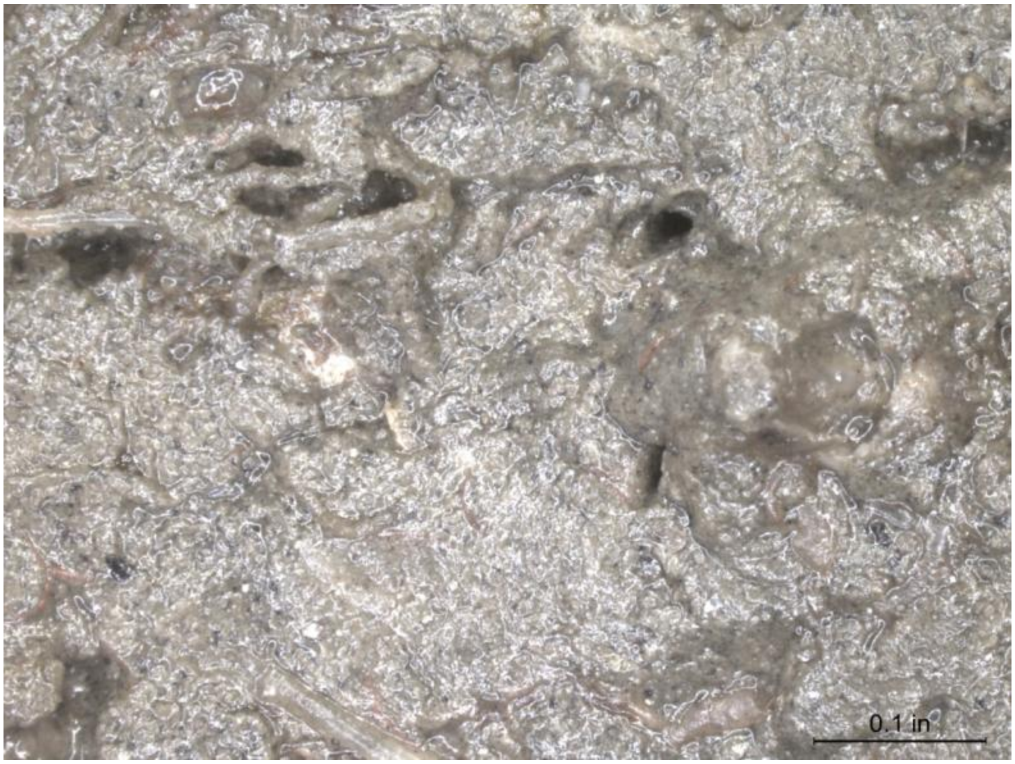


(a) Duplex 2205 Stainless Steel Screen 1, After Cleaning 10X

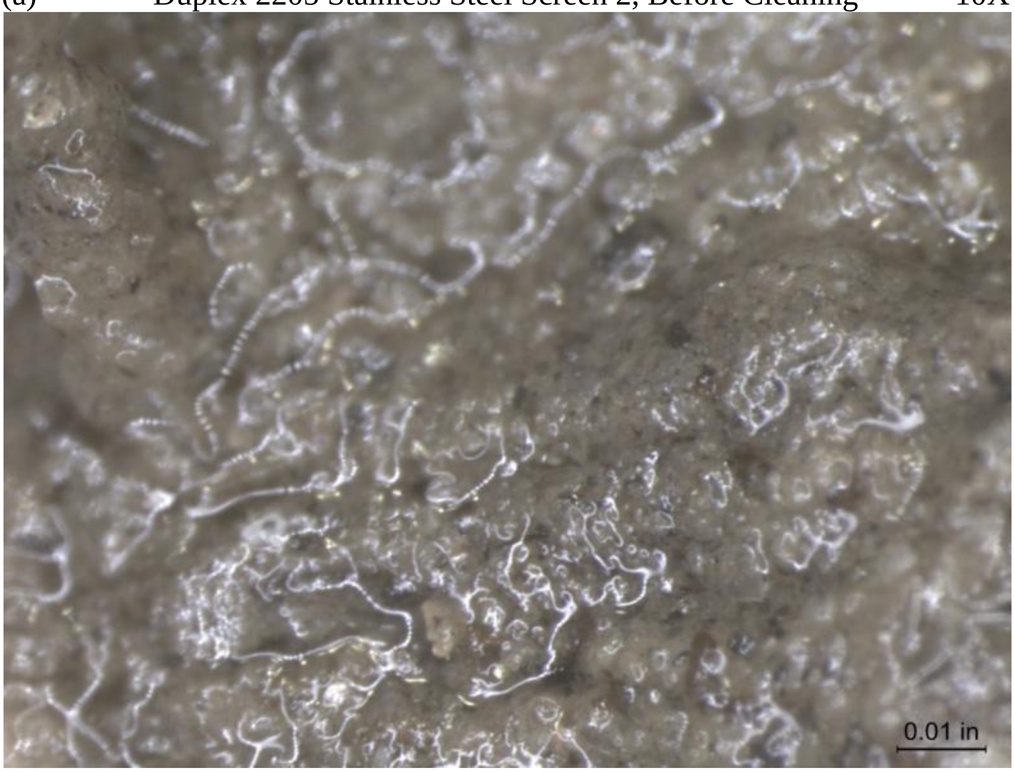


(b) Duplex 2205 Stainless Steel Screen 1, After Cleaning 50X

Figure 14 Optical macrographs of duplex 2205 stainless steel screen 1 after a 3 month corrosion test, after cleaning.

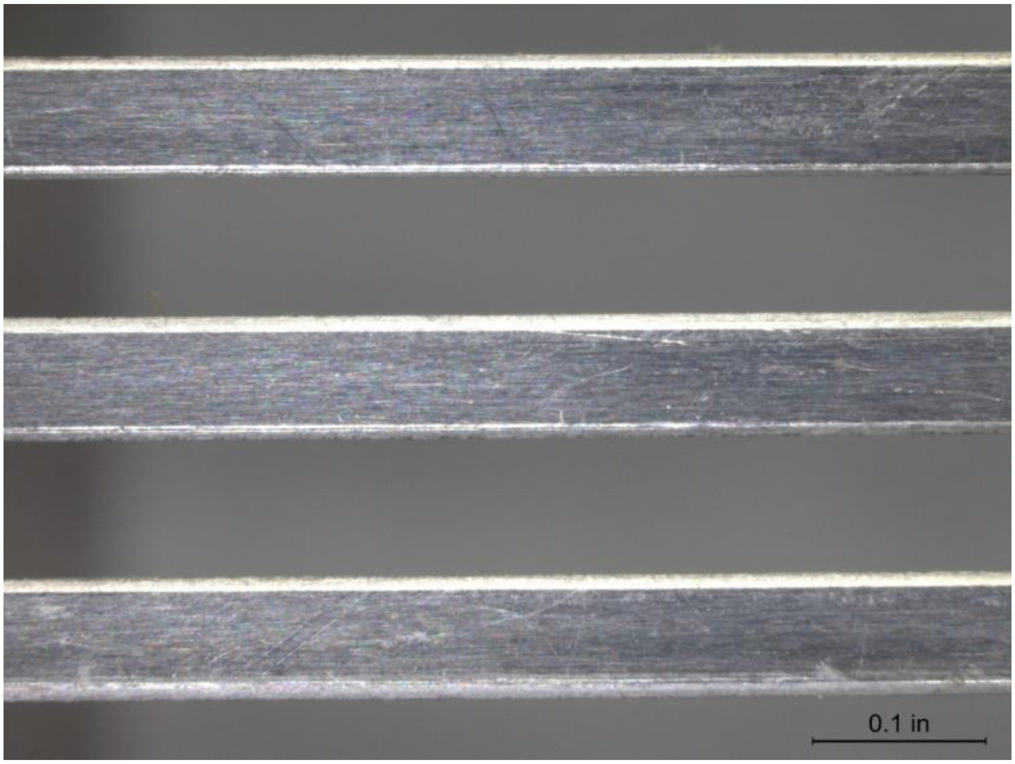


(a) Duplex 2205 Stainless Steel Screen 2, Before Cleaning 10X

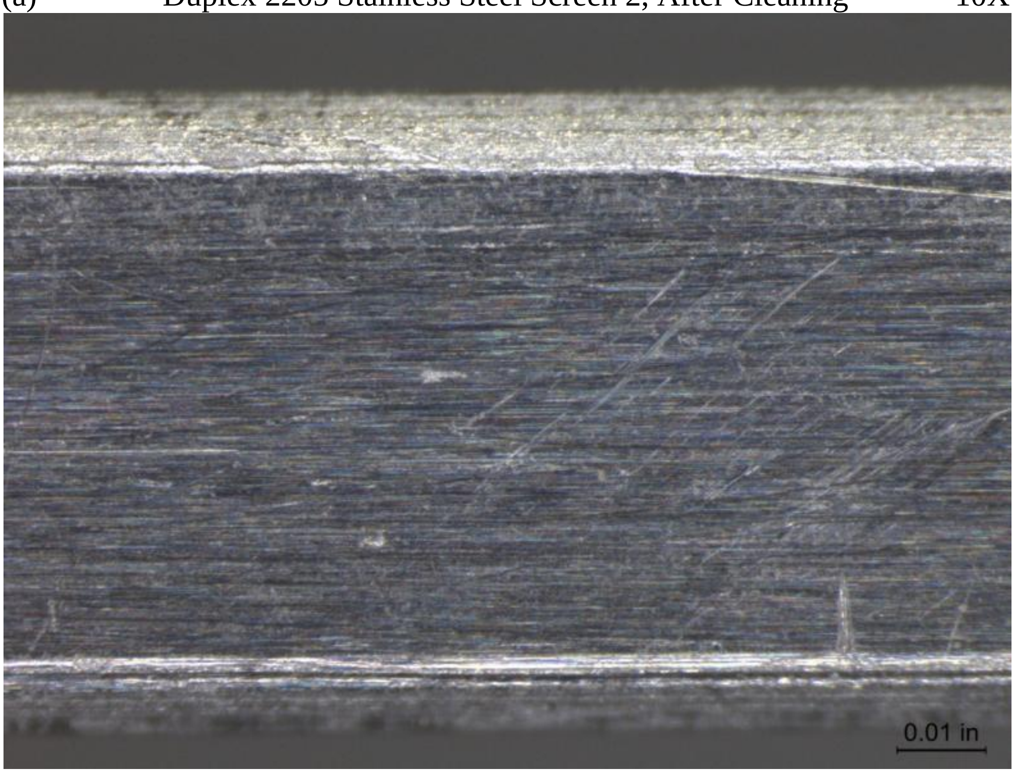


(b) Duplex 2205 Stainless Steel Screen 2, Before Cleaning 50X

Figure 15 Optical macrographs of duplex 2205 stainless steel screen 2 after a 6 month corrosion test, before cleaning.



(a) Duplex 2205 Stainless Steel Screen 2, After Cleaning 10X



(b) Duplex 2205 Stainless Steel Screen 2, After Cleaning 50X

Figure 16 Optical macrographs of duplex 2205 stainless steel screen 2 after a 6 month corrosion test, after cleaning.

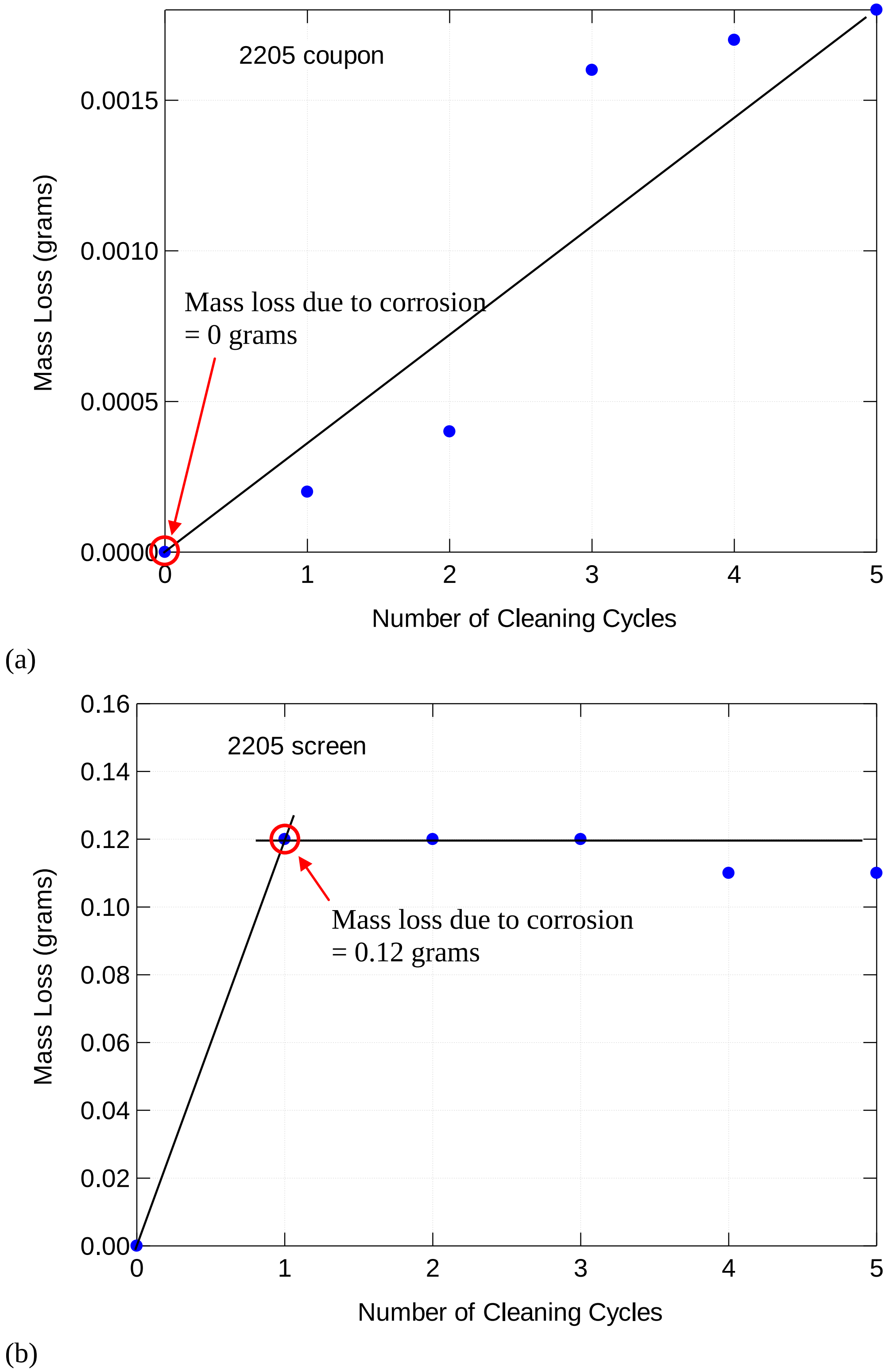
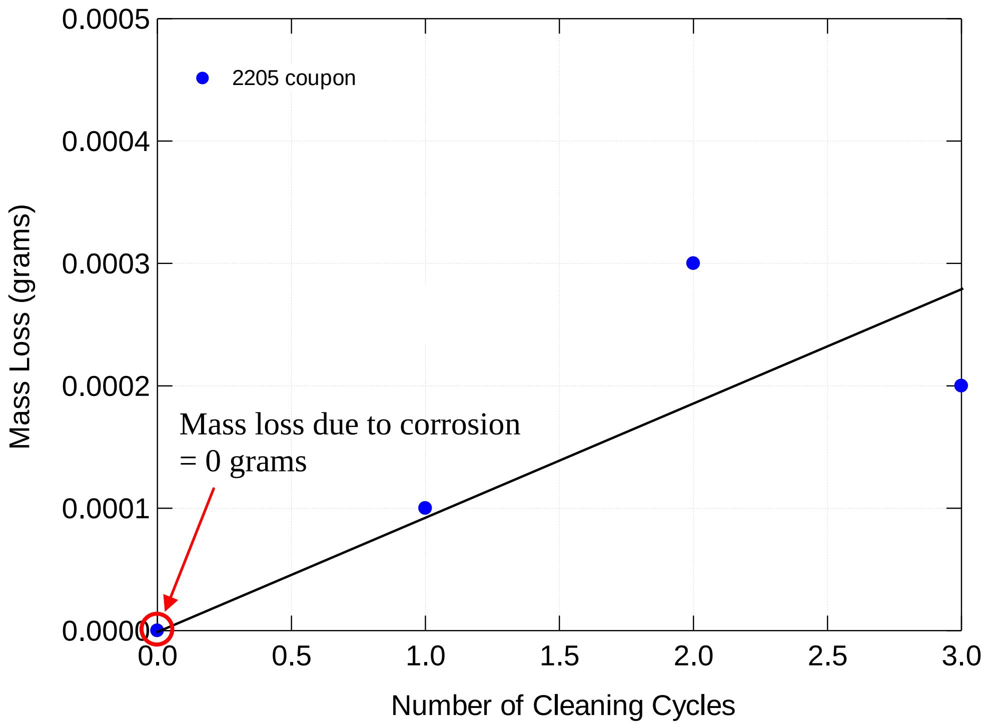
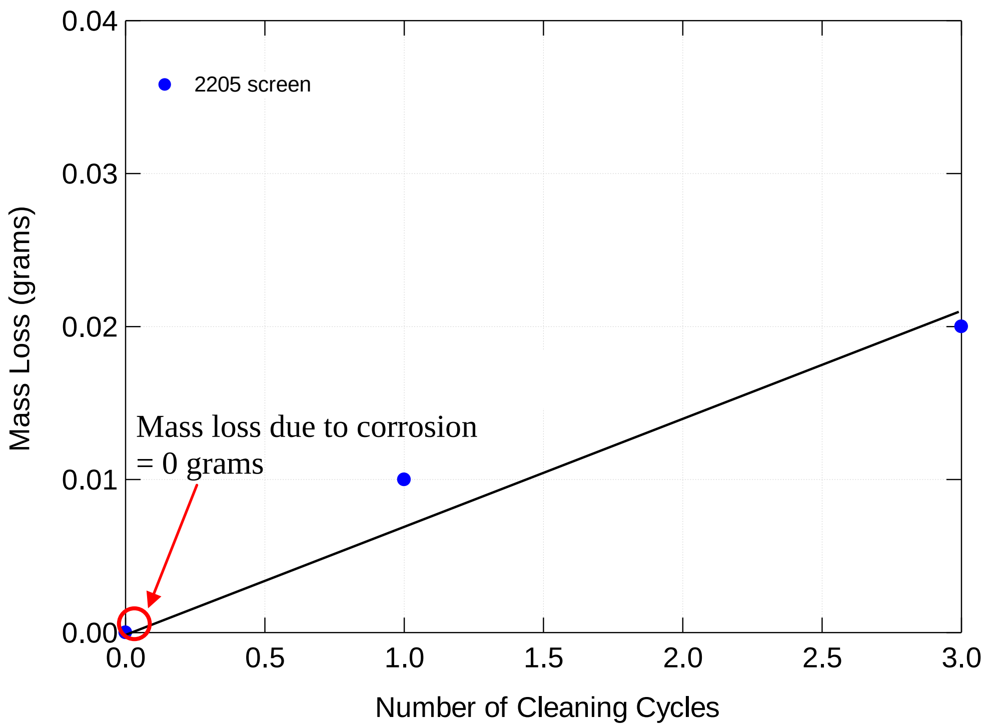


Figure 17 Mass loss of the duplex 2205 stainless steel (a) coupon 6 and (b) screen 1 during cleaning.

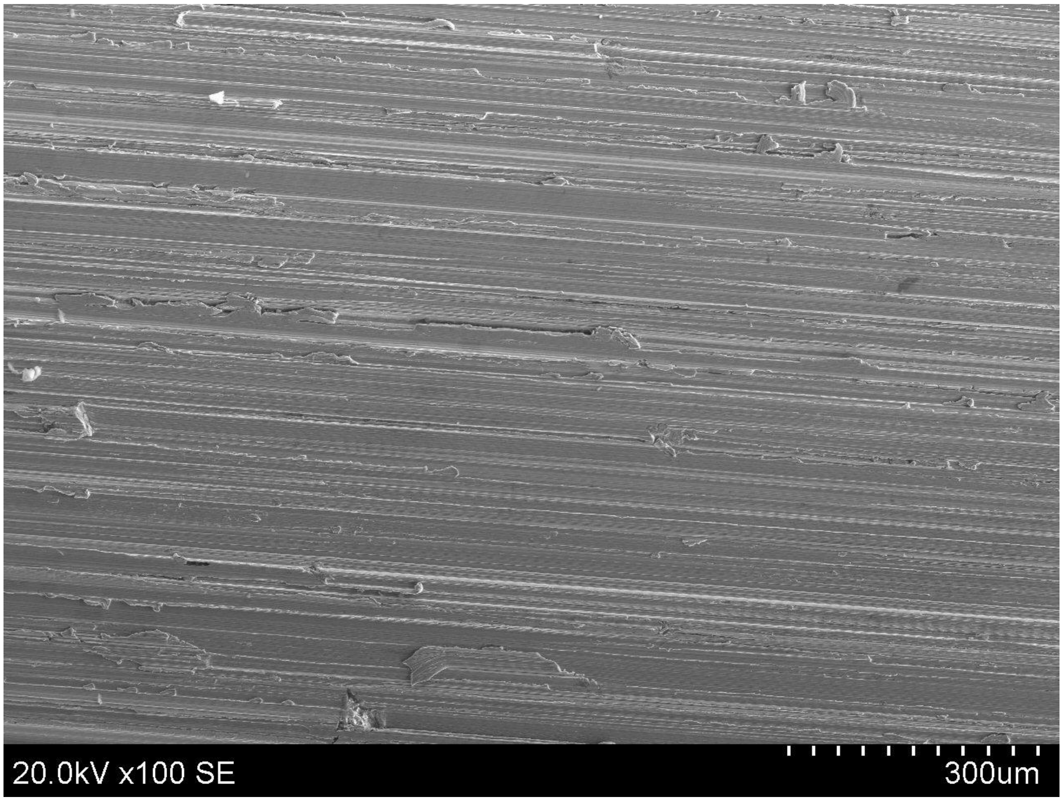


(a)

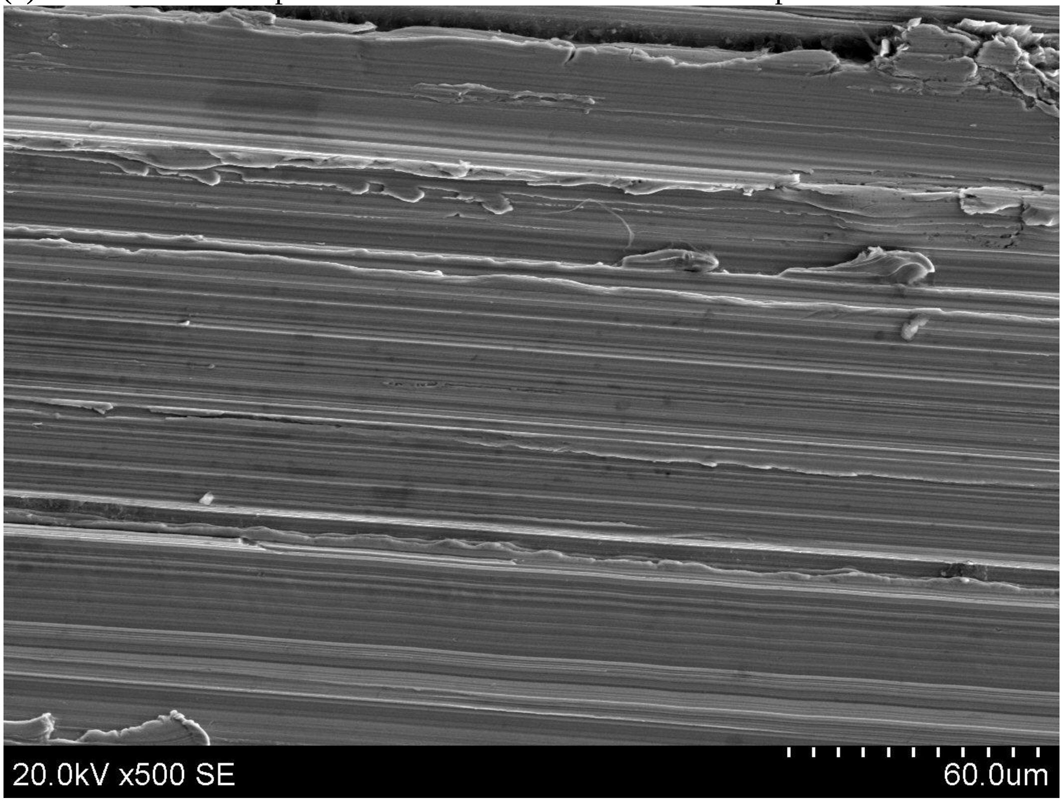


(b)

Figure 18 Mass loss of the duplex 2205 stainless steel (a) coupon 7 and (b) screen 2 during cleaning.

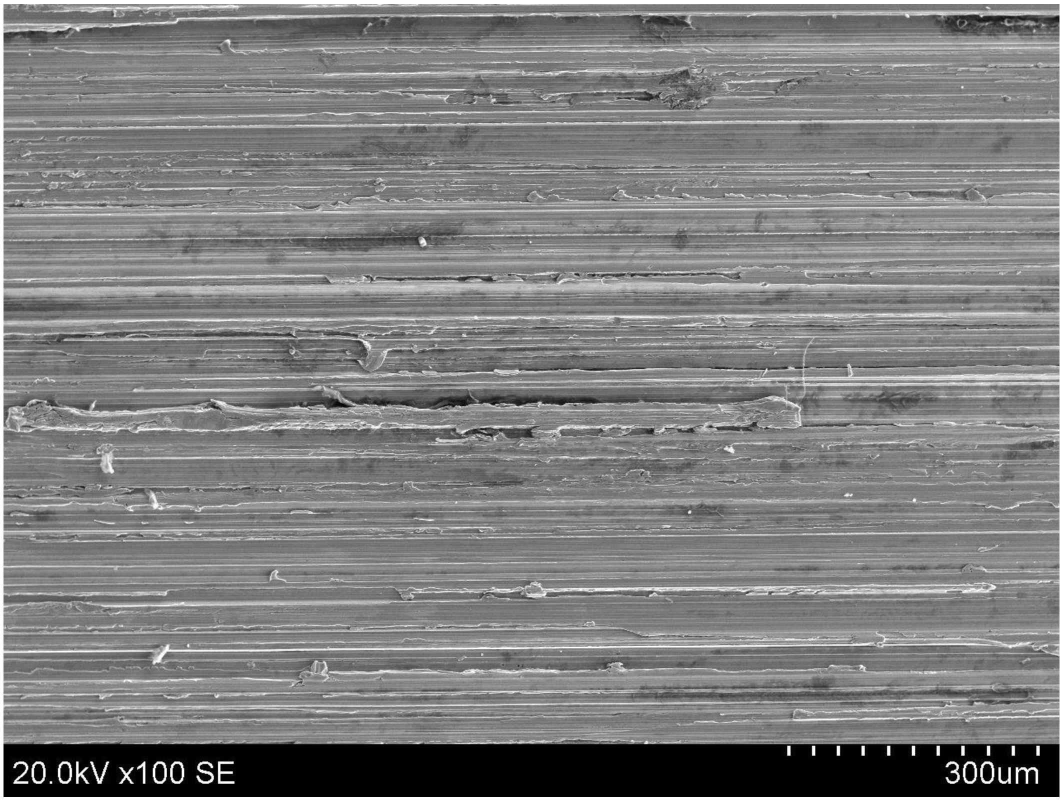


(a) Duplex 2205 Stainless Steel Baseline Coupon 100X

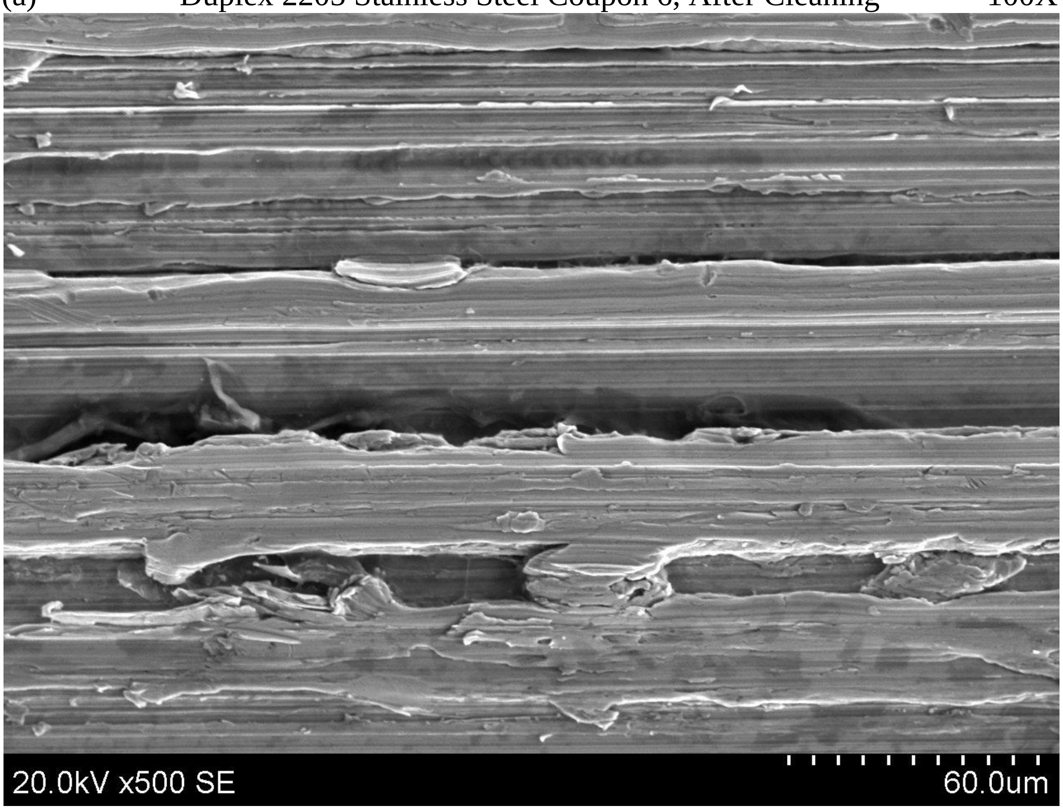


(b) Duplex 2205 Stainless Steel Baseline Coupon 500X

Figure 19 Scanning electron micrographs of the duplex 2205 stainless steel baseline coupon.

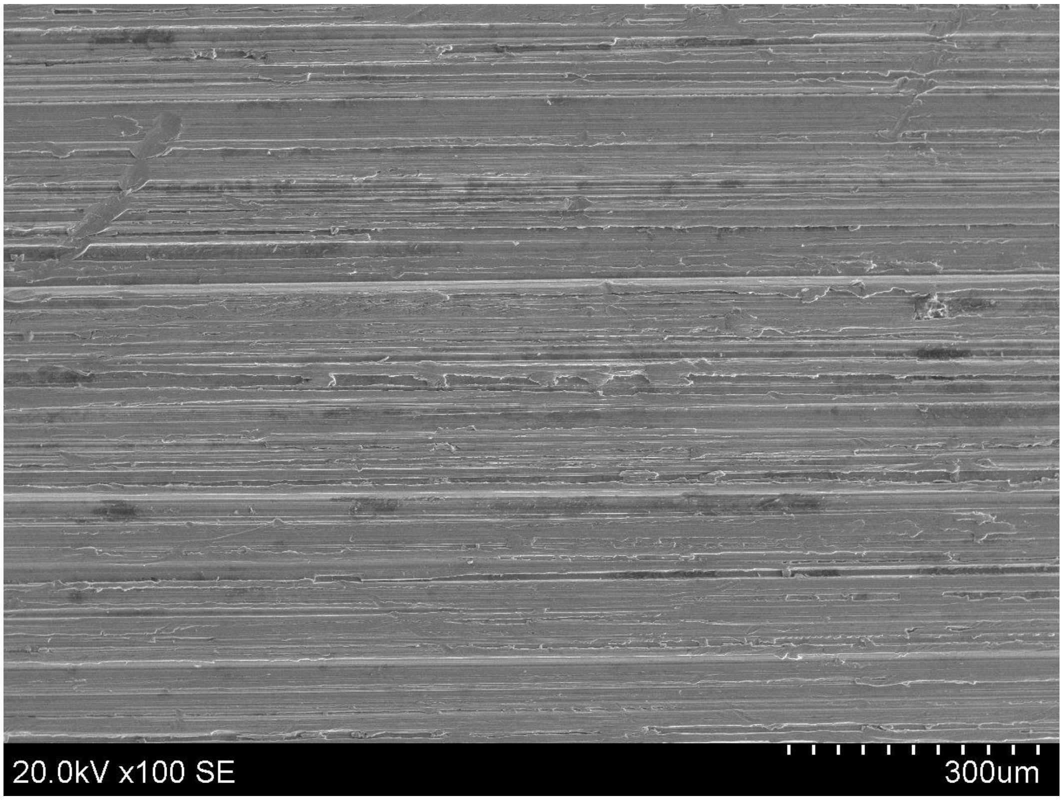


(a) Duplex 2205 Stainless Steel Coupon 6, After Cleaning 100X

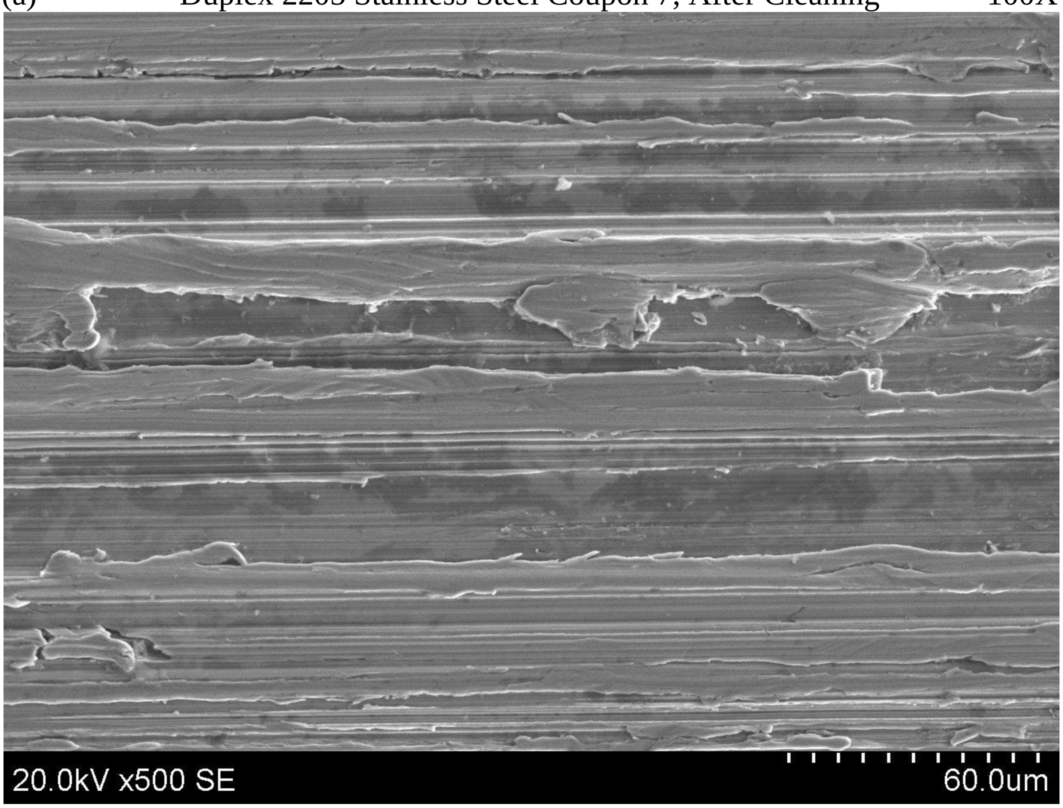


(b) Duplex 2205 Stainless Steel Coupon 6, After Cleaning 500X

Figure 20 Scanning electron micrographs of duplex stainless steel coupon 6 after a 3 month corrosion test, after cleaning.

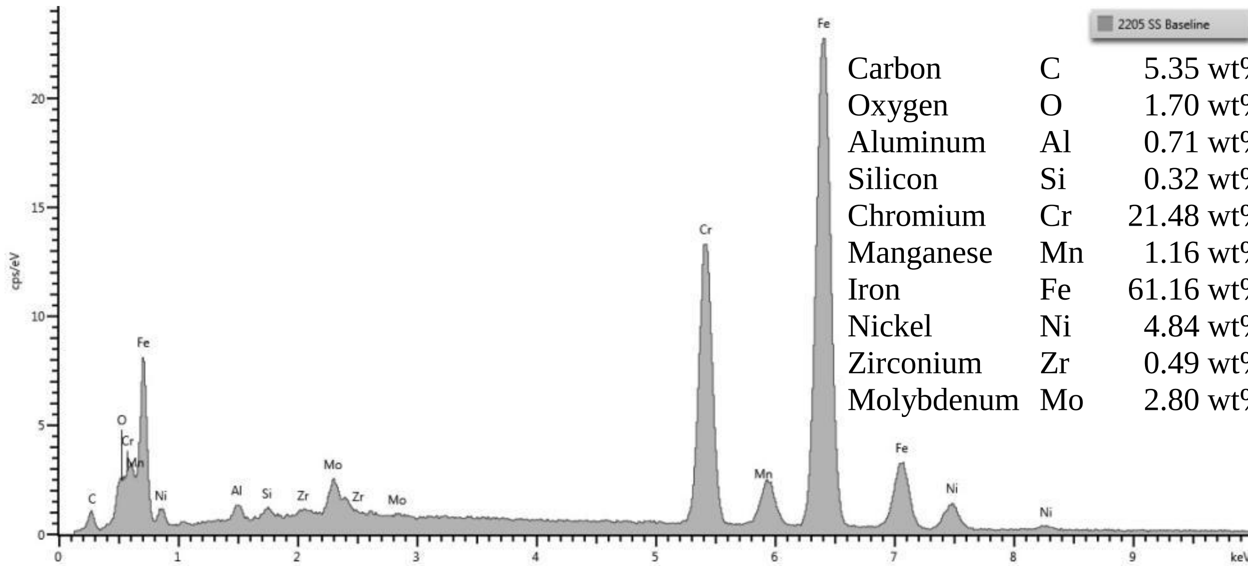


(a) Duplex 2205 Stainless Steel Coupon 7, After Cleaning 100X



(b) Duplex 2205 Stainless Steel Coupon 7, After Cleaning 500X

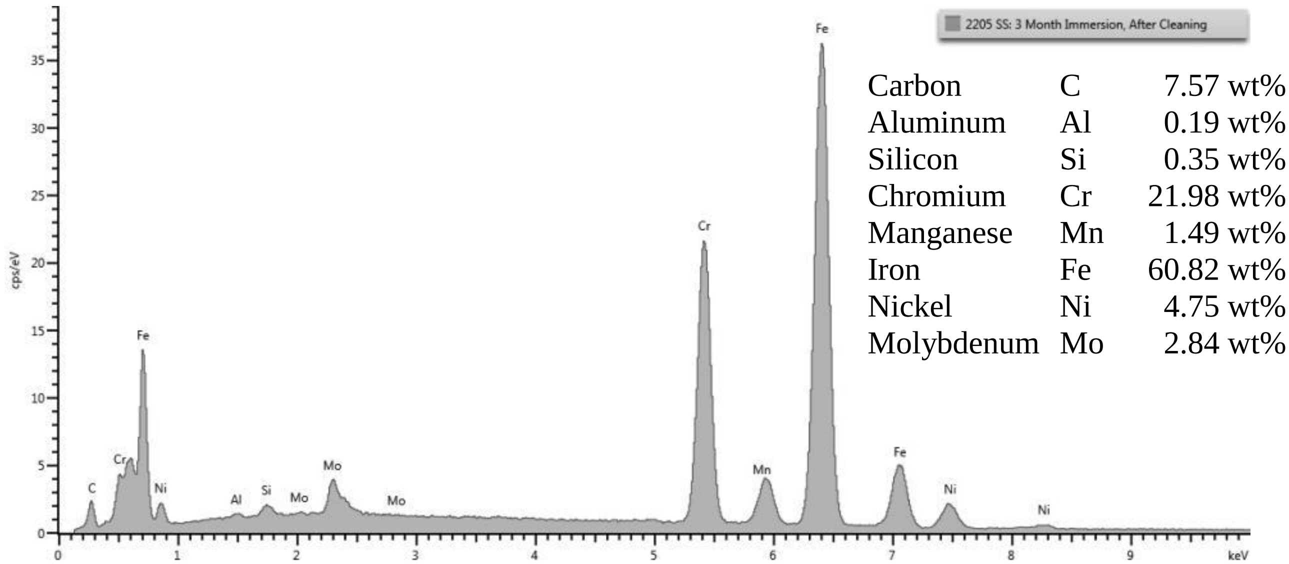
Figure 21 Scanning electron micrographs of duplex stainless steel coupon 7 after a 6 month corrosion test, after cleaning.



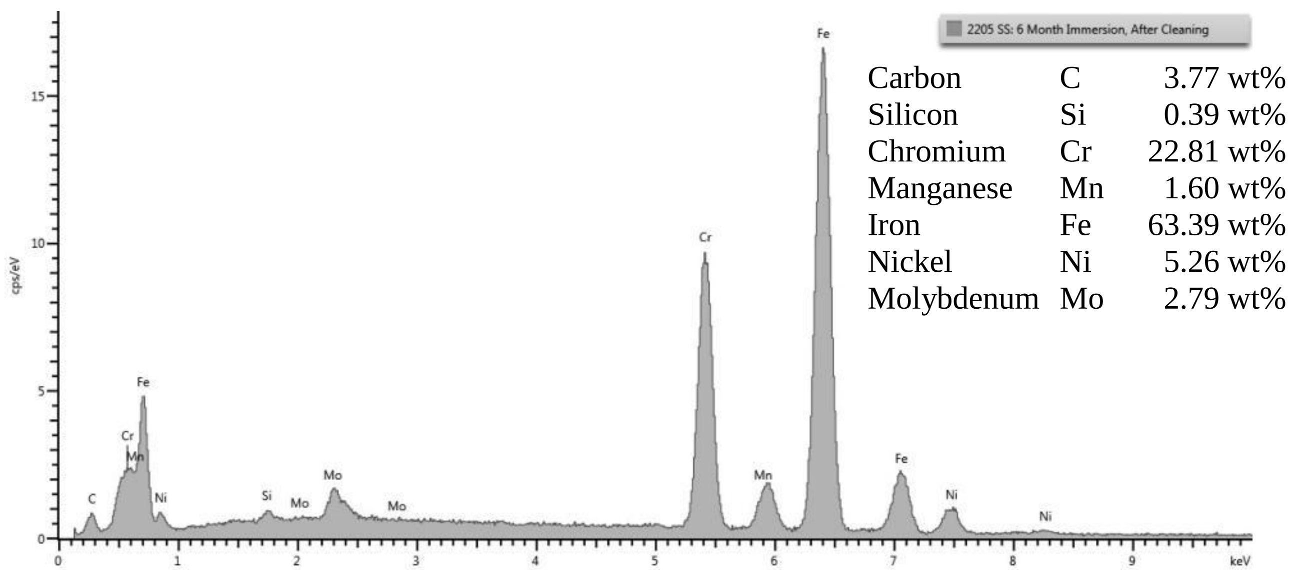
Carbon	C	5.35 wt%
Oxygen	O	1.70 wt%
Aluminum	Al	0.71 wt%
Silicon	Si	0.32 wt%
Chromium	Cr	21.48 wt%
Manganese	Mn	1.16 wt%
Iron	Fe	61.16 wt%
Nickel	Ni	4.84 wt%
Zirconium	Zr	0.49 wt%
Molybdenum	Mo	2.80 wt%

(a) Duplex 2205 Stainless Steel Baseline Coupon

Figure 22 Energy dispersive x-ray spectra of the duplex 2205 stainless steel baseline coupon.

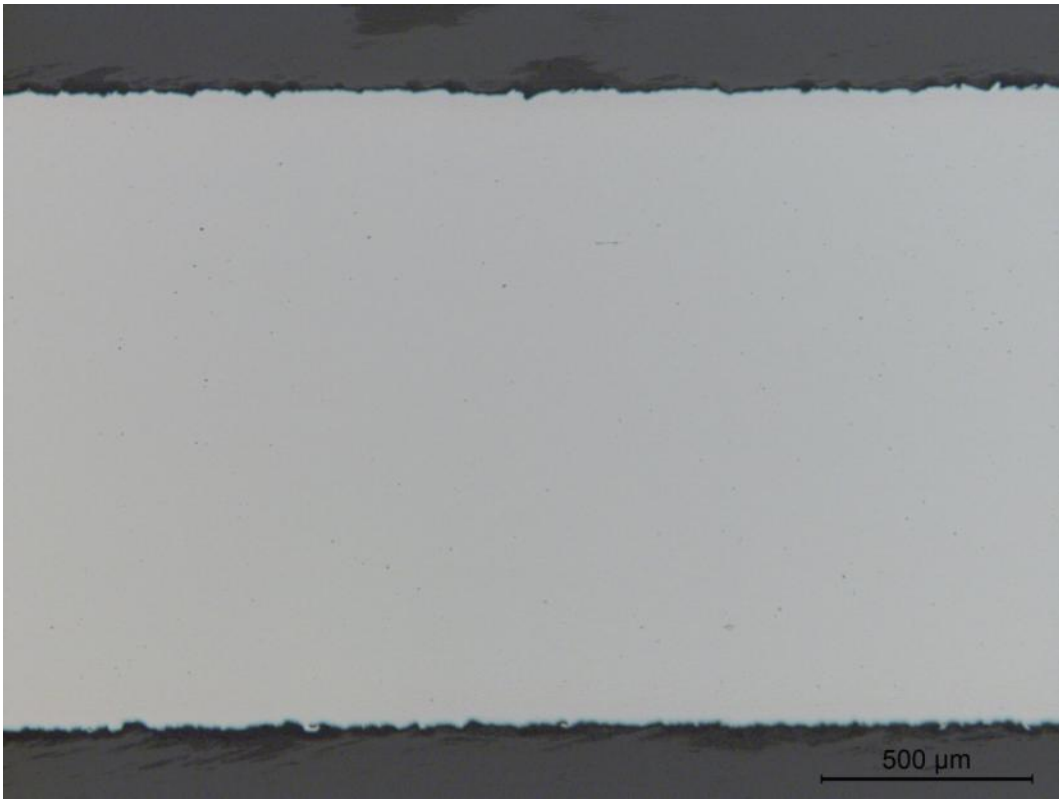


(a) Duplex 2205 Stainless Steel Coupon 6, After Cleaning



(b) Duplex 2205 Stainless Steel Coupon 7, After Cleaning

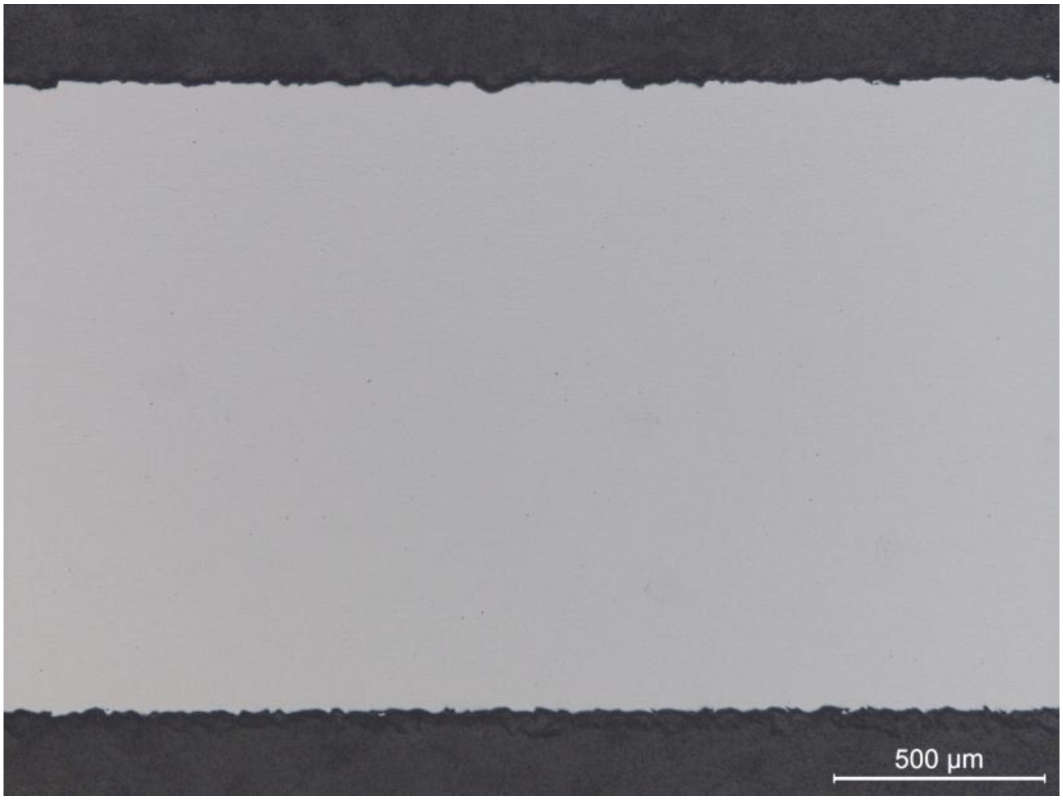
Figure 23 Energy dispersive x-ray spectra of (a) coupon 6 after a 3 month corrosion test and (b) coupon 7 after a 6 month corrosion test, after cleaning. Both coupons were not analyzed by energy dispersive x-ray spectroscopy before cleaning due to the marine life on the surface of the coupon.



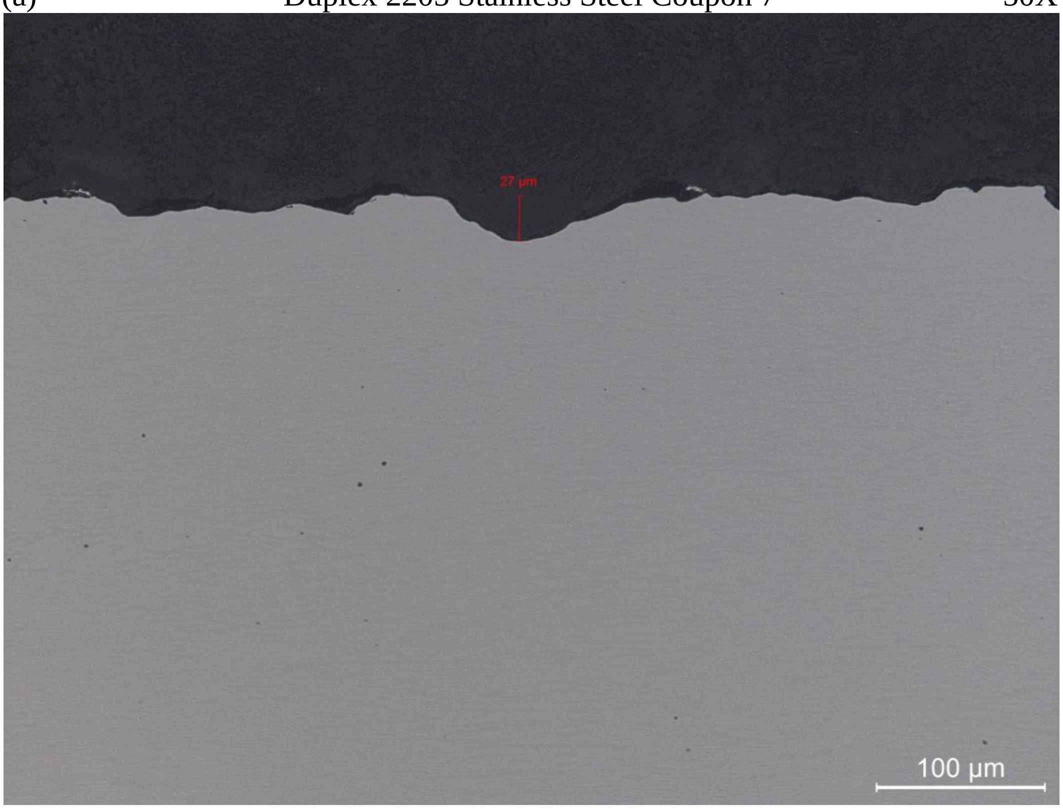
(a) Duplex 2205 Stainless Steel Coupon 6 50X

(b) Duplex 2205 Stainless Steel Coupon 6 200X

Figure 24 Optical micrographs of duplex stainless steel coupon 6.



(a) Duplex 2205 Stainless Steel Coupon 7 50X



(b) Duplex 2205 Stainless Steel Coupon 7 200X

Figure 25 Optical micrographs of duplex stainless steel coupon 7.

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Report No. 5005.0361A **February 9, 2015**

CORROSION EVALUATION OF 2205 DUPLEX STAINLESS STEEL COUPONS AND SCREENS WITH ANTI-BIOFOULING COATING

Customer Authorization: Verbal

Report To: V & A Engineering
Attn: Manuel Najar
155 Grand Avenue, Suite 700
Oakland, CA 94612

1.0 INTRODUCTION

Five coupons, five wedge wire screens, and one plate were submitted by V&A Engineering for corrosion evaluation. The coupons were 1-inch by 3-inches by ¼-inch thick. The wedge wire screens were 4-inches by 4-inches by 1-inch tall with 2 mm spacing. The plate was 4-inches by 4-inches by 1/8-inch thick. The sample was reportedly a 2205 duplex stainless steel alloy with a bio-fouling coating.

Four coupons and four screens were to be placed in seawater for a period up to one year. After every 3 month interval, one coupon and one screen were to be removed from the test system and examined for corrosion. The purpose of this evaluation was to document the samples in the baseline as-received condition, then again after 3, 6, 9, and 12 months of water exposure, record any loss in mass, examine for any pitting corrosion, and estimate the corrosion rate.

The samples were evaluated by the following laboratory procedures:

1) Visual examination and weighing
2) Cleaning per ASTM G1[1]
3) Scanning electron microscopy
4) Metallography

The results of the evaluation showed minimal mass loss and corrosion for the coupon and screen after 3 months and 6 months of corrosion testing. The coupon and the screen, after 3 months and 6 months of corrosion testing, had a corrosion rate of approximately 0.002 millimeters per year.

[1] G1: Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

2.0 EVALUATION[2]

2.1 Visual Examination

The sample identifications for the coupons and wedge wire screens and their corresponding immersion times are shown in Table 1. The coupons had identification numbers stamped on the front face by V&A Engineering. A number of notches, corresponding to the sample number, were sawed at the edge of each screen for identification after the corrosion test. The weights of the samples were recorded. Coupons 6 – 9 and screens 1 – 5 were sent back to V&A for corrosion testing. Coupon 10 was the baseline sample and documented by photography, optical stereoscopy and scanning electron microscopy for comparison to the tested samples. Screen 5 was documented as a baseline by photography and optical stereoscopy, and then sent to V&A for testing.

Photographs of the baseline coupon are shown in Figure 1. Photographs of coupon 1, after 3 months of corrosion testing, are shown in Figure 2. Photographs of coupon 2, after 6 months of corrosion testing, are shown in Figure 3.

A photograph of the baseline screen is shown in Figure 4. A photograph of screen 1, after 3 months of corrosion testing, is shown in Figure 5. A photograph of screen 2, after 6 months of corrosion testing, is shown in Figure 6.

2.2 Cleaning

The coupon and screen were cleaned with solution C.7.1 per ASTM G1.[3] One cleaning cycle was approximately 5 minutes. After each cleaning cycle, the samples were rinsed in water, dried, and weighed. The cleaning and weighing cycle was completed five times for the coupon and screen. The weights of the samples as-received, after corrosion testing but before cleaning, and after each cleaning cycle are presented in Table 2.

Optical macrographs of the baseline coupon and screen are shown in Figures 7 and 12, respectively. Representative optical macrographs of the samples after a 3 month corrosion test, before and after cleaning, are shown in Figures 8 – 9 and 13 – 14. Representative optical macrographs of the sample after a 6 month corrosion test, before and after cleaning, are shown in Figures 10 – 11 and 15 – 16.

The mass loss versus the number of cleaning cycles was plotted, shown in Figure 17 – 18. The equations for best fit lines AB and BC, calculated using IGOR Pro, are listed in Table 3. Point B, indicated by the red circle in each plot, corresponds to the mass loss due to corrosion during the cleaning process for each sample. This mass loss was subtracted from the weight of the sample before cleaning and from the weight of the sample as-received to determine the total mass loss from corrosion. The corrosion rate of each sample was determined by the formula specified in Section 8.1 of ASTM G1:

---

[2] The magnifications of the optical and scanning electron micrographs in this report are approximate and should not be used as a basis for dimensional analyses unless otherwise indicated.
[3] 100 mL nitric acid + 900 ml reagent water.

$$Corrosion\ Rate = \frac{K\ x\ W}{A\ x\ T\ x\ D}$$

where K = 8.76×10^4, T = time of exposure in hours, A = area in cm^2, W = mass loss in grams, and D = density in g/cm^3. The total mass loss from corrosion and the calculated corrosion rate of each sample is shown in Table 4.

2.3 Scanning Electron Microscopy

The baseline coupon, coupon 1, and coupon 2 were examined with a scanning electron microscope. Representative scanning electron micrographs of the baseline coupon are shown in Figure 19. Representative scanning electron micrographs of coupon 1 before and after cleaning are shown in Figures 20 – 21. Representative scanning electron micrographs of coupon 2 before and after cleaning are shown in Figures 22 – 23.

An energy dispersive x-ray spectrum of the baseline coupon is shown in Figure 24. Energy dispersive x-ray spectra of coupon 1 before and after cleaning are shown in Figure 25. Energy dispersive x-ray spectra of coupon 2 before and after cleaning are shown in Figure 26.

2.4 Metallography

Cross sections were taken from the coupon and prepared for a metallographic examination. Optical micrographs of the surface for coupon 1 are shown in Figure 27. Small, shallow pits were observed in coupon 1, one such pit measured 20 µm in depth. Optical micrographs of the surface for coupon 2 are shown in Figure 28. A sharp narrow pit was observed in coupon 2, measuring 34 µm in depth.

3.0 DISCUSSION

The coupon and screen showed minimal mass loss and pitting after 3 and 6 months of corrosion testing.

After 3 months of corrosion testing, the coupon had lost 0.023 grams of material and had a corrosion rate of 0.002 millimeters per year. After 3 months of corrosion testing, the screen had lost 0.25 grams of material and had a corrosion rate of 0.002 millimeters per year.

After 6 months of corrosion testing, the coupon had lost 0.031 grams of material and had a corrosion rate of 0.002 millimeters per year. After 6 months of corrosion testing, the screen had lost 0.43 grams of material and had a corrosion rate of 0.002 millimeters per year.

4.0 CONCLUSIONS[4]

The following conclusions are based upon the submitted samples and the evidence gathered:

1. The coupon, after 3 months of corrosion testing, had a mass loss of 0.023 grams and a corrosion rate of 0.002 mm / year.

2. The screen, after 3 months of corrosion testing, had a mass loss of 0.25 grams and a corrosion rate of 0.002 mm / year.

3. The coupon, after 6 months of corrosion testing, had a mass loss of 0.031 grams and a corrosion rate of 0.002 mm / year.

4. The screen, after 6 months of corrosion testing, had a mass loss of 0.43 grams and a corrosion rate of 0.002 mm / year.

Prepared by:	Reviewed by:
Norman Yuen	Audrey A. Fasching, Ph.D., P.E.
Materials Engineer	Senior Materials Engineer

[4] The conclusions in this report are based upon the available information and evidence provided by the client and gathered by Anamet, within the scope of work authorized by the client, and they are hereby presented by Anamet to a reasonable degree of engineering and scientific certainty. Anamet reserves the right to amend or supplement its conclusions or opinions presented in this report should additional data or information become available, or further work be approved by the client.

Table 1
Sample Identifications

Description		V&A Engineering Identification (As-Received)	Anamet Identification (in report)	Notes
Alloy	Part			
2205 Duplex Stainless Steel with anti-biofouling coating	**Flat Plate** 4-inch x 4-inch x 1/8-inch	None	Plate	None
	Coupon 1-inch x 3-inch x 1/8-inch with autogenous weld bead	2205 SS 1	Coupon 1*	3 Month Immersion
		2205 SS 2	Coupon 2*	6 Month Immersion
		2205 SS 3	Coupon 3*	9 Month Immersion
		2205 SS 4	Coupon 4*	12 Month Immersion
		2205 SS 5	Coupon 5	Baseline Sample (no exposure)
	Wedge Wire Screen 4-inch x 4-inch x 1-inch with 2 mm spacing	None	Screen 1*	3 Month Immersion
		None	Screen 2*	6 Month Immersion
		None	Screen 3*	9 Month Immersion
		None	Screen 4*	12 Month Immersion
		None	Screen 5*	12 Month Immersion

* Cable ties were attached to each sample to designate sample identification. The number of cable ties per sample corresponded to the sample number.

Table 2
Sample Weights

Sample	Baseline Measurement	Measurements after 3 Months Corrosion Testing				
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)
Coupon 1	24.1892	24.1683	24.1668	24.1666	24.1665	-
Screen 1	339.91	340.03	339.70	339.66	339.63	339.63

Sample	Baseline Measurement	Measurements after 6 Months Corrosion Testing				
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)
Coupon 2	24.2019	24.1714	24.1711	24.1701	24.1694	24.1691
Screen 2	341.67	341.34	341.24	341.24	341.25	-

Table 3
Equations of Lines AB and BC for Corrosion Testing Samples

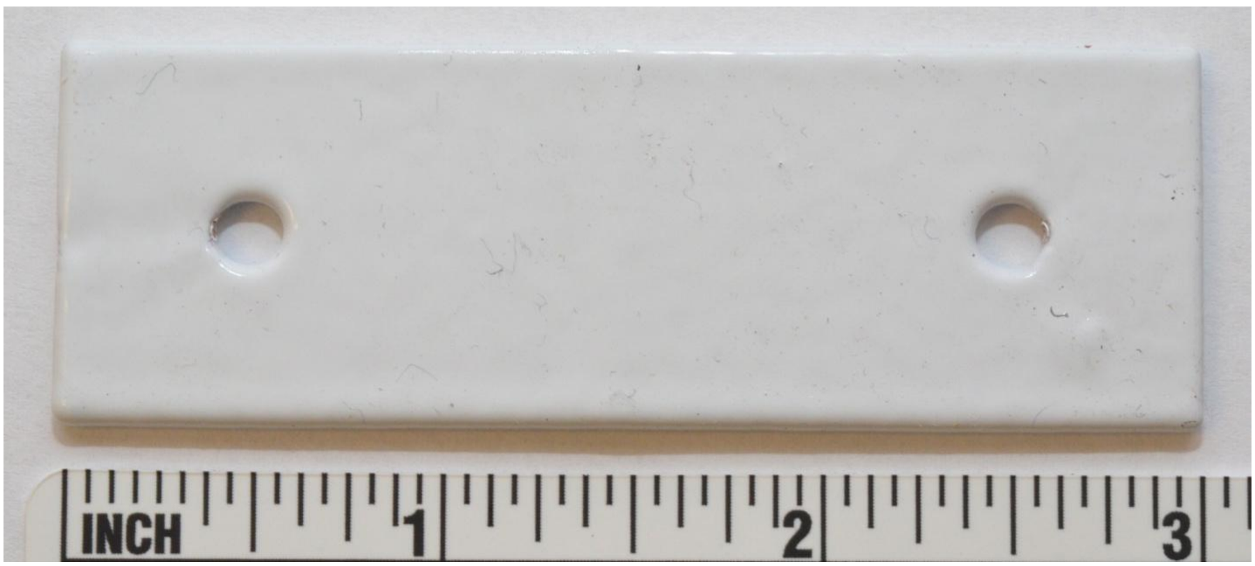
Sample	Line AB	Line BC	Point B (Approximate Mass Loss from Corrosion During Cleaning)
Coupon 1	y = 0.0015x	y = 0.0001x + 0.0015	0.0016 grams
Coupon 2	N/A	y = 0.0001x	0.0000 grams
Screen 1	y = 0.33x	y = 0.02x + 0.35	0.37 grams
Screen 2	y = 0.10x	y = 0.10	0.10 grams

Table 4
Total Mass Loss from Corrosion and Corrosion Rate

Sample	Total Mass Loss from Corrosion*	Corrosion Rate
Coupon 1	0.023 grams	0.002 mm / year
Coupon 2	0.031 grams	0.002 mm / year
Screen 1	0.25 grams	0.002 mm / year
Screen 2	0.43 grams	0.002 mm / year

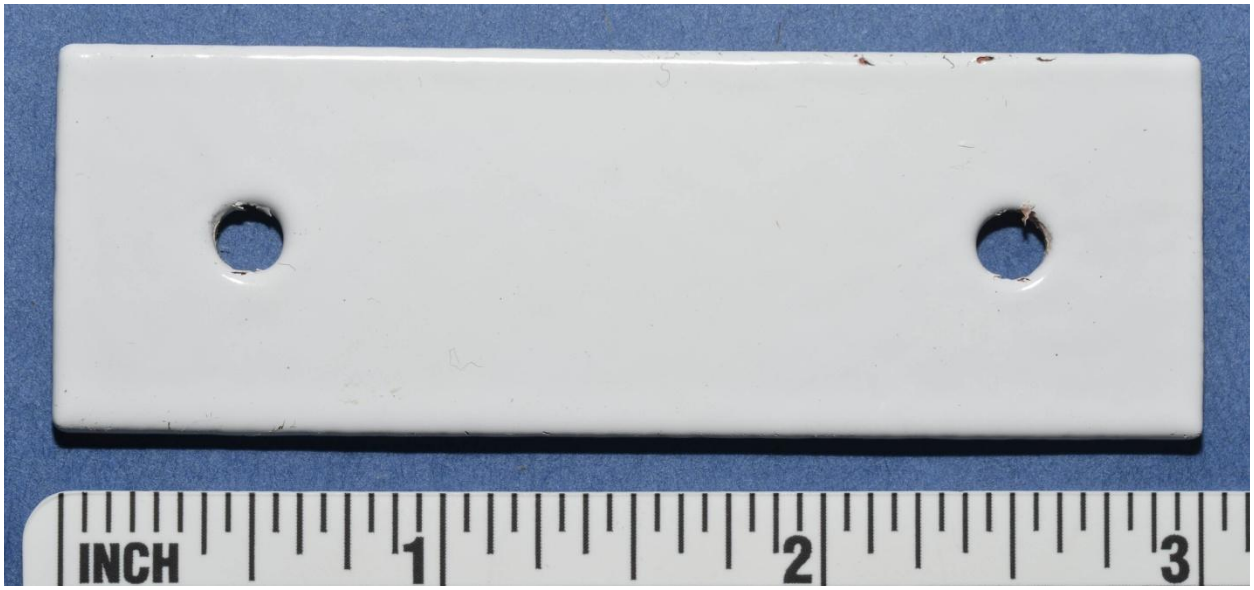
* Weight As-Received – (Weight Before Cleaning – Mass Loss from Corrosion During Cleaning)

(a) Coated Duplex 2205 Stainless Steel Baseline Coupon, Front Side

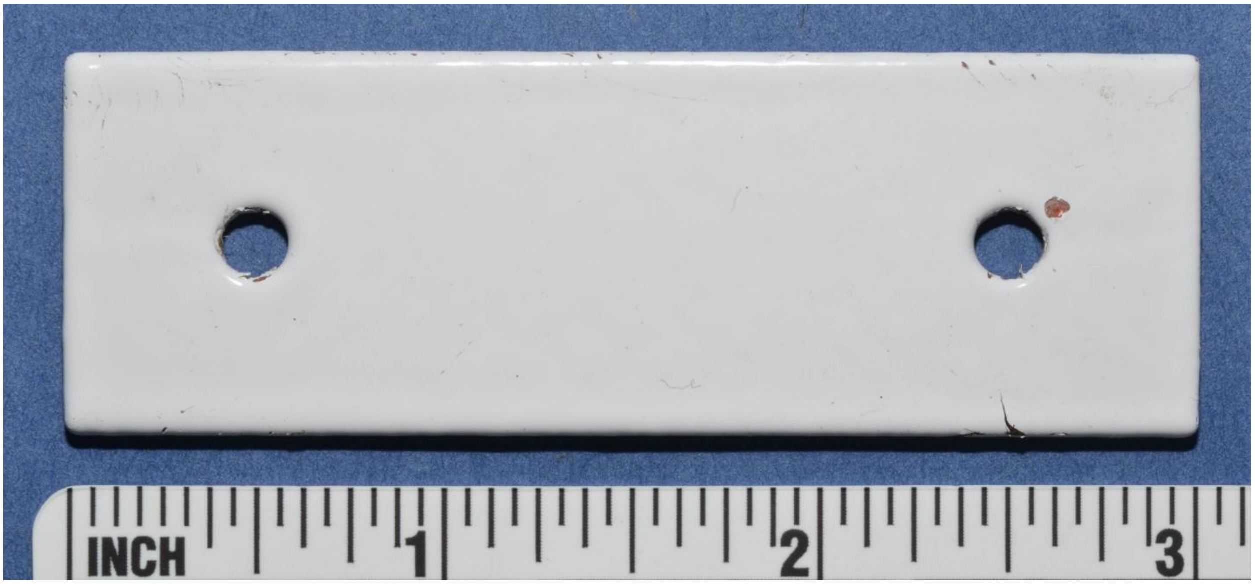


(b) Coated Duplex 2205 Stainless Steel Baseline Coupon, Back Side

Figure 1 Photographs of the duplex 2205 stainless steel with anti-biofouling coating baseline coupon (a) front and (b) back side.



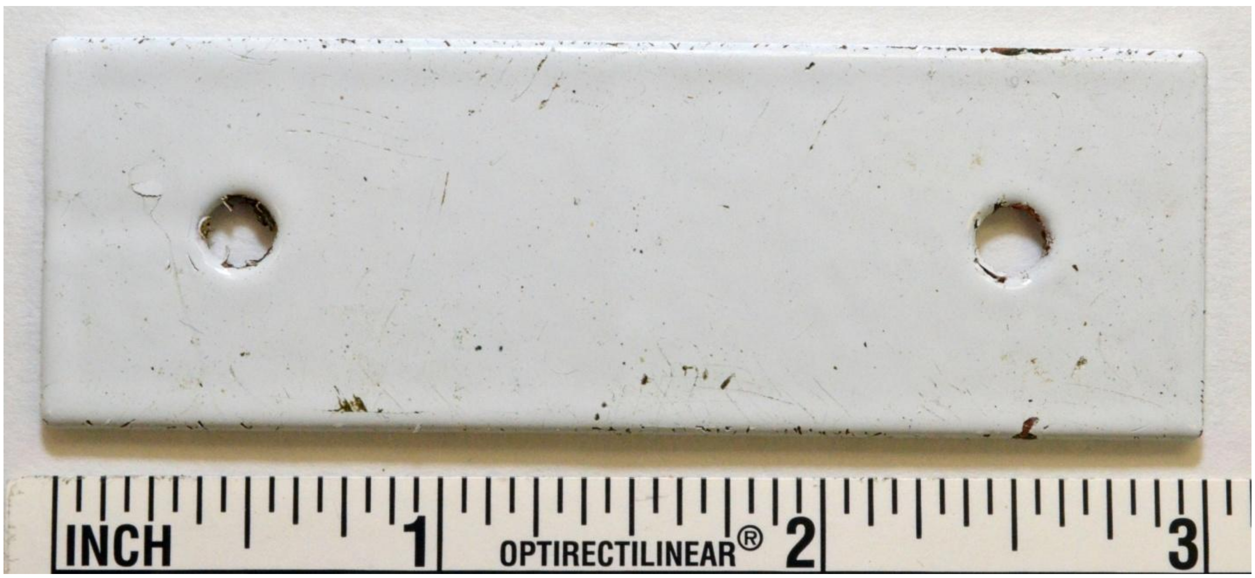
(a) Coated Duplex 2205 Stainless Steel Coupon 1, Front Side



(b) Coated Duplex 2205 Stainless Steel Coupon 1, Back Side

Figure 2 Photographs of duplex 2205 stainless steel with anti-biofouling coating coupon 1 (a) front and (b) back side after a 3 month corrosion test.

(a) Coated Duplex 2205 Stainless Steel Coupon 2, Front Side



(b) Coated Duplex 2205 Stainless Steel Coupon 2, Back Side

Figure 3 Photographs of duplex 2205 stainless steel with anti-biofouling coating coupon 2 (a) front and (b) back side after a 6 month corrosion test.

(a) Coated Duplex 2205 Stainless Steel Baseline Screen

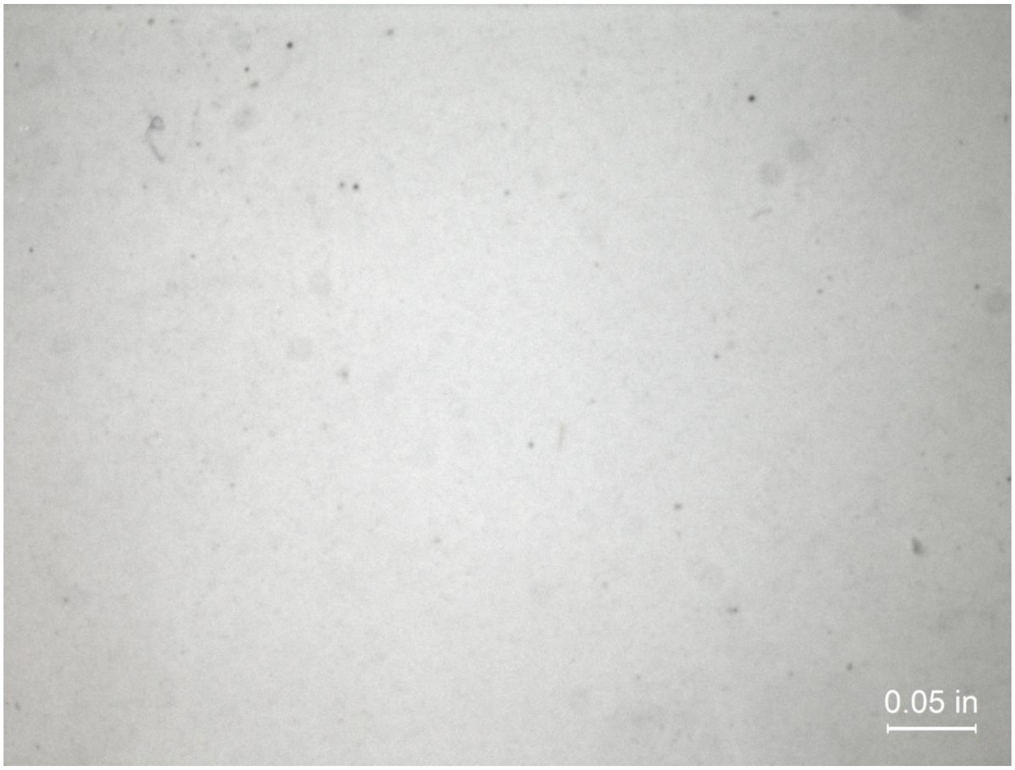
Figure 4 Photograph of the duplex 2205 stainless steel with anti-biofouling coating baseline screen.

(a) Coated Duplex 2205 Stainless Steel Screen 1

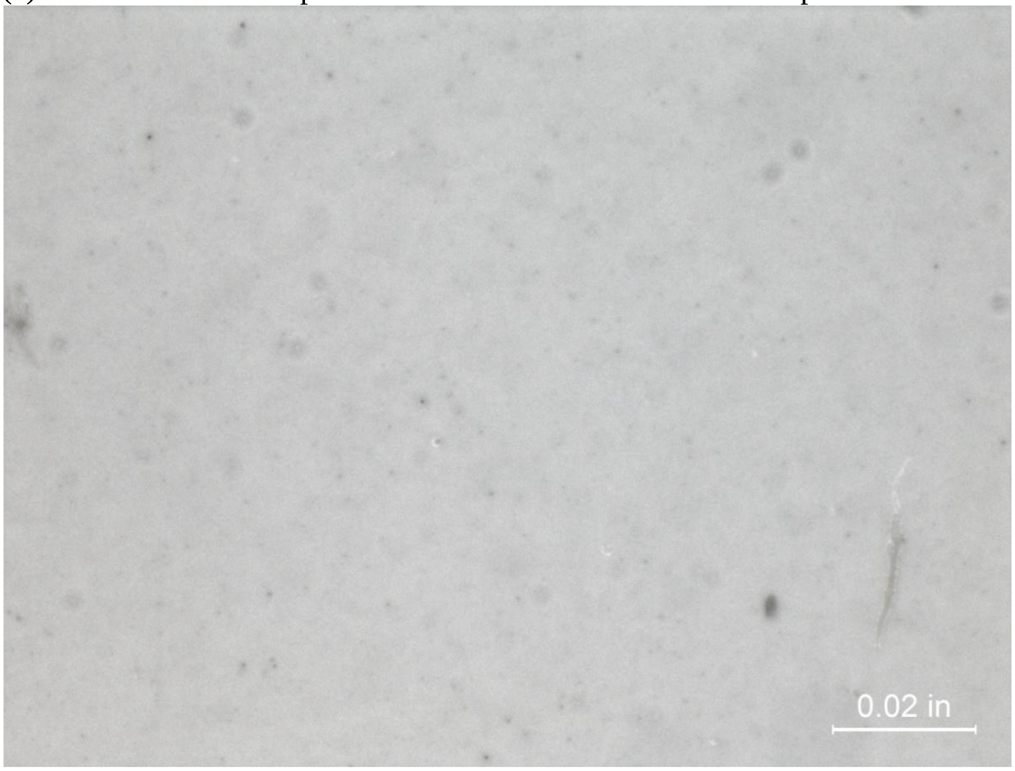
Figure 5 Photograph of duplex 2205 stainless steel with anti-biofouling coating screen 1 after a 3 month corrosion test.

(a) Coated Duplex 2205 Stainless Steel Screen 2

Figure 6 Photograph of duplex 2205 stainless steel with anti-biofouling coating screen 2 after a 6 month corrosion test.

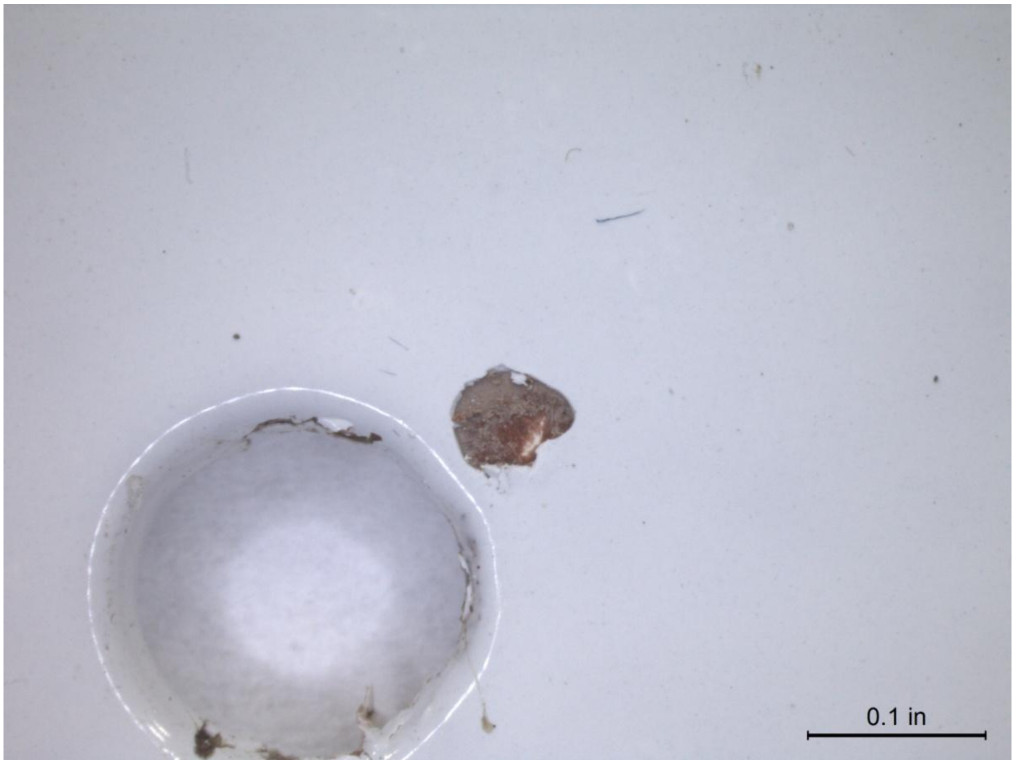


(a) Coated Duplex 2205 Stainless Steel Baseline Coupon 10X

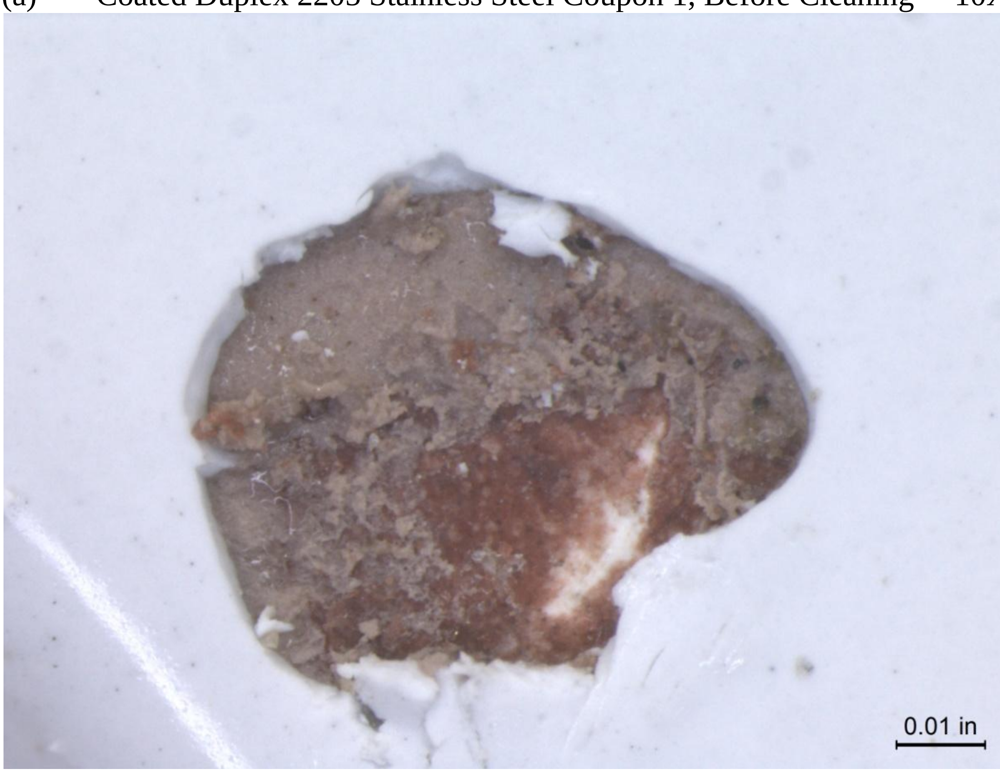


(b) Coated Duplex 2205 Stainless Steel Baseline Coupon 40X

Figure 7 Optical macrographs of the duplex 2205 stainless steel with anti-biofouling coating baseline coupon.

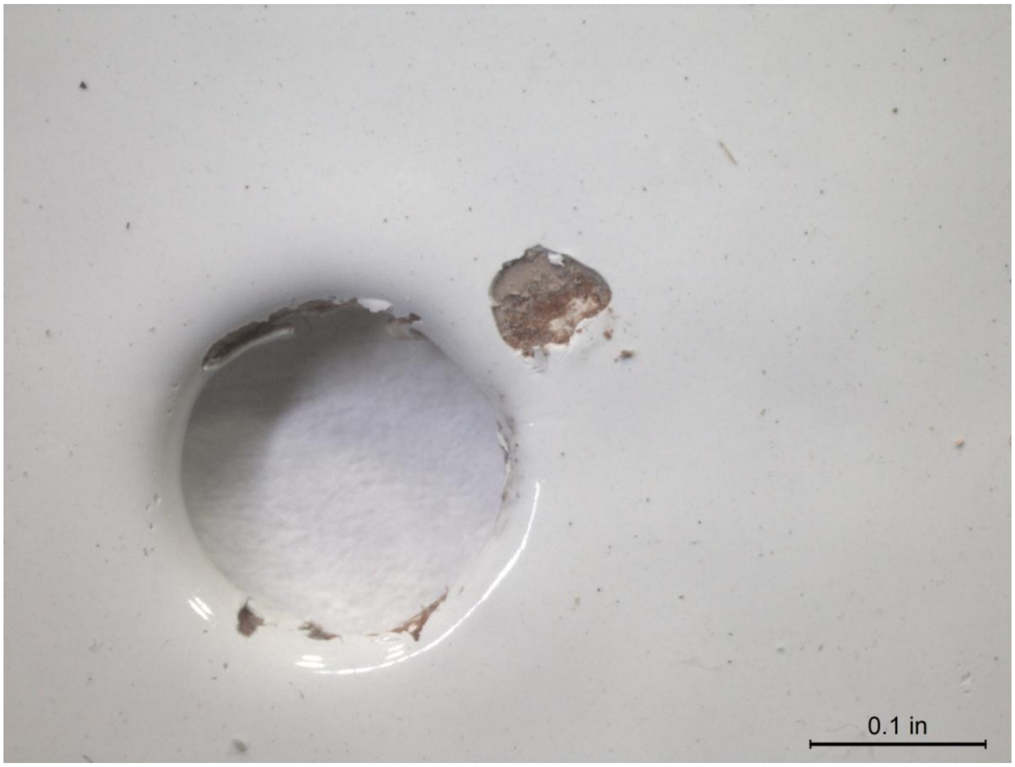


(a) Coated Duplex 2205 Stainless Steel Coupon 1, Before Cleaning 10X

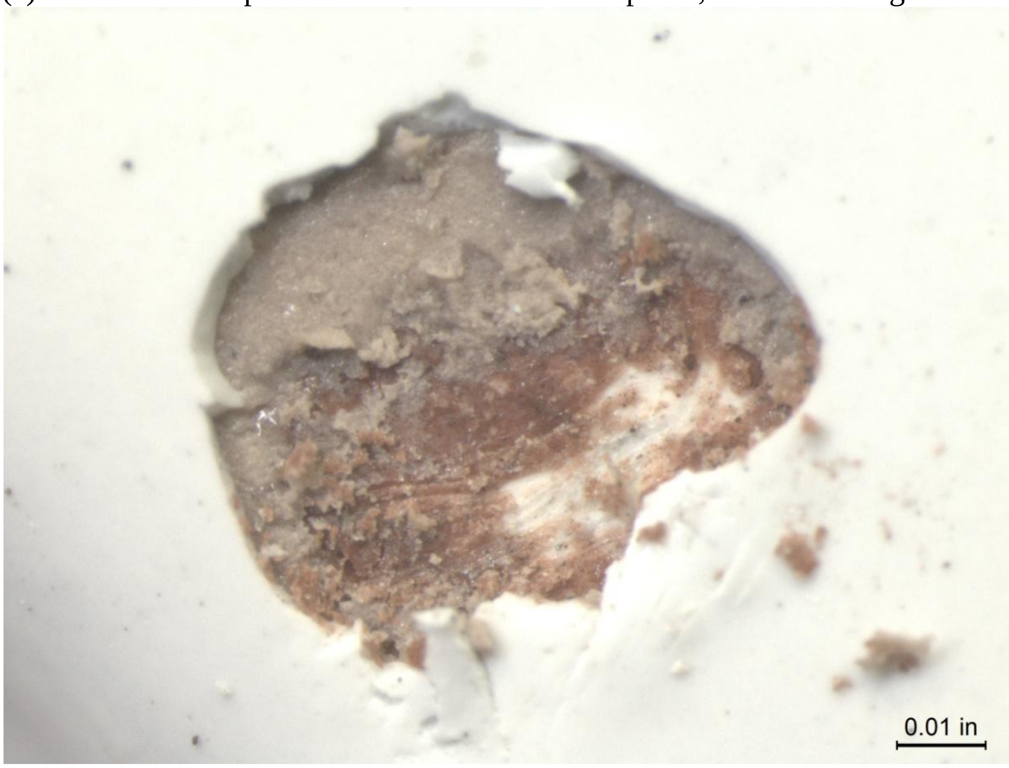


(b) Coated Duplex 2205 Stainless Steel Coupon 1, Before Cleaning 50X

Figure 8 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 1 after a 3 month corrosion test, before cleaning.

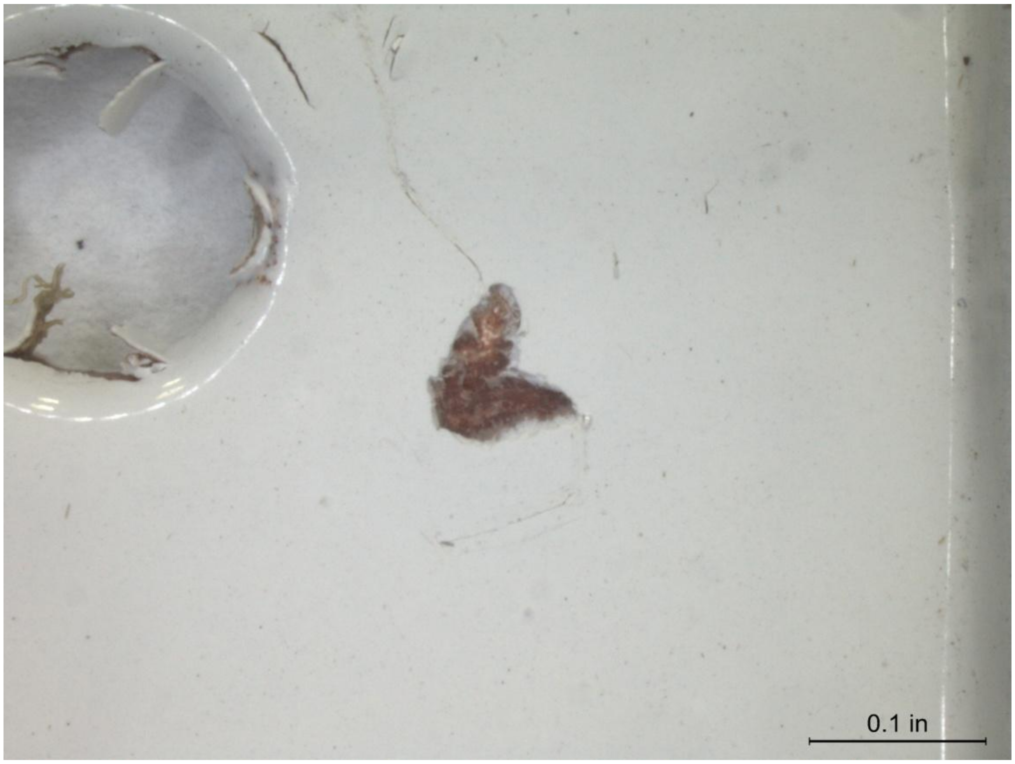


(a) Coated Duplex 2205 Stainless Steel Coupon 1, After Cleaning 10X



(b) Coated Duplex 2205 Stainless Steel Coupon 1, After Cleaning 50X

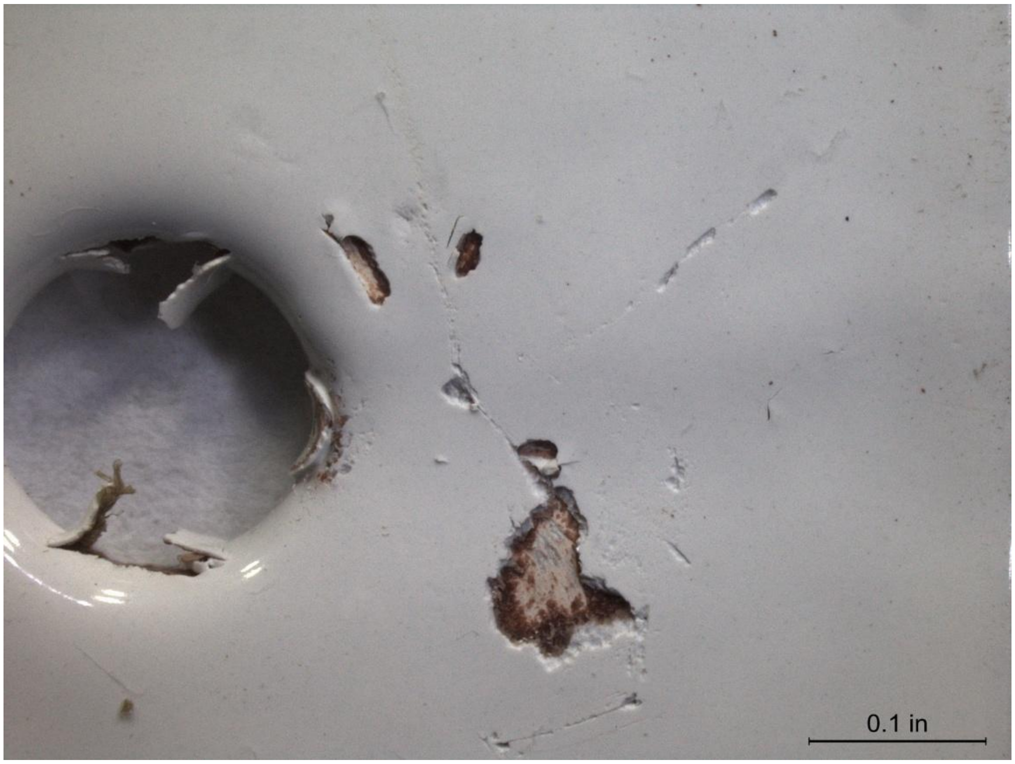
Figure 9 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 1 after a 3 month corrosion test, after cleaning.



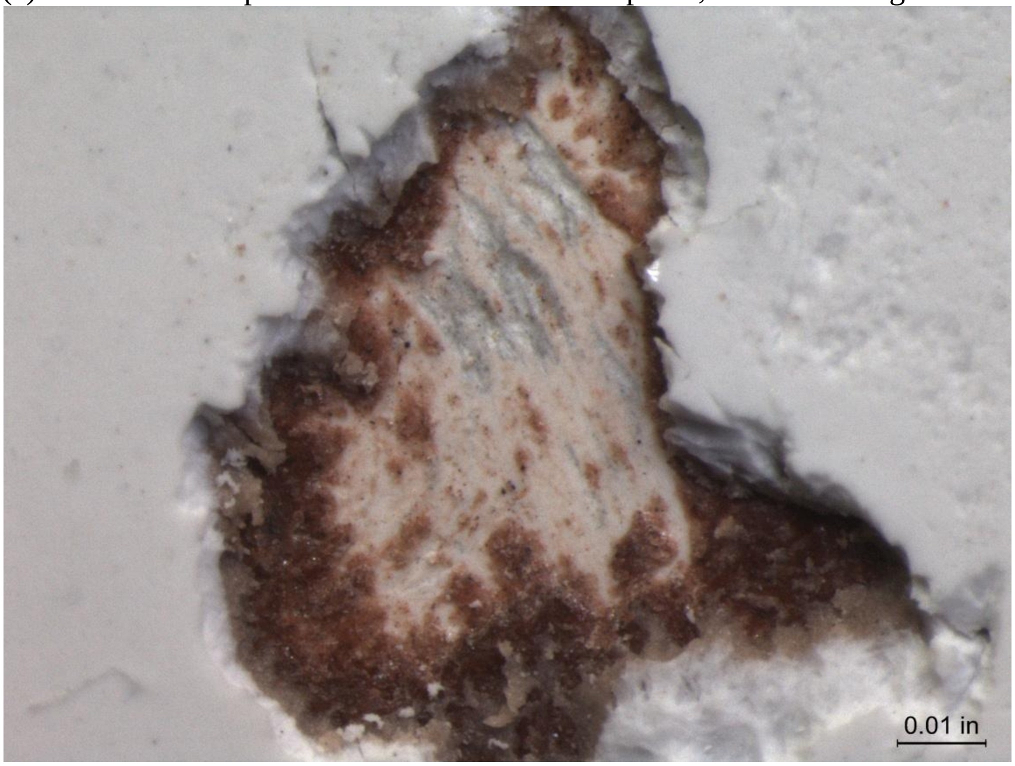
(a) Coated Duplex 2205 Stainless Steel Coupon 2, Before Cleaning 10X

(b) Coated Duplex 2205 Stainless Steel Coupon 2, Before Cleaning 50X

Figure 10 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 2 after a 6 month corrosion test, before cleaning.

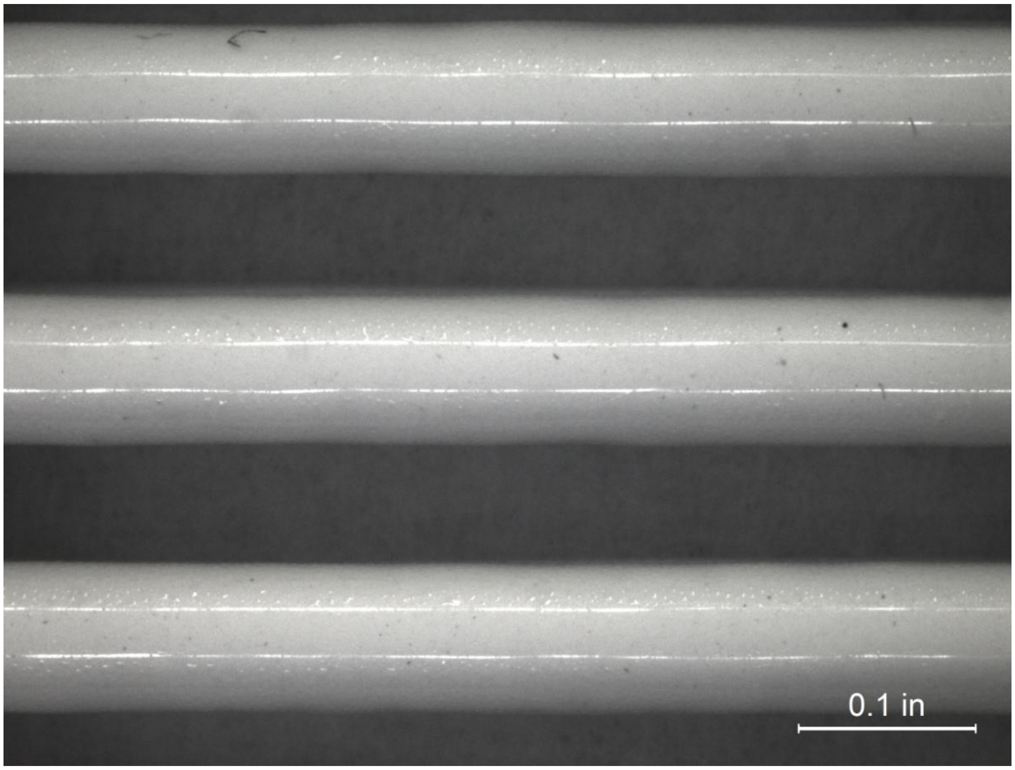


(a) Coated Duplex 2205 Stainless Steel Coupon 2, After Cleaning 10X



(b) Coated Duplex 2205 Stainless Steel Coupon 2, After Cleaning 50X

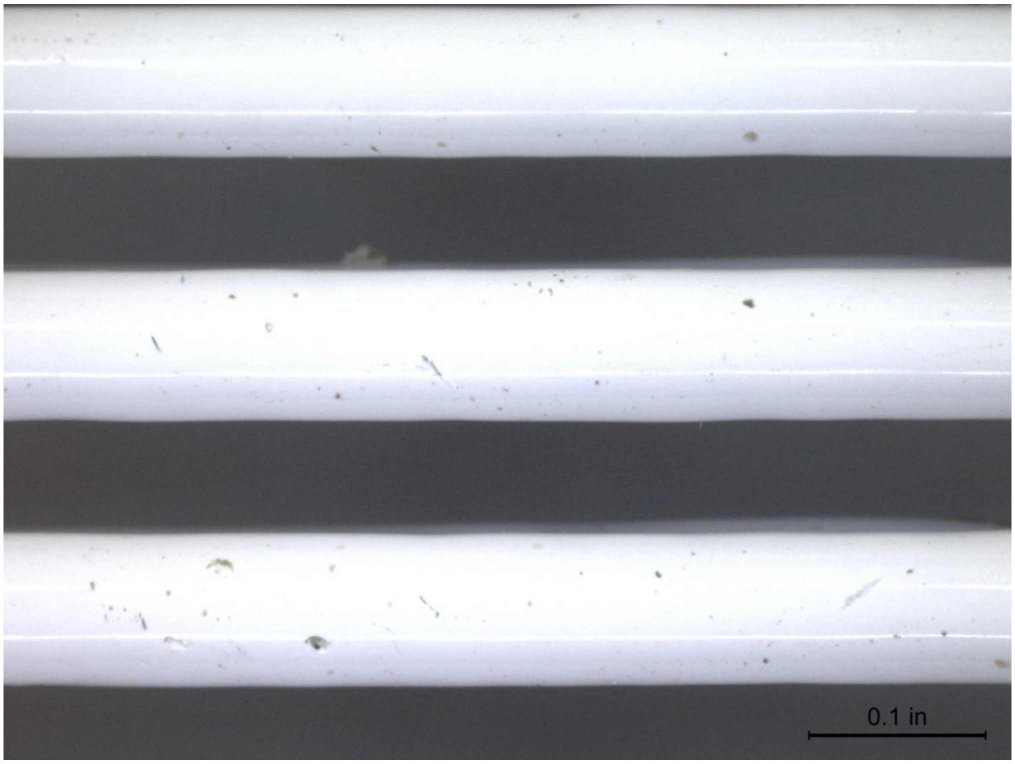
Figure 11 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 2 after a 6 month corrosion test, after cleaning.



(a) Coated Duplex 2205 Stainless Steel Baseline Screen 10X

(b) Coated Duplex 2205 Stainless Steel Baseline Screen 50X

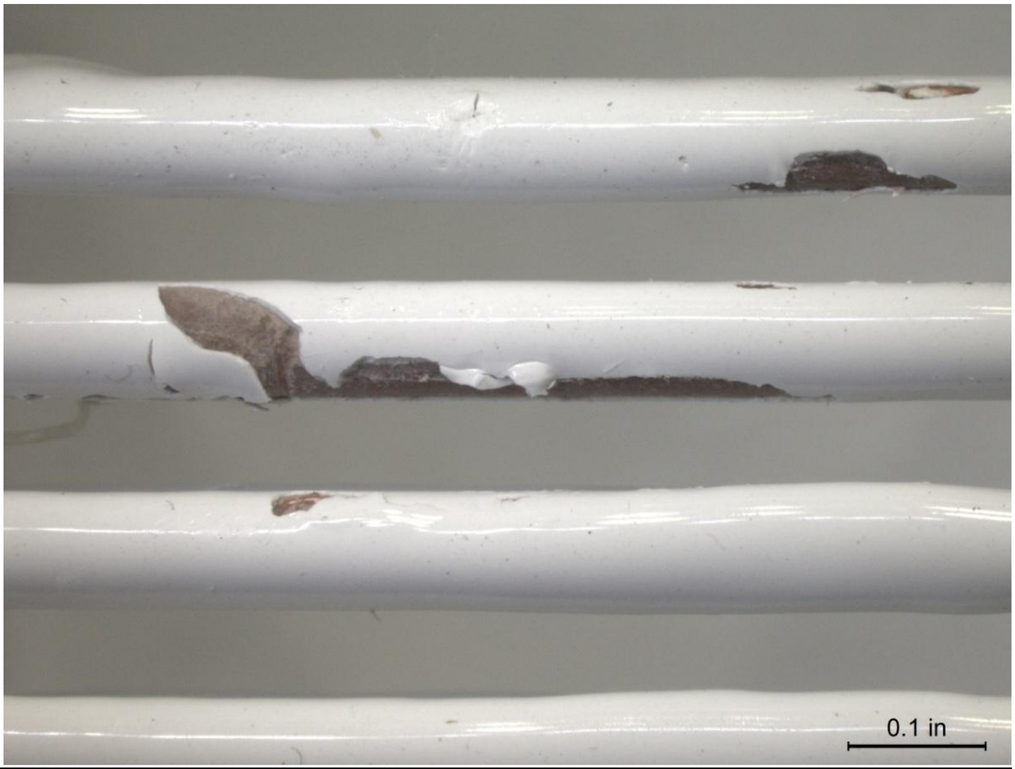
Figure 12 Optical macrographs of the duplex 2205 stainless steel with anti-biofouling coating baseline screen.



(a) Coated Duplex 2205 Stainless Steel Screen 1, Before Cleaning 10X

(b) Coated Duplex 2205 Stainless Steel Screen 1, Before Cleaning 50X

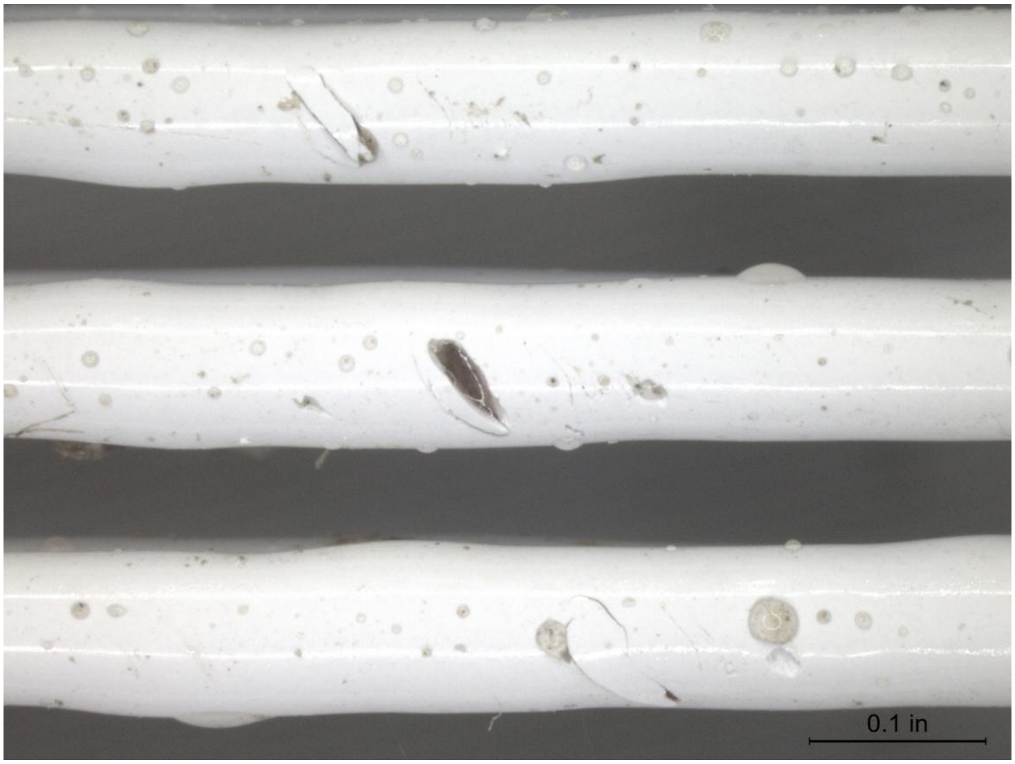
Figure 13 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating screen 1 after a 3 month corrosion test, before cleaning.



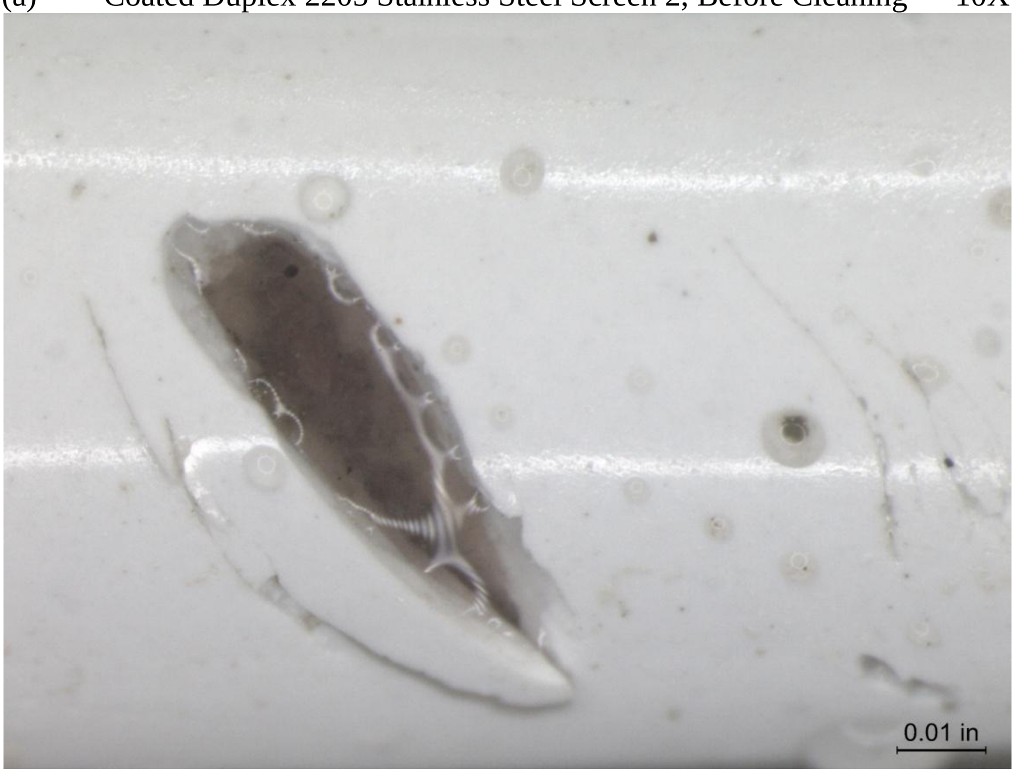
(a) Coated Duplex 2205 Stainless Steel Screen 1, After Cleaning 10X

(b) Coated Duplex 2205 Stainless Steel Screen 1, After Cleaning 50X

Figure 14 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating screen 1 after a 3 month corrosion test, after cleaning.

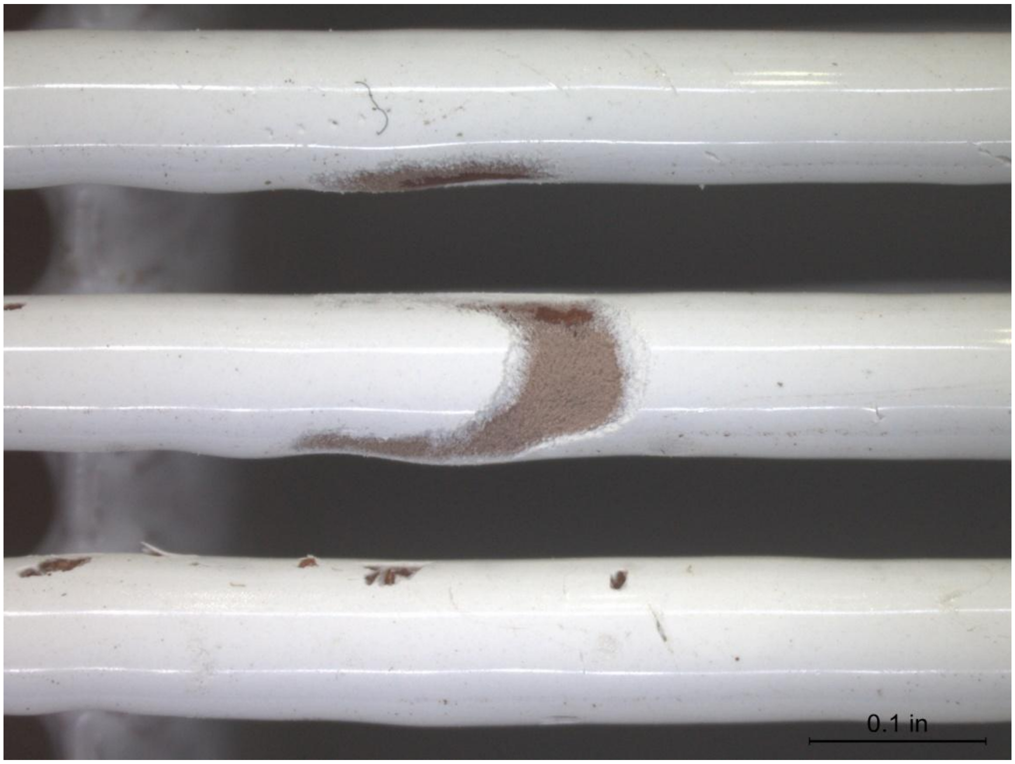


(a) Coated Duplex 2205 Stainless Steel Screen 2, Before Cleaning 10X



(b) Coated Duplex 2205 Stainless Steel Screen 2, Before Cleaning 50X

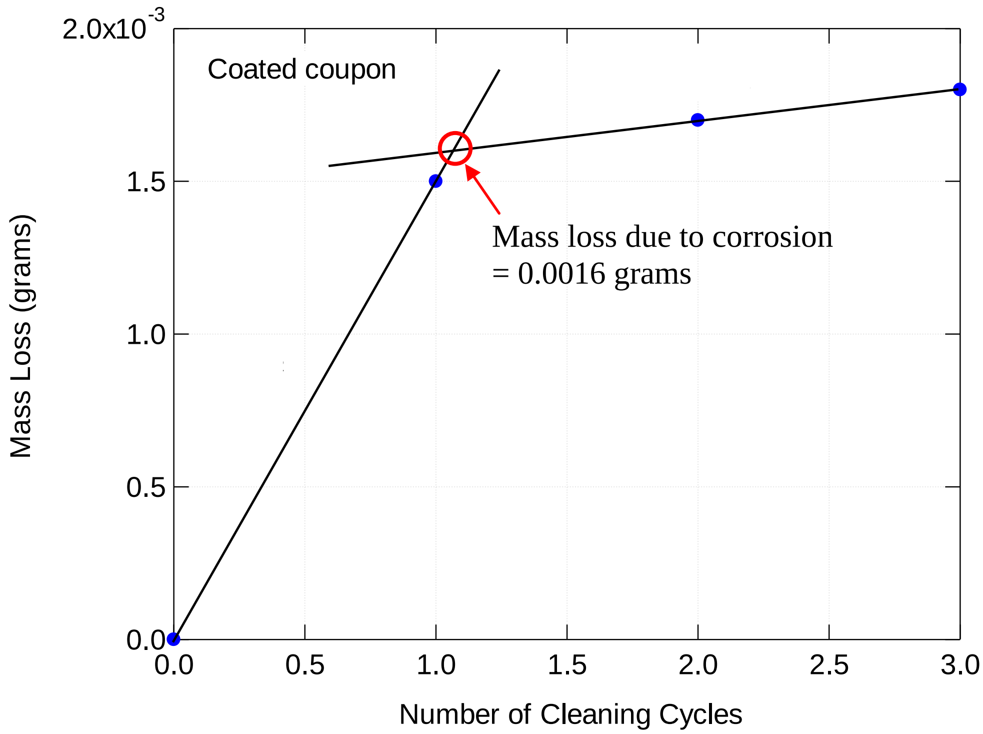
Figure 15 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating screen 2 after a 6 month corrosion test, before cleaning.



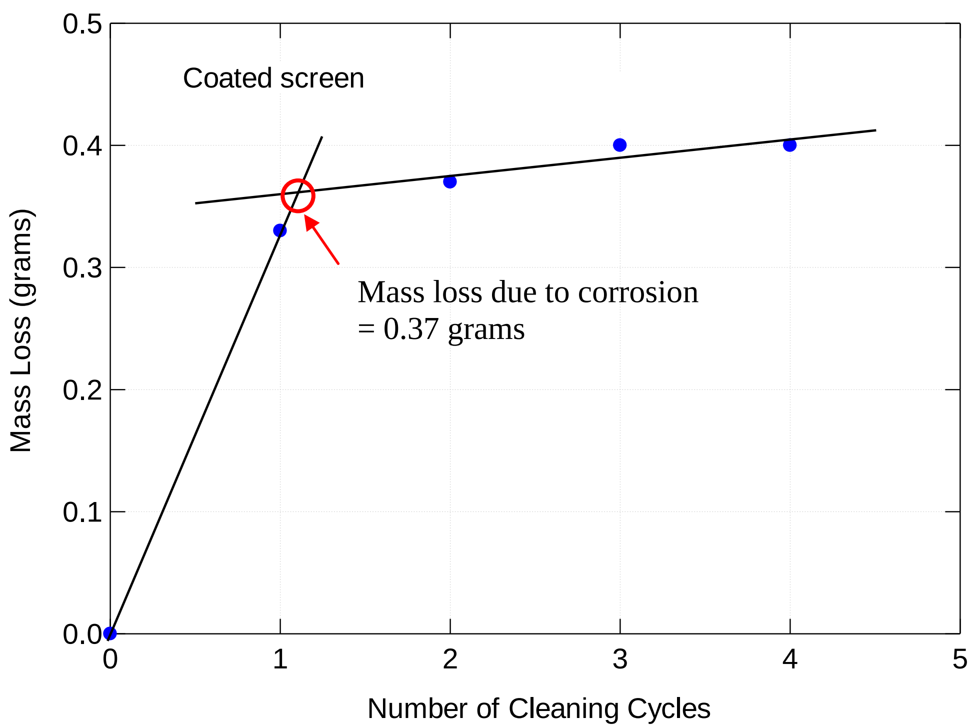
(a) Coated Duplex 2205 Stainless Steel Screen 2, After Cleaning 10X

(b) Coated Duplex 2205 Stainless Steel Screen 2, After Cleaning 50X

Figure 16 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating screen 2 after a 6 month corrosion test, after cleaning.

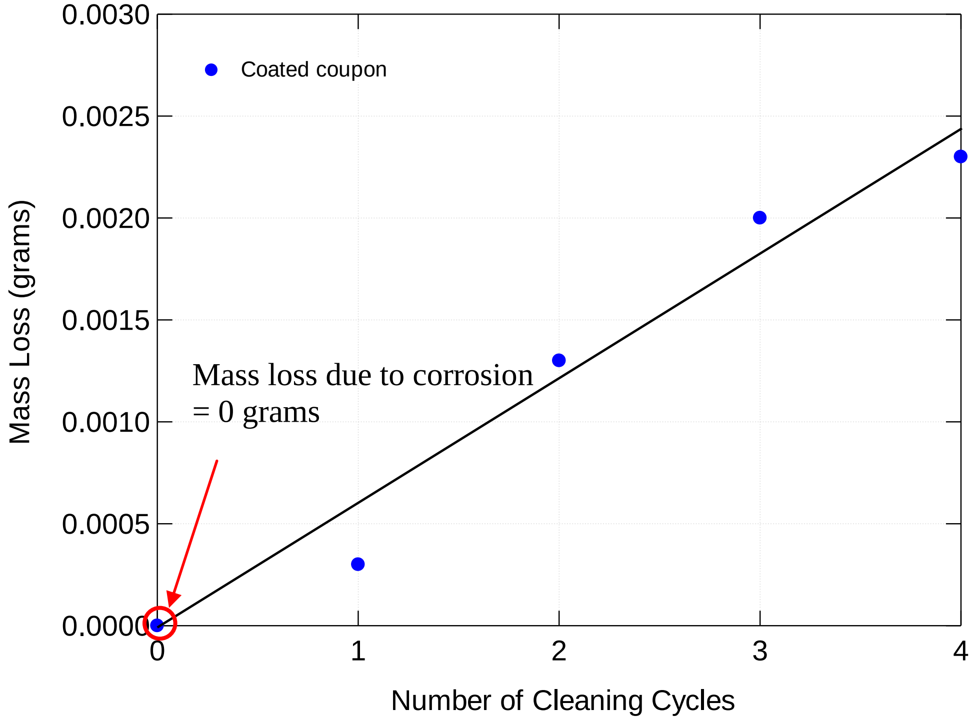


(a)

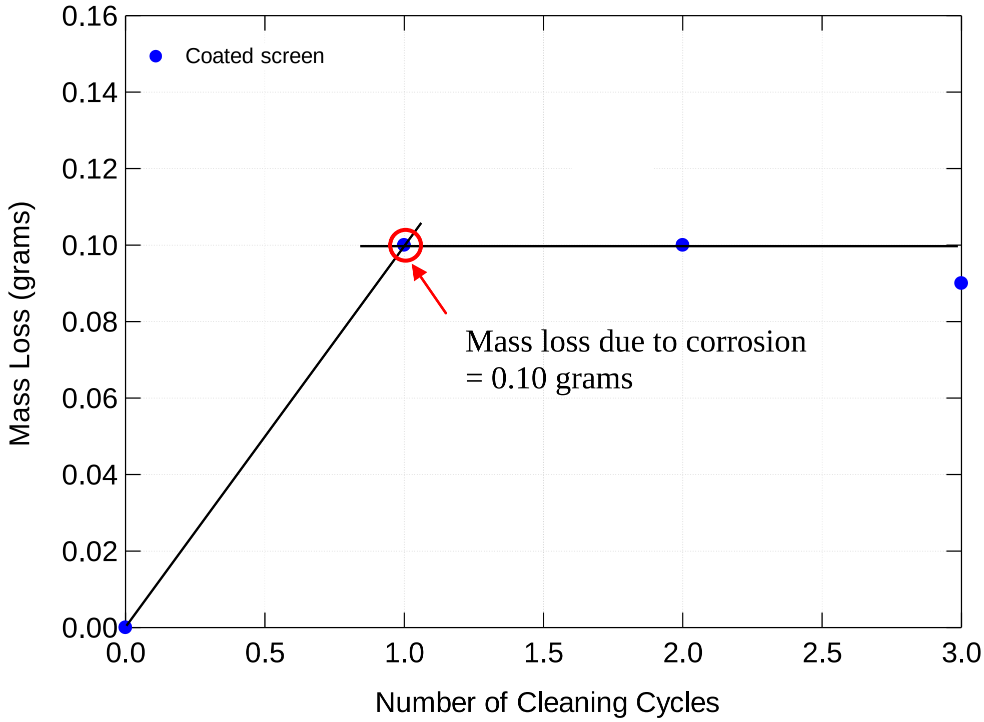


(b)

Figure 17 Mass loss of the duplex 2205 stainless steel with anti-biofouling coating (a) coupon 1 and (b) screen 1 during cleaning.

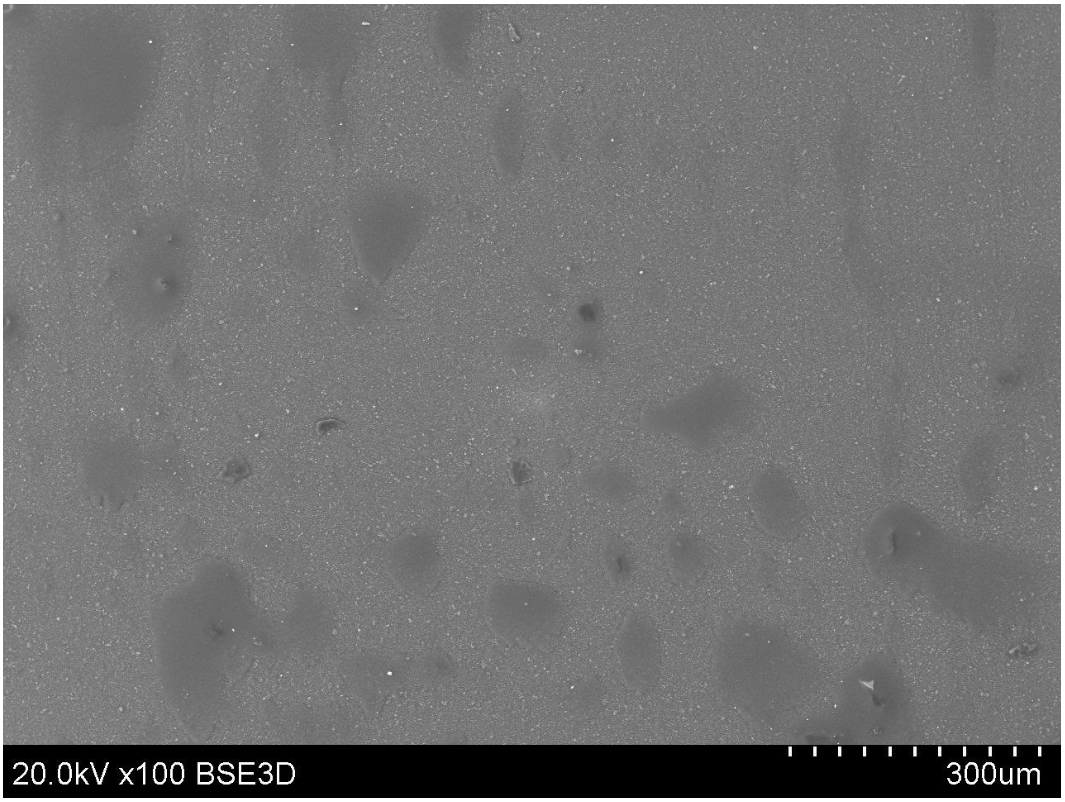


(a)

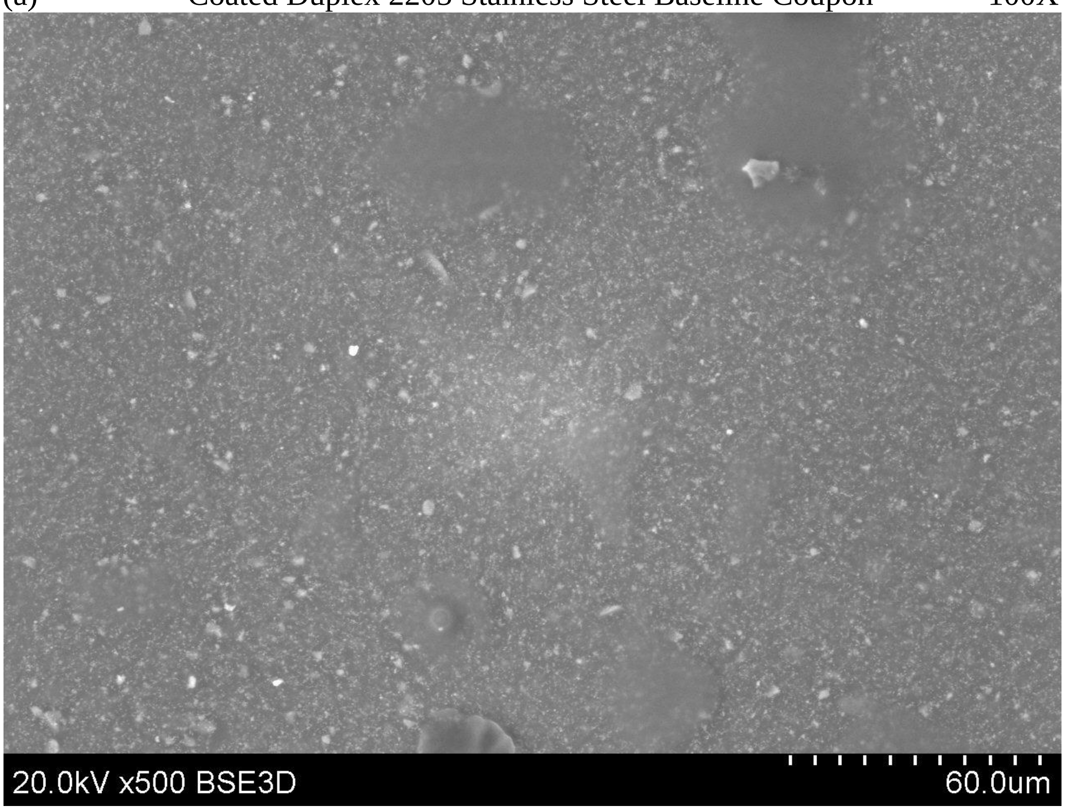


(b)

Figure 18 Mass loss of the duplex 2205 stainless steel with anti-biofouling coating (a) coupon 2 and (b) screen 2 during cleaning.

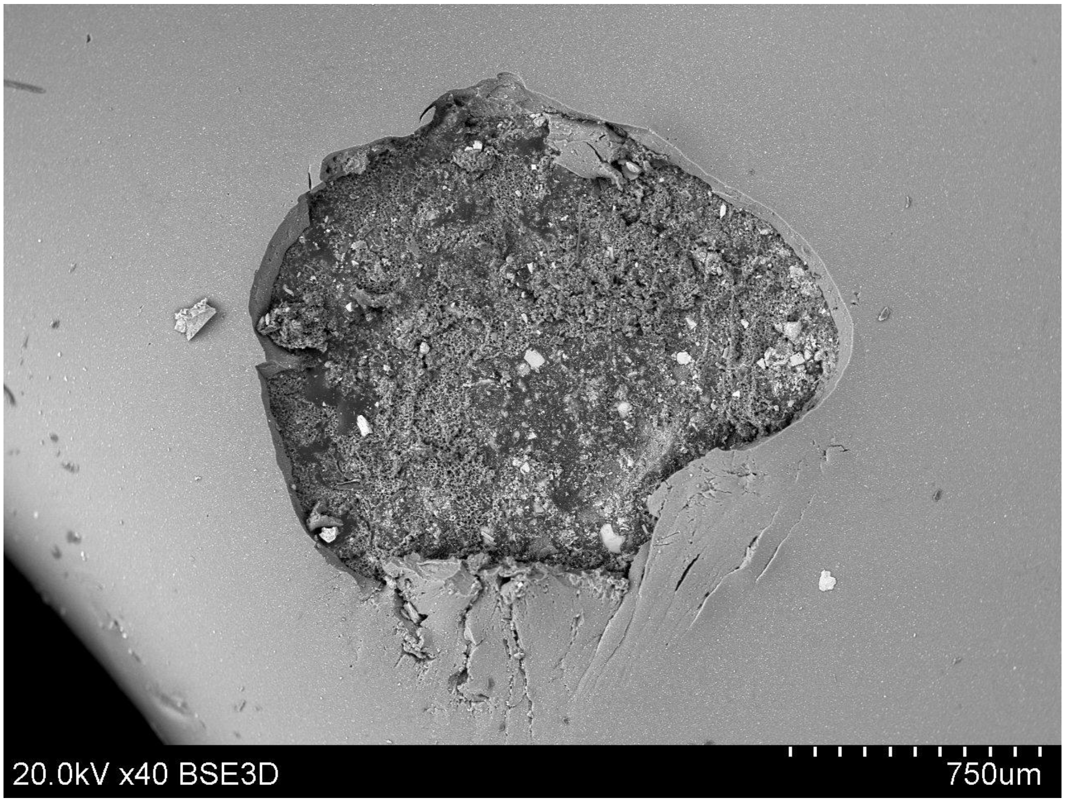


(a) Coated Duplex 2205 Stainless Steel Baseline Coupon 100X

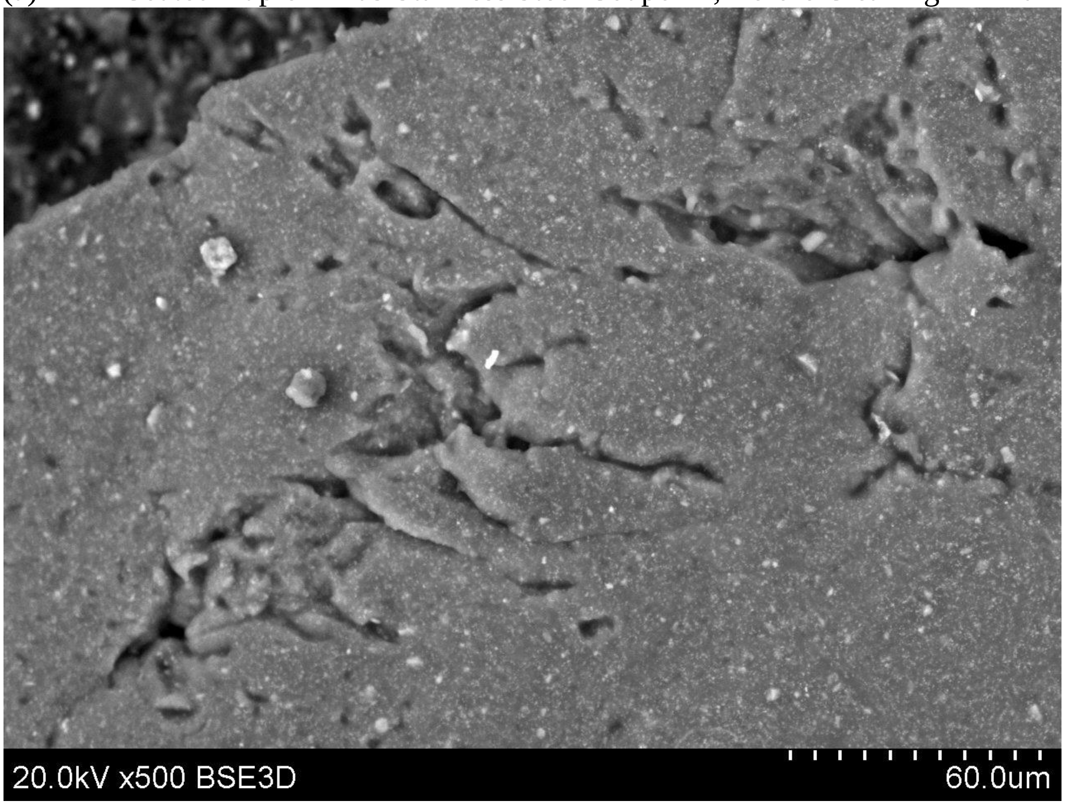


(b) Coated Duplex 2205 Stainless Steel Baseline Coupon 500X

Figure 19 Scanning electron micrographs of the duplex 2205 stainless steel with anti-biofouling coating baseline coupon.

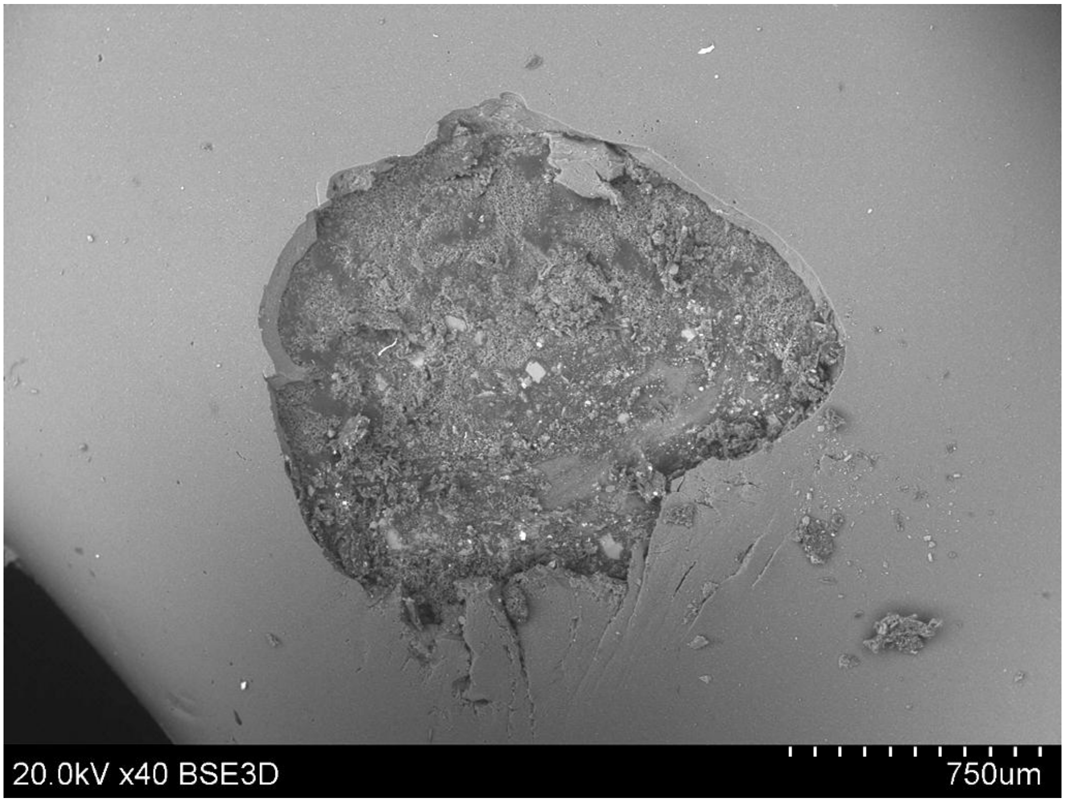


(a) Coated Duplex 2205 Stainless Steel Coupon 1, Before Cleaning 40X

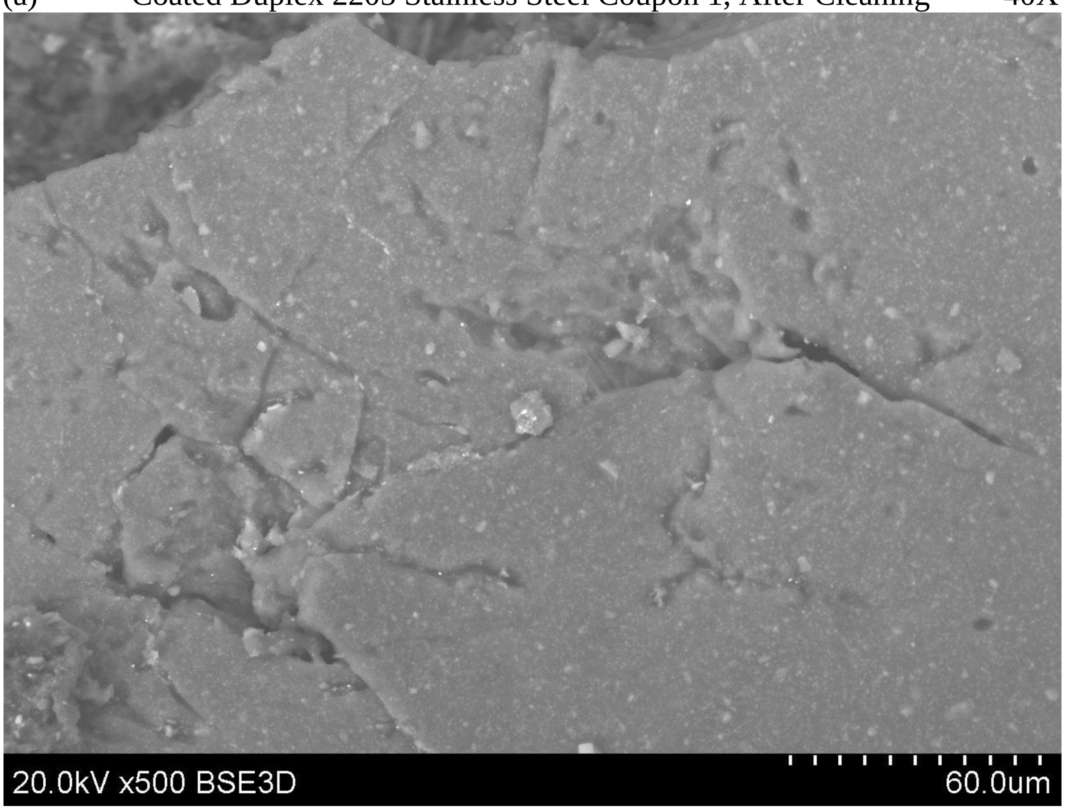


(b) Coated Duplex 2205 Stainless Steel Coupon 1, Before Cleaning 500X

Figure 20 Scanning electron micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 1 after a 3 month corrosion test, before cleaning.

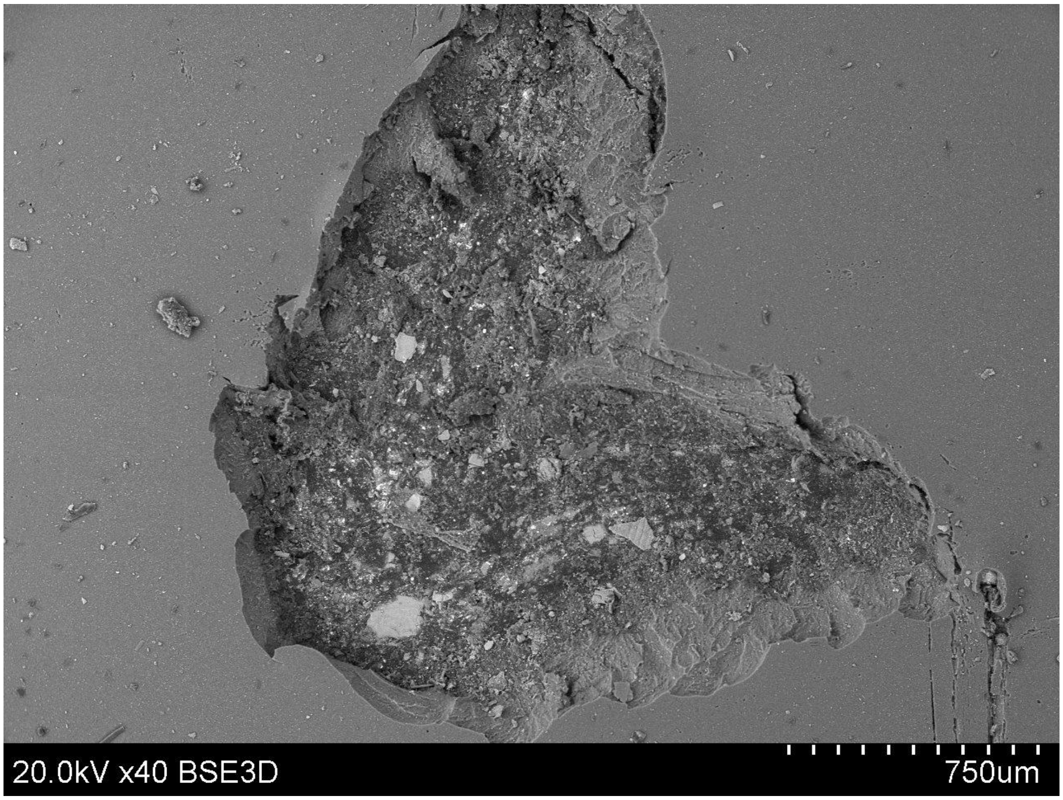


(a) Coated Duplex 2205 Stainless Steel Coupon 1, After Cleaning 40X

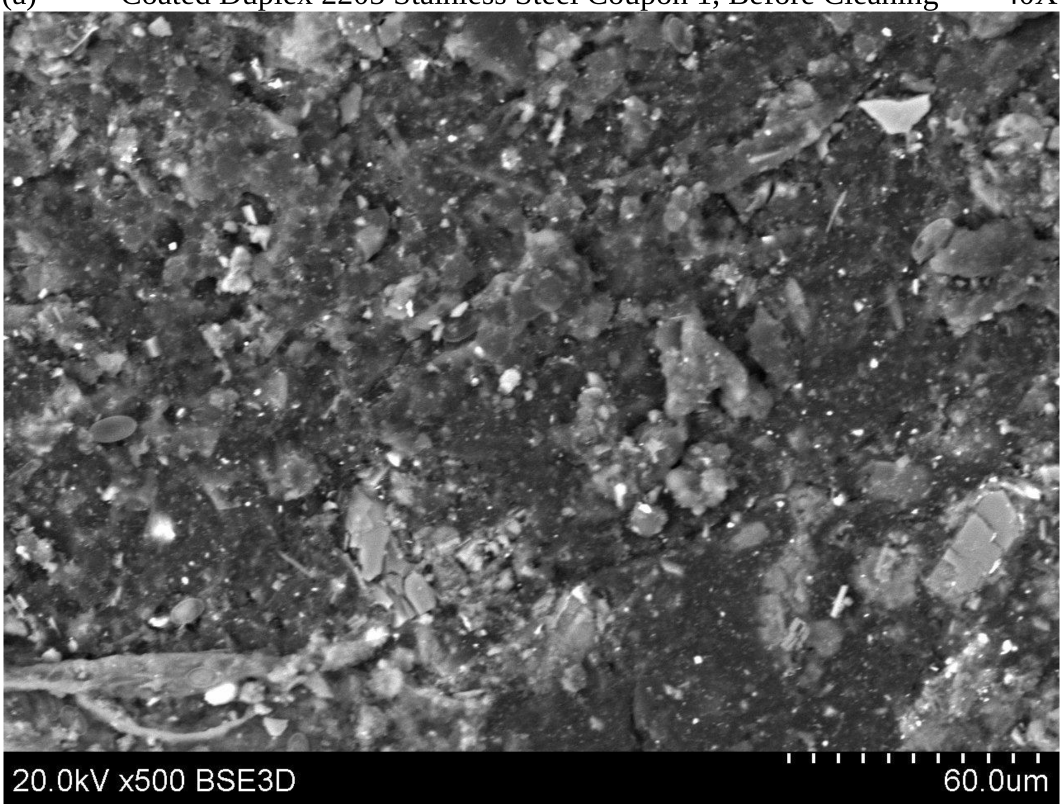


(b) Coated Duplex 2205 Stainless Steel Coupon 1, After Cleaning 500X

Figure 21 Scanning electron micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 1 after a 3 month corrosion test, after cleaning.

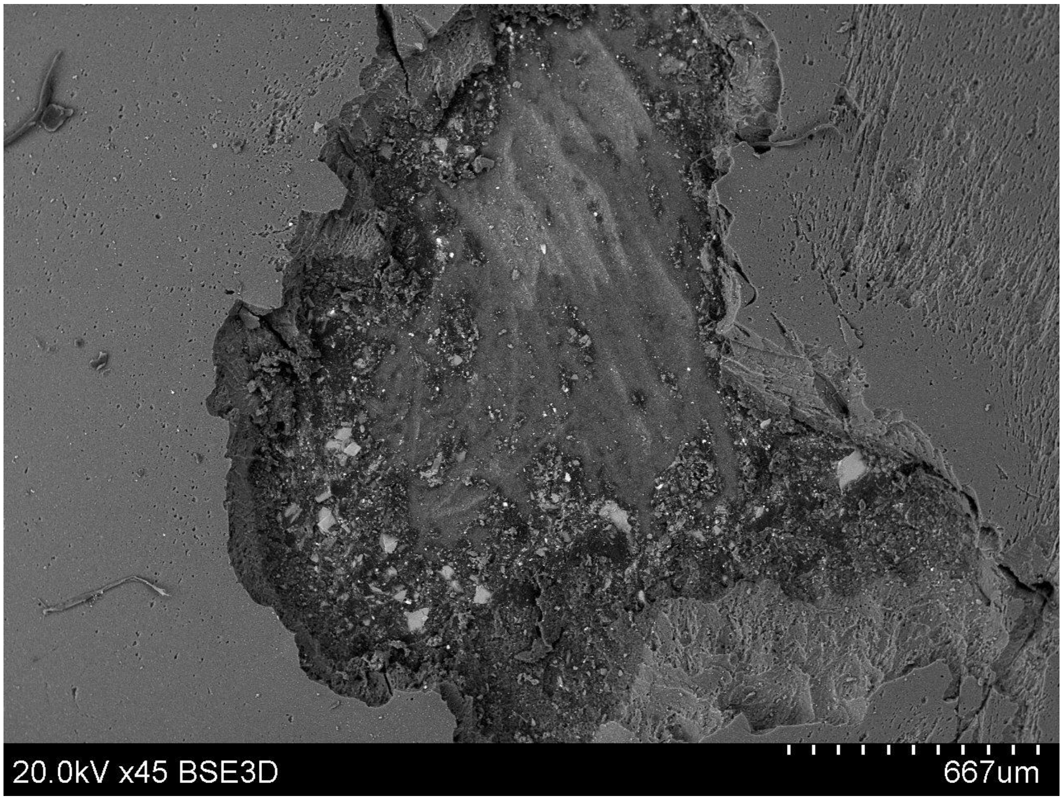


(a) Coated Duplex 2205 Stainless Steel Coupon 1, Before Cleaning 40X

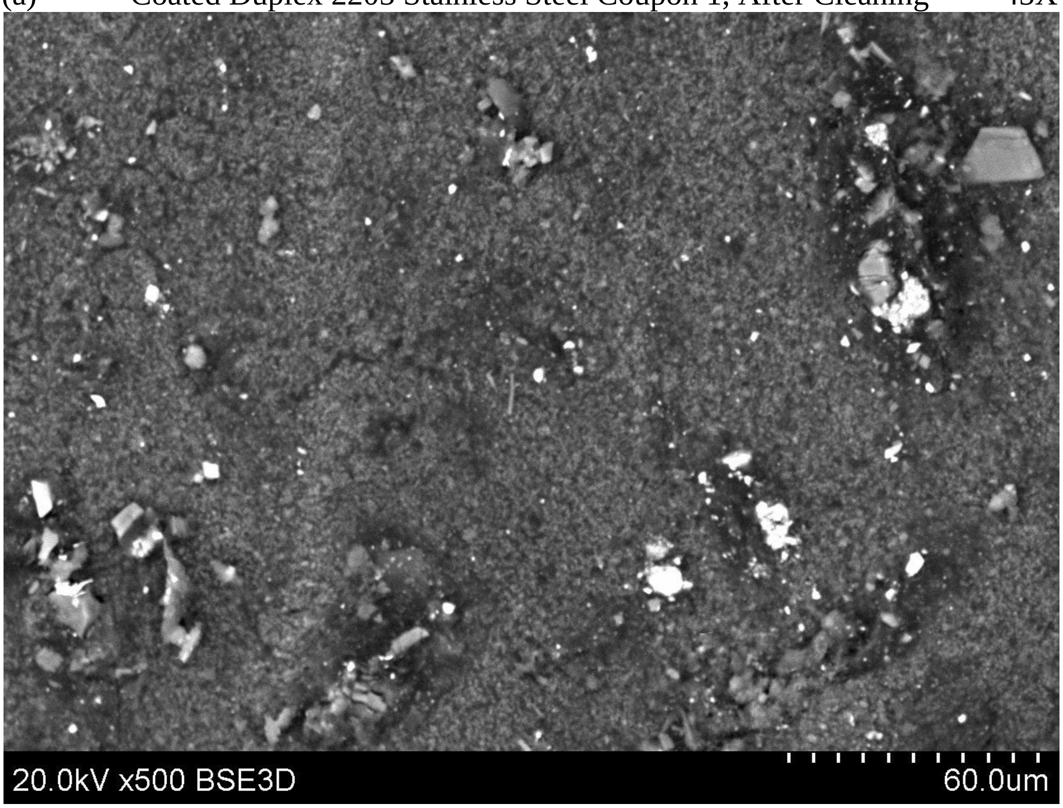


(b) Coated Duplex 2205 Stainless Steel Coupon 1, Before Cleaning 500X

Figure 22 Scanning electron micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 2 after a 6 month corrosion test, before cleaning.

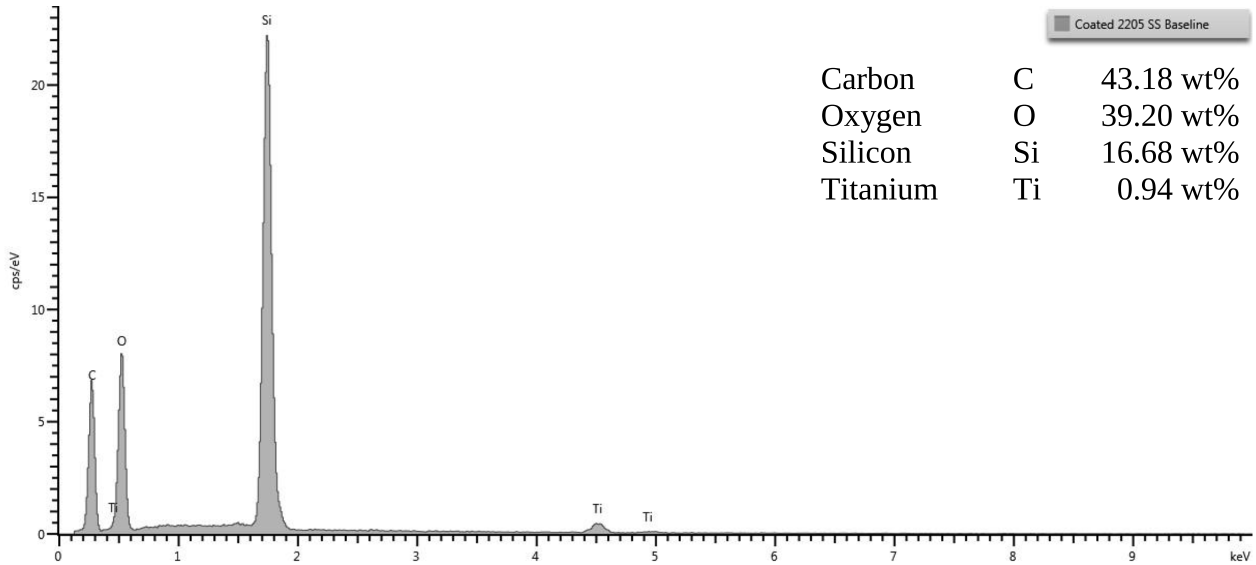


(a) Coated Duplex 2205 Stainless Steel Coupon 1, After Cleaning 45X



(b) Coated Duplex 2205 Stainless Steel Coupon 1, After Cleaning 500X

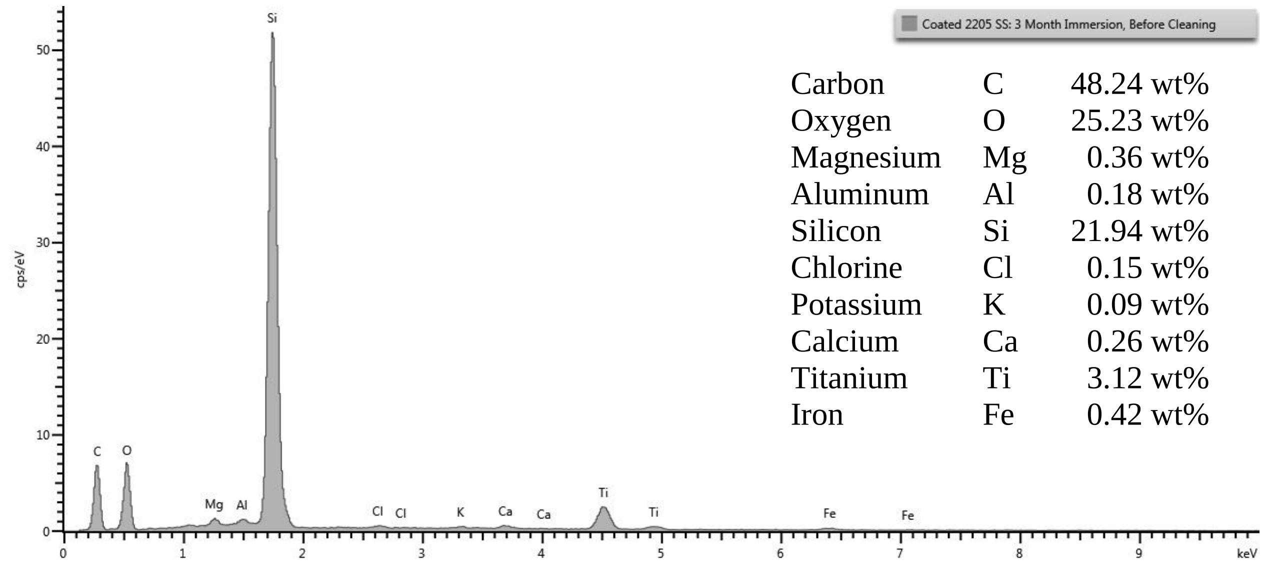
Figure 23 Scanning electron micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 2 after a 6 month corrosion test, after cleaning.



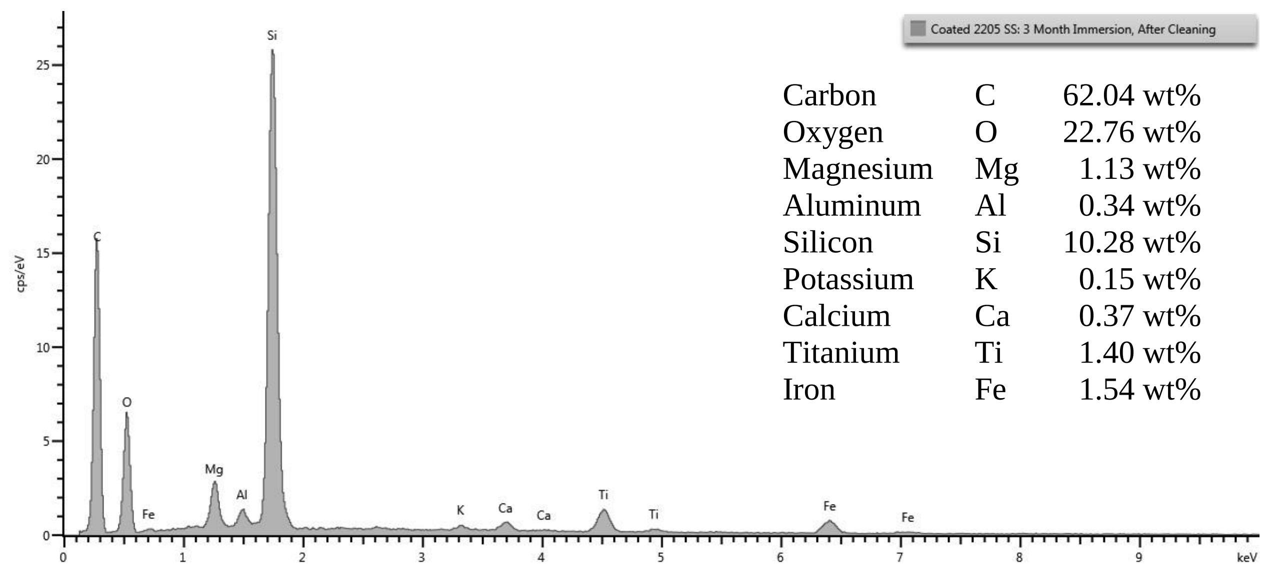
Carbon	C	43.18 wt%
Oxygen	O	39.20 wt%
Silicon	Si	16.68 wt%
Titanium	Ti	0.94 wt%

(a) Coated Duplex 2205 Stainless Steel Baseline Coupon

Figure 24 Energy dispersive x-ray spectra of the duplex 2205 stainless steel with anti-biofouling coating baseline coupon.

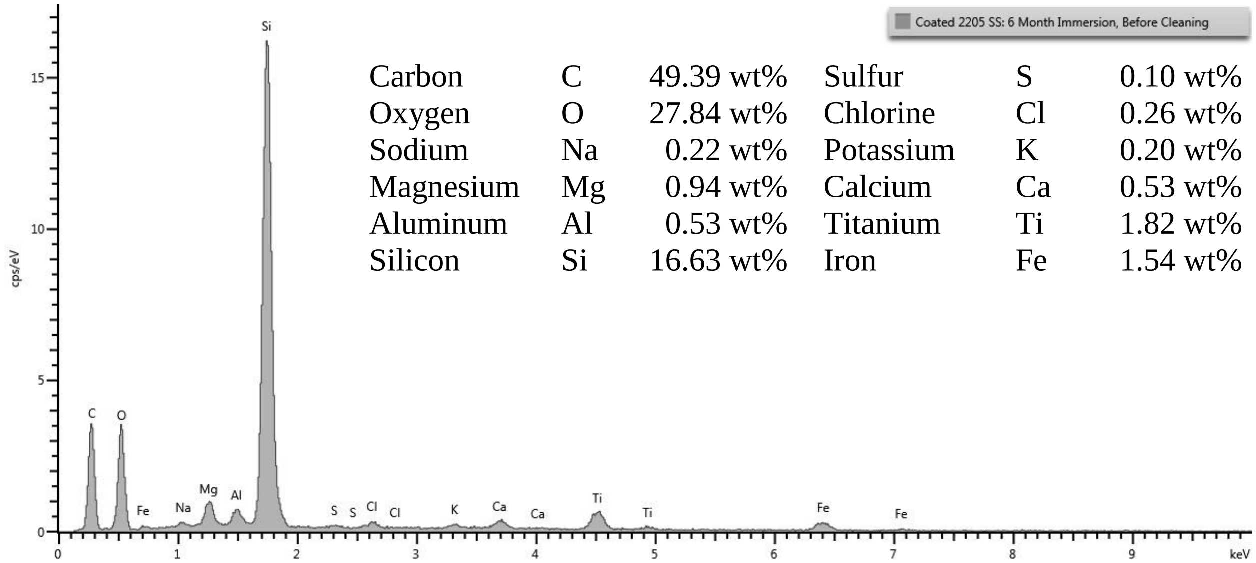


(a) Coated Duplex 2205 Stainless Steel Coupon 1, Before Cleaning

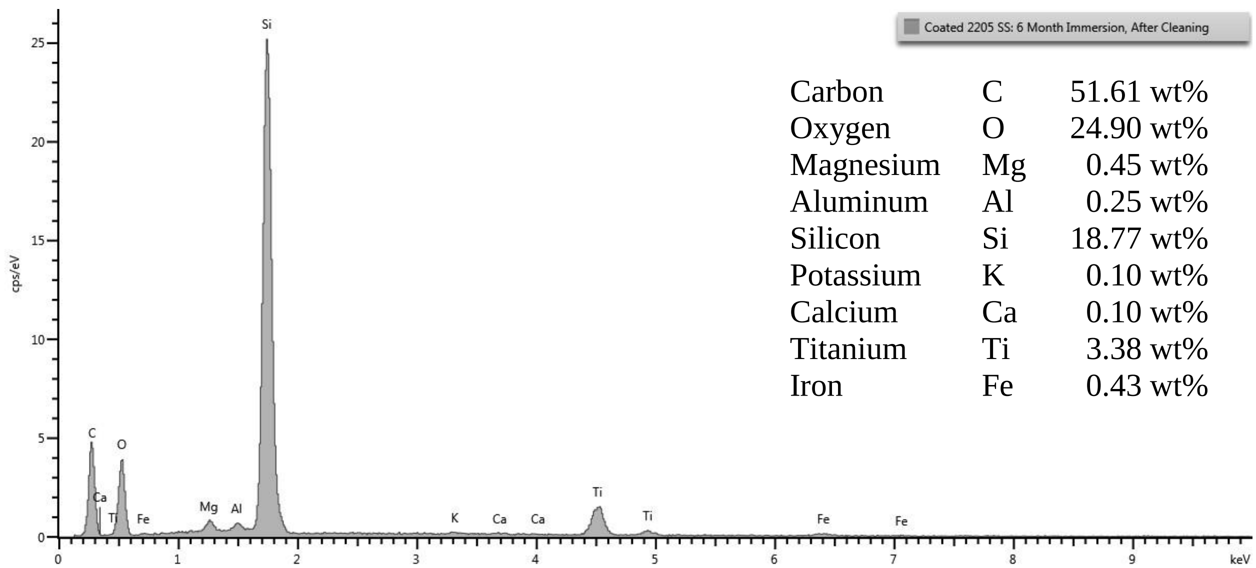


(b) Coated Duplex 2205 Stainless Steel Coupon 1, After Cleaning

Figure 25 Energy dispersive x-ray spectra of duplex 2205 stainless steel with anti-biofouling coating coupon 1 after a 3 month corrosion test (a) before cleaning and (b) after cleaning.

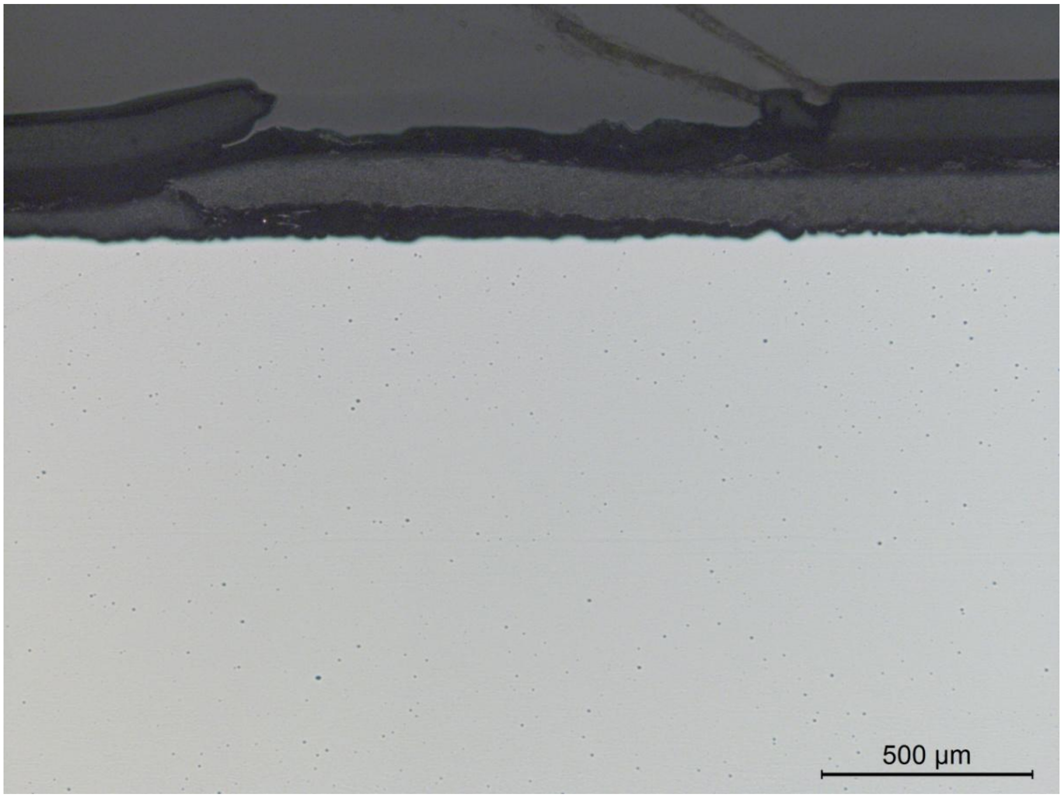


(a) Coated Duplex 2205 Stainless Steel Coupon 2, Before Cleaning

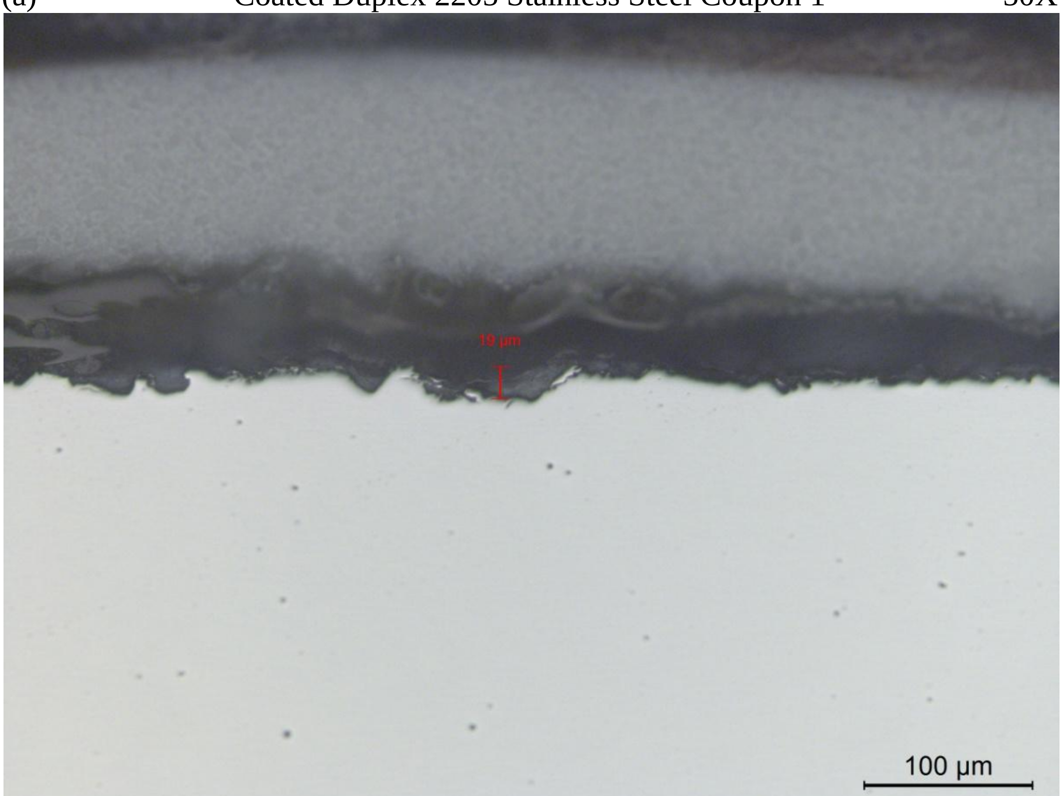


(b) Coated Duplex 2205 Stainless Steel Coupon 2, After Cleaning

Figure 26 Energy dispersive x-ray spectra of duplex 2205 stainless steel with anti-biofouling coating coupon 2 after a 6 month corrosion test (a) before cleaning and (b) after cleaning.



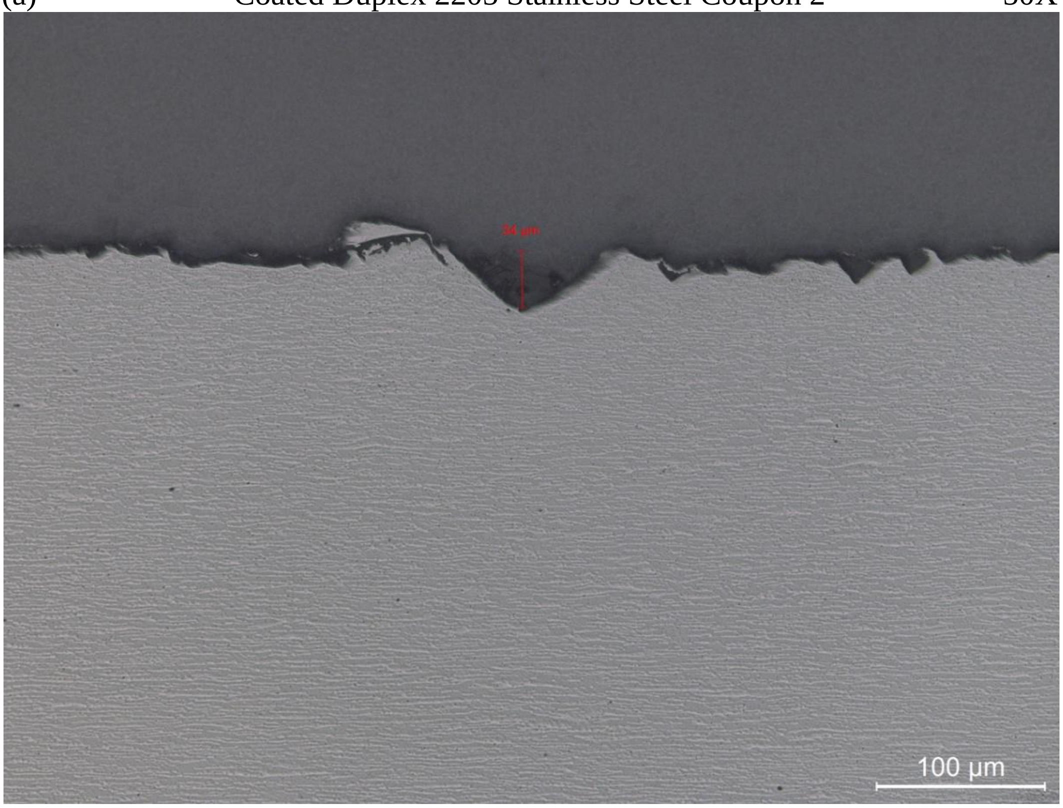
(a) Coated Duplex 2205 Stainless Steel Coupon 1 50X



(b) Coated Duplex 2205 Stainless Steel Coupon 1 200X

Figure 27 Optical micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 1.

(a) Coated Duplex 2205 Stainless Steel Coupon 2 50X



(b) Coated Duplex 2205 Stainless Steel Coupon 2 200X

Figure 28 Optical micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 2.

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Report No. 5005.0361C **January 30, 2015**

CORROSION EVALUATION OF CDA 706 COUPONS AND SCREENS

Customer Authorization: Verbal

Report To: V & A Engineering
Attn: Manuel Najar
155 Grand Avenue, Suite 700
Oakland, CA 94612

1.0 INTRODUCTION

Five coupons, five wedge wire screens, and one plate were submitted by V&A Engineering for corrosion evaluation. The coupons were 1-inch by 3-inches by ¼-inch thick. The wedge wire screens were 4-inches by 4-inches by 1-inch tall with 4 mm spacing. The plate was 4-inches by 4-inches by 1/8-inch thick. The sample was reportedly CDA 706, a 90-Copper, 10-Nickel alloy.

Four coupons and four screens were to be placed in seawater for a period up to one year. After every 3 month interval, one coupon and one screen were to be removed from the test system and examined for corrosion. The purpose of this evaluation was to document the samples in the baseline as-received condition, then again after 3, 6, 9, and 12 months of water exposure, record any loss in mass, examine for any pitting corrosion, and estimate the corrosion rate.

The samples were evaluated by the following laboratory procedures:

1) Visual examination and weighing
2) Cleaning per ASTM G1[1]
3) Scanning electron microscopy
4) Metallography

The results of the evaluation showed minimal mass loss and corrosion for the coupon and screen after 3 months and 6 months of corrosion testing. The coupon and screen, after 3 months of corrosion testing, had a corrosion rate of approximately 0.022 millimeters per year and 0.129 millimeters per year, respectively. The coupon and screen, after 6 months of corrosion testing, had a corrosion rate of approximately 0.023 millimeters per year and 0.067 millimeters per year, respectively.

[1] G1: Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

2.0 EVALUATION[2]

2.1 Visual Examination

The sample identifications for the coupons and wedge wire screens and their corresponding immersion times are shown in Table 1. The coupons had identification numbers stamped on the front face by V&A Engineering. A number of notches, corresponding to the sample number, were sawed at the edge of each screen for identification after the corrosion test. The weights of the samples were recorded. Coupons 1 – 4 and screens 1 – 5 were sent back to V&A for corrosion testing. Coupon 5 was the baseline sample and documented by photography, optical stereoscopy and scanning electron microscopy for comparison to the tested samples. Screen 5 was documented as a baseline by photography and optical stereoscopy, and then sent to V&A for testing.

Photographs of the baseline coupon are shown in Figure 1. Photographs of coupon 1, after 3 months of corrosion testing, are shown in Figure 2. Photographs of coupon 2, after 6 months of corrosion testing, are shown in Figure 3.

A photograph of the baseline screen is shown in Figure 4. A photograph of screen 1, after 3 months of corrosion testing, is shown in Figure 5. A photograph of screen 2, after 6 months of corrosion testing, is shown in Figure 6.

2.2 Cleaning

The coupon and screen were cleaned with solution C.2.1 per ASTM G1.[3] One cleaning cycle was approximately 1 minute. After each cleaning cycle, the samples were rinsed in water, dried, and weighed. The cleaning and weighing cycle was completed five times for the coupon and screen. The weights of the samples as-received, after corrosion testing but before cleaning, and after each cleaning cycle are presented in Table 2.

Optical macrographs of the baseline coupon and screen are shown in Figures 7 and 12, respectively. Representative optical macrographs of the samples after a 3 month corrosion test, before and after cleaning, are shown in Figures 8 – 9 and 13 – 14. Representative optical macrographs of the sample after a 6 month corrosion test, before and after cleaning, are shown in Figures 10 – 11 and 15 – 16.

The mass loss versus the number of cleaning cycles was plotted, shown in Figures 17 – 18. The equations for best fit lines AB and BC, calculated using IGOR Pro, are listed in Table 3. Point B, indicated by the red circle in each plot, corresponds to the mass loss due to corrosion during the cleaning process for each sample. This mass loss was subtracted from the weight of the sample before cleaning and from the weight of the sample as-received to determine the total mass loss from corrosion. The corrosion rate of each sample was determined by the formula specified in Section 8.1 of ASTM G1:

---

[2] The magnifications of the optical and scanning electron micrographs in this report are approximate and should not be used as a basis for dimensional analyses unless otherwise indicated.

[3] 500 mL hydrochloric acid + 500 ml reagent water.

$$Corrosion\ Rate = \frac{K\ x\ W}{A\ x\ T\ x\ D}$$

where K = 8.76 x 10^4, T = time of exposure in hours, A = area in cm^2, W = mass loss in grams, and D = density in g/cm^3. The total mass loss from corrosion and the calculated corrosion rate of each sample is shown in Table 4.

2.3 Scanning Electron Microscopy

The baseline coupon, coupon 1, and coupon 2 were examined with a scanning electron microscope. Representative scanning electron micrographs of the baseline coupon are shown in Figure 19. Representative scanning electron micrographs of coupon 1 before and after cleaning are shown in Figures 20 – 21. Representative scanning electron micrographs of coupon 2 before and after cleaning are shown in Figures 22 – 23.

An energy dispersive x-ray spectrum of the baseline coupon is shown in Figure 24. Energy dispersive x-ray spectra of coupon 1 before and after cleaning are shown in Figure 25. Energy dispersive x-ray spectra of coupon 2 before and after cleaning are shown in Figure 26.

2.4 Metallography

Cross sections were taken from the coupon and prepared for a metallographic examination. Optical micrographs of the surface for coupon 1 are shown in Figure 27. A wide, shallow pit was observed in coupon 1, measuring 80 µm. An optical micrograph of the surface for coupon 2 is shown in Figure 28. Shallow pits were observed in coupon 2, measuring 22 mm in depth.

3.0 DISCUSSION

The coupon and screen showed minimal mass loss and pitting after 3 and 6 months of corrosion testing.

After 3 months of corrosion testing, the coupon had lost 0.256 grams of material and had a corrosion rate of 0.022 millimeters per year. After 3 months of corrosion testing, the screen had lost 14.48 grams of material and had a corrosion rate of 0.129 millimeters per year.

After 6 months of corrosion testing, the coupon had lost 0.550 grams of material and had a corrosion rate of 0.023 millimeters per year. After 6 months of corrosion testing, the screen had lost 15.24 grams of material and had a corrosion rate of 0.067 millimeters per year.

4.0 CONCLUSIONS[4]

The following conclusions are based upon the submitted samples and the evidence gathered:

1. The coupon, after 3 months of corrosion testing, had a mass loss of 0.256 grams and a corrosion rate of 0.022 mm / year.

2. The screen, after 3 months of corrosion testing, had a mass loss of 14.48 grams and a corrosion rate of 0.129 mm / year.

3. The coupon, after 6 months of corrosion testing, had a mass loss of 0.550 grams and a corrosion rate of 0.023 mm / year.

4. The screen, after 6 months of corrosion testing, had a mass loss of 15.24 grams and a corrosion rate of 0.067 mm / year.

Prepared by:	Reviewed by:
Norman Yuen Materials Engineer	Audrey A. Fasching, Ph.D., P.E. Senior Materials Engineer

[4] The conclusions in this report are based upon the available information and evidence provided by the client and gathered by Anamet, within the scope of work authorized by the client, and they are hereby presented by Anamet to a reasonable degree of engineering and scientific certainty. Anamet reserves the right to amend or supplement its conclusions or opinions presented in this report should additional data or information become available, or further work be approved by the client.

Table 1
Sample Identifications

<table>
<tr><th colspan="2">Description</th><th rowspan="2">V&A Engineering Identification (As-Received)</th><th rowspan="2">Anamet Identification (in report)</th><th rowspan="2">Notes</th></tr>
<tr><th>Alloy</th><th>Part</th></tr>
<tr><td rowspan="11">CDA 706 (Cu 90 – Ni 10)</td><td>Flat Plate
4-inch x 4-inch x 1/8-inch</td><td>CDA 706 1</td><td>Plate</td><td>None</td></tr>
<tr><td rowspan="5">Coupon
1-inch x 3-inch x 1/8-inch with autogenous weld bead</td><td>CDA 706W 1</td><td>Coupon 1</td><td>3 Month Immersion</td></tr>
<tr><td>CDA 706W 2</td><td>Coupon 2</td><td>6 Month Immersion</td></tr>
<tr><td>CDA 706W 3</td><td>Coupon 3</td><td>9 Month Immersion</td></tr>
<tr><td>CDA 706W 4</td><td>Coupon 4</td><td>12 Month Immersion</td></tr>
<tr><td>CDA 706W 5</td><td>Coupon 5</td><td>Baseline Sample (no exposure)</td></tr>
<tr><td rowspan="5">Wedge Wire Screen
4-inch x 4-inch x 1-inch with 2 mm spacing</td><td>None</td><td>Screen 1</td><td>3 Month Immersion</td></tr>
<tr><td>None</td><td>Screen 2</td><td>6 Month Immersion</td></tr>
<tr><td>None</td><td>Screen 3</td><td>9 Month Immersion</td></tr>
<tr><td>None</td><td>Screen 4</td><td>12 Month Immersion</td></tr>
<tr><td>None</td><td>Screen 5</td><td>12 Month Immersion</td></tr>
</table>

Table 2
Sample Weights

Sample	Baseline Measurement	Measurements after 3 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 1	25.8560	25.6429	25.6003	25.5972	25.5954	25.5930	25.5915
Screen 1	310.59	301.27	298.54	296.15	295.97	295.80	295.78

Sample	Baseline Measurement	Measurements after 6 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 2	25.9215	25.4409	25.3721	25.3689	25.3689	25.3650	25.3630
Screen 2	310.45	300.16	295.21	295.17	295.13	295.11	-

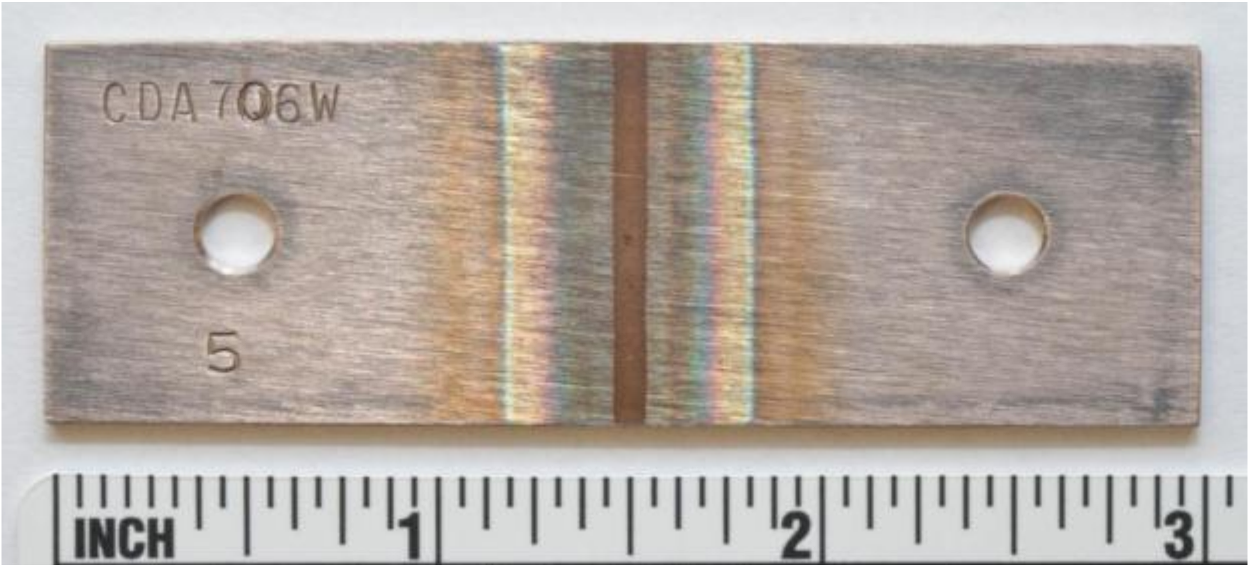
Table 3
Equations of Lines AB and BC for Corrosion Testing Samples

Sample	Line AB	Line BC	Point B (Approximate Mass Loss from Corrosion)
Coupon 1	y = 0.043x	y = 0.002x + 0.041	0.043 grams
Coupon 2	y = 0.061x	y = 0.002x + 0.067	0.069 grams
Screen 1	y = 2.59x	y = 0.13x + 4.90	5.16 grams
Screen 2	y = 4.95x	y = 0.03x + 4.92	4.95 grams

Table 4
Total Mass Loss from Corrosion and Corrosion Rate

Sample	Total Mass Loss from Corrosion*	Corrosion Rate
Coupon 1	0.256 grams	0.022 mm / year
Coupon 2	0.550 grams	0.023 mm / year
Screen 1	14.48 grams	0.129 mm / year
Screen 2	15.24 grams	0.067 mm / year

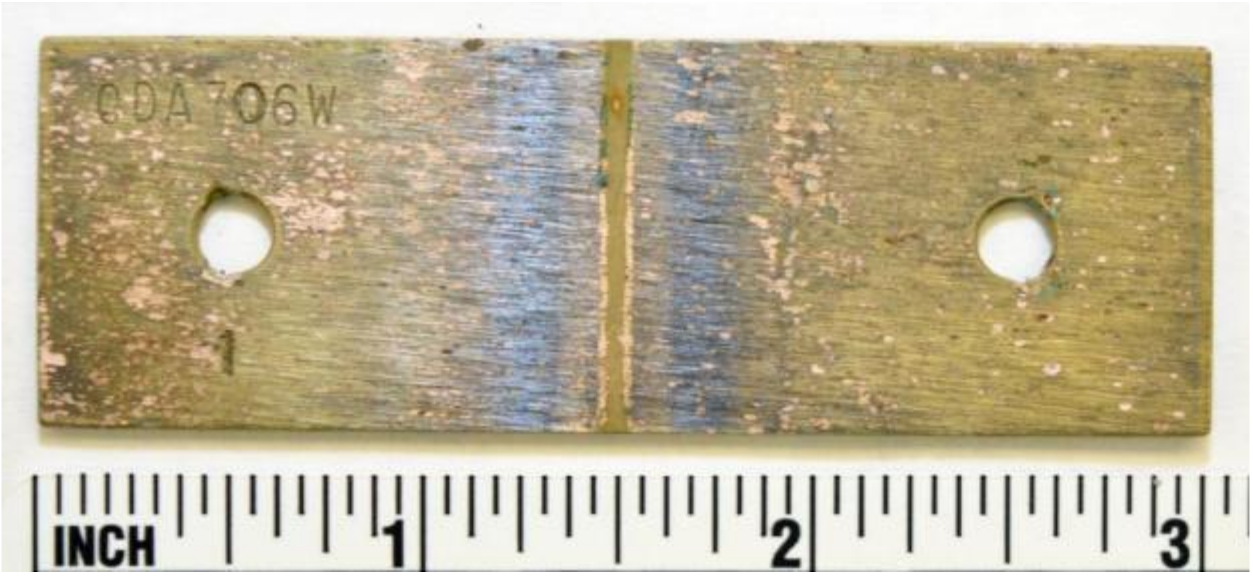
* Weight As-Received – (Weight Before Cleaning – Mass Loss from Corrosion During Cleaning)



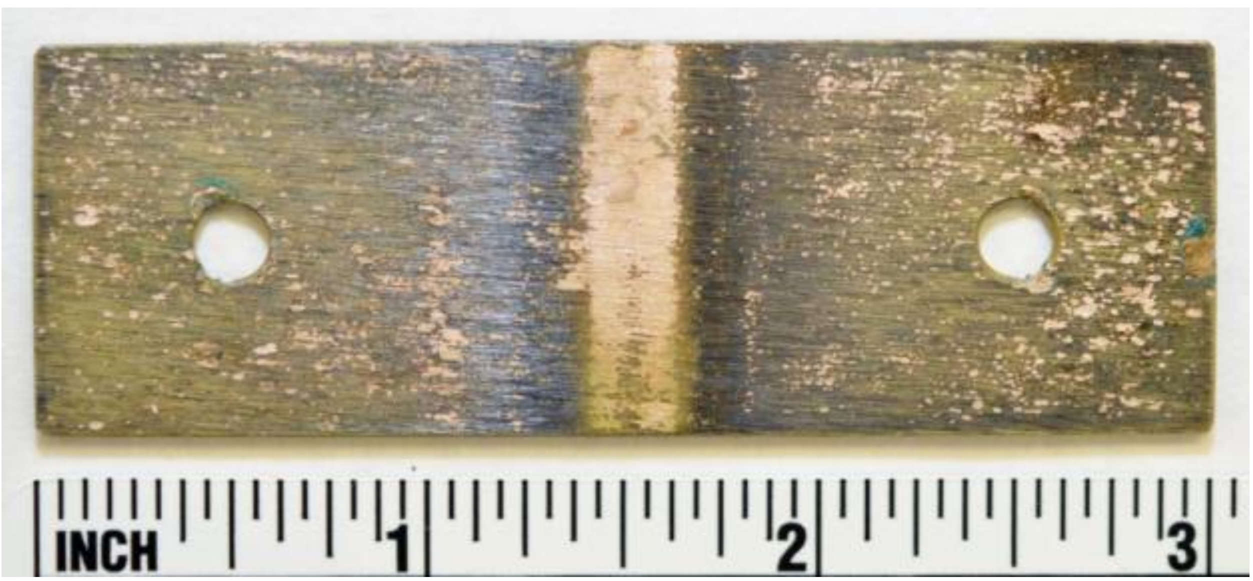
(a) CDA 706 Baseline Coupon, Front Side

(b) CDA 706 Baseline Coupon, Back Side

Figure 1 Photographs of the CDA 706 baseline coupon (a) front and (b) back side.

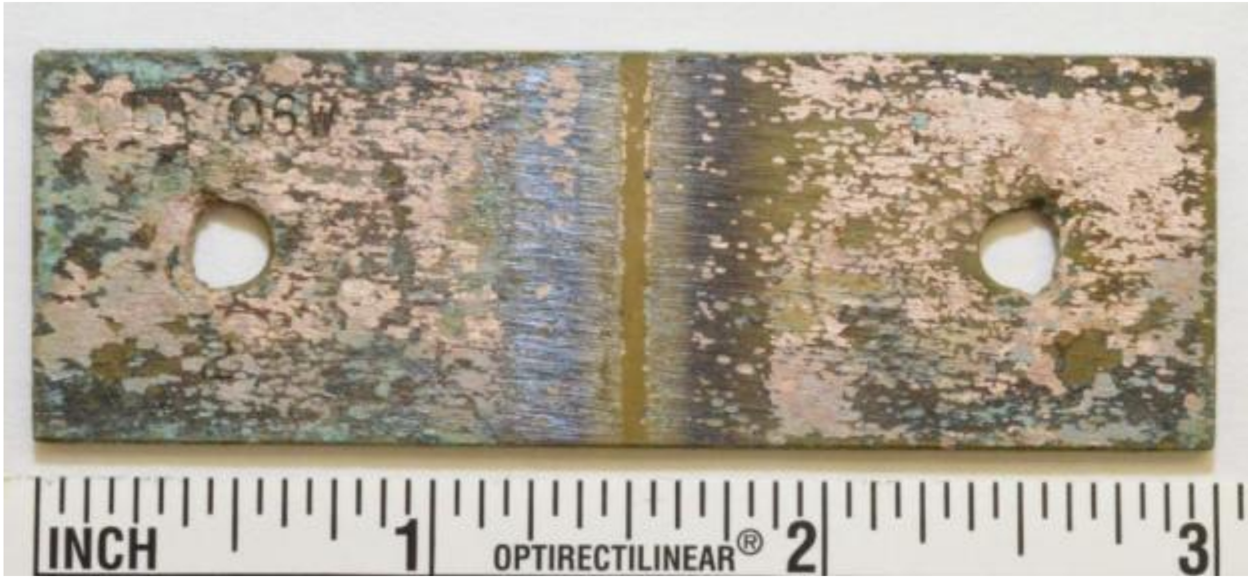


(a) CDA 706 Coupon 1, Front Side

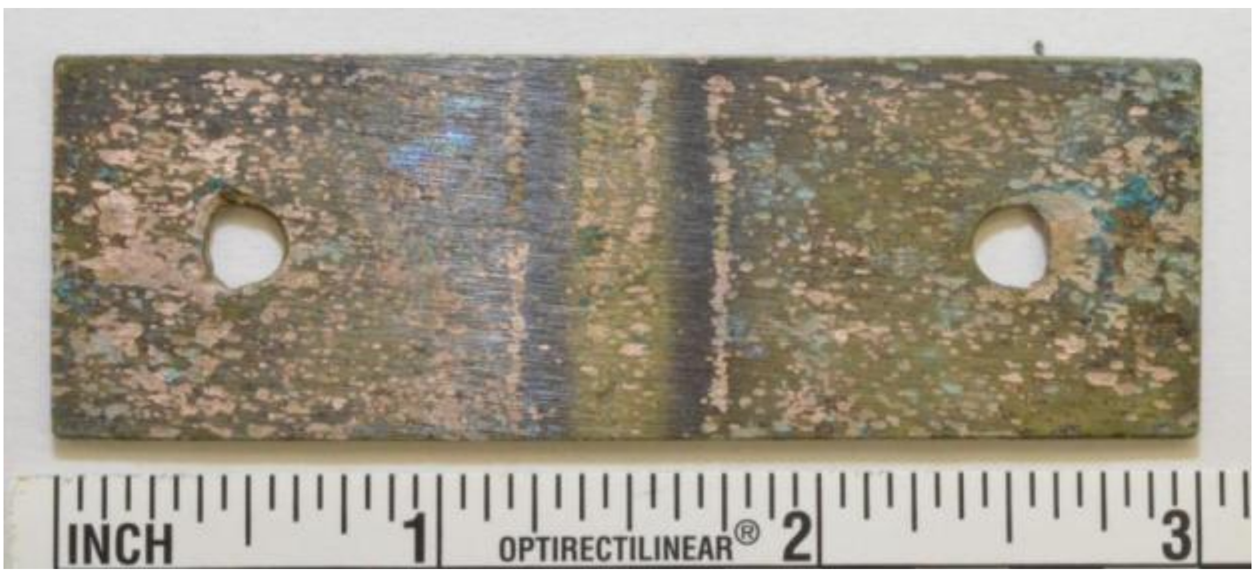


(b) CDA 706 Coupon 1, Back Side

Figure 2 Photographs of CDA 706 coupon 1 (a) front and (b) back side after a 3 month corrosion test.



(a) CDA 706 Coupon 2, Front Side



(b) CDA 706 Coupon 2, Back Side

Figure 3 Photographs of CDA 706 coupon 2 (a) front and (b) back side after a 6 month corrosion test.

(a) CDA 706 Baseline Screen

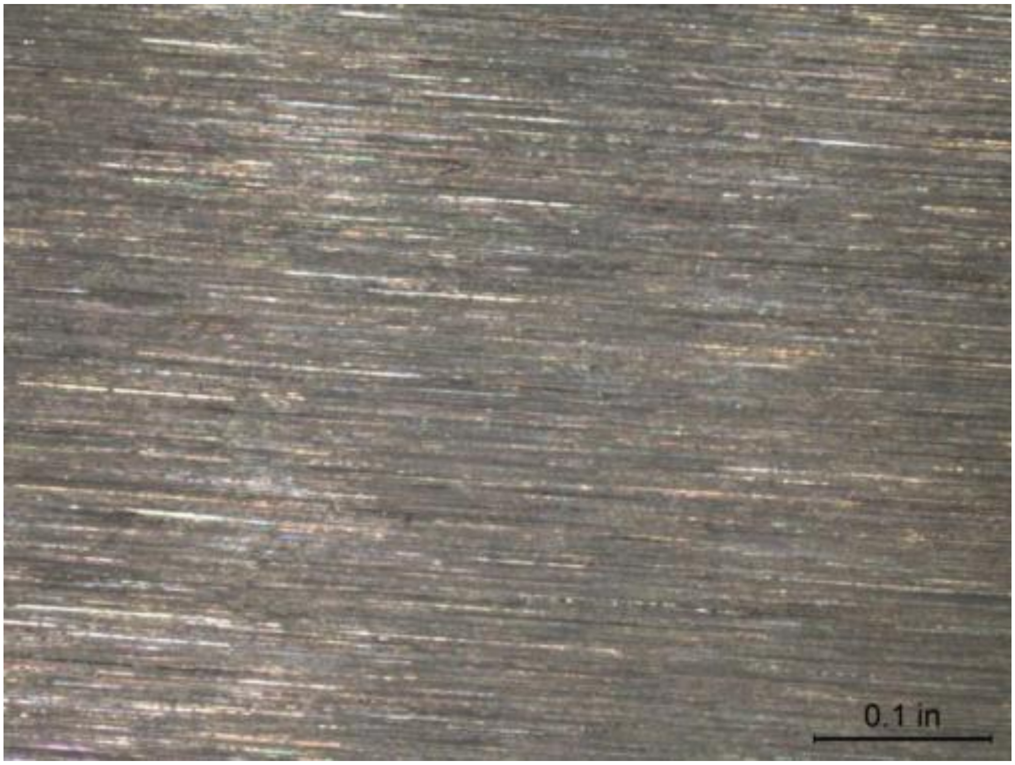
Figure 4 Photograph of the CDA 706 baseline screen.

(a) CDA 706 Screen 1

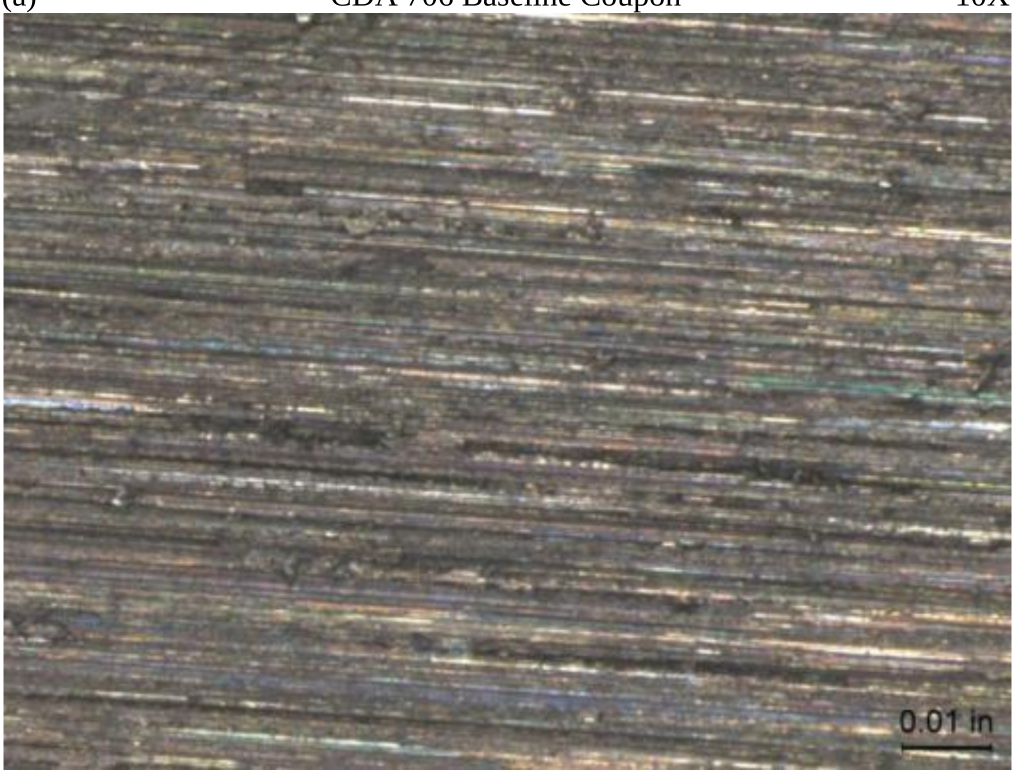
Figure 5 Photograph of CDA 706 screen 1 after a 3 month corrosion test.

(a) CDA 706 Screen 2

Figure 6 Photograph of CDA 706 screen 2 after a 6 month corrosion test.

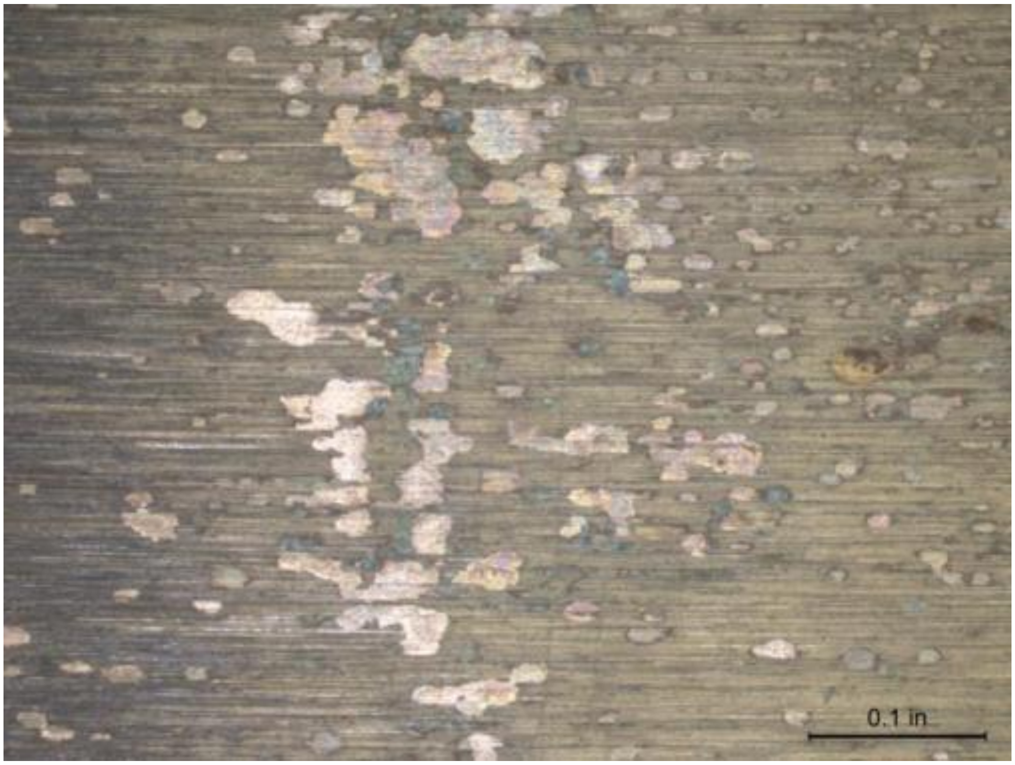


(a) CDA 706 Baseline Coupon 10X

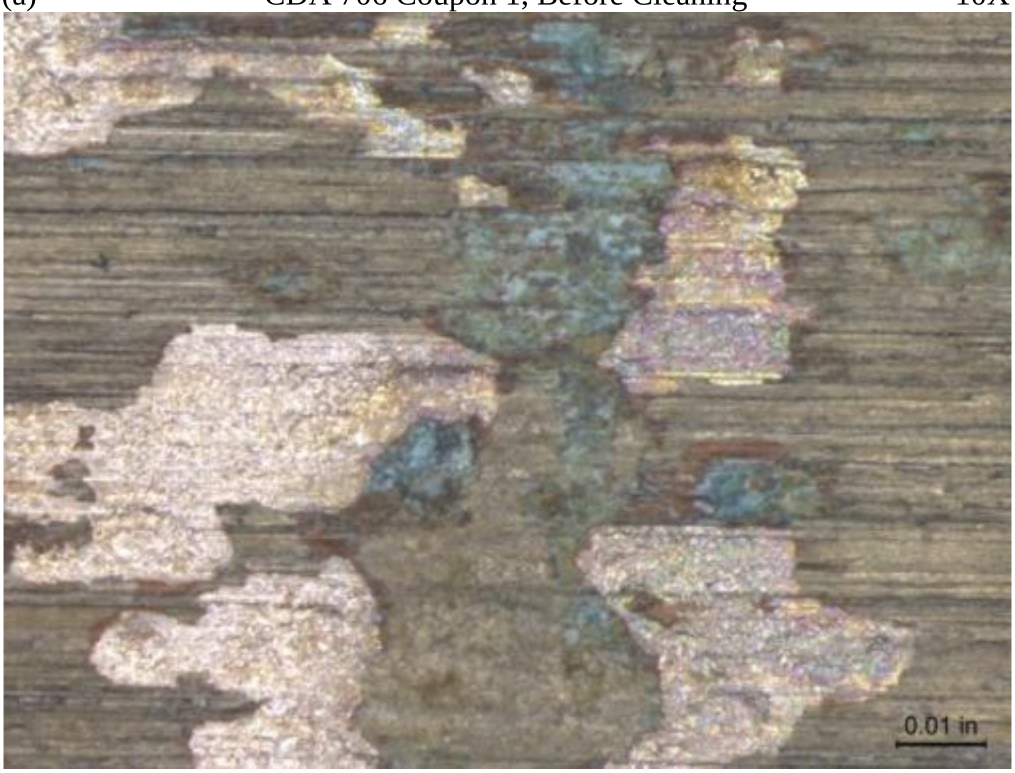


(b) CDA 706 Baseline Coupon 50X

Figure 7 Optical macrographs of the CDA 706 baseline coupon.



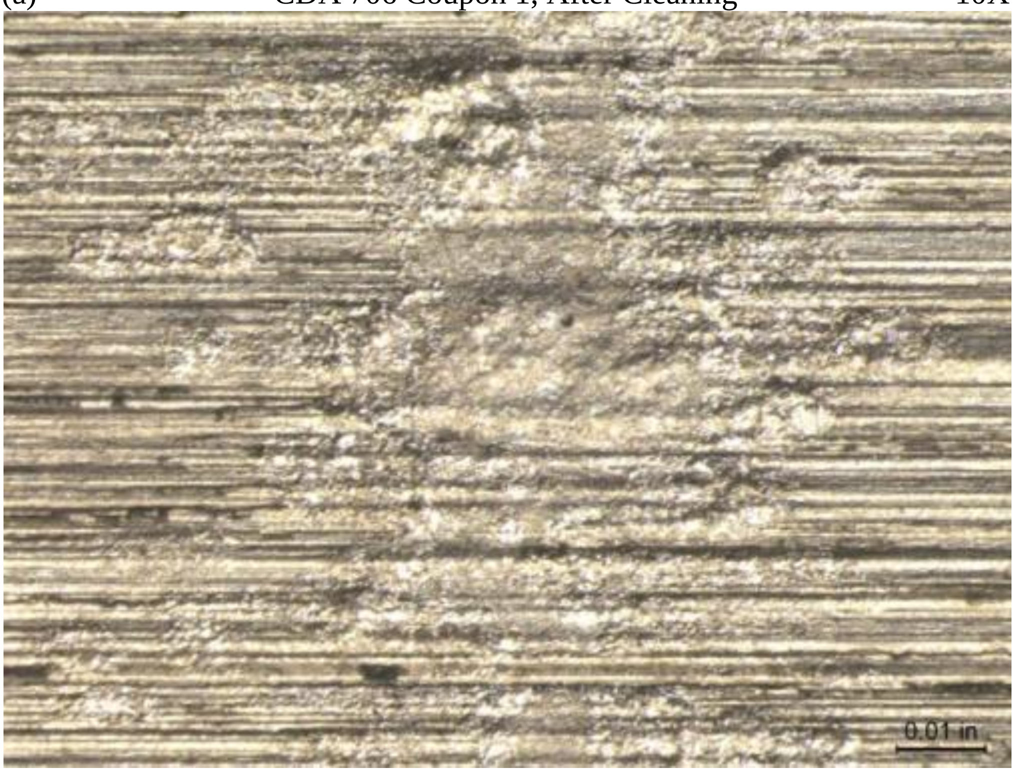
(a) CDA 706 Coupon 1, Before Cleaning 10X



(b) CDA 706 Coupon 1, Before Cleaning 50X

Figure 8 Optical macrographs of CDA 706 coupon 1 after a 3 month corrosion test, before cleaning.

(a) CDA 706 Coupon 1, After Cleaning 10X



(b) CDA 706 Coupon 1, After Cleaning 50X

Figure 9 Optical macrographs of CDA 706 coupon 1 after a 3 month corrosion test, after cleaning.

(a) CDA 706 Coupon 2, Before Cleaning 10X

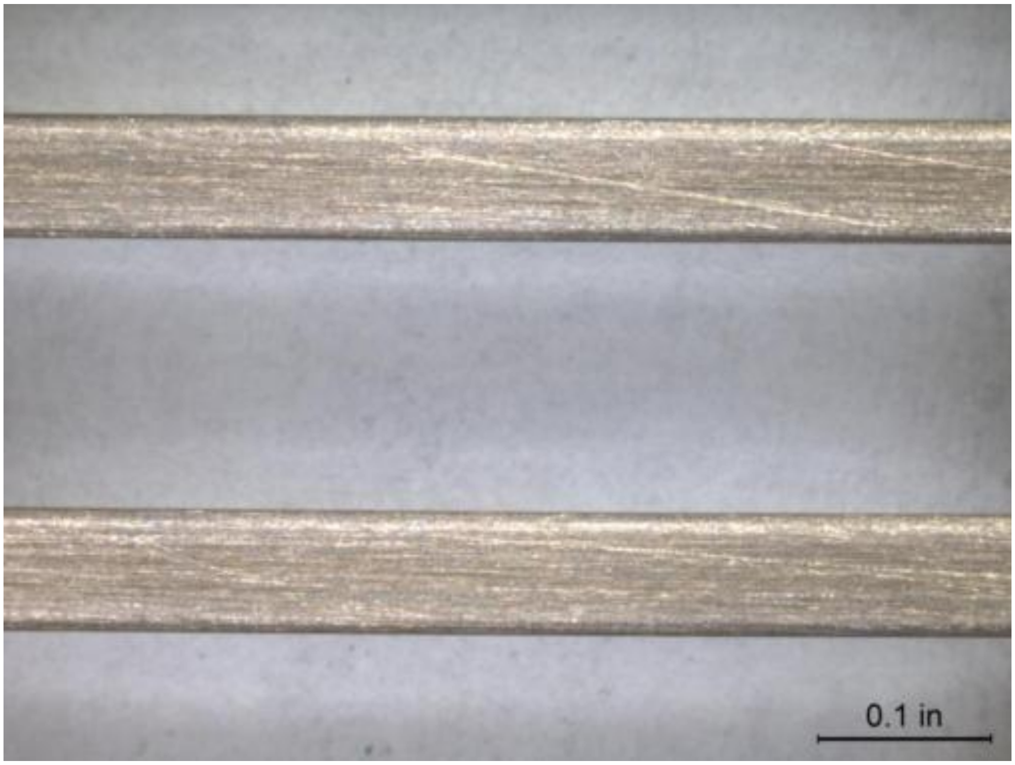
(b) CDA 706 Coupon 2, Before Cleaning 50X

Figure 10 Optical macrographs of CDA 706 coupon 2 after a 6 month corrosion test, before cleaning.

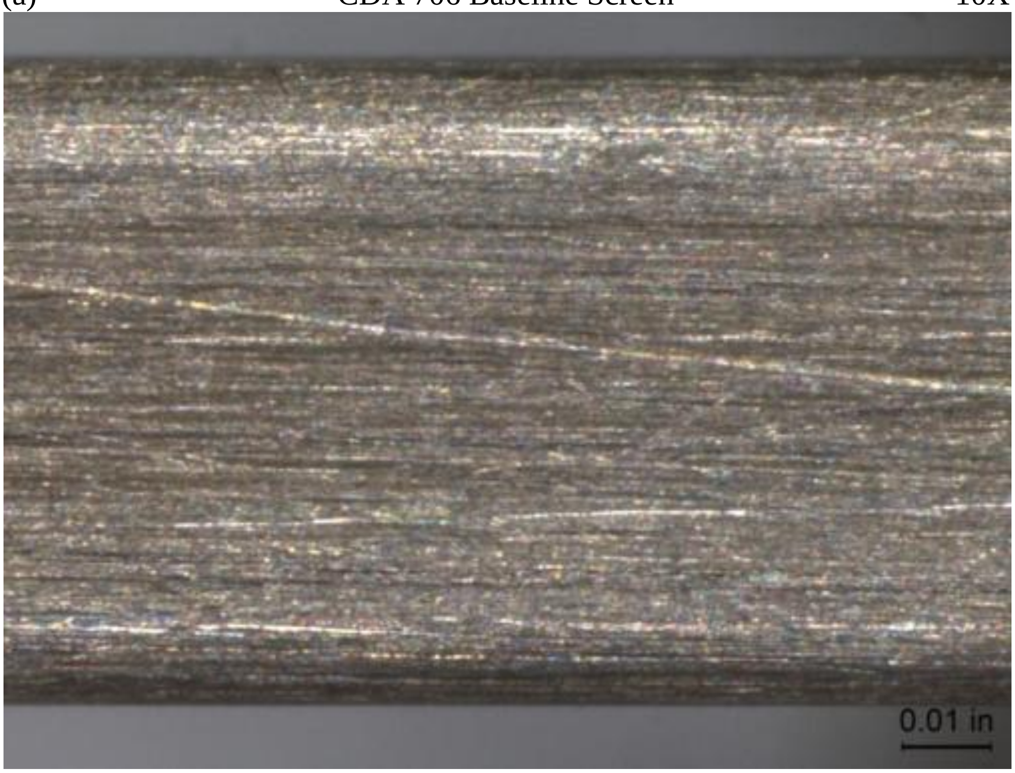
(a) CDA 706 Coupon 2, After Cleaning 10X

(b) CDA 706 Coupon 2, After Cleaning 50X

Figure 11 Optical macrographs of CDA 706 coupon 2 after a 6 month corrosion test, after cleaning.

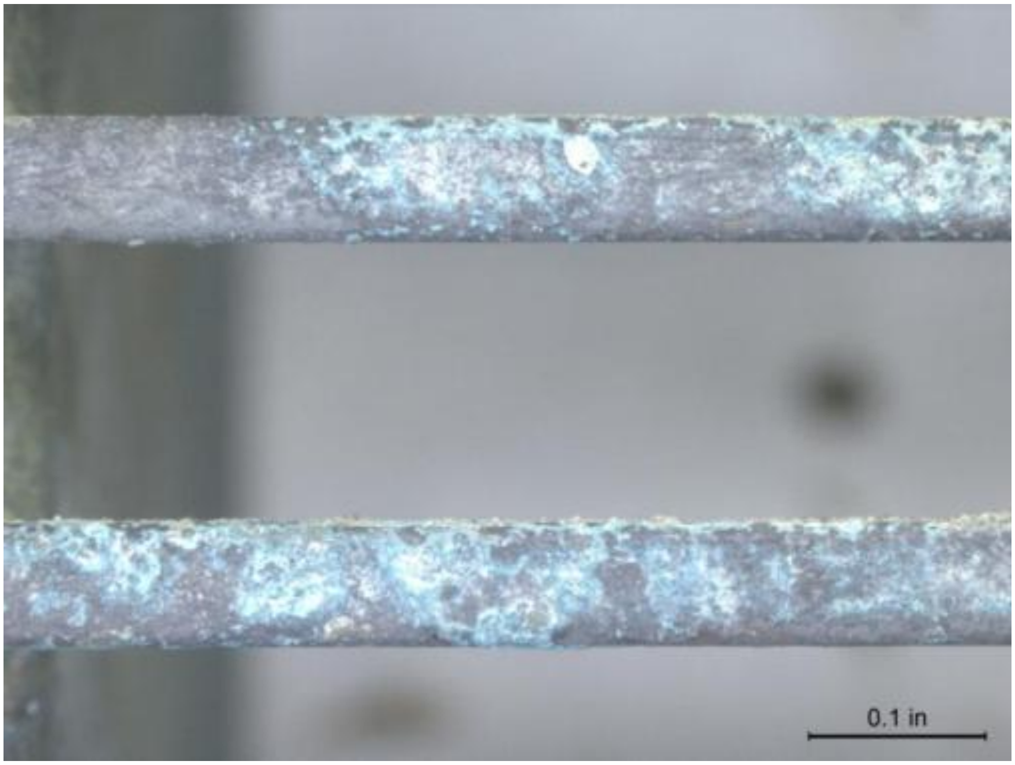


(a) CDA 706 Baseline Screen 10X

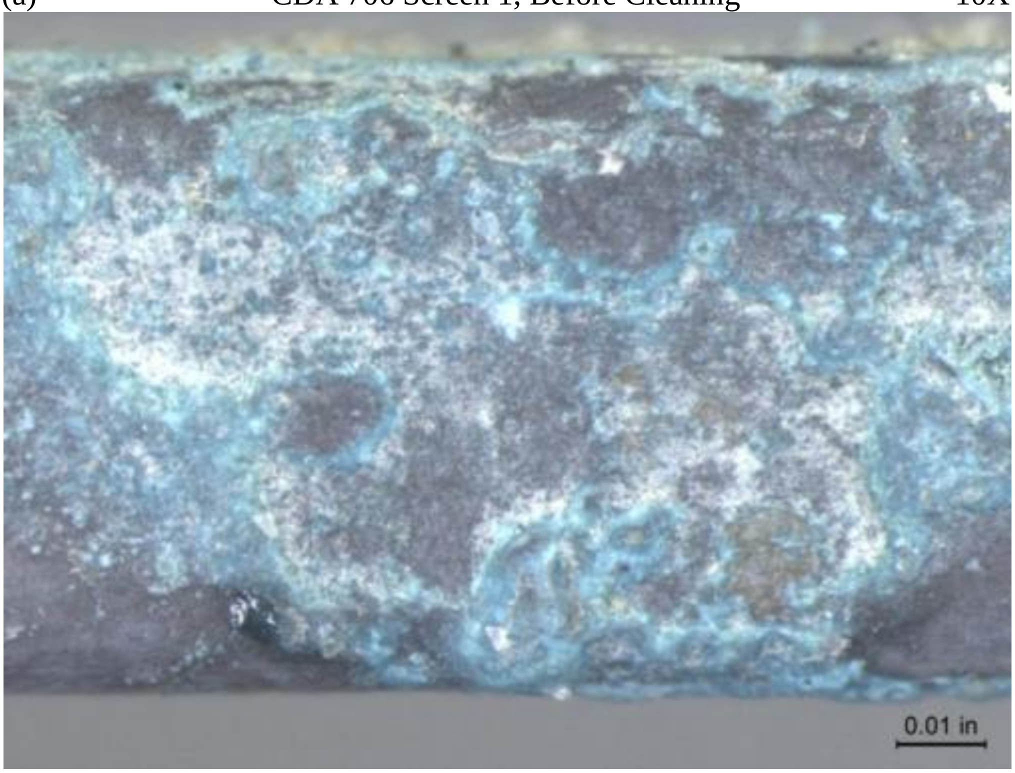


(b) CDA 706 Baseline Screen 50X

Figure 12 Optical macrographs of the CDA 706 baseline screen.

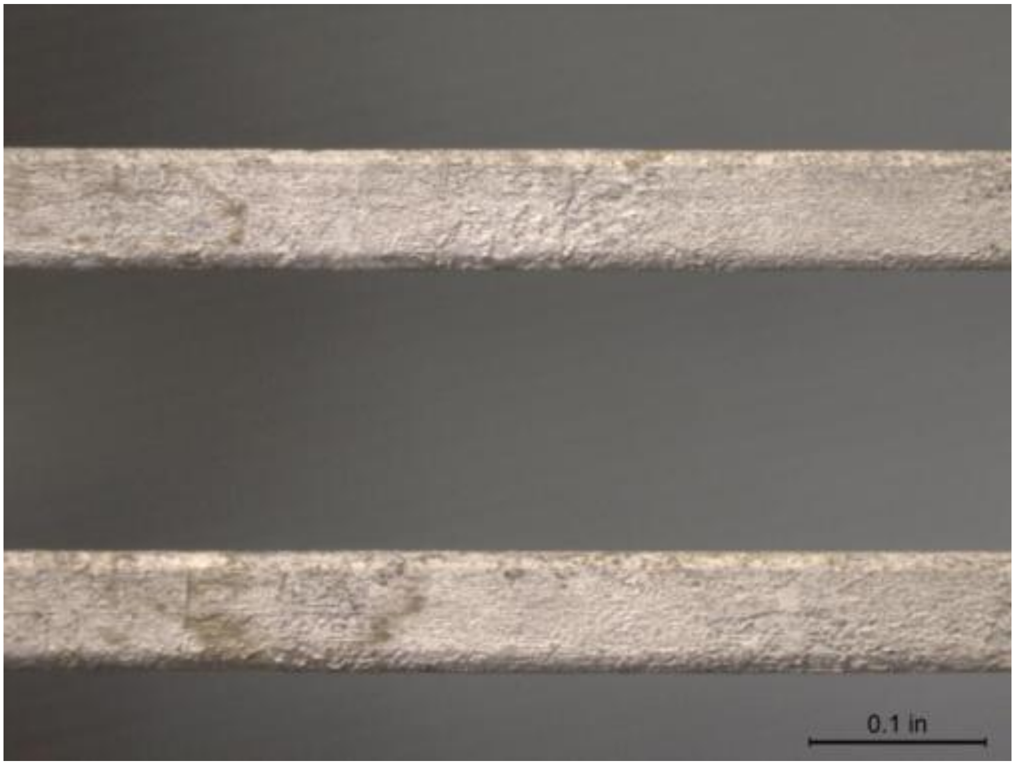


(a) CDA 706 Screen 1, Before Cleaning 10X



(b) CDA 706 Screen 1, Before Cleaning 50X

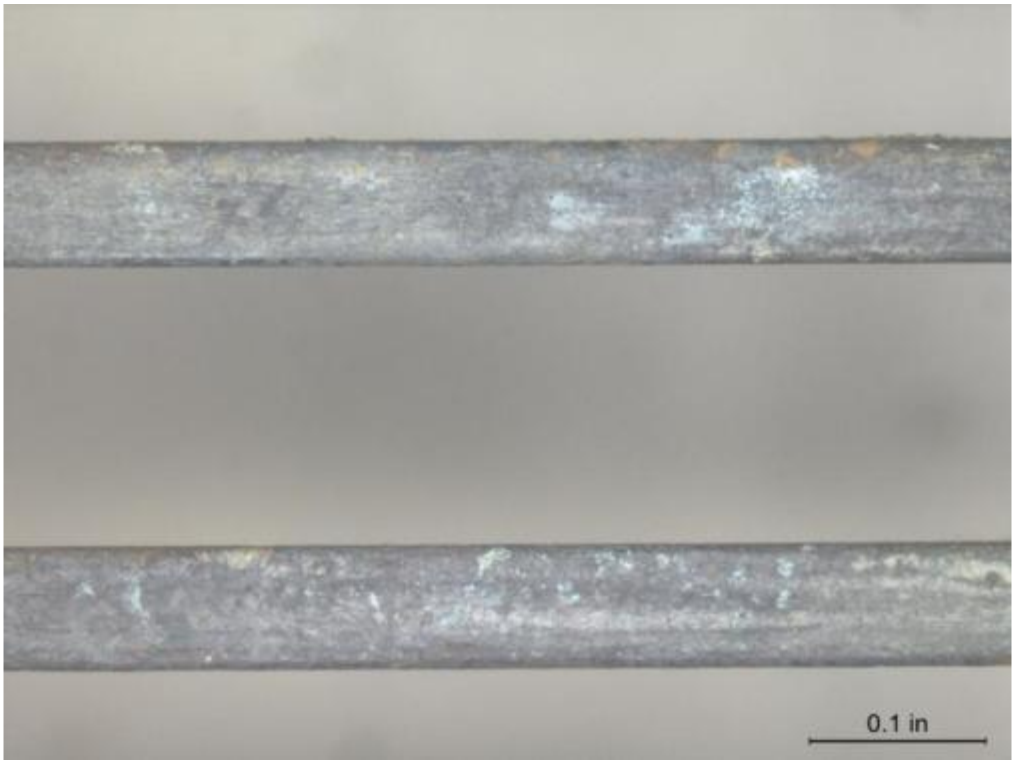
Figure 13 Optical macrographs of CDA 706 screen 1 after a 3 month corrosion test, before cleaning.



(a) CDA 706 Screen 1, After Cleaning 10X

(b) CDA 706 Screen 1, After Cleaning 50X

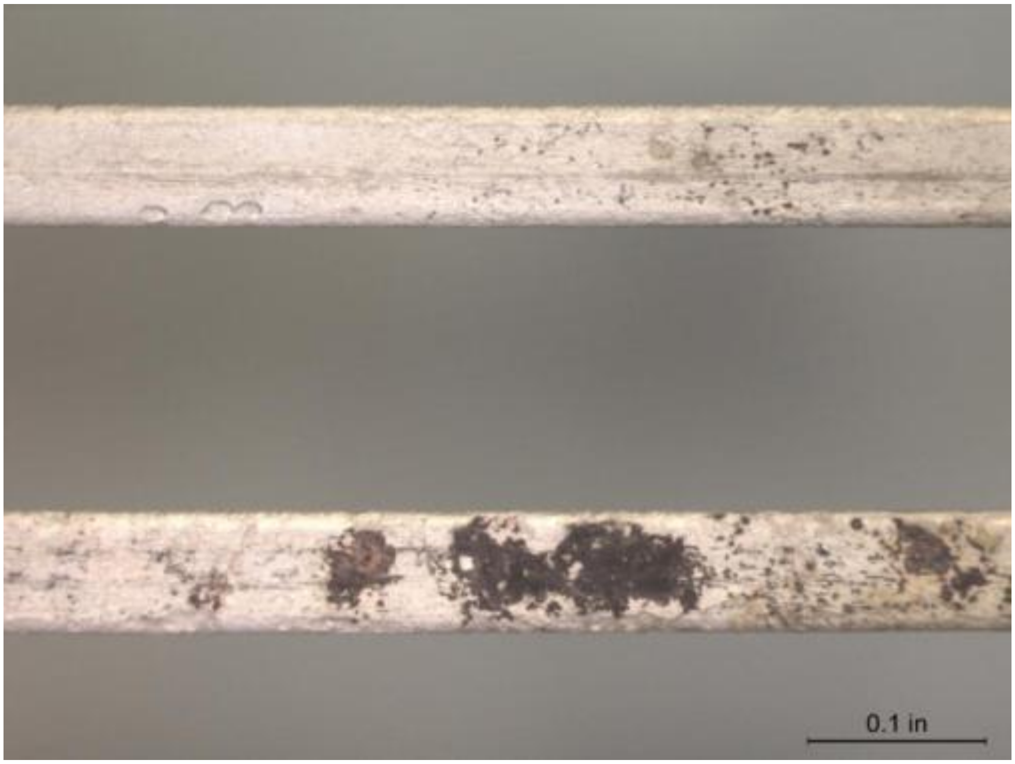
Figure 14 Optical macrographs of CDA 706 screen 1 after a 3 month corrosion test, after cleaning.



(a) CDA 706 Screen 2, Before Cleaning 10X

(b) CDA 706 Screen 2, Before Cleaning 50X

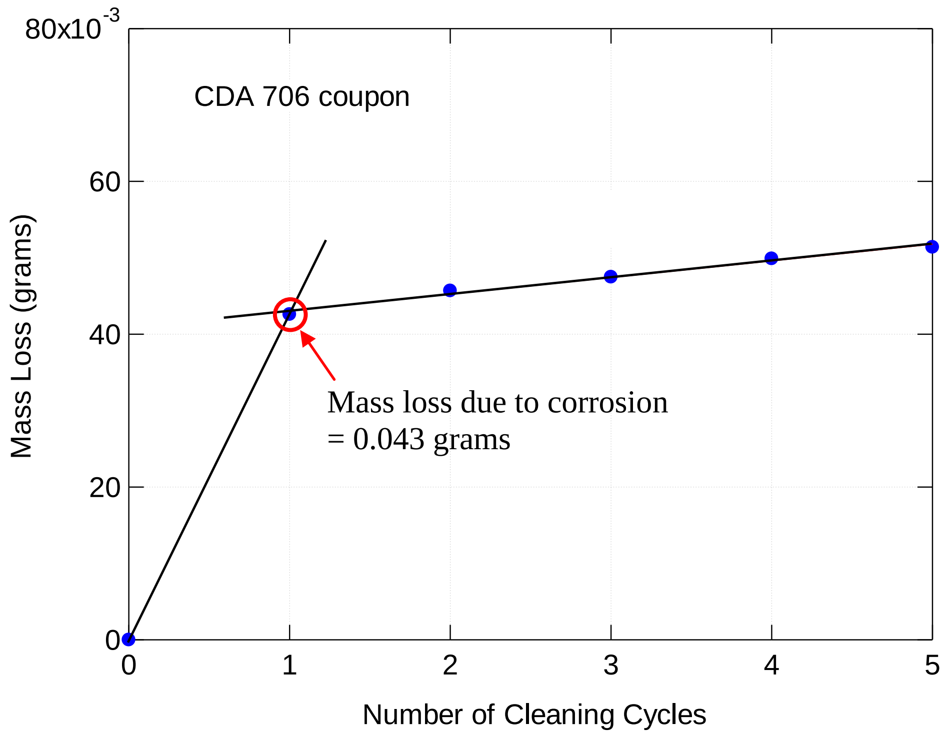
Figure 15 Optical macrographs of CDA 706 screen 2 after a 6 month corrosion test, before cleaning.



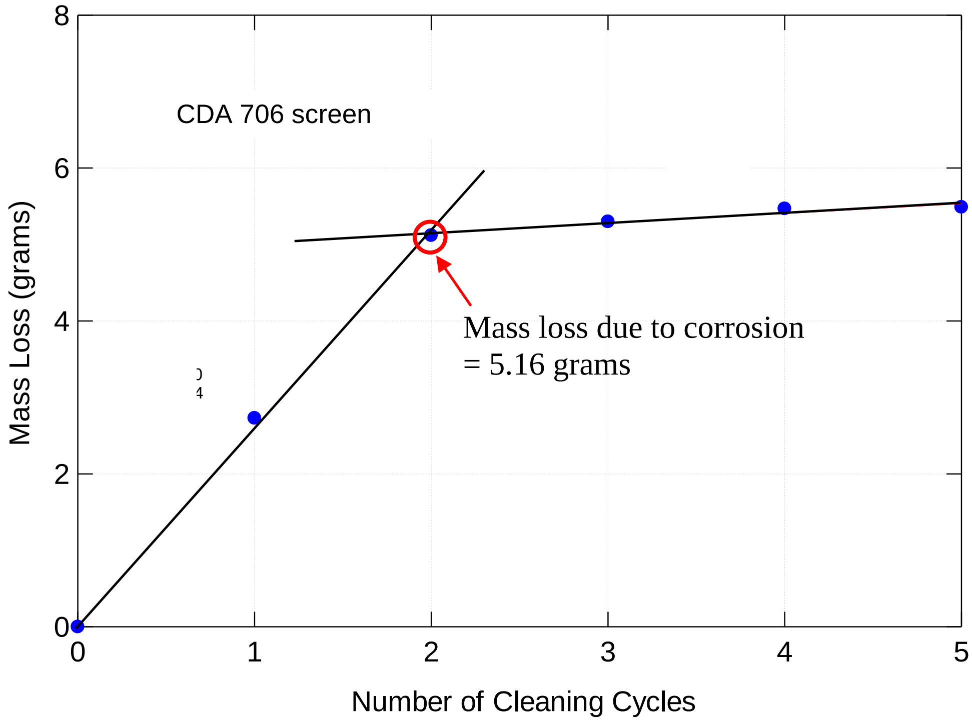
(a) CDA 706 Screen 2, After Cleaning 10X

(b) CDA 706 Screen 2, After Cleaning 50X

Figure 16 Optical macrographs of CDA 706 screen 2 after a 6 month corrosion test, after cleaning.

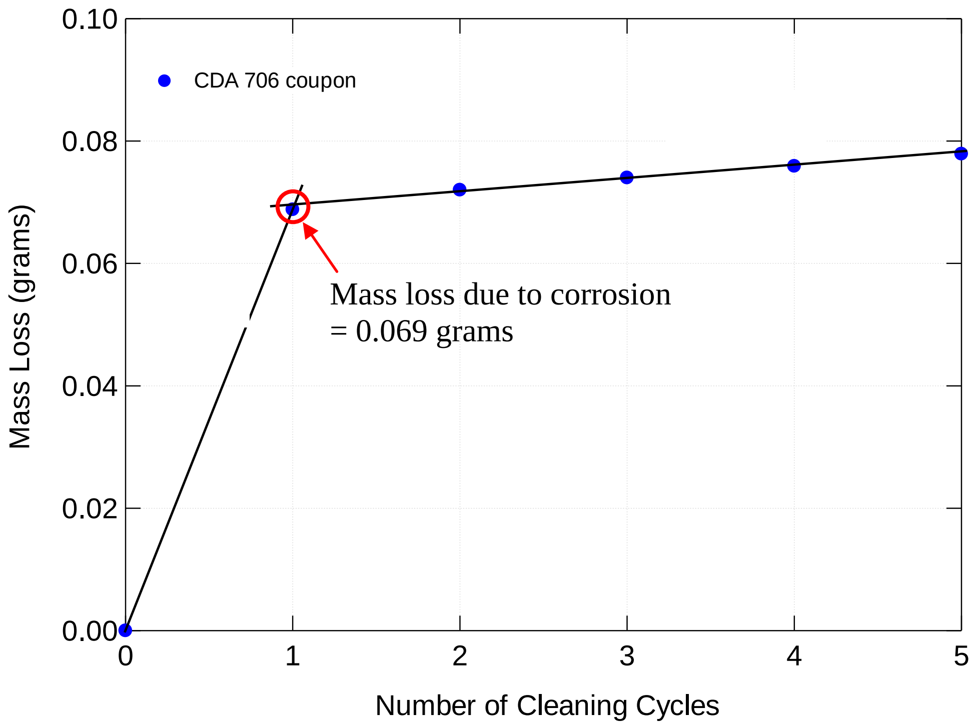


(a)

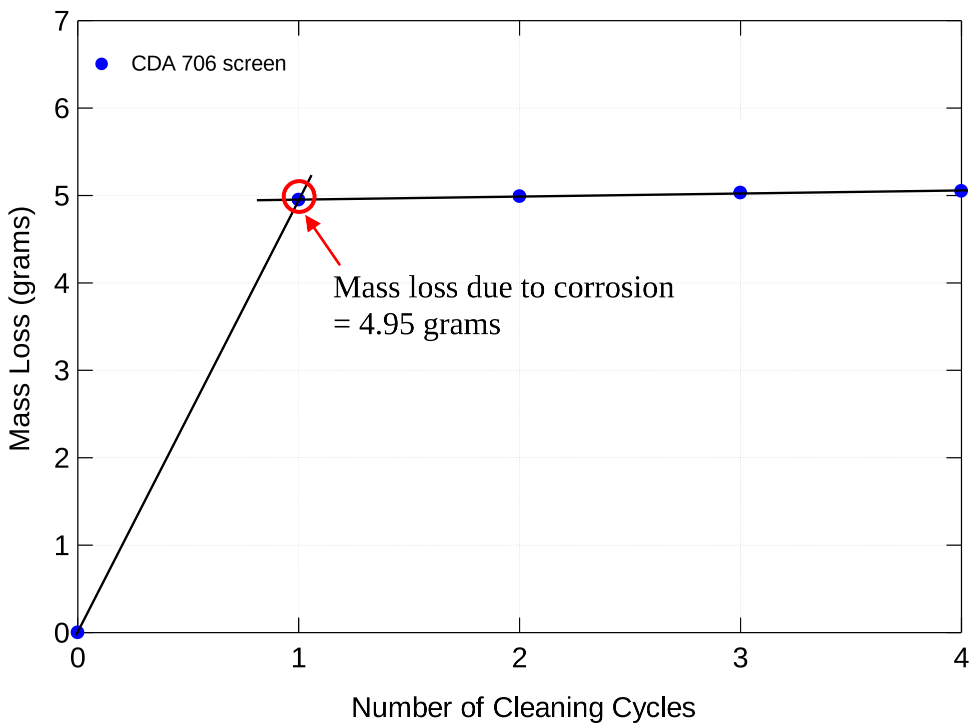


(b)

Figure 17   Mass loss of CDA 706 (a) coupon 1 and (b) screen 1 during cleaning.

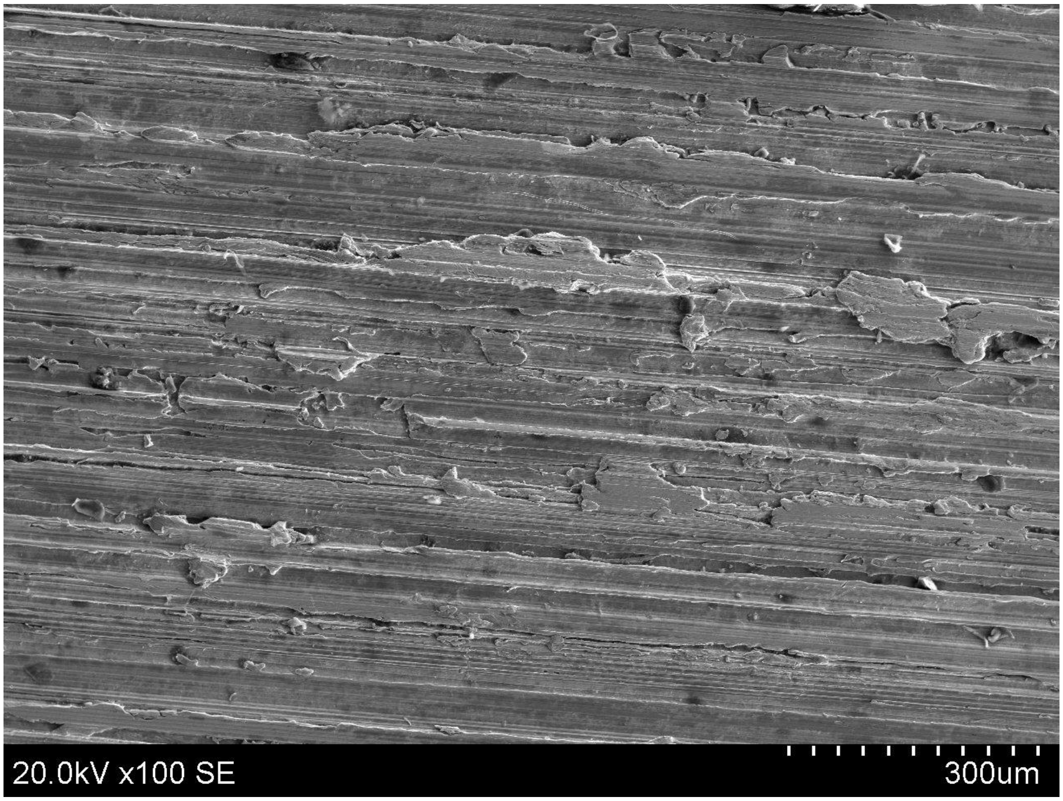


(a)

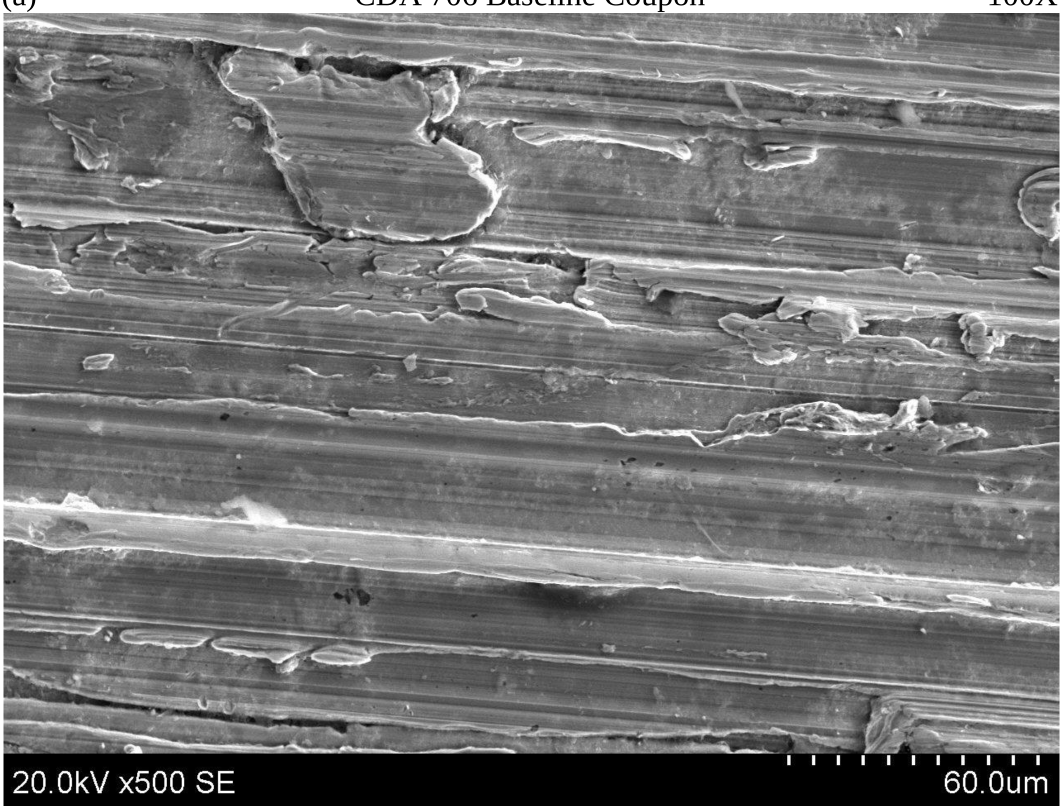


(b)

Figure 18 Mass loss of CDA 706 (a) coupon 2 and (b) screen 2 during cleaning.

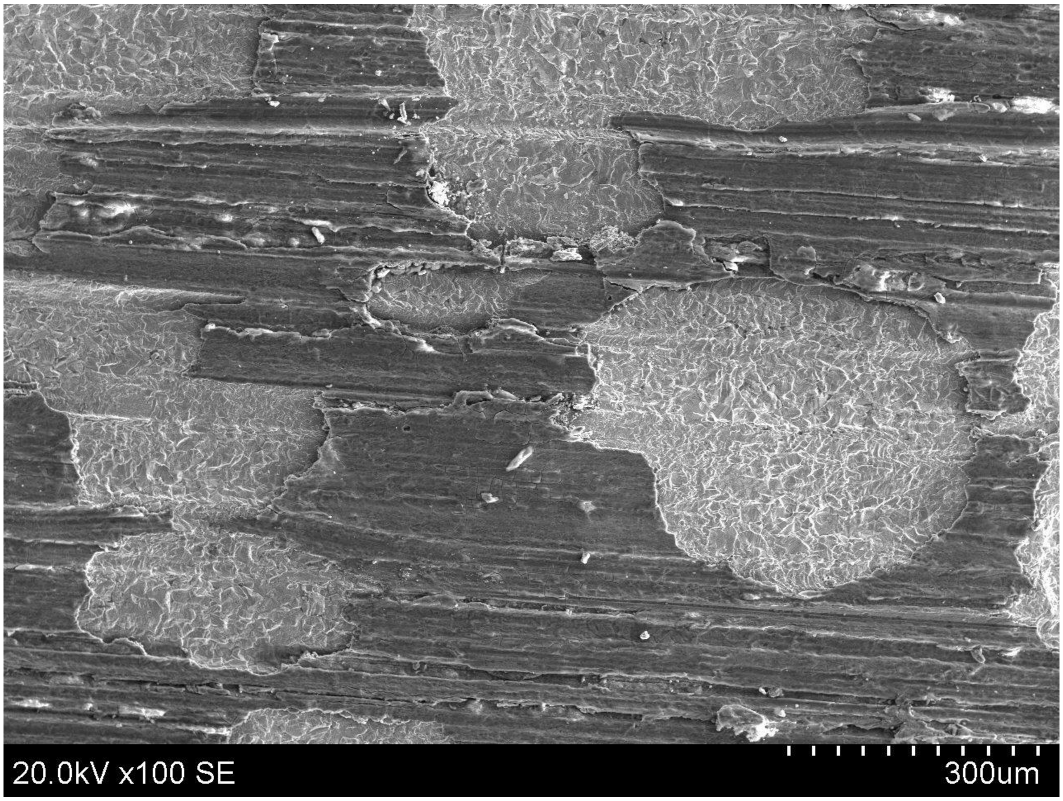


(a) CDA 706 Baseline Coupon 100X

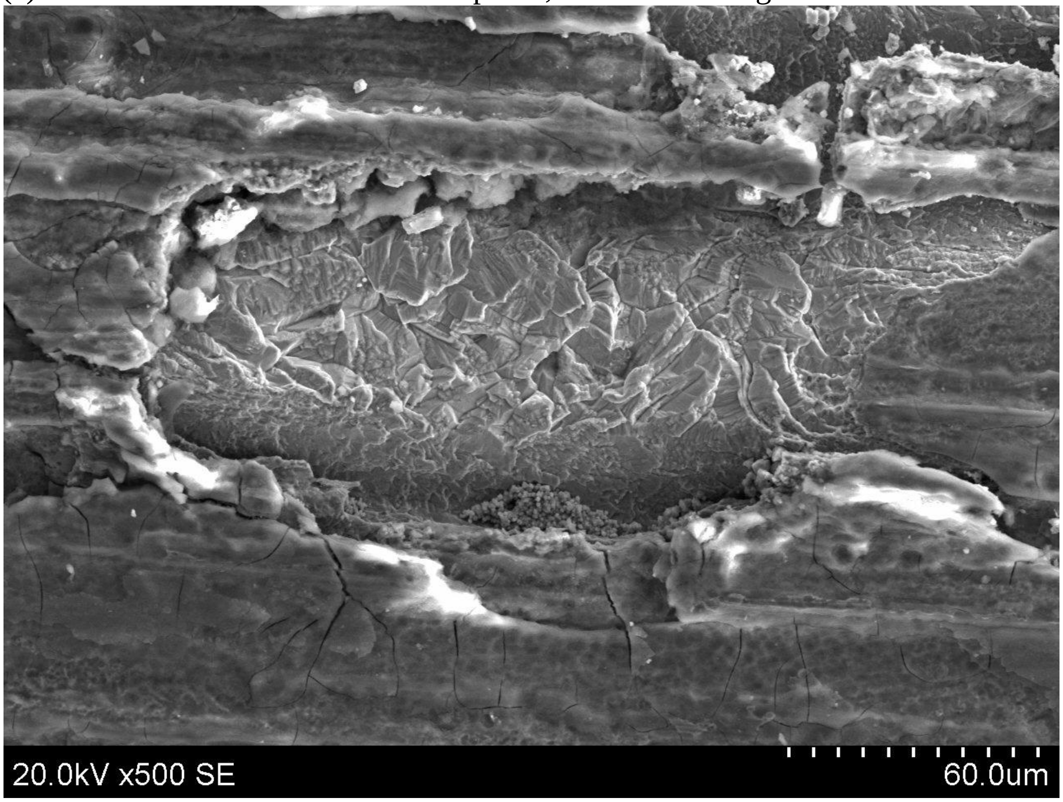


(b) CDA 706 Baseline Coupon 500X

Figure 19 Scanning electron micrographs of the CDA 706 baseline coupon.

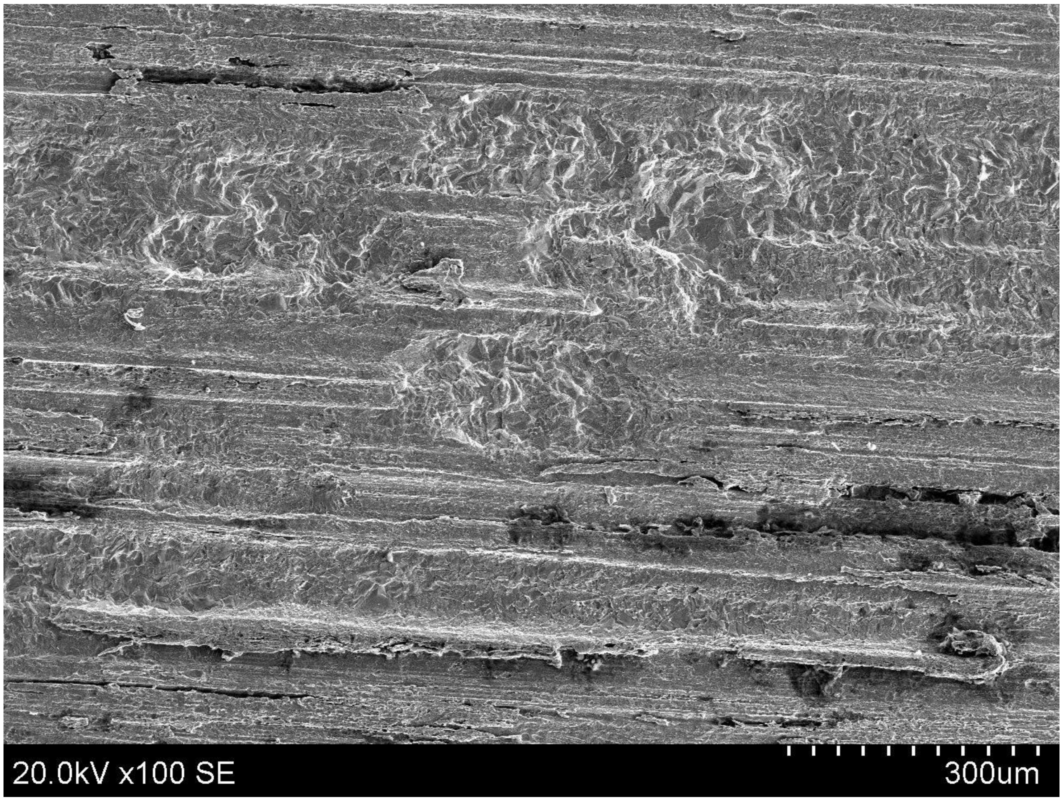


(a) CDA 706 Coupon 1, Before Cleaning 100X

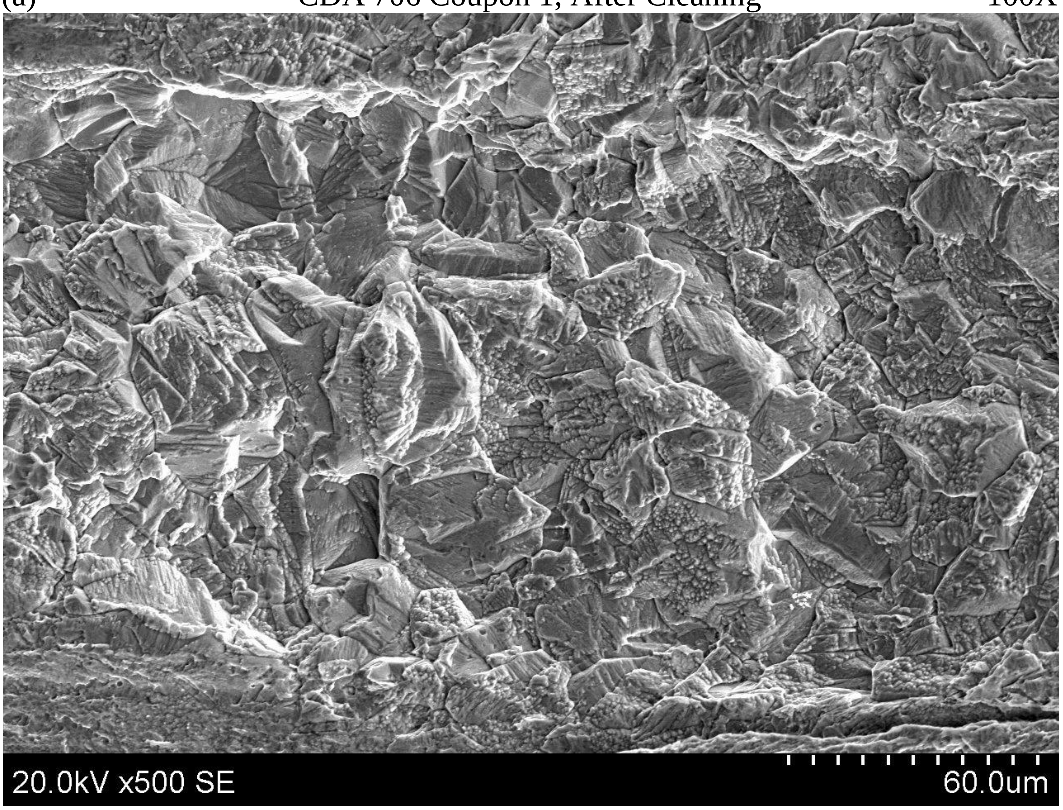


(b) CDA 706 Coupon 1, Before Cleaning 500X

Figure 20 Scanning electron micrographs of CDA 706 coupon 1 after a 3 month corrosion test, before cleaning.

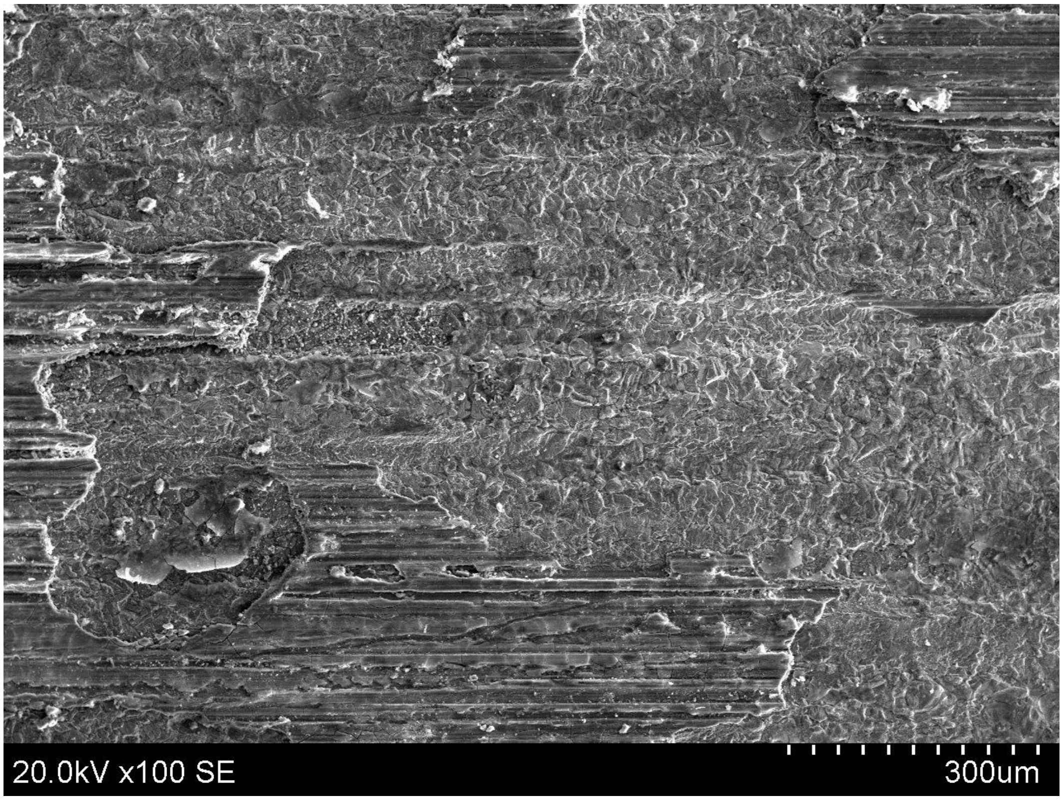


(a) CDA 706 Coupon 1, After Cleaning 100X

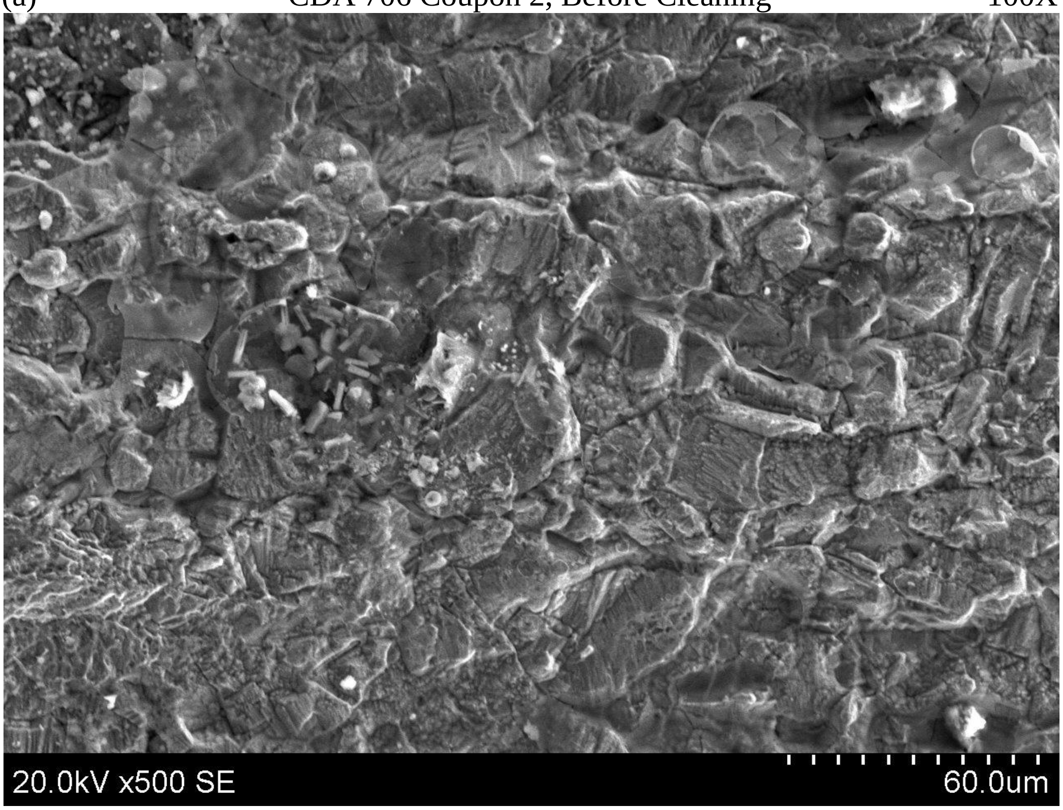


(b) CDA 706 Coupon 1, After Cleaning 500X

Figure 21 Scanning electron micrographs of CDA 706 coupon 1 after a 3 month corrosion test, after cleaning.

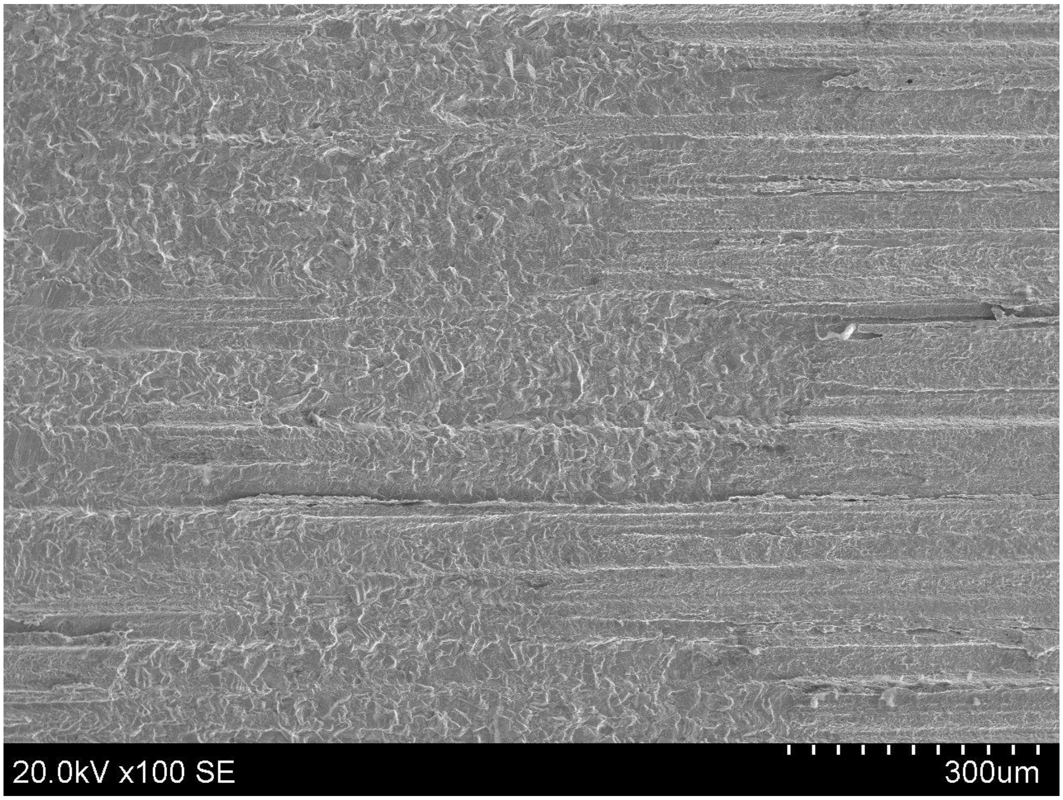


(a) CDA 706 Coupon 2, Before Cleaning 100X

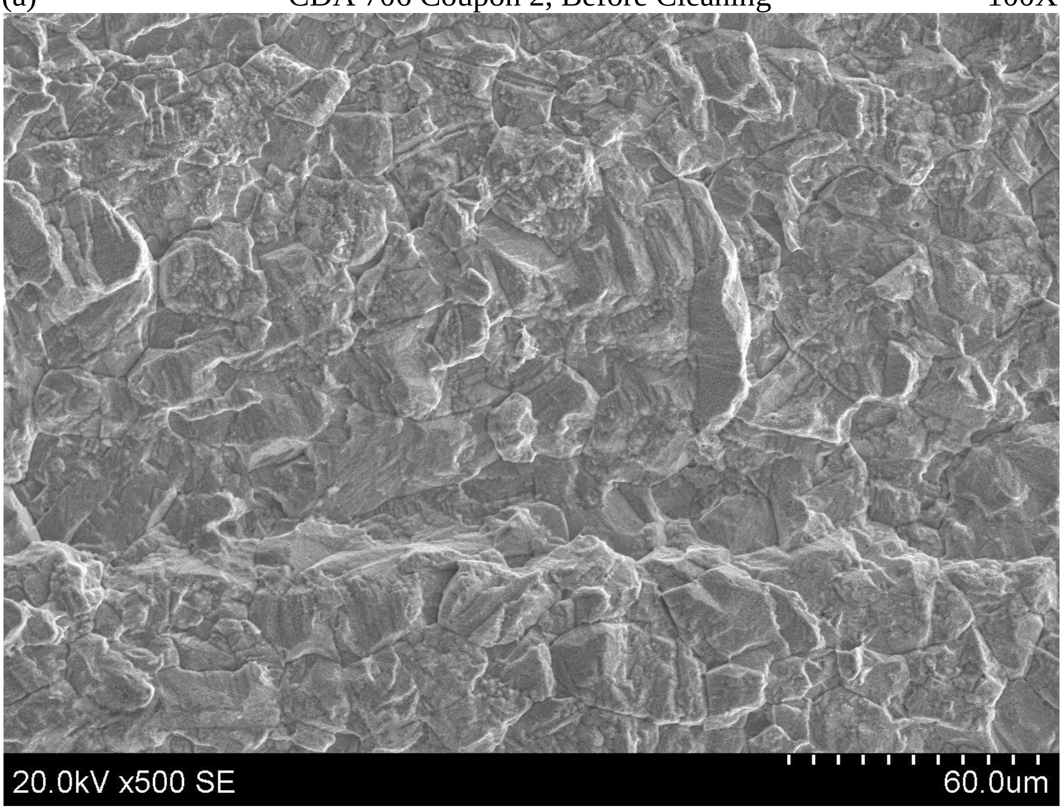


(b) CDA 706 Coupon 2, Before Cleaning 500X

Figure 22 Scanning electron micrographs of CDA 706 coupon 2 after a 6 month corrosion test, before cleaning.

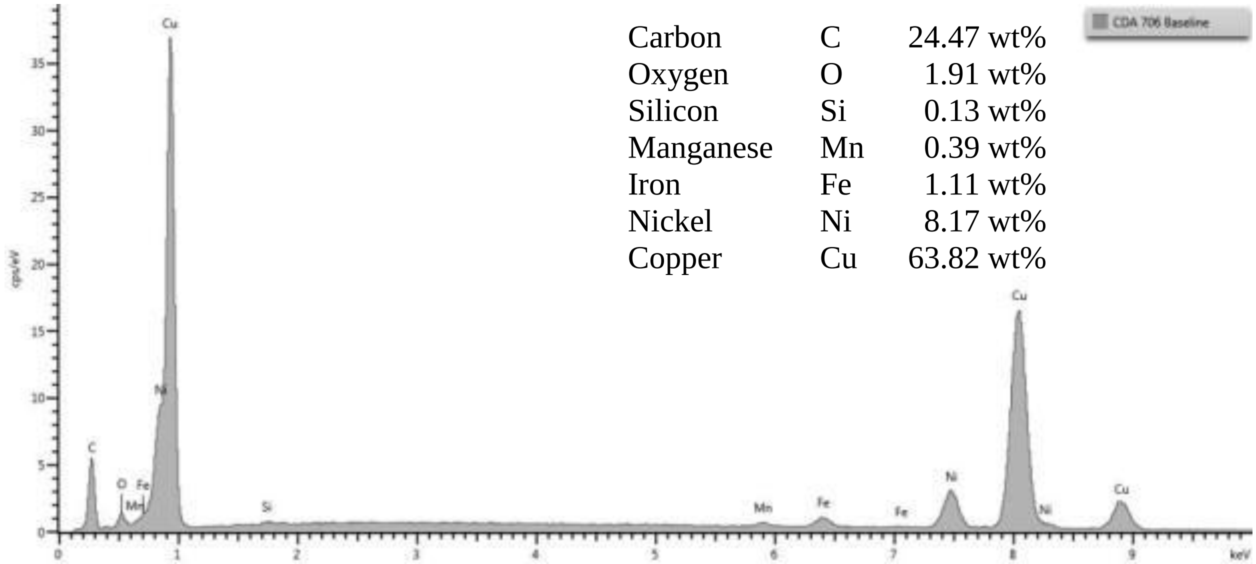


(a) CDA 706 Coupon 2, Before Cleaning 100X



(b) CDA 706 Coupon 2, Before Cleaning 500X

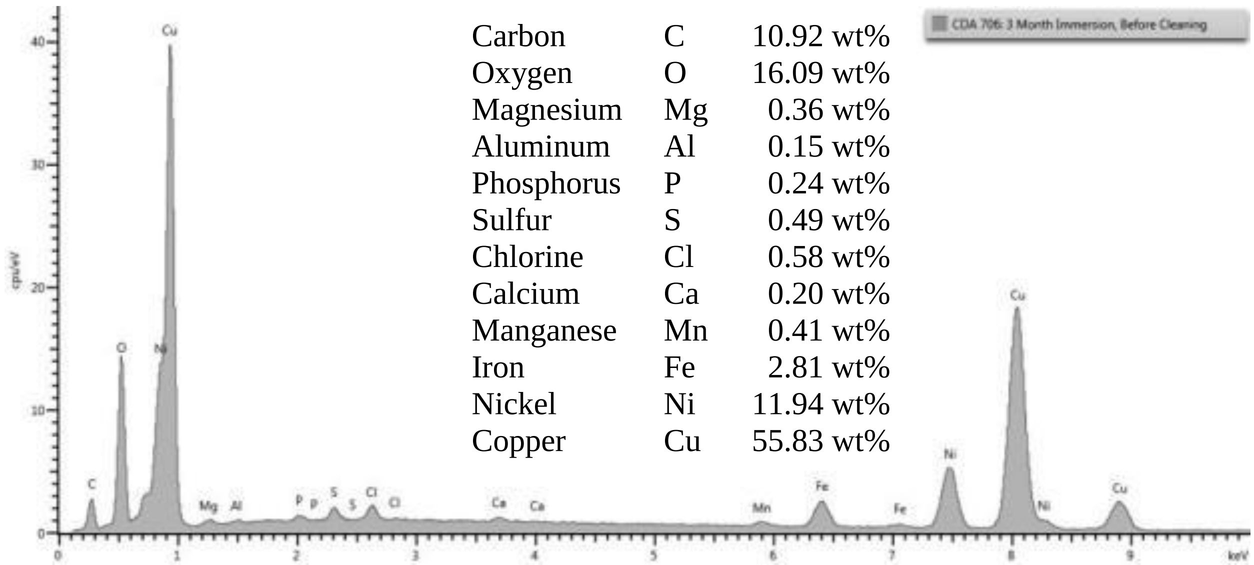
Figure 23 Scanning electron micrographs of CDA 706 coupon 2 after a 6 month corrosion test, after cleaning.



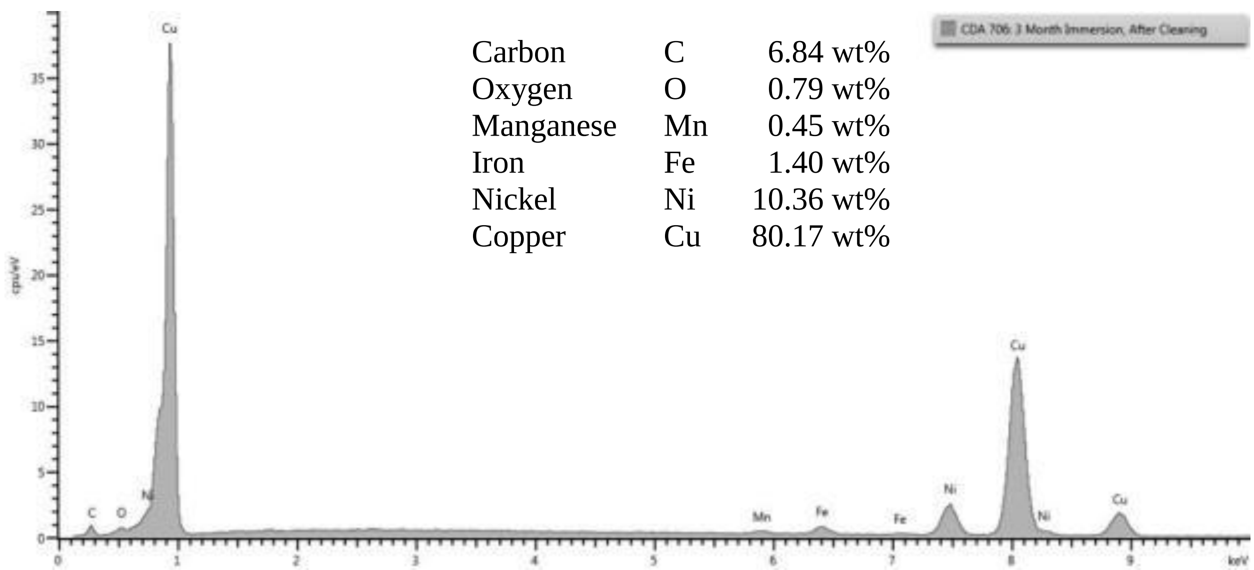
Carbon	C	24.47 wt%
Oxygen	O	1.91 wt%
Silicon	Si	0.13 wt%
Manganese	Mn	0.39 wt%
Iron	Fe	1.11 wt%
Nickel	Ni	8.17 wt%
Copper	Cu	63.82 wt%

(b) CDA 706 Baseline Coupon

Figure 24 Energy dispersive x-ray spectra of the CDA 706 baseline coupon.

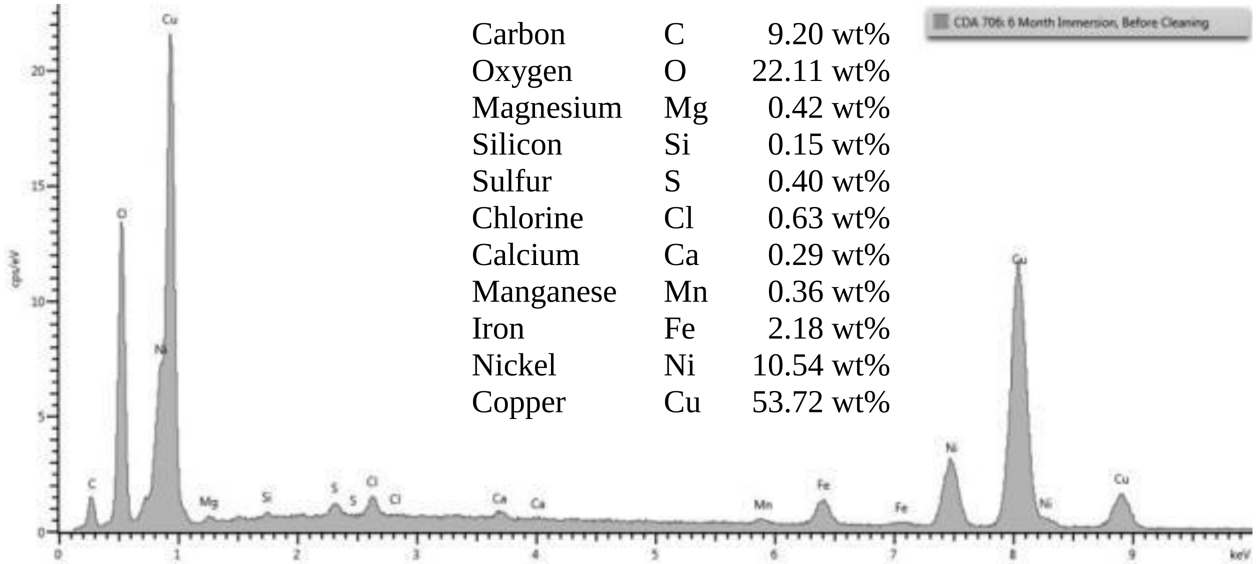


(a) CDA 706 Coupon 1, Before Cleaning

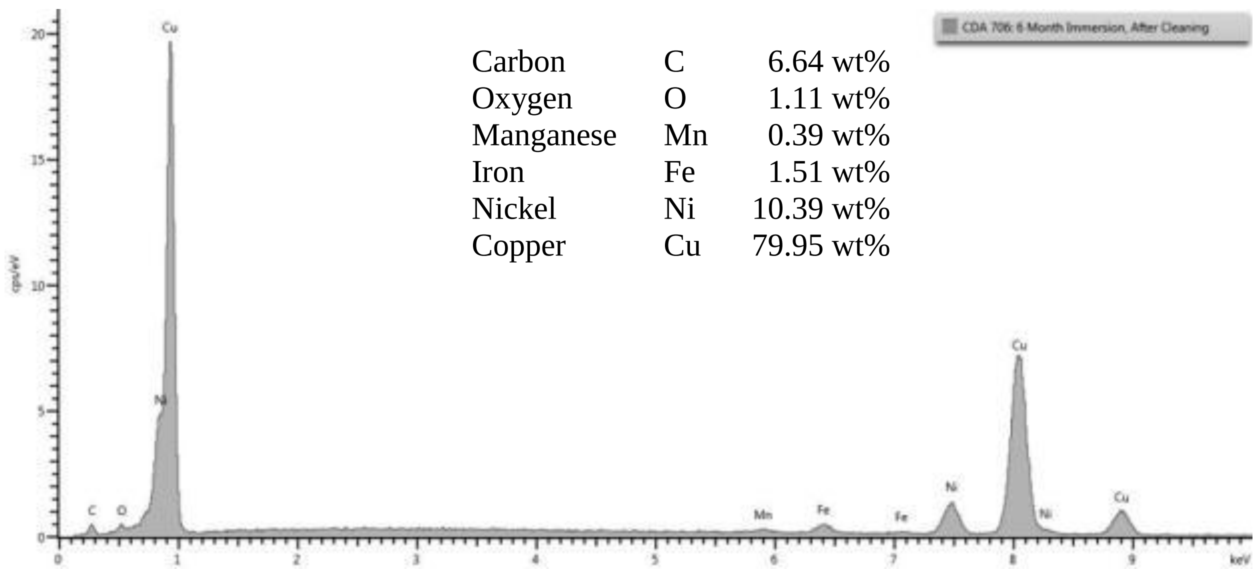


(b) CDA 706 Coupon 1, After Cleaning

Figure 25 Energy dispersive x-ray spectra of CDA 706 coupon 1 after a 3 month corrosion test (a) before cleaning and (b) after cleaning.



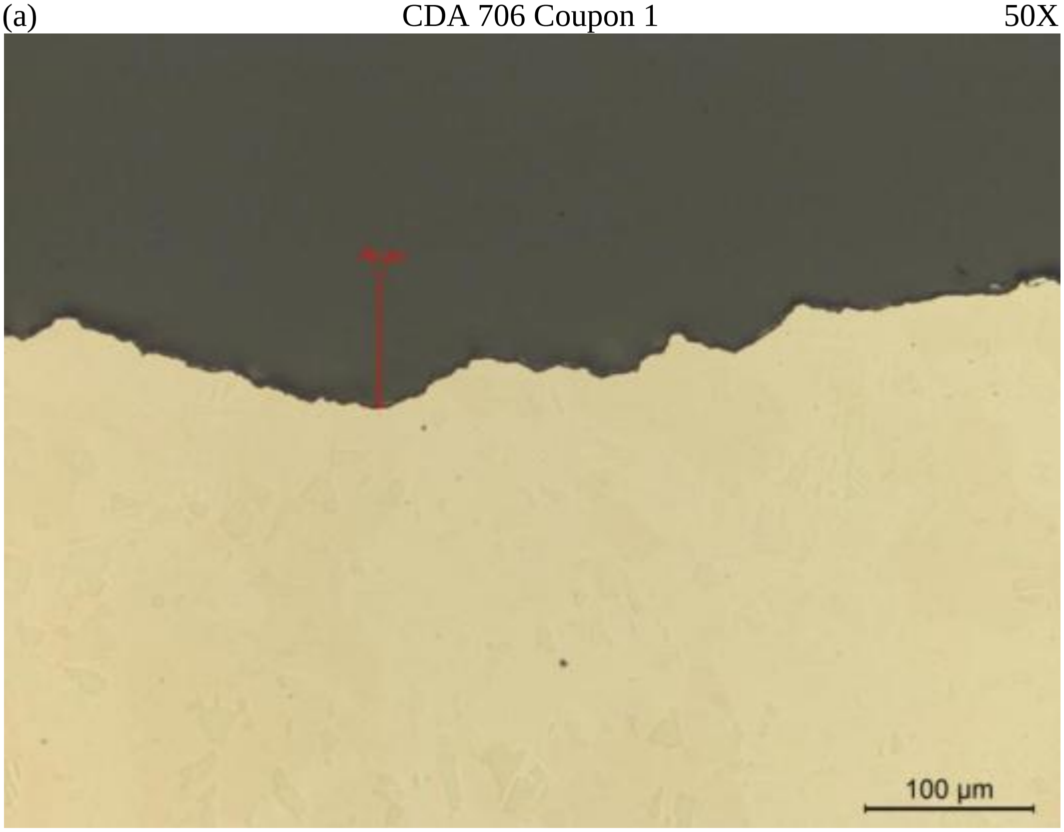
(a) CDA 706 Coupon 2, Before Cleaning



(b) CDA 706 Coupon 2, After Cleaning

Figure 26 Energy dispersive x-ray spectra of CDA 706 coupon 2 after a 6 month corrosion test (a) before cleaning and (b) after cleaning.

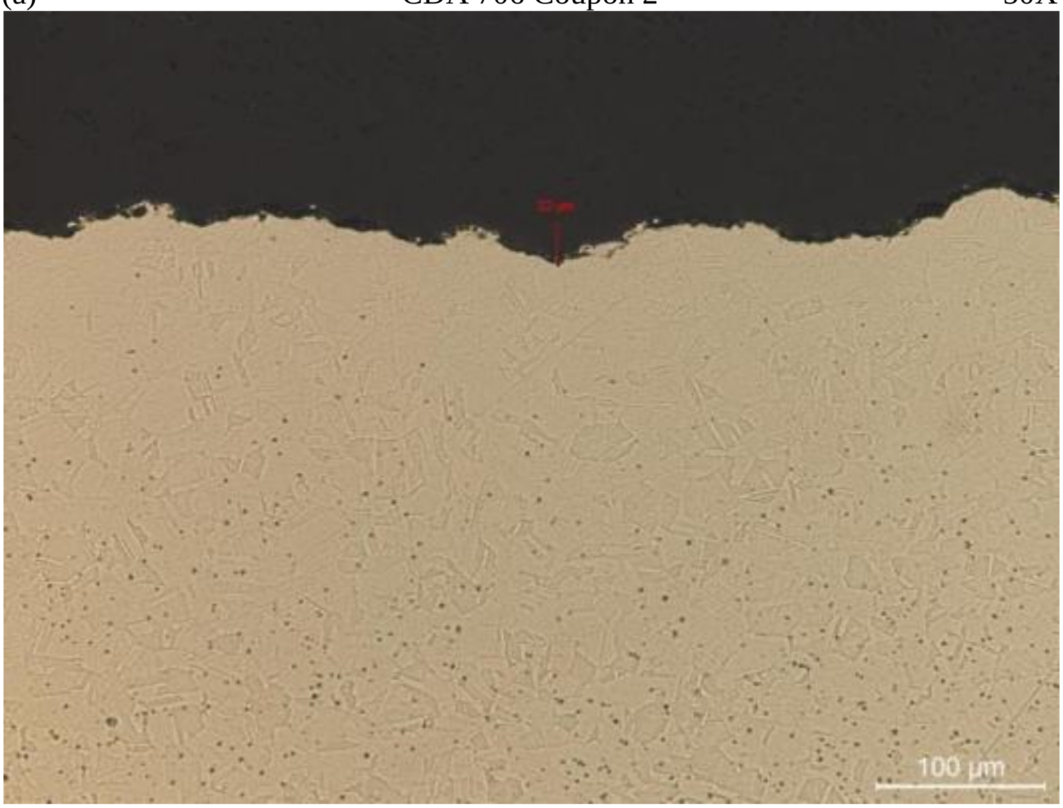
(a) CDA 706 Coupon 1 50X



(b) CDA 706 Coupon 1 200X

Figure 27 Optical micrographs of CDA 706 coupon 1.

(a) CDA 706 Coupon 2 50X



(b) CDA 706 Coupon 2 200X

Figure 28 Optical micrographs of CDA 706 coupon 2.

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Report No. 5005.0361D **January 30, 2015**

CORROSION EVALUATION OF CDA 715 COUPONS AND SCREENS

Customer Authorization: Verbal

Report To: V & A Engineering
Attn: Manuel Najar
155 Grand Avenue, Suite 700
Oakland, CA 94612

1.0 INTRODUCTION

Five coupons, five wedge wire screens, and one plate were submitted by V&A Engineering for corrosion evaluation. The coupons were 1-inch by 3-inches by ¼-inch thick. The wedge wire screens were 4-inches by 4-inches by 1/4-inch tall with 2 mm spacing. The plate was 4-inches by 4-inches by 1/8-inch thick. The sample was reportedly CDA 715, a 70-Copper, 30-Nickel alloy.

Four coupons and four screens were to be placed in seawater for a period up to one year. After every 3 month interval, one coupon and one screen were to be removed from the test system and examined for corrosion. The purpose of this evaluation was to document the samples in the baseline as-received condition, then again after 3, 6, 9, and 12 months of water exposure, record any loss in mass, examine for any pitting corrosion, and estimate the corrosion rate.

The samples were evaluated by the following laboratory procedures:

1) Visual examination and weighing
2) Cleaning per ASTM G1[1]
3) Scanning electron microscopy
4) Metallography

The results of the evaluation showed minimal mass loss and corrosion for the coupon and screen after 3 months and 6 months of corrosion testing. The coupon and screen, after 3 months of corrosion testing, had a corrosion rate of approximately 0.021 millimeters per year and 0.022 millimeters per year, respectively. The coupon and screen, after 6 months of corrosion testing, had a corrosion rate of approximately 0.016 millimeters per year and 0.022 millimeters per year, respectively.

[1] G1: Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

2.0 EVALUATION[2]

2.1 Visual Examination

The sample identifications for the coupons and wedge wire screens and their corresponding immersion times are shown in Table 1. The coupons had identification numbers stamped on the front face by V&A Engineering. A number of notches, corresponding to the sample number, were sawed at the edge of each screen for identification after the corrosion test. The weights of the samples were recorded. Coupons 1 – 4 and screens 1 – 5 were sent back to V&A for corrosion testing. Coupon 5 was the baseline sample and documented by photography, optical stereoscopy and scanning electron microscopy for comparison to the tested samples. Screen 5 was documented as a baseline by photography and optical stereoscopy, and then sent to V&A for testing.

Photographs of the baseline coupon are shown in Figure 1. Photographs of coupon 1, after 3 months of corrosion testing, are shown in Figure 2. Photographs of coupon 2, after 6 months of corrosion testing, are shown in Figure 3.

A photograph of the baseline screen is shown in Figure 4. A photograph of screen 1, after 3 months of corrosion testing, is shown in Figure 5. A photograph of screen 2, after 6 months of corrosion testing, is shown in Figure 6.

2.2 Cleaning

The coupon and screen were cleaned with solution C.2.1 per ASTM G1.[3] One cleaning cycle was approximately 1 minute. After each cleaning cycle, the samples were rinsed in water, dried, and weighed. The cleaning and weighing cycle was completed five times for the coupon and four times for the screen. The weights of the samples as-received, after corrosion testing but before cleaning, and after each cleaning cycle are presented in Table 2.

Optical macrographs of the baseline coupon and screen are shown in Figures 7 and 12, respectively. Representative optical macrographs of the samples after a 3 month corrosion test, before and after cleaning, are shown in Figures 8 – 9 and 13 – 14. Representative optical macrographs of the sample after a 6 month corrosion test, before and after cleaning, are shown in Figures 10 – 11 and 15 – 16.

The mass loss versus the number of cleaning cycles was plotted, shown in Figures 17 – 18. The equations for best fit lines AB and BC, calculated using IGOR Pro, are listed in Table 3. Point B, indicated by the red circle in each plot, corresponds to the mass loss due to corrosion during the cleaning process for each sample. This mass loss was subtracted from the weight of the sample before cleaning and from the weight of the sample as-received to determine the total mass loss from corrosion. The corrosion rate of each sample was determined by the formula specified in Section 8.1 of ASTM G1:

[2] The magnifications of the optical and scanning electron micrographs in this report are approximate and should not be used as a basis for dimensional analyses unless otherwise indicated.
[3] 500 mL hydrochloric acid + 500 ml reagent water.

$$Corrosion\ Rate = \frac{K\ x\ W}{A\ x\ T\ x\ D}$$

where K = 8.76 x 10^4, T = time of exposure in hours, A = area in cm^2, W = mass loss in grams, and D = density in g/cm^3. The total mass loss from corrosion and the calculated corrosion rate of each sample is shown in Table 4.

2.3 Scanning Electron Microscopy

The baseline coupon, coupon 1, and coupon 2 were examined with a scanning electron microscope. Representative scanning electron micrographs of the baseline coupon are shown in Figure 19. Representative scanning electron micrographs of coupon 1 before and after cleaning are shown in Figures 20 – 21. Representative scanning electron micrographs of coupon 2 before and after cleaning are shown in Figures 22 – 23.

An energy dispersive x-ray spectrum of the baseline coupon is shown in Figure 24. Energy dispersive x-ray spectra of coupon 1 before and after cleaning are shown in Figure 25. Energy dispersive x-ray spectra of coupon 2 before and after cleaning are shown in Figure 26.

2.4 Metallography

A cross section was taken from the coupon and prepared for a metallographic examination. Optical micrographs of the surface for coupon 1 are shown in Figure 27. An elliptical pit was observed in coupon 1, measuring 50 µm deep. Optical micrographs of the surface for coupon 2 are shown in Figure 28. An elliptical pit was observed in coupon 2, measuring 22 µm deep.

3.0 DISCUSSION

The coupon and screen showed minimal mass loss and pitting after 3 and 6 months of corrosion testing.

After 3 months of corrosion testing, the coupon had lost 0.248 grams of material and had a corrosion rate of 0.021 millimeters per year. After 3 months of corrosion testing, the screen had lost 2.04 grams of material and had a corrosion rate of 0.022 millimeters per year.

After 6 months of corrosion testing, the coupon had lost 0.386 grams of material and had a corrosion rate of 0.016 millimeters per year. After 6 months of corrosion testing, the screen had lost 4.05 grams of material and had a corrosion rate of 0.022 millimeters per year.

4.0 CONCLUSIONS[4]

The following conclusions are based upon the submitted samples and the evidence gathered:

1. The coupon, after 3 months of corrosion testing, had a mass loss of 0.248 grams and a corrosion rate of 0.021 mm / year.
2. The screen, after 3 months of corrosion testing, had a mass loss of 2.04 grams and a corrosion rate of 0.022 mm / year.
3. The coupon, after 6 months of corrosion testing, had a mass loss of 0.386 grams and a corrosion rate of 0.016 mm / year.
4. The screen, after 6 months of corrosion testing, had a mass loss of 4.05 grams and a corrosion rate of 0.022 mm / year.

Prepared by:

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Materials Engineer

Reviewed by:

Audrey A. Fasching, Ph.D., P.E.
Senior Materials Engineer

[4] The conclusions in this report are based upon the available information and evidence provided by the client and gathered by Anamet, within the scope of work authorized by the client, and they are hereby presented by Anamet to a reasonable degree of engineering and scientific certainty. Anamet reserves the right to amend or supplement its conclusions or opinions presented in this report should additional data or information become available, or further work be approved by the client.

Table 1
Sample Identifications

Description		V&A Engineering Identification (As-Received)	Anamet Identification (in report)	Notes
Alloy	Part			
CDA 715 (Cu 70 – Ni 30)	**Flat Plate** 4-inch x 4-inch x 1/8-inch	CDA 715 1	Plate	None
	Coupon 1-inch x 3-inch x 1/8-inch with autogenous weld bead	CDA 715W 1	Coupon 1	3 Month Immersion
		CDA 715W 2	Coupon 2	6 Month Immersion
		CDA 715W 3	Coupon 3	9 Month Immersion
		CDA 715W 4	Coupon 4	12 Month Immersion
		CDA 715W 5	Coupon 5	Baseline Sample (no exposure)
	Wedge Wire Screen 4-inch x 4-inch x 1-inch with 2 mm spacing	None	Screen 1	3 Month Immersion
		None	Screen 2	6 Month Immersion
		None	Screen 3	9 Month Immersion
		None	Screen 4	12 Month Immersion
		None	Screen 5	12 Month Immersion

Table 2
Sample Weights

Sample	Baseline Measurement	Measurements after 3 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 1	23.3284	23.1538	23.0863	32.0802	23.0795	23.0782	23.0770
Screen 1	210.45	209.34	208.52	208.42	208.41	208.41	-

Sample	Baseline Measurement	Measurements after 6 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 2	24.8463	24.5762	24.4601	24.4578	24.4571	24.4530	24.4519
Screen 2	211.63	208.66	207.58	207.57	207.57	207.53	-

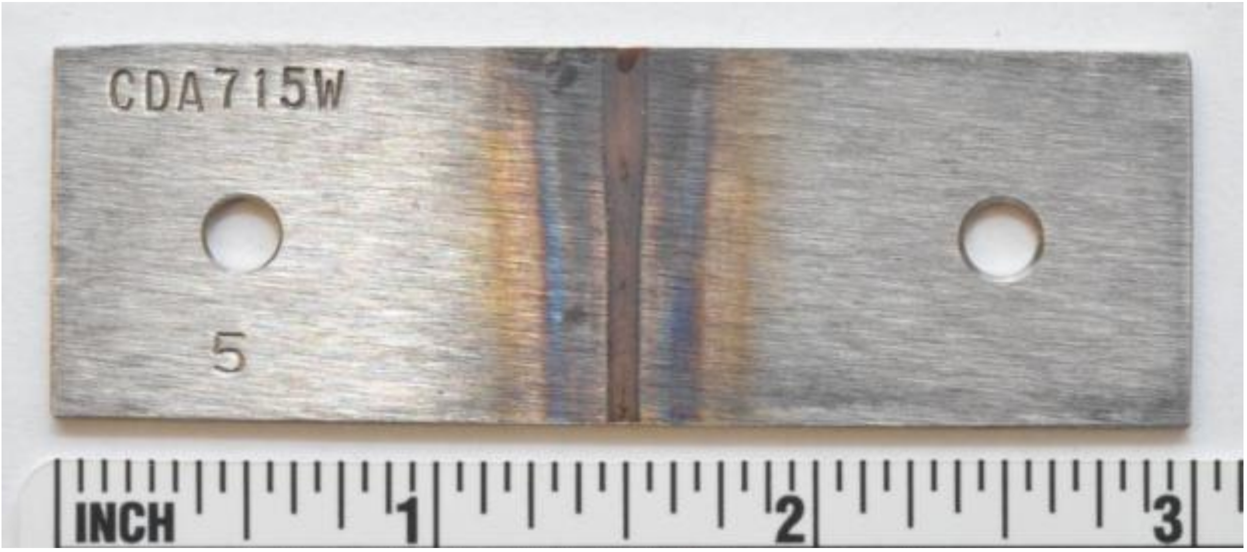
Table 3
Equations of Lines AB and BC for Corrosion Testing Samples

Sample	Line AB	Line BC	Point B (Approximate Mass Loss from Corrosion During Cleaning)
Coupon 1	y = 0.068x	y = 0.001x + 0.072	0.073 grams
Coupon 2	y = 0.116x	y = 0.002x + 0.114	0.116 grams
Screen 1	y = 0.83x	y = 0.01x + 0.92	0.93 grams
Screen 2	y = 1.08x	y = 0.02x + 1.06	1.08 grams

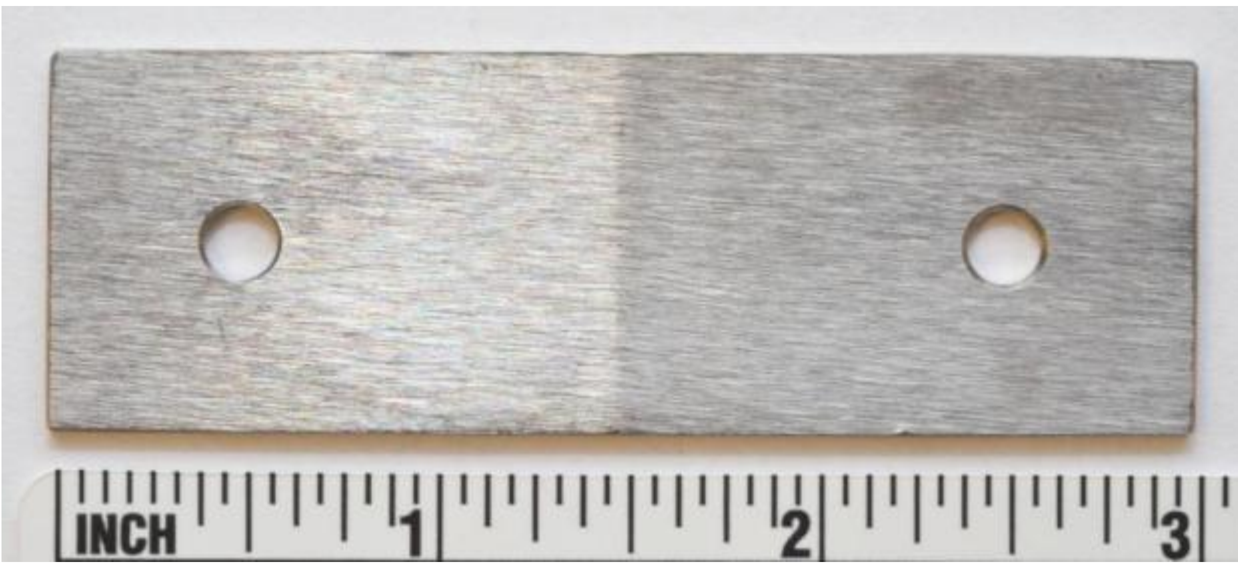
Table 4
Total Mass Loss from Corrosion and Corrosion Rates

Sample	Total Mass Loss from Corrosion*	Corrosion Rate
Coupon 1	0.248 grams	0.021 mm / year
Coupon 2	0.386 grams	0.016 mm / year
Screen 1	2.04 grams	0.022 mm / year
Screen 2	4.05 grams	0.022 mm / year

* Weight As-Received – (Weight Before Cleaning – Mass Loss from Corrosion During Cleaning)

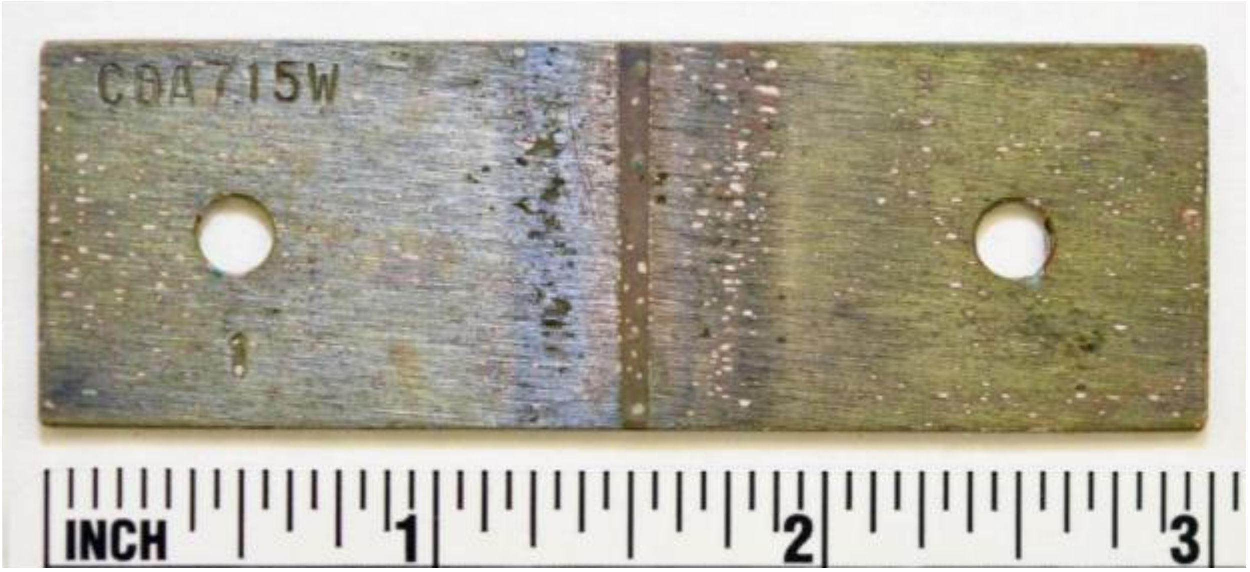


(a) CDA 715 Baseline Coupon, Front Side

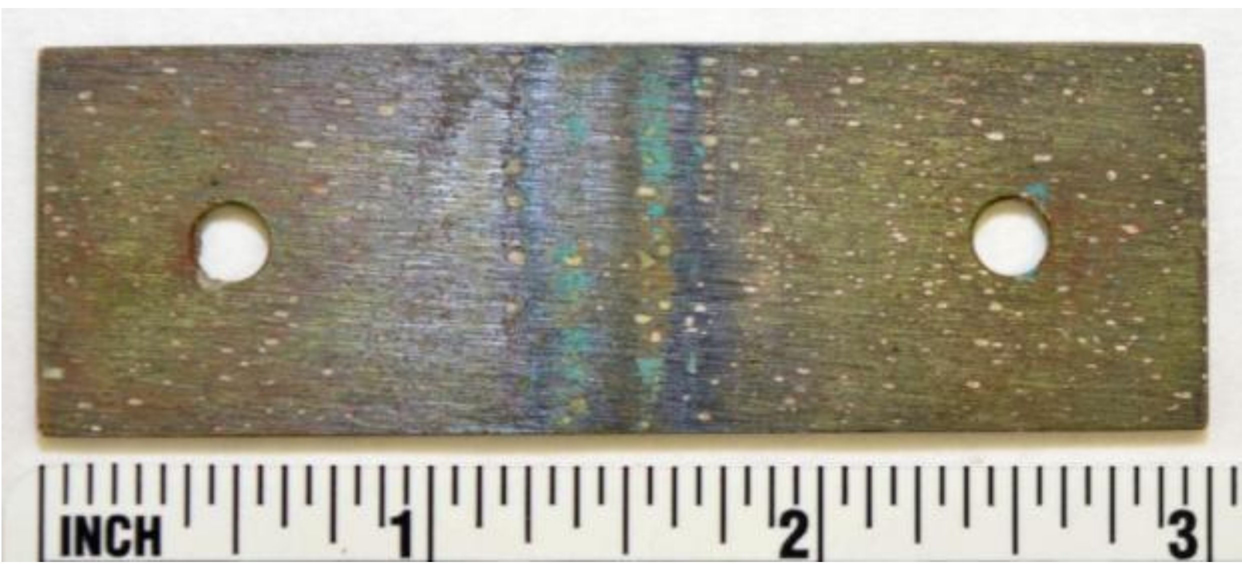


(b) CDA 715 Baseline Coupon, Back Side

Figure 1 Photographs of the CDA 715 baseline coupon (a) front and (b) back side.

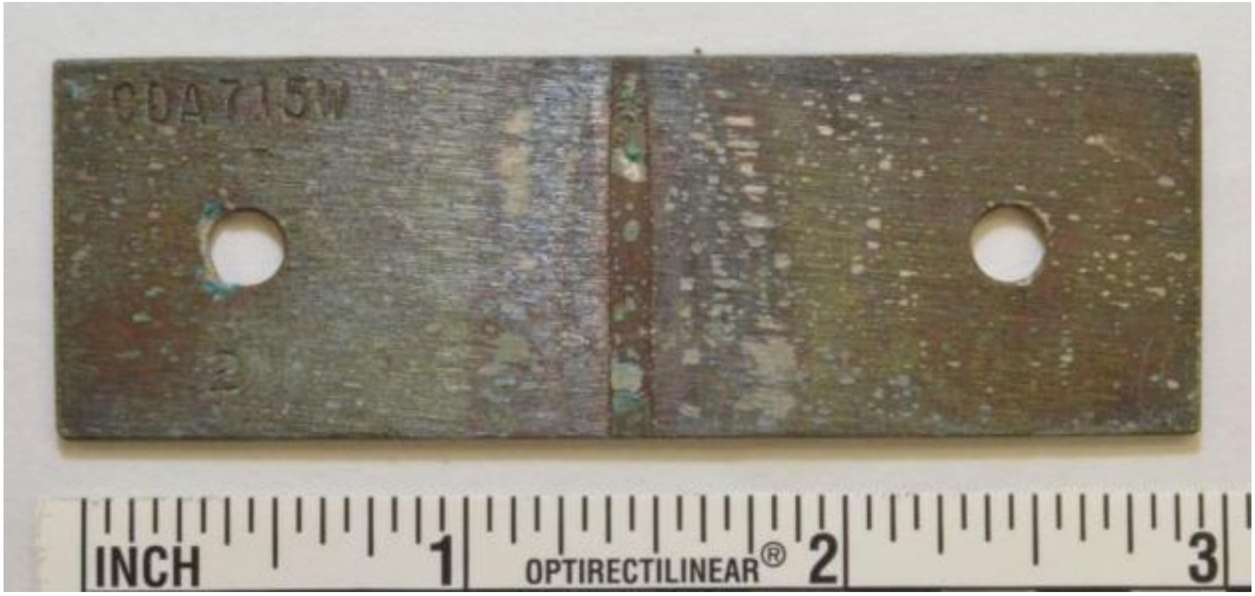


(a) CDA 715 Coupon 1, Front Side

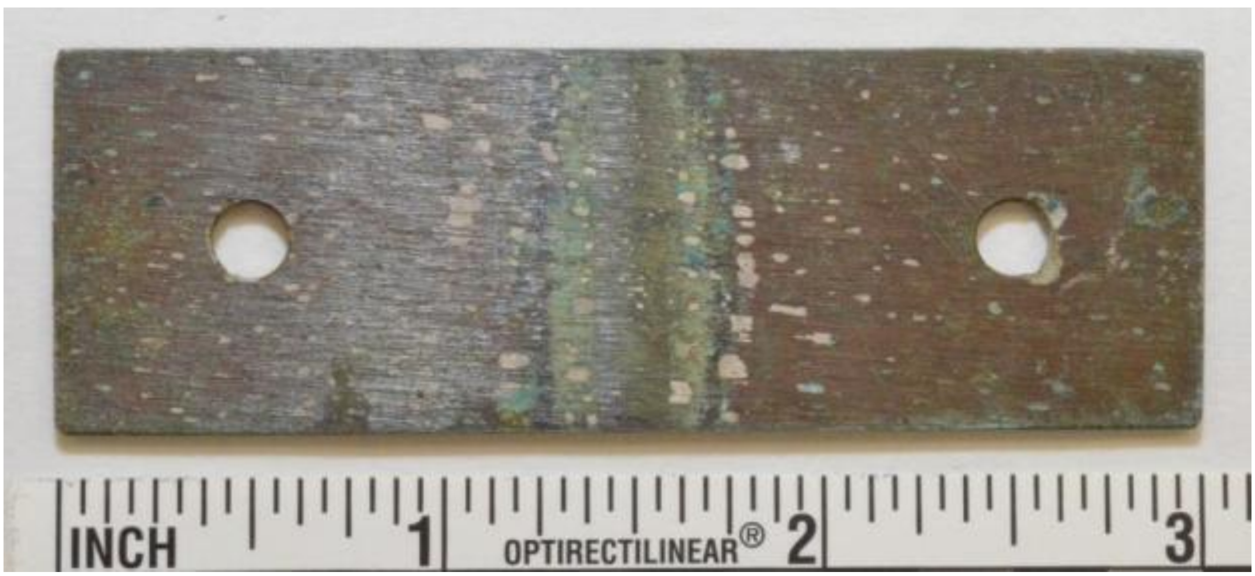


(b) CDA 715 Coupon 1, Back Side

Figure 2 Photographs of CDA 715 coupon 1 (a) front and (b) back side after a 3 month corrosion test.

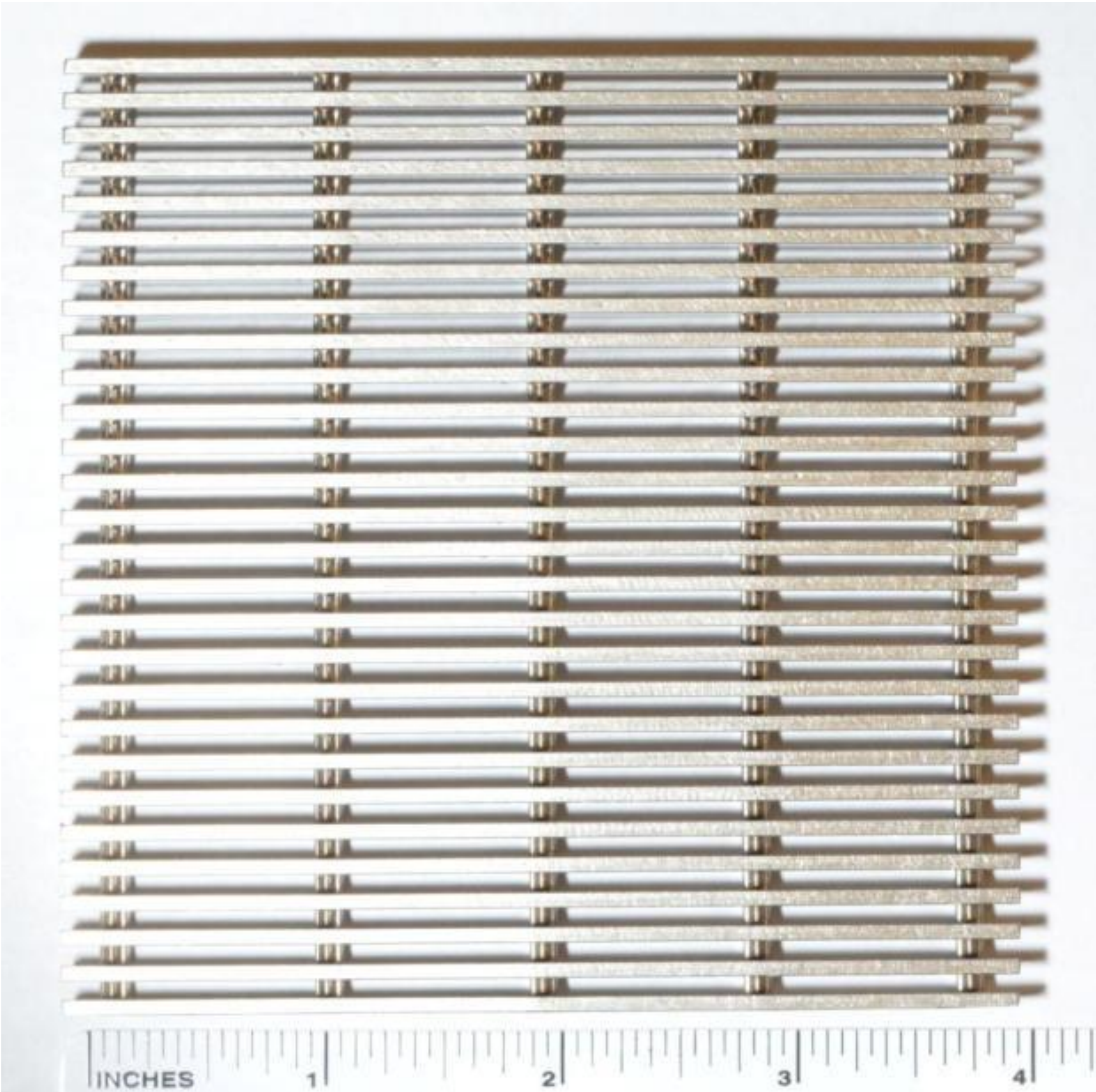


(a) CDA 715 Coupon 2, Front Side



(b) CDA 715 Coupon 2, Back Side

Figure 3 Photographs of CDA 715 coupon 2 (a) front and (b) back side after a 6 month corrosion test.



(a) CDA 715 Baseline Screen

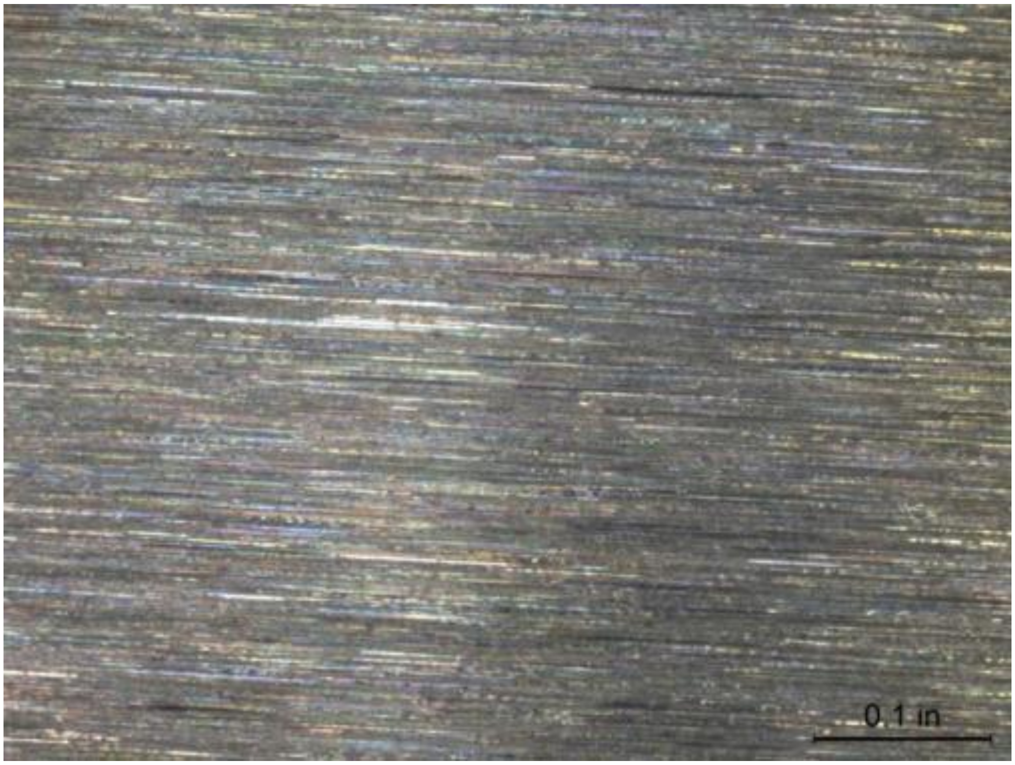
Figure 4 Photograph of the CDA 715 baseline screen.

(a) CDA 715 Screen 1

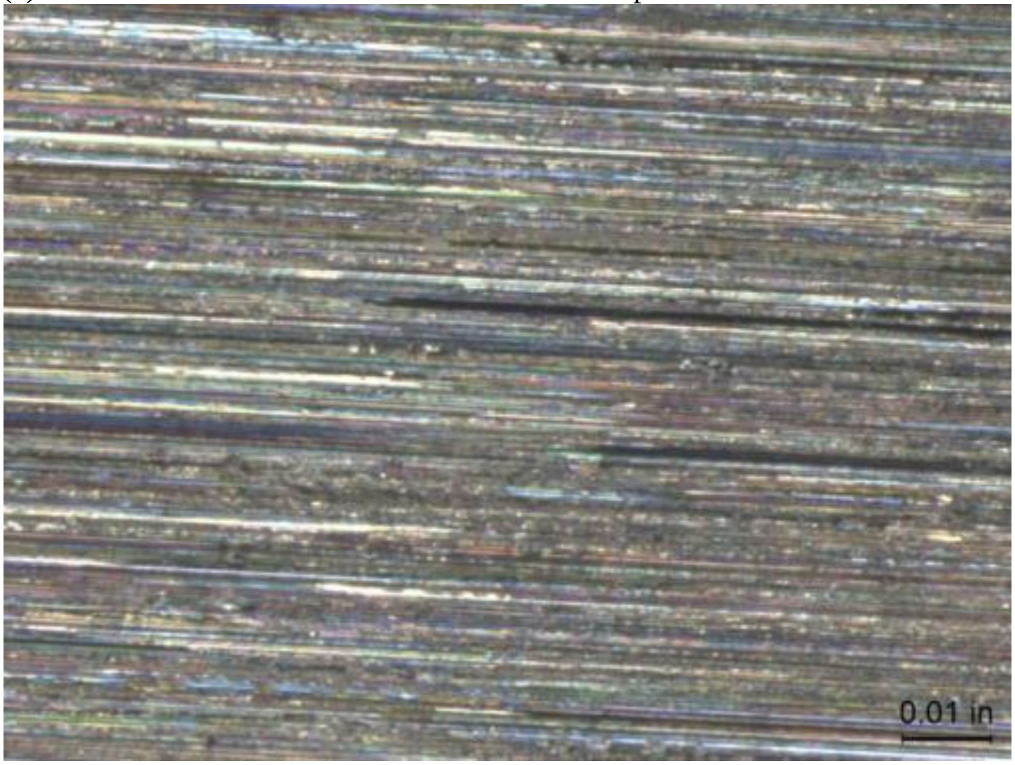
Figure 5 Photograph of CDA 715 screen 1 after a 3 month corrosion test.

(a) CDA 715 Screen 2

Figure 6 Photograph of CDA 715 screen 2 after a 6 month corrosion test.



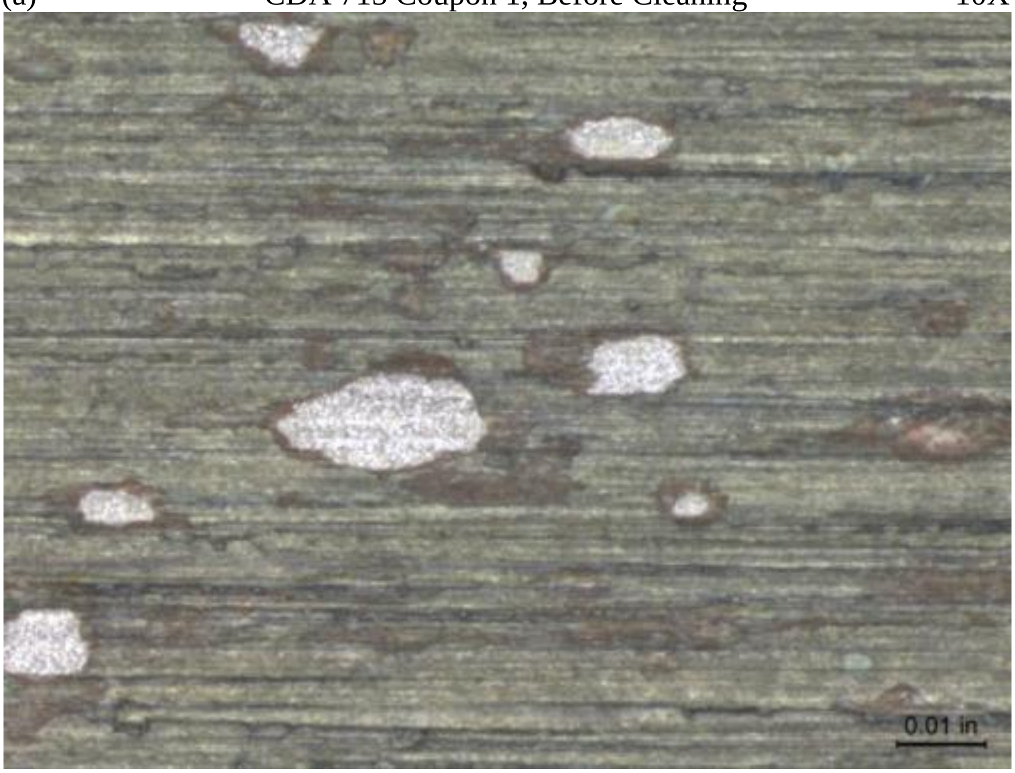
(a) CDA 715 Baseline Coupon 10X



(b) CDA 715 Baseline Coupon 50X

Figure 7 Optical macrographs of the CDA 715 baseline coupon.

(a) CDA 715 Coupon 1, Before Cleaning 10X



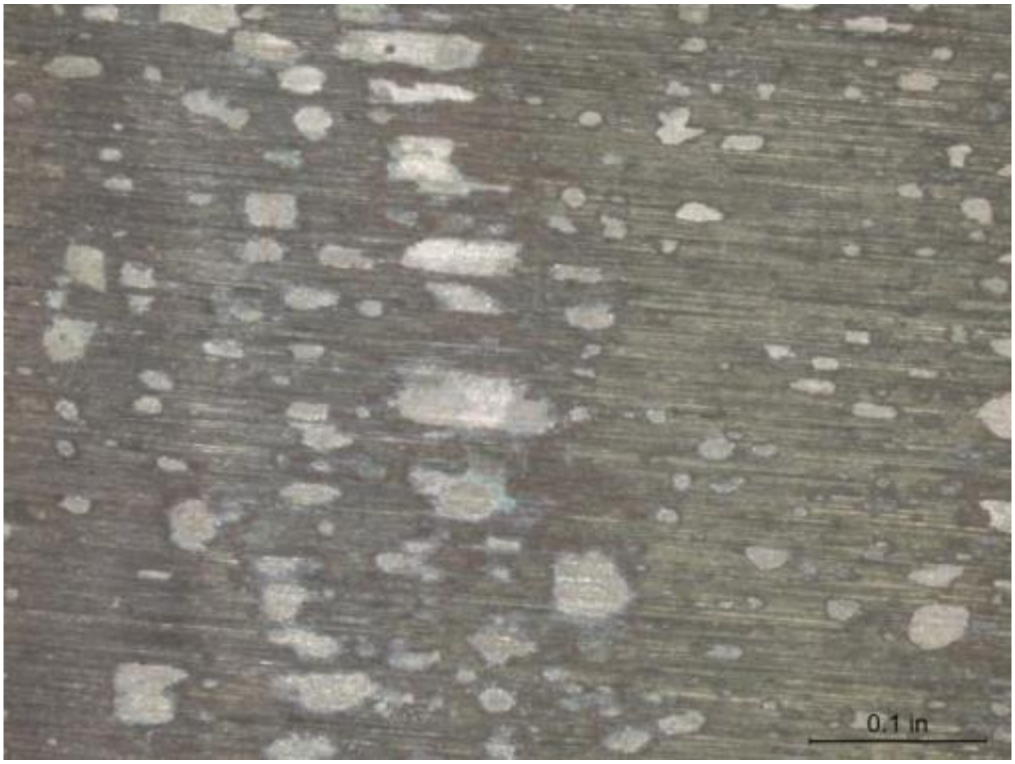
(b) CDA 715 Coupon 1, Before Cleaning 50X

Figure 8 Optical macrographs of CDA 715 coupon 1 after a 3 month corrosion test, before cleaning.

(a) CDA 715 Coupon 1, After Cleaning 10X

(b) CDA 715 Coupon 1, After Cleaning 50X

Figure 9 Optical macrographs of CDA 715 coupon 1 after a 3 month corrosion test, after cleaning.



(a) CDA 715 Coupon 2, Before Cleaning 10X

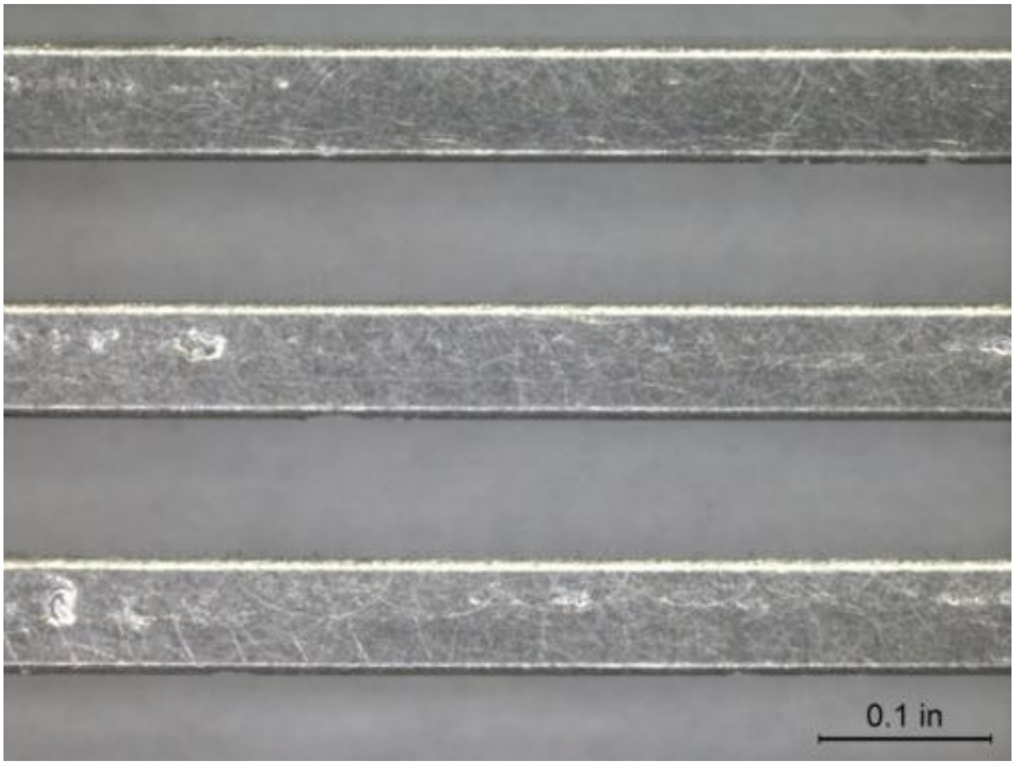
(b) CDA 715 Coupon 2, Before Cleaning 50X

Figure 10 Optical macrographs of CDA 715 coupon 2 after a 6 month corrosion test, before cleaning.

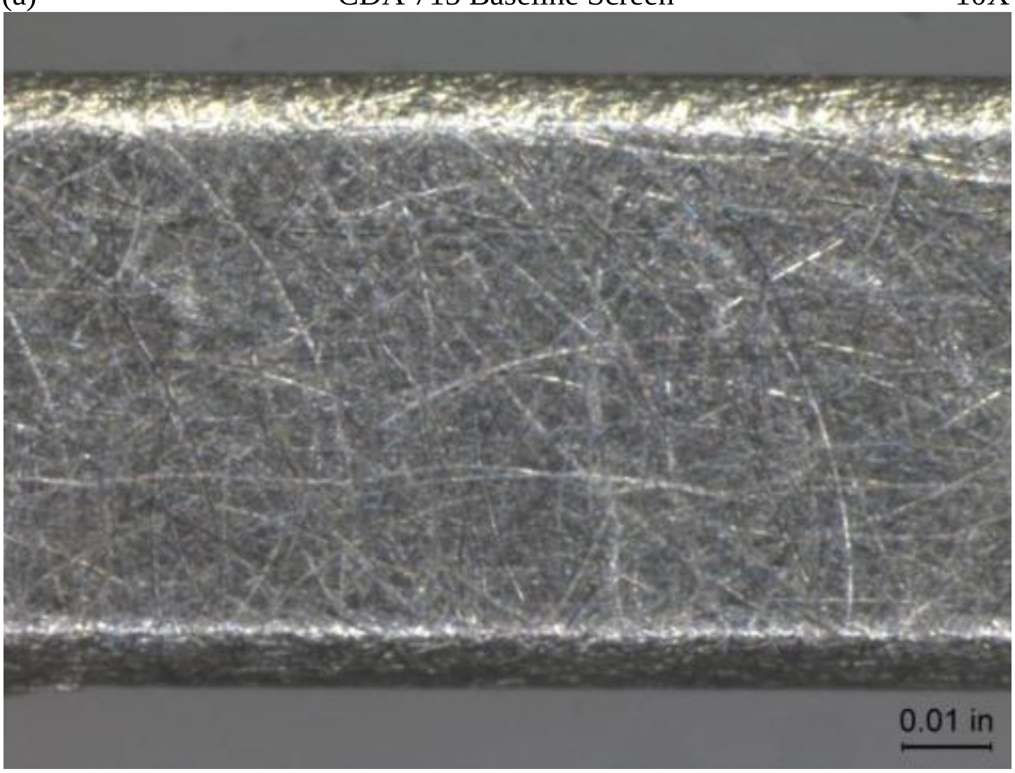
(a) CDA 715 Coupon 2, After Cleaning 10X

(b) CDA 715 Coupon 2, After Cleaning 50X

Figure 11 Optical macrographs of CDA 715 coupon 2 after a 6 month corrosion test, after cleaning.

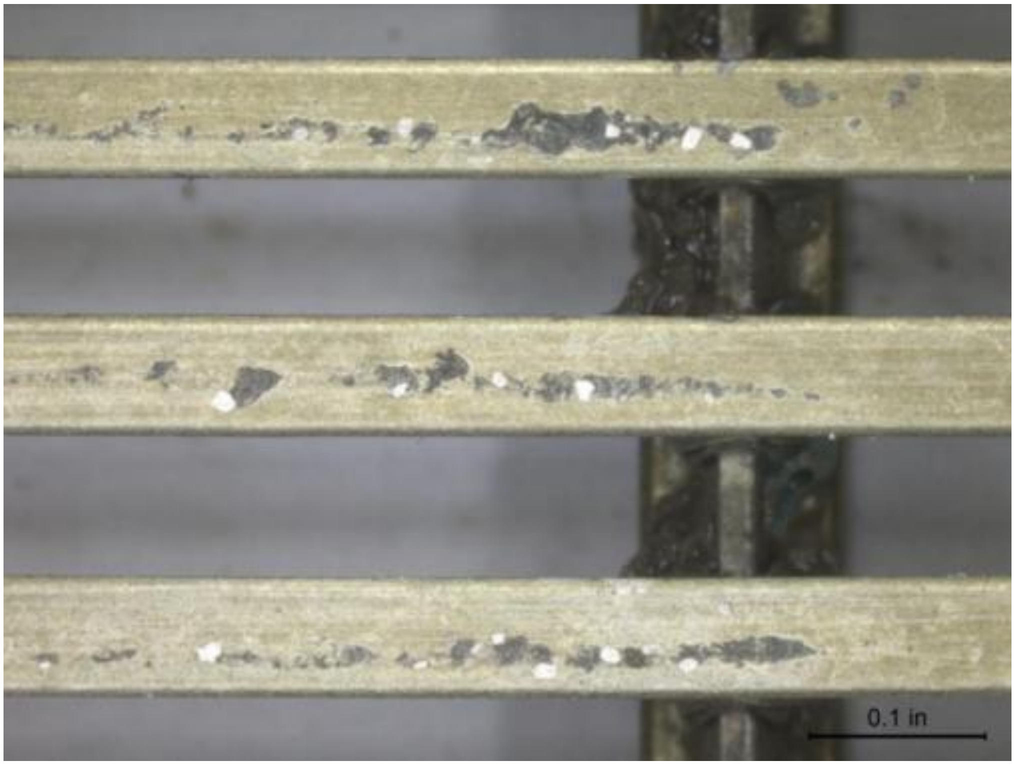


(a) CDA 715 Baseline Screen 10X

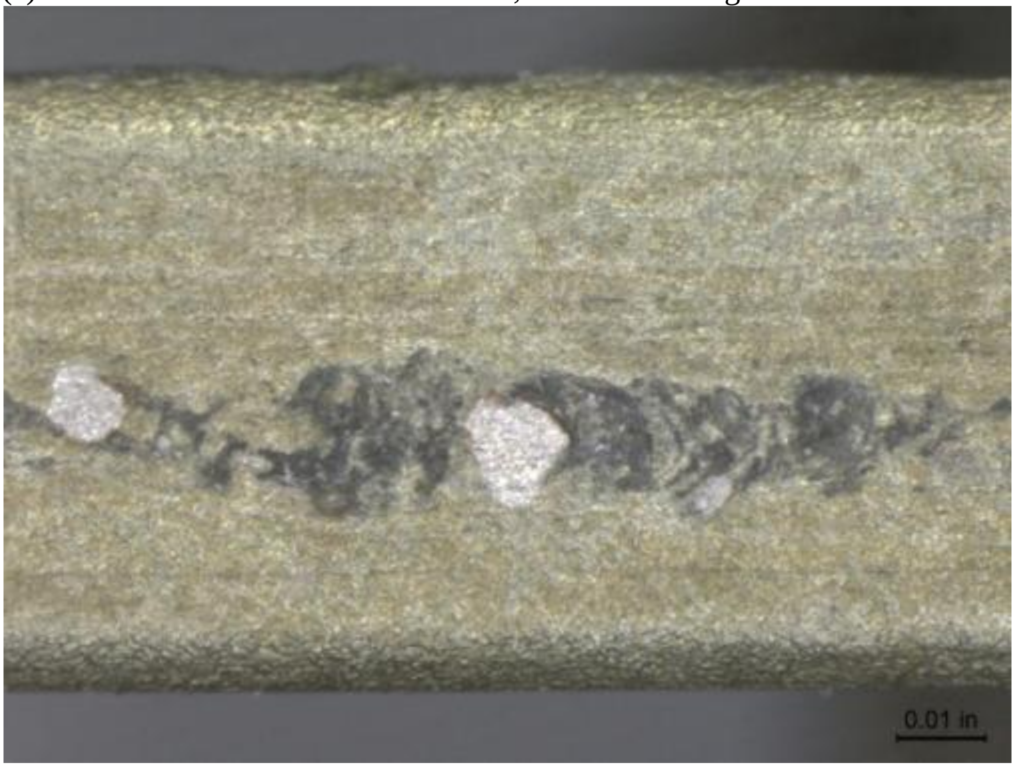


(b) CDA 715 Baseline Screen 50X

Figure 12 Optical macrographs of the CDA 715 baseline screen.

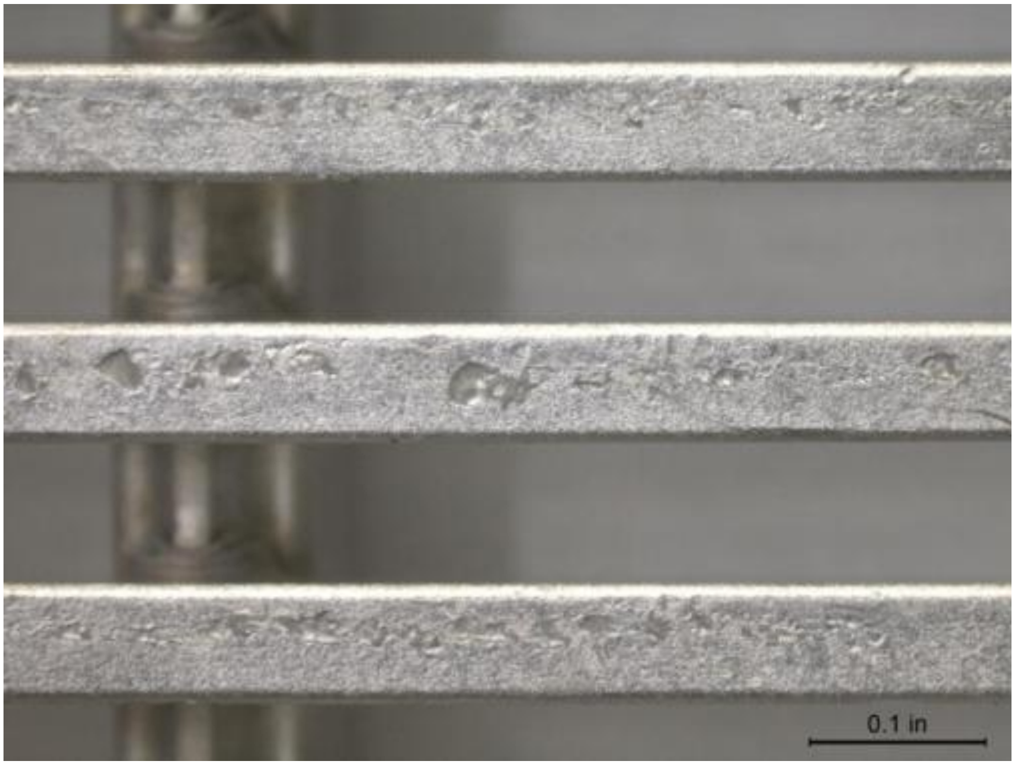


(a) CDA 715 Screen 1, Before Cleaning 10X



(b) CDA 715 Screen 1, Before Cleaning 50X

Figure 13 Optical macrographs of CDA 715 screen 1 after a 3 month corrosion test, before cleaning.



(a) CDA 715 Screen 1, After Cleaning 10X

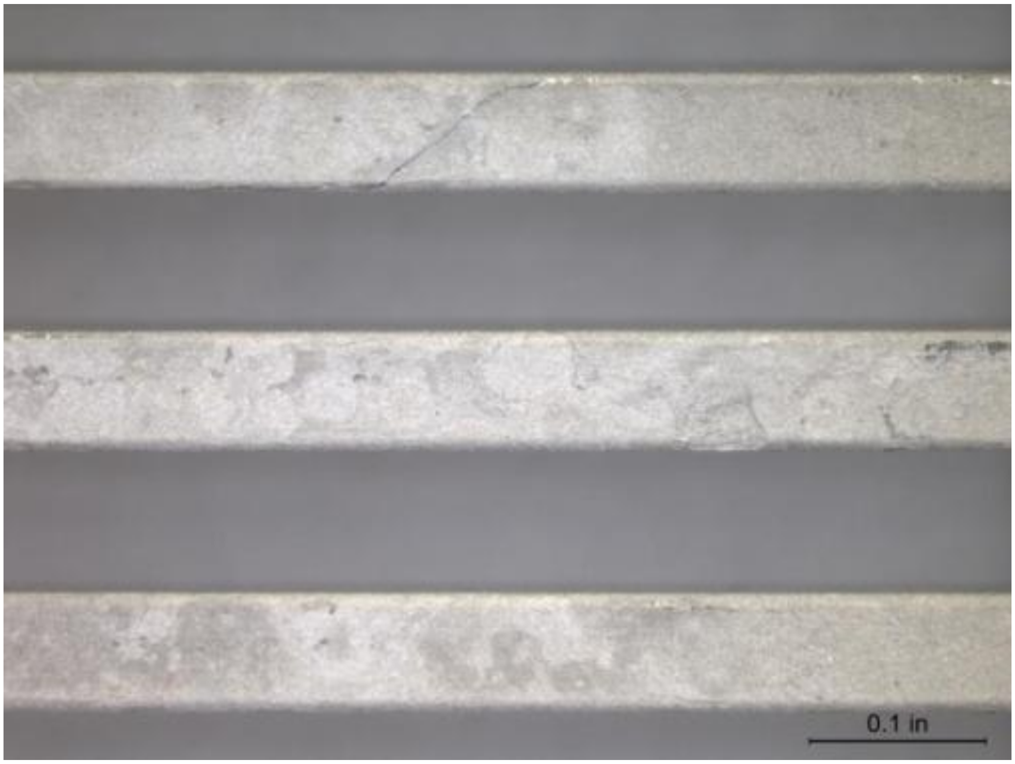
(b) CDA 715 Screen 1, After Cleaning 50X

Figure 14 Optical macrographs of CDA 715 screen 1 after a 3 month corrosion test, after cleaning.

(a) CDA 715 Screen 2, Before Cleaning 10X

(b) CDA 715 Screen 2, Before Cleaning 50X

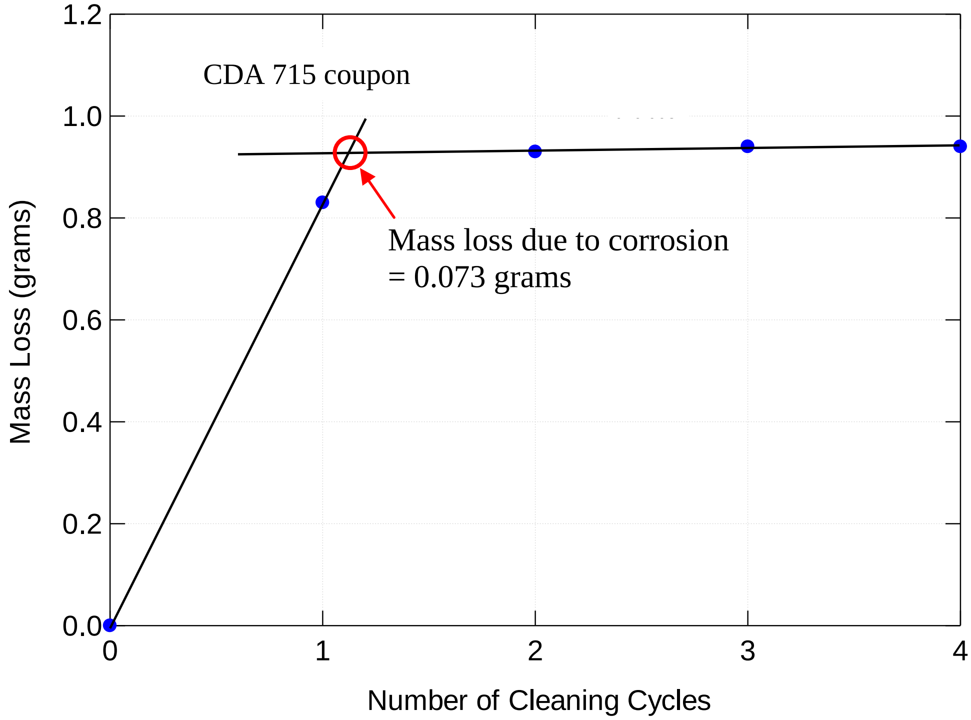
Figure 15 Optical macrographs of CDA 715 screen 2 after a 6 month corrosion test, before cleaning.



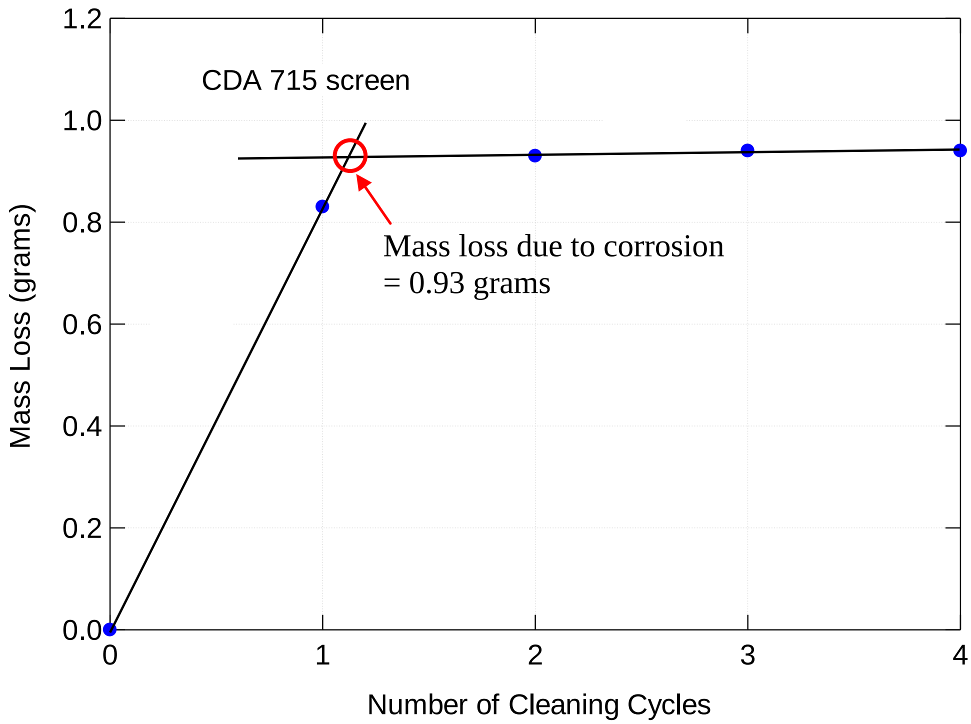
(a) CDA 715 Screen 2, After Cleaning 10X

(b) CDA 715 Screen 2, After Cleaning 50X

Figure 16 Optical macrographs of CDA 715 screen 2 after a 6 month corrosion test, after cleaning.

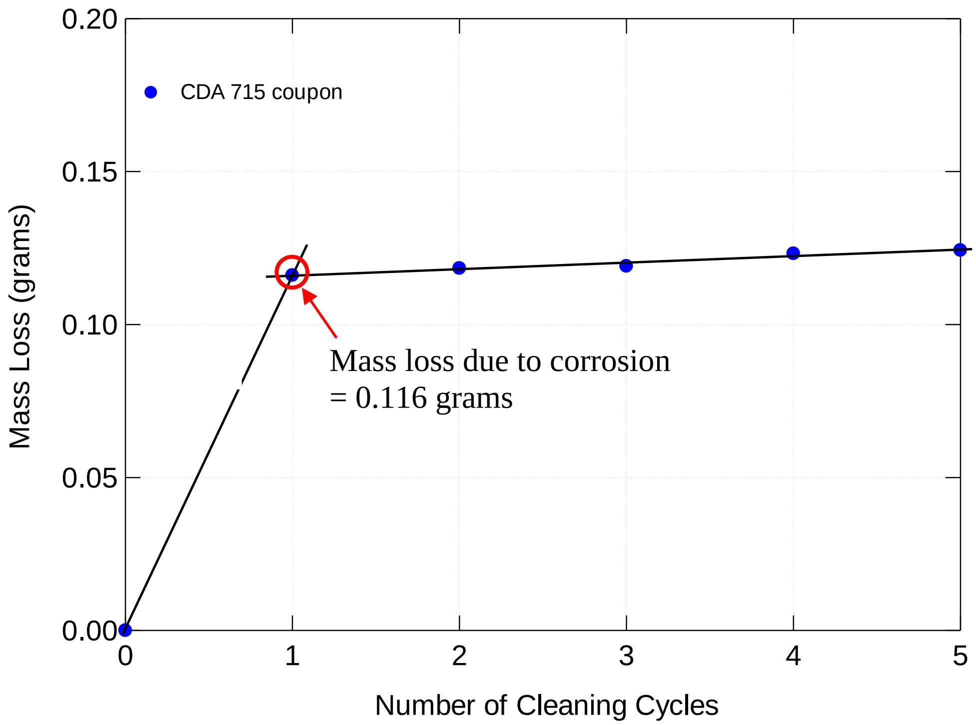


(a)

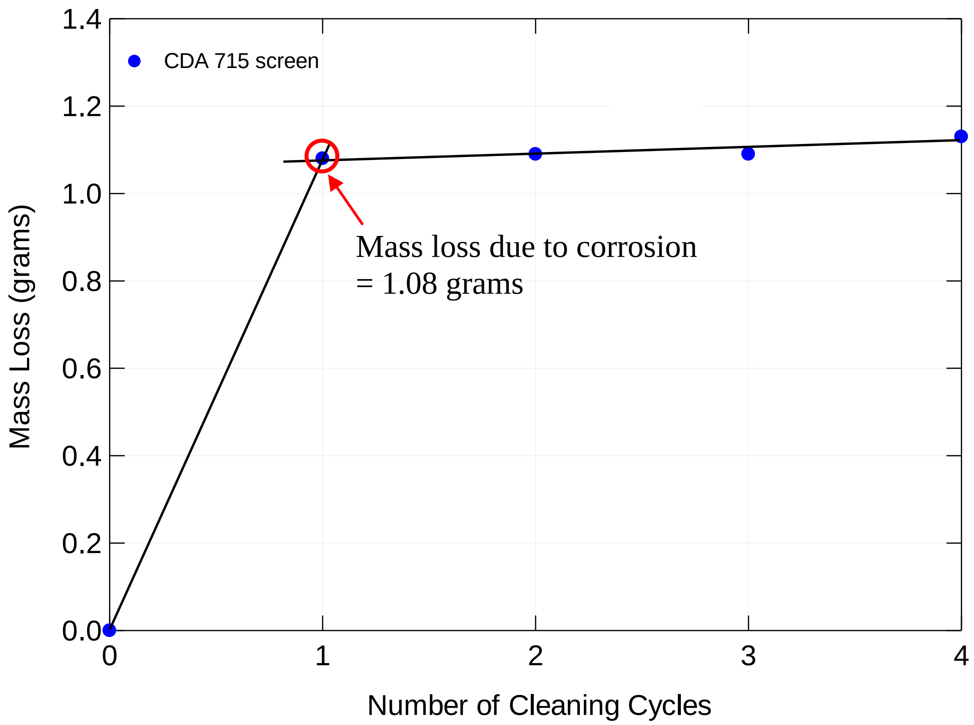


(b)

Figure 17 Mass loss of CDA 715 (a) coupon 1 and (b) screen 1 during cleaning.

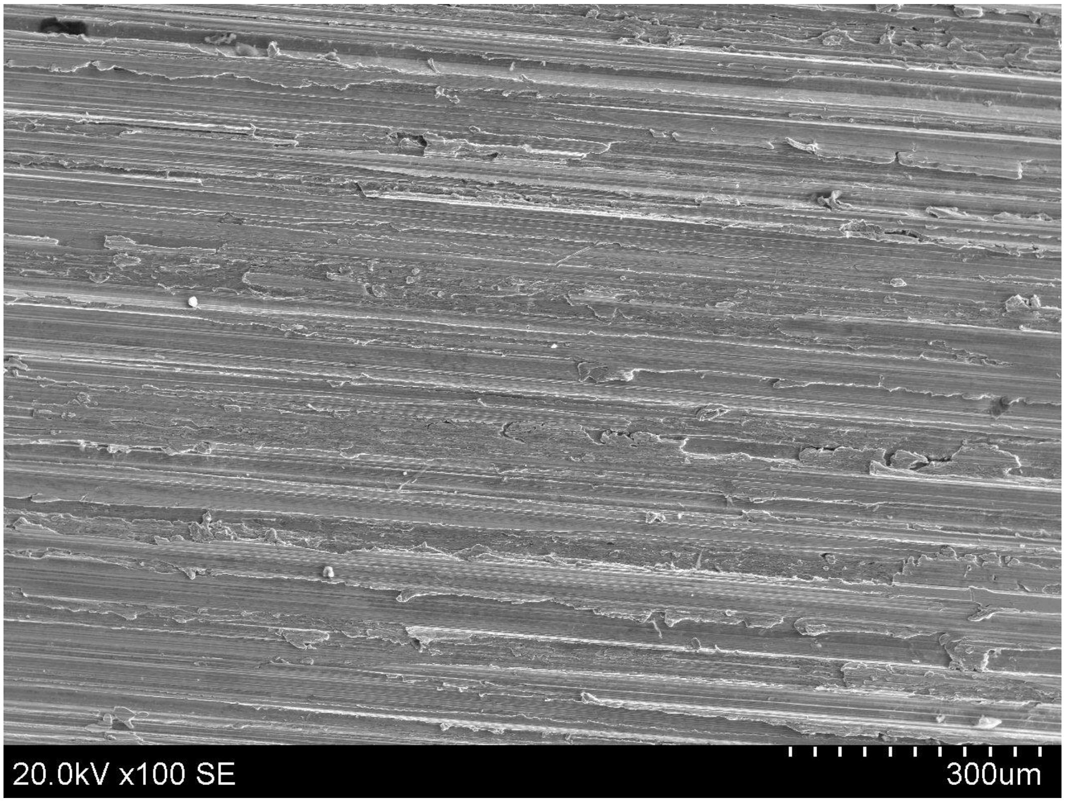


(a)

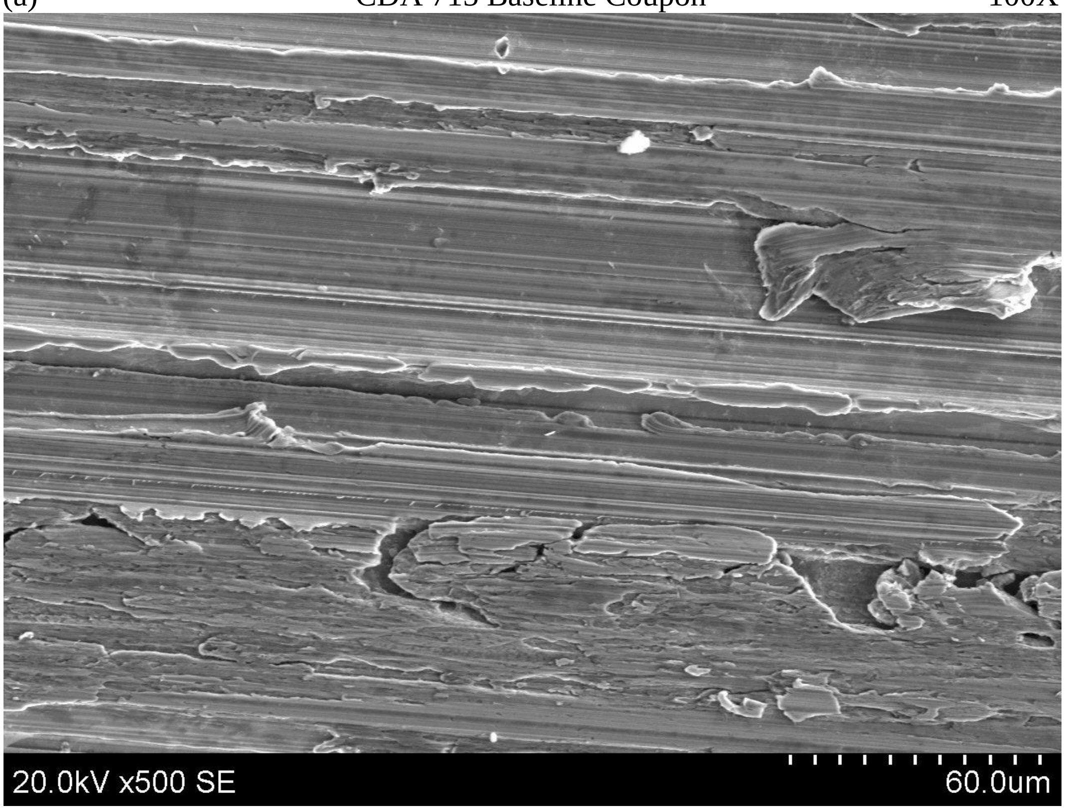


(b)

Figure 18 Mass loss of CDA 715 (a) coupon 2 and (b) screen 2 during cleaning.

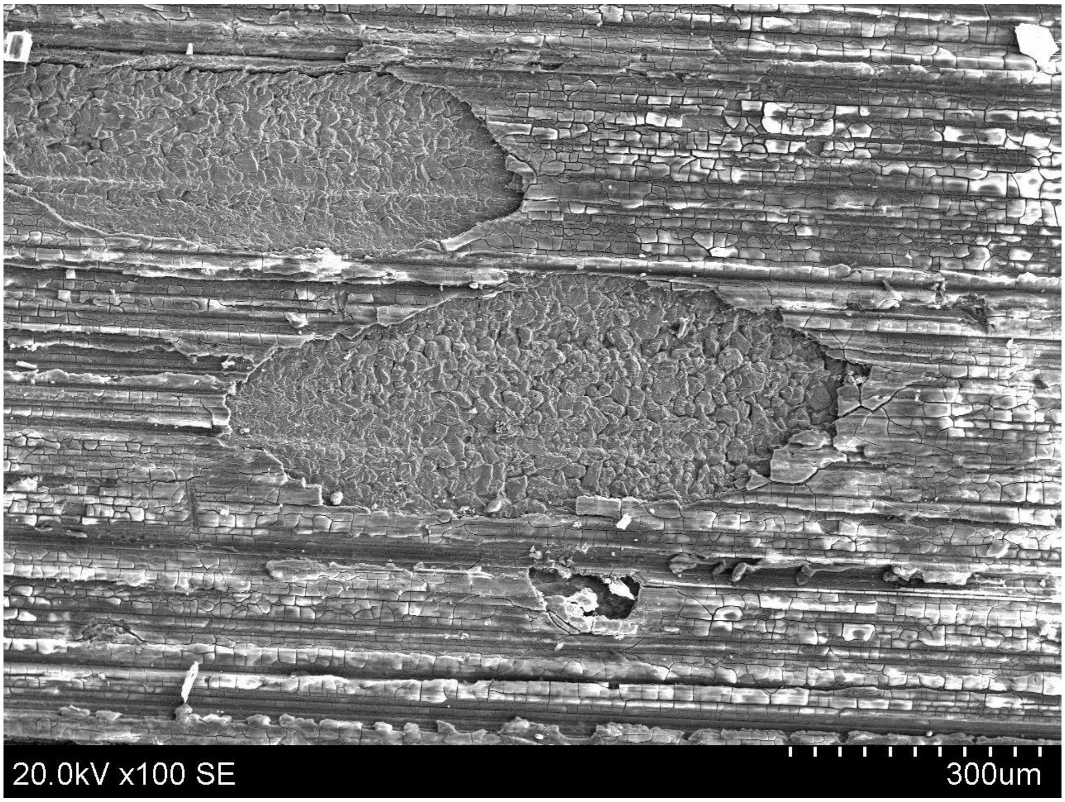


(a) CDA 715 Baseline Coupon 100X

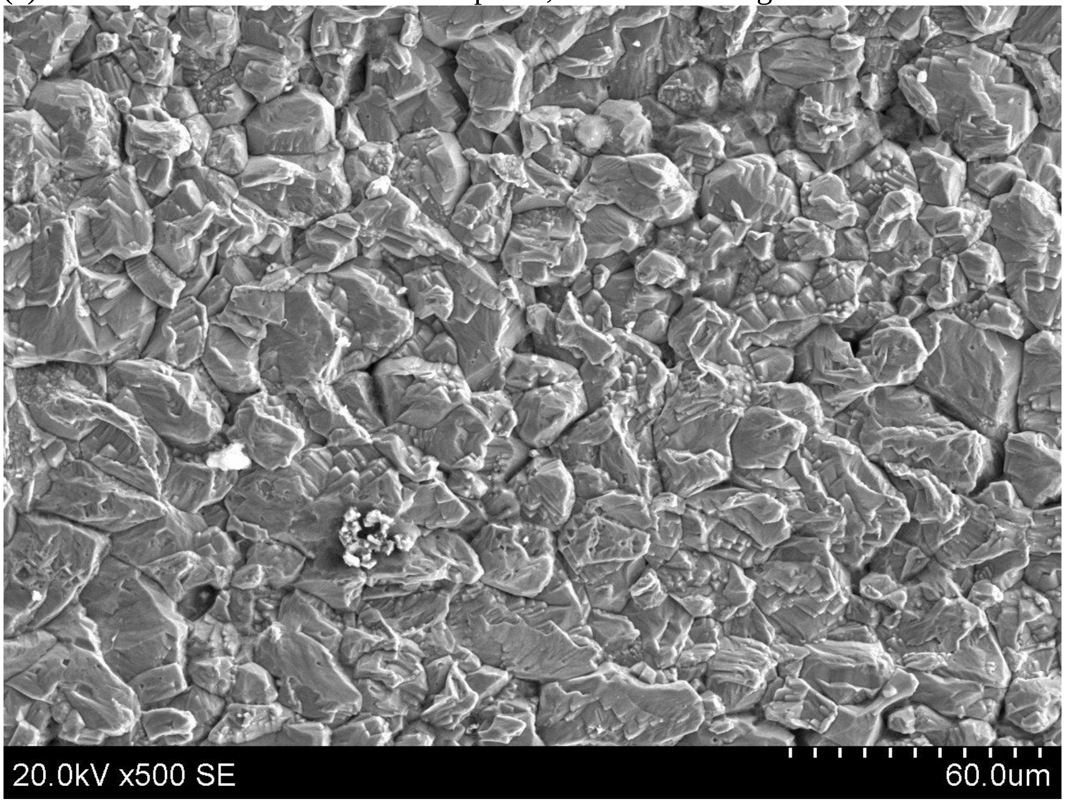


(b) CDA 715 Baseline Coupon 500X

Figure 19 Scanning electron micrographs of the CDA 715 baseline coupon.

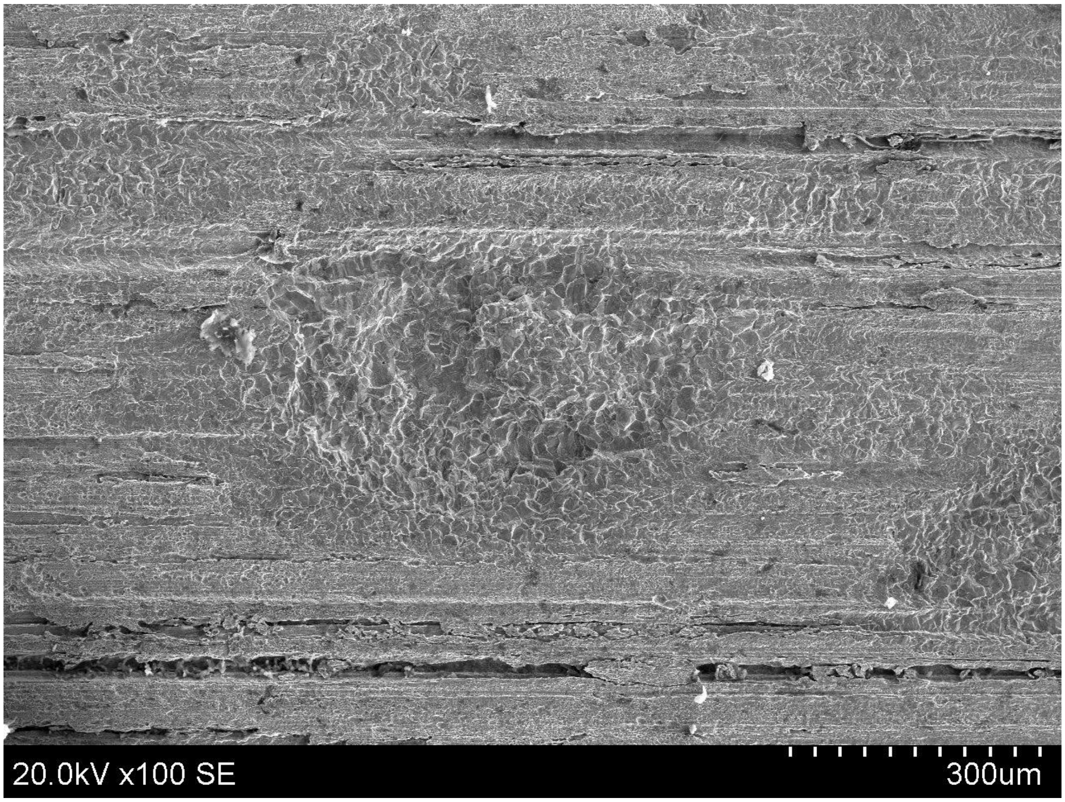


(a) CDA 715 Coupon 1, Before Cleaning 100X

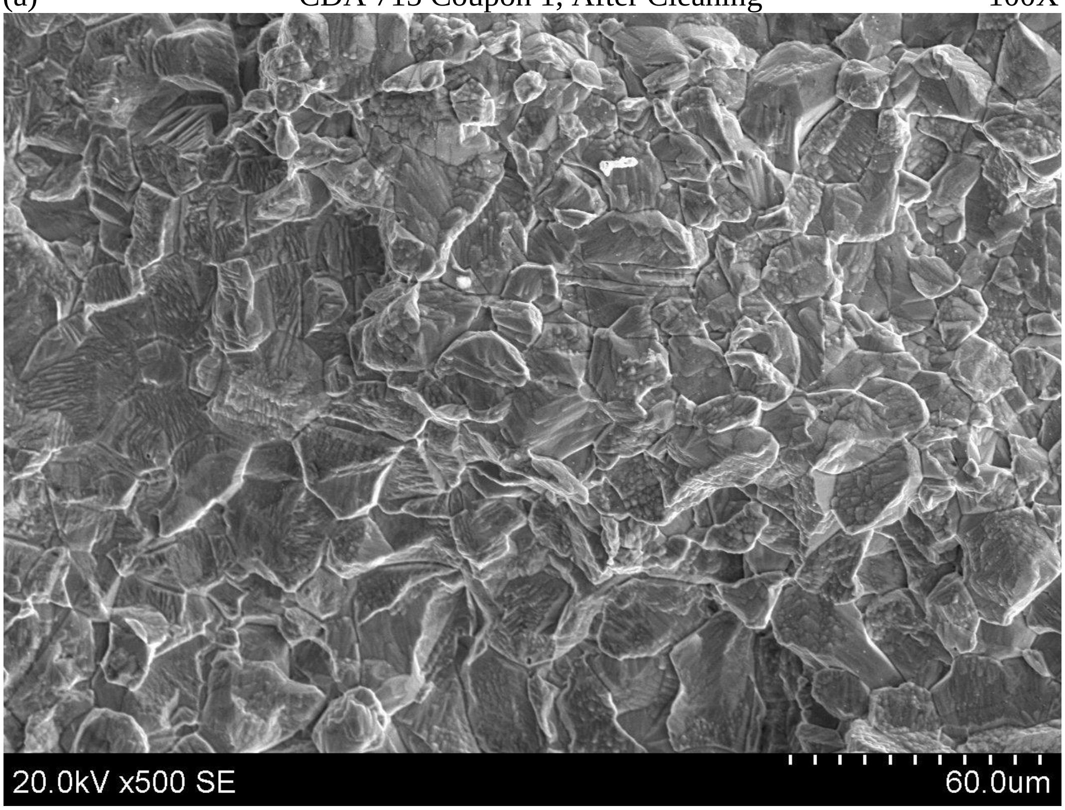


(b) CDA 715 Coupon 1, Before Cleaning 500X

Figure 20 Scanning electron micrographs of CDA 715 coupon 1 after a 3 month immersion test, before cleaning.



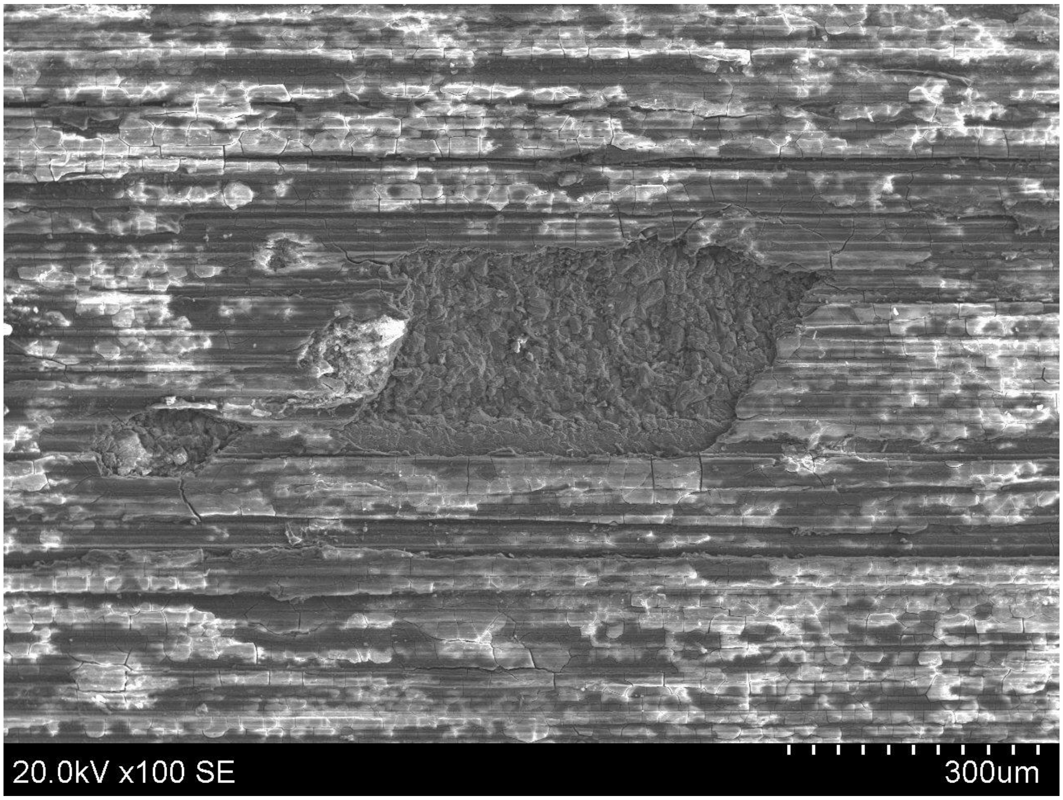
(a) CDA 715 Coupon 1, After Cleaning 100X



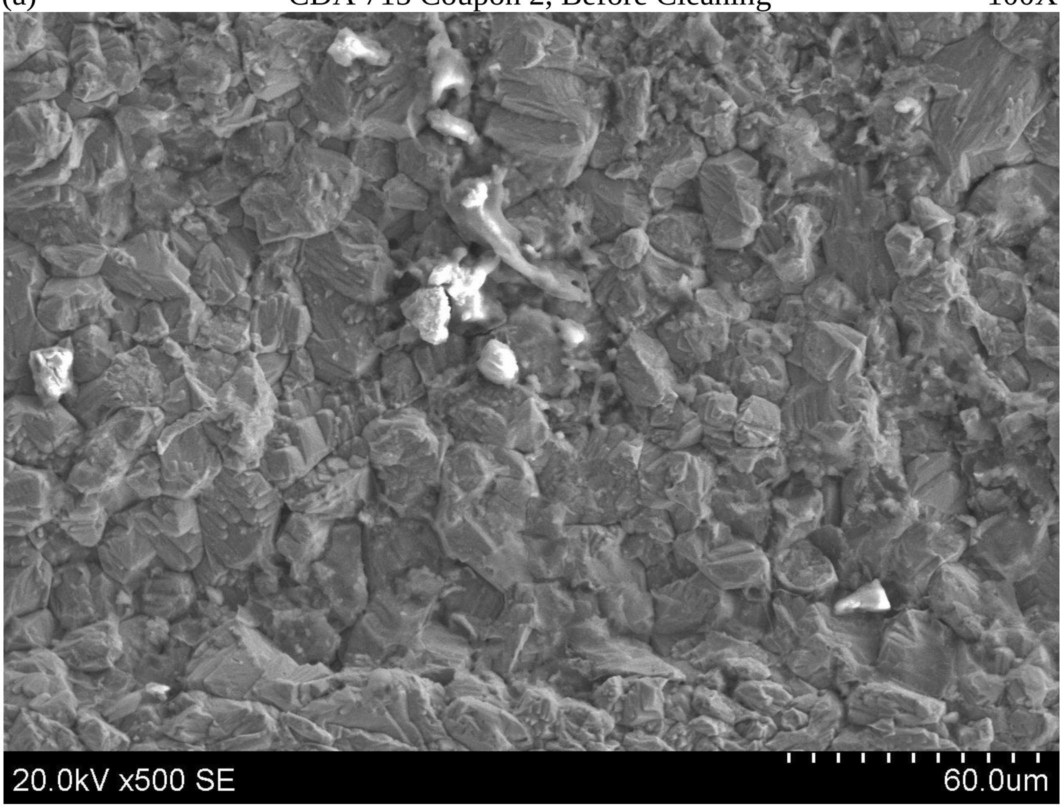
(b) CDA 715 Coupon 1, After Cleaning 500X

Figure 21 Scanning electron micrographs of CDA 715 coupon 1 after a 3 month immersion test, after cleaning

.

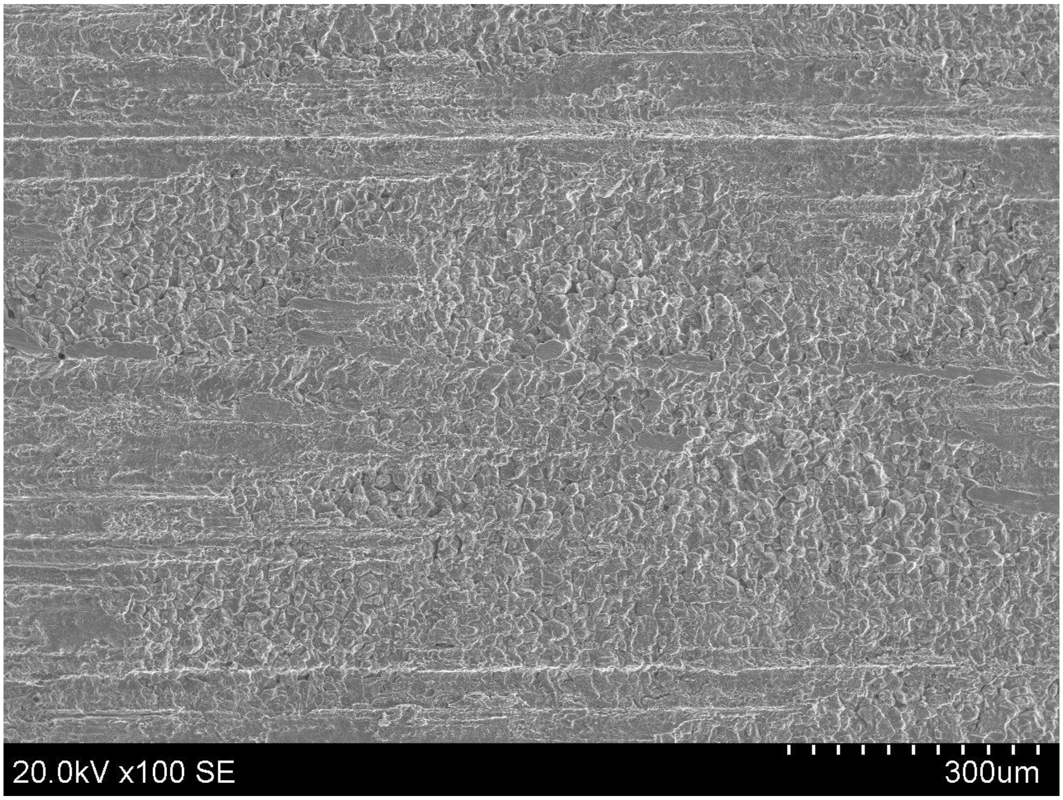


(a) CDA 715 Coupon 2, Before Cleaning 100X

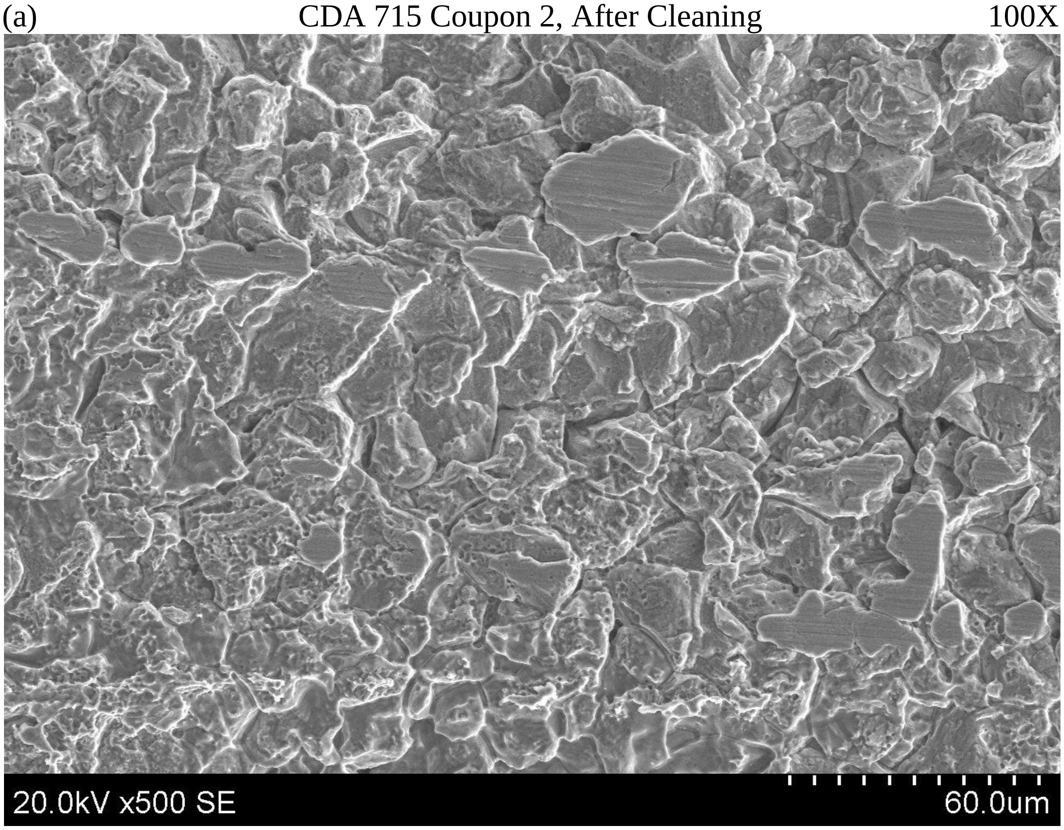


(b) CDA 715 Coupon 2, Before Cleaning 500X

Figure 22 Scanning electron micrographs of CDA 715 coupon 2 after a 6 month immersion test, before cleaning.

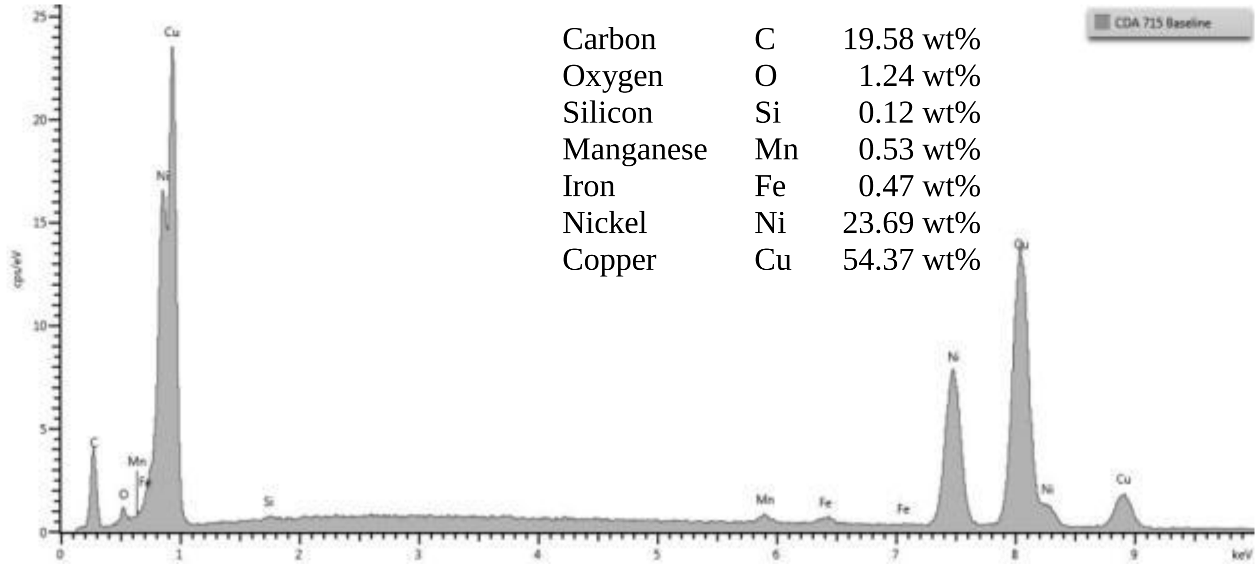


(a) CDA 715 Coupon 2, After Cleaning 100X



(b) CDA 715 Coupon 2, After Cleaning 500X

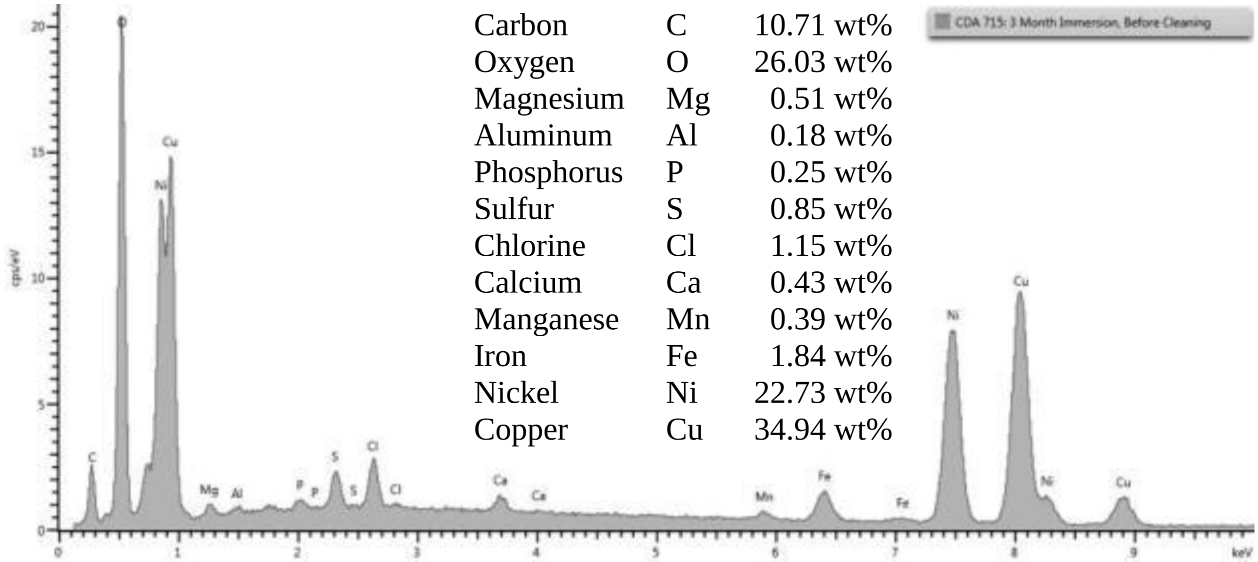
Figure 23 Scanning electron micrographs of CDA 715 coupon 2 after a 6 month immersion test, after cleaning



Carbon	C	19.58 wt%
Oxygen	O	1.24 wt%
Silicon	Si	0.12 wt%
Manganese	Mn	0.53 wt%
Iron	Fe	0.47 wt%
Nickel	Ni	23.69 wt%
Copper	Cu	54.37 wt%

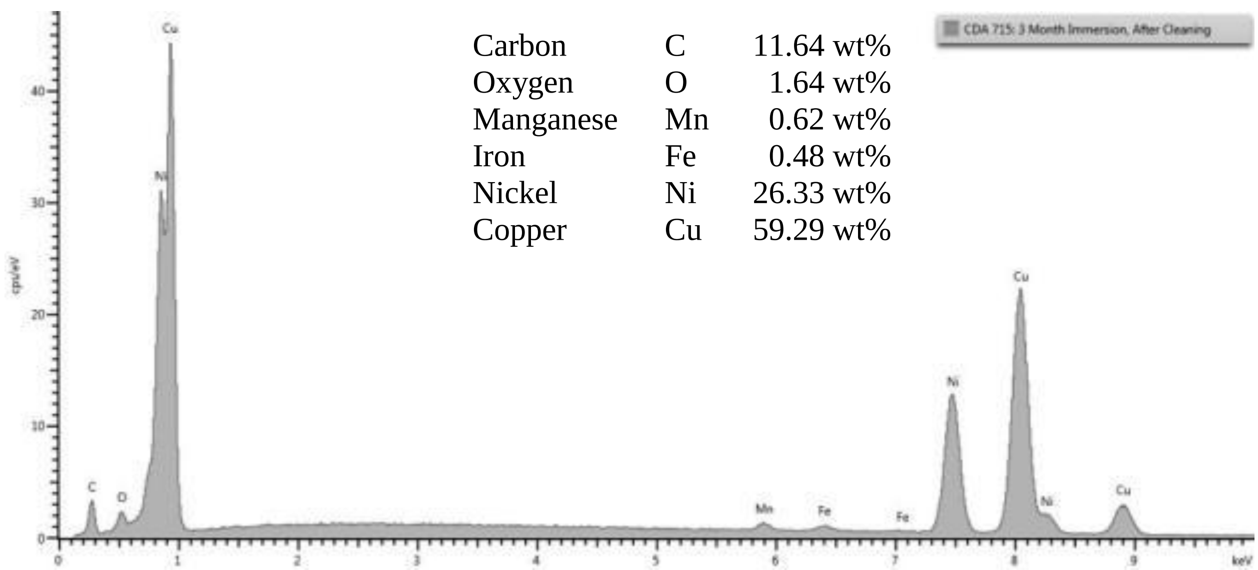
(a) CDA 715 Baseline Coupon

Figure 24 Energy dispersive x-ray spectra of the CDA 715 baseline coupon.



Carbon	C	10.71 wt%
Oxygen	O	26.03 wt%
Magnesium	Mg	0.51 wt%
Aluminum	Al	0.18 wt%
Phosphorus	P	0.25 wt%
Sulfur	S	0.85 wt%
Chlorine	Cl	1.15 wt%
Calcium	Ca	0.43 wt%
Manganese	Mn	0.39 wt%
Iron	Fe	1.84 wt%
Nickel	Ni	22.73 wt%
Copper	Cu	34.94 wt%

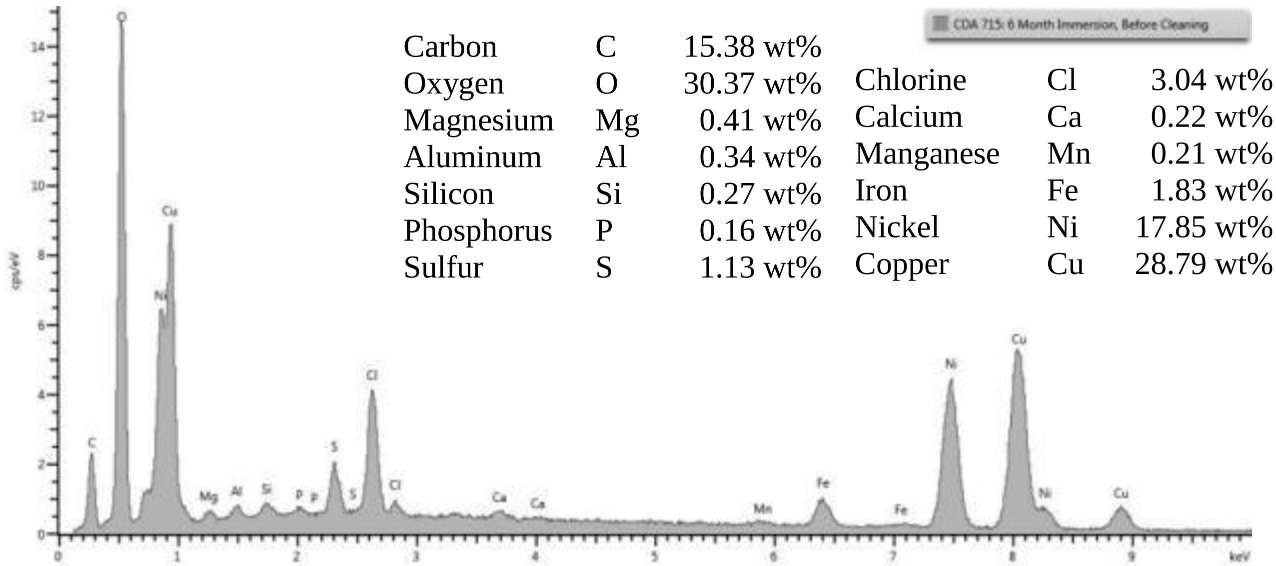
(a) CDA 715 Coupon 1, Before Cleaning



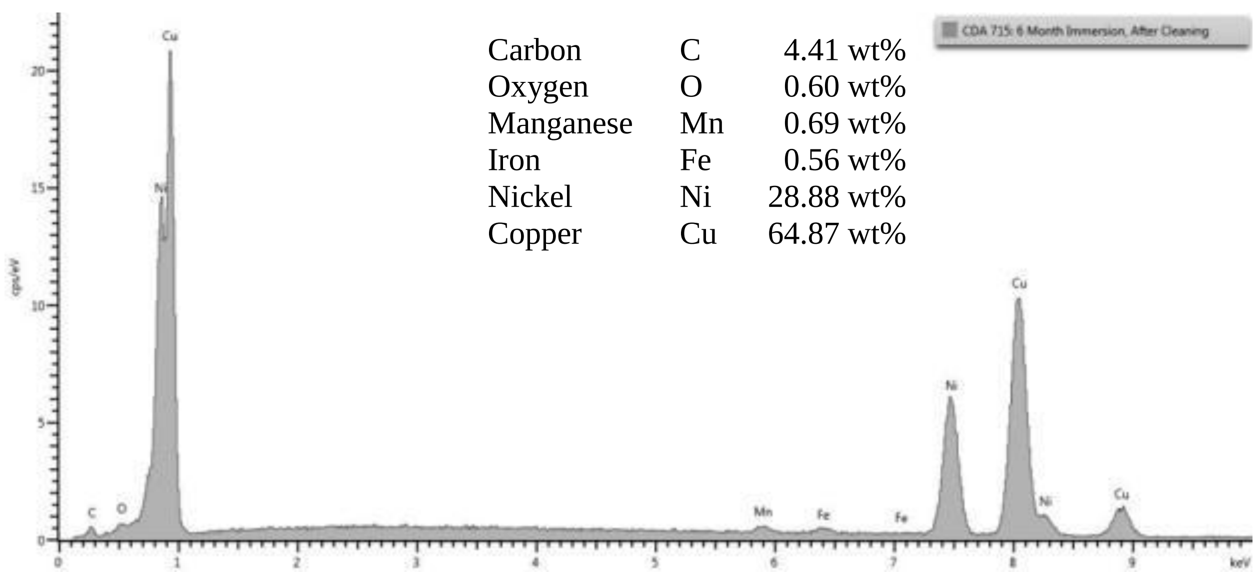
Carbon	C	11.64 wt%
Oxygen	O	1.64 wt%
Manganese	Mn	0.62 wt%
Iron	Fe	0.48 wt%
Nickel	Ni	26.33 wt%
Copper	Cu	59.29 wt%

(b) CDA 715 Coupon 1, After Cleaning

Figure 25 Energy dispersive x-ray spectra of CDA 715 coupon 1 after a 3 month corrosion test (a) before cleaning and (b) after cleaning.

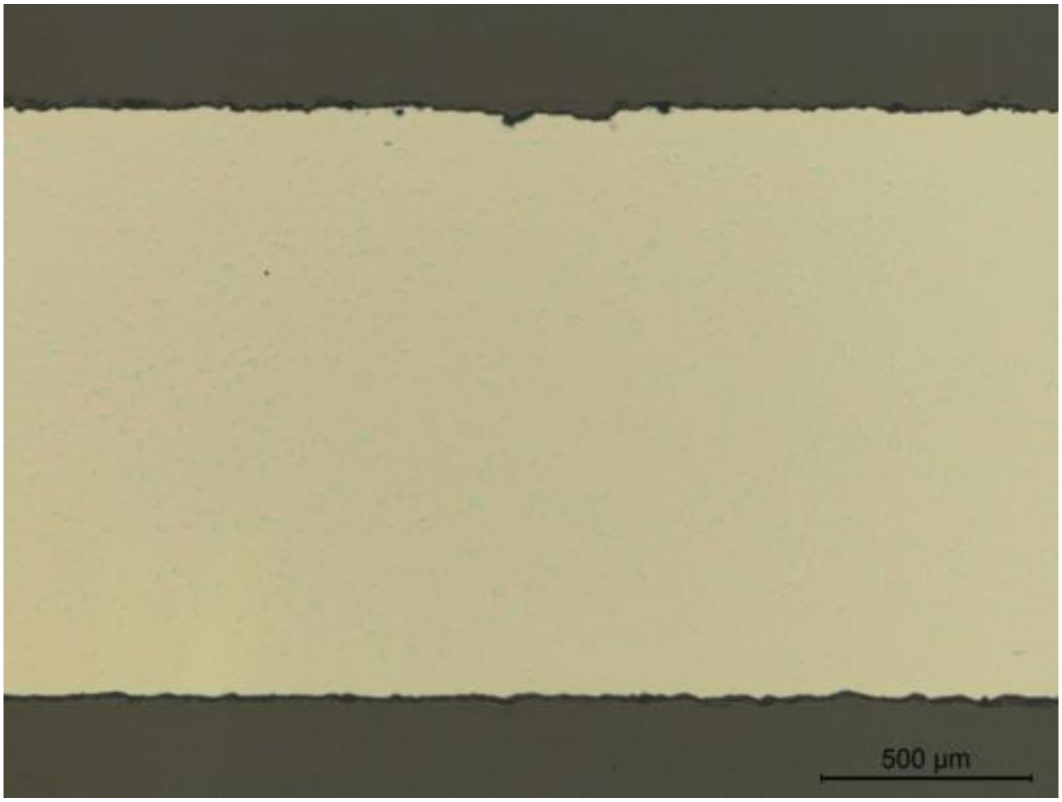


(a) CDA 715 Coupon 2, Before Cleaning

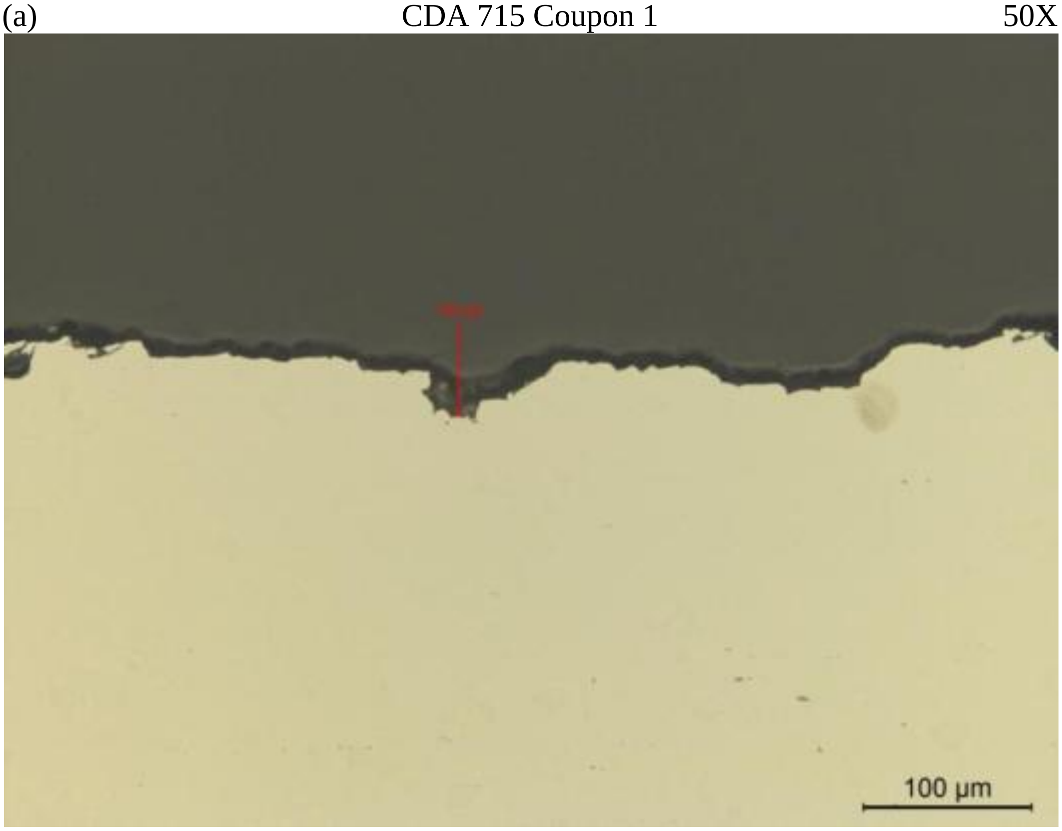


(b) CDA 715 Coupon 2, After Cleaning

Figure 26 Energy dispersive x-ray spectra of CDA 715 coupon 2 after a 6 month corrosion test (a) before cleaning and (b) after cleaning.



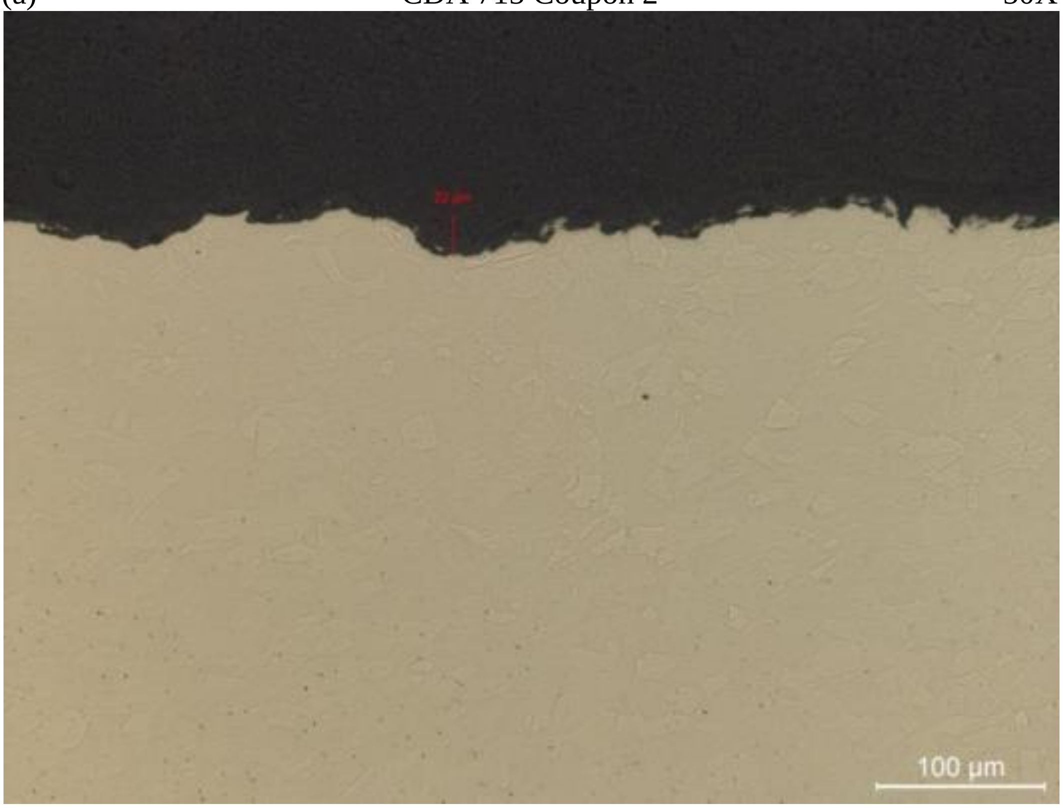
(a) CDA 715 Coupon 1 50X



(b) CDA 715 Coupon 1 200X

Figure 27 Optical micrographs of CDA 715 coupon 1.

(a) CDA 715 Coupon 2 50X



(b) CDA 715 Coupon 2 200X

Figure 28 Optical micrographs of CDA 715 coupon 2.

Report No. 5005.0361E **January 30, 2015**

CORROSION EVALUATION OF Z-ALLOY COUPONS AND SCREENS

Customer Authorization: Verbal

Report To: V & A Engineering
Attn: Manuel Najar
155 Grand Avenue, Suite 700
Oakland, CA 94612

1.0 INTRODUCTION

Five coupons, five wedge wire screens, and one plate were submitted by V&A Engineering for corrosion evaluation. The coupons were 1-inch by 3-inches by ¼-inch thick. The wedge wire screens were 4-inches by 4-inches by 1-inch tall with 2 mm spacing. The plate was 4-inches by 4-inches by 1/8-inch thick. The sample was reportedly a Z-Alloy, a proprietary material from Johnson Screens.

Four coupons and four screens were to be placed in seawater for a period up to one year. After every 3 month interval, one coupon and one screen were to be removed from the test system and examined for corrosion. The purpose of this evaluation was to document the samples in the baseline as-received condition, then again after 3, 6, 9, and 12 months of water exposure, record any loss in mass, examine for any pitting corrosion, and estimate the corrosion rate.

The samples were evaluated by the following laboratory procedures:

1) Visual examination and weighing
2) Cleaning per ASTM G1[1]
3) Scanning electron microscopy
4) Metallography

The results of the evaluation showed moderate mass loss and corrosion for the coupon and screen after 3 months and 6 months of corrosion testing. The coupon and screen, after 3 months of corrosion testing, had a corrosion rate of approximately 0.015 millimeters per year and 0.113 millimeters per year, respectively. The coupon and screen, after 6 months of corrosion testing, had a corrosion rate of approximately 0.010 millimeters per year and 0.062 millimeters per year, respectively.

[1] G1: Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

2.0 EVALUATION[2]

2.1 Visual Examination

The sample identifications for the coupons and wedge wire screens and their corresponding immersion times are shown in Table 1. The coupons had identification numbers stamped on the front face by V&A Engineering. A number of notches, corresponding to the sample number, were sawed at the edge of each screen for identification after the corrosion test. The weights of the samples were recorded. Coupons 1 – 4 and screens 1 – 5 were sent back to V&A for corrosion testing. Coupons 5 and 6 were the baseline samples and documented by photography, optical stereoscopy and scanning electron microscopy for comparison to the tested samples. Screen 5 was documented as a baseline by photography and optical stereoscopy, and then sent to V&A for testing.

Photographs of the baseline coupon are shown in Figure 1. Photographs of coupon 1, after 3 months of corrosion testing, are shown in Figure 2. Photographs of coupon 2, after 6 months of corrosion testing, are shown in Figure 3.

A photograph of the baseline screen is shown in Figure 4. A photograph of screen 1, after 3 months of corrosion testing, is shown in Figure 5. A photograph of screen 2, after 6 months of corrosion testing, is shown in Figure 6.

2.2 Cleaning

The coupon and screen were cleaned with solution C.2.1 per ASTM G1.[3] One cleaning cycle was approximately 1 minute. After each cleaning cycle, the samples were rinsed in water, dried, and weighed. The cleaning and weighing cycle was completed five times for the coupon and screen. The weights of the samples as-received, after corrosion testing but before cleaning, and after each cleaning cycle are presented in Table 2.

Optical macrographs of the baseline coupon and screen are shown in Figures 7 and 12, respectively. Representative optical macrographs of the samples after a 3 month corrosion test, before and after cleaning, are shown in Figures 8 – 9 and 13 – 14. Representative optical macrographs of the sample after a 6 month corrosion test, before and after cleaning, are shown in Figures 10 – 11 and 15 – 16.

The mass loss versus the number of cleaning cycles was plotted, shown in Figures 17 – 18. The equations for best fit lines AB and BC, calculated using IGOR Pro, are listed in Table 3. Point B, indicated by the red circle in each plot, corresponds to the mass loss due to corrosion during the cleaning process for each sample. This mass loss was subtracted from the weight of the sample before cleaning and from the weight of the sample as-received to determine the total mass loss from corrosion. The corrosion rate of each sample was determined by the formula specified in Section 8.1 of ASTM G1:

[2] The magnifications of the optical and scanning electron micrographs in this report are approximate and should not be used as a basis for dimensional analyses unless otherwise indicated.
[3] 500 mL hydrochloric acid + 500 ml reagent water.

$$Corrosion\ Rate = \frac{K\ x\ W}{A\ x\ T\ x\ D}$$

where K = 8.76 x 10^4, T = time of exposure in hours, A = area in cm^2, W = mass loss in grams, and D = density in g/cm^3. The density of the Z-Alloy was determined by cutting a section out of the baseline coupon, measuring the length, width, and thickness, and weighing the section with a balance. The total mass loss from corrosion and the calculated corrosion rate of each sample is shown in Table 4.

2.3 Scanning Electron Microscopy

The baseline coupon, coupon 1, and coupon 2 were examined with a scanning electron microscope. Representative scanning electron micrographs of the baseline coupon are shown in Figure 19. Representative scanning electron micrographs of coupon 1 before and after cleaning are shown in Figures 20 – 21. Representative scanning electron micrographs of coupon 2 before and after cleaning are shown in Figures 22 – 23.

An energy dispersive x-ray spectrum of the baseline coupon is shown in Figure 24. Energy dispersive x-ray spectra of coupon 1 before and after cleaning are shown in Figure 25. Energy dispersive x-ray spectra of coupon 2 before and after cleaning are shown in Figure 26.

2.4 Metallography

Cross sections were taken from the coupon and prepared for a metallographic examination. An optical micrograph of the surface for coupon 1 is shown in Figure 27. A wide, shallow pit was observed in coupon 1, measuring 0.2 mm in depth. An optical micrograph of the surface for coupon 2 is shown in Figure 28. Small pits were observed in coupon 2, measuring 13 mm in depth.

3.0 DISCUSSION

The coupon and screen showed moderate mass loss and pitting after 3 and 6 months of corrosion testing.

After 3 months of corrosion testing, the coupon had lost 0.172 grams of material and had a corrosion rate of 0.015 millimeters per year. After 3 months of corrosion testing, the screen had lost 14.96 grams of material and had a corrosion rate of 0.113 millimeters per year.

After 6 months of corrosion testing, the coupon had lost 0.236 grams of material and had a corrosion rate of 0.010 millimeters per year. After 6 months of corrosion testing, the screen had lost 16.71 grams of material and had a corrosion rate of 0.062 millimeters per year.

4.0 CONCLUSIONS[4]

The following conclusions are based upon the submitted samples and the evidence gathered:

1. The coupon, after 3 months of corrosion testing, had a mass loss of 0.172 grams and a corrosion rate of 0.015 mm / year.

2. The screen, after 3 months of corrosion testing, had a mass loss of 14.96 grams and a corrosion rate of 0.113 mm / year.

3. The coupon, after 6 months of corrosion testing, had a mass loss of 0.236 grams and a corrosion rate of 0.010 mm / year.

4. The screen, after 6 months of corrosion testing, had a mass loss of 16.71 grams and a corrosion rate of 0.062 mm / year.

Prepared by:

Norman Yuen
Materials Engineer

Reviewed by:

Audrey A. Fasching, Ph.D., P.E.
Senior Materials Engineer

[4] The conclusions in this report are based upon the available information and evidence provided by the client and gathered by Anamet, within the scope of work authorized by the client, and they are hereby presented by Anamet to a reasonable degree of engineering and scientific certainty. Anamet reserves the right to amend or supplement its conclusions or opinions presented in this report should additional data or information become available, or further work be approved by the client.

Table 1
Sample Identifications

Description		V&A Engineering Identification (As-Received)	Anamet Identification (in report)	Notes
Alloy	Part			
Z Alloy	**Flat Plate** 4-inch x 4-inch x 1/8-inch	Z	Plate	None
	Coupon 1-inch x 3-inch x 1/8-inch with autogenous weld bead	1	Coupon 1	3 Month Immersion
		2	Coupon 2	6 Month Immersion
		3	Coupon 3	9 Month Immersion
		4	Coupon 4	12 Month Immersion
		5	Coupon 5	Baseline Sample (no exposure)
		6	Coupon 6	Baseline Sample (no exposure)
	Wedge Wire Screen 4-inch x 4-inch x 1-inch with 2 mm spacing	None	Screen 1	3 Month Immersion
		None	Screen 2	6 Month Immersion
		None	Screen 3	9 Month Immersion
		None	Screen 4	12 Month Immersion
		None	Screen 5	12 Month Immersion

Table 2
Sample Weights

Sample	Baseline Measurement	Measurements after 3 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 1	26.8665	26.7135	26.6958	26.6926	26.6911	26.6887	26.6872
Screen 1	361.74	352.24	348.56	346.76	346.62	346.50	346.48

Sample	Baseline Measurement	Measurements after 6 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 2	27.0660	26.8593	26.8299	26.8273	26.8255	26.8230	26.8211
Screen 2	359.36	347.99	342.66	342.58	342.48	342.44	-

Table 3
Equations of Line AB and BC for Corrosion Testing Samples

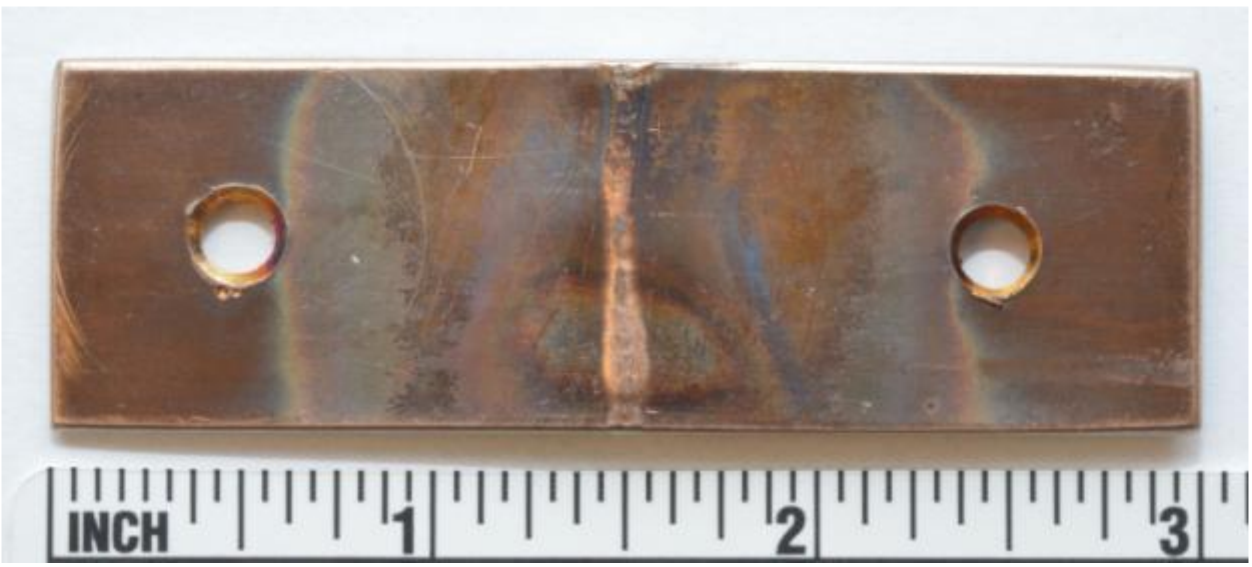
Sample	Line AB	Line BC	Point B (Approximate Mass Loss from Corrosion During Cleaning)
Coupon 1	y = 0.018x	y = 0.002x + 0.017	0.019 grams
Coupon 2	y = 0.029x	y = 0.002x + 0.027	0.029 grams
Screen 1	y = 3.68x	y = 0.10x + 5.31	5.46 grams
Screen 2	y = 5.33x	y = 0.08x + 5.26	5.34 grams

Table 4
Total Mass Loss from Corrosion and Corrosion Rate

Sample	Total Mass Loss from Corrosion*	Corrosion Rate
Coupon 1	0.172 grams	0.015 mm / year
Coupon 2	0.236 grams	0.010 mm / year
Screen 1	14.96 grams	0.113 mm / year
Screen 2	16.71 grams	0.062 mm / year

* Weight As-Received – (Weight Before Cleaning – Mass Loss from Corrosion During Cleaning)

(a) Z-Alloy Baseline Coupon, Front Side



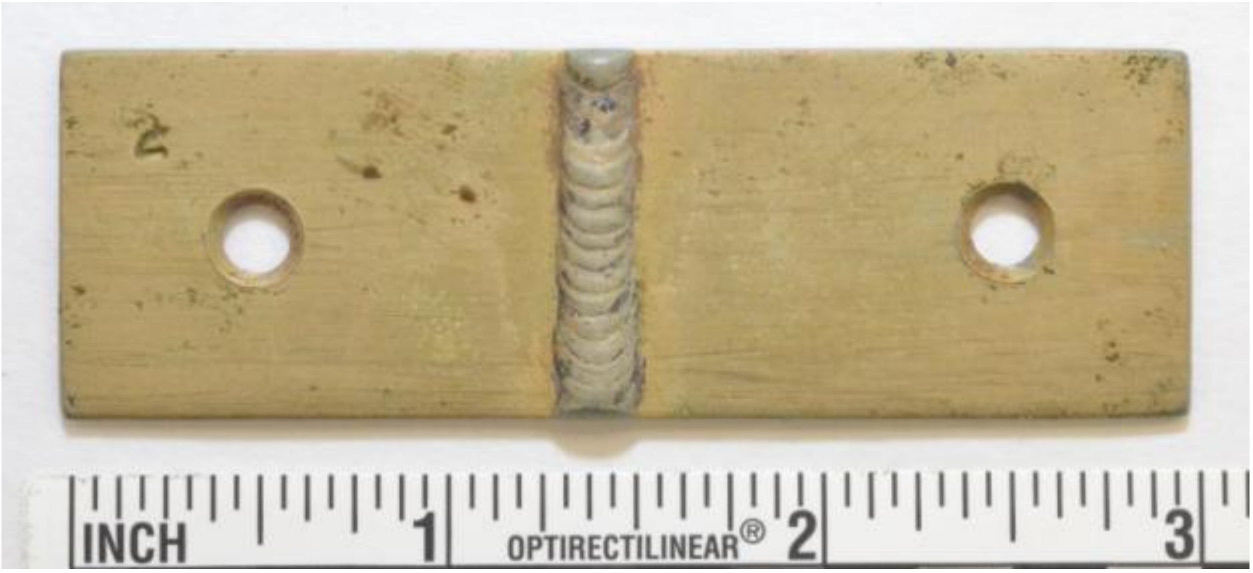
(b) Z-Alloy Baseline Coupon, Back Side

Figure 1 Photographs of the Z-Alloy baseline coupon (a) front and (b) back side.

(a) Z-Alloy Coupon 1 Front Side

(b) Z-Alloy Coupon 1 Back Side

Figure 2 Photographs of Z-Alloy coupon 1 (a) front and (b) back side after a 3 month corrosion test.



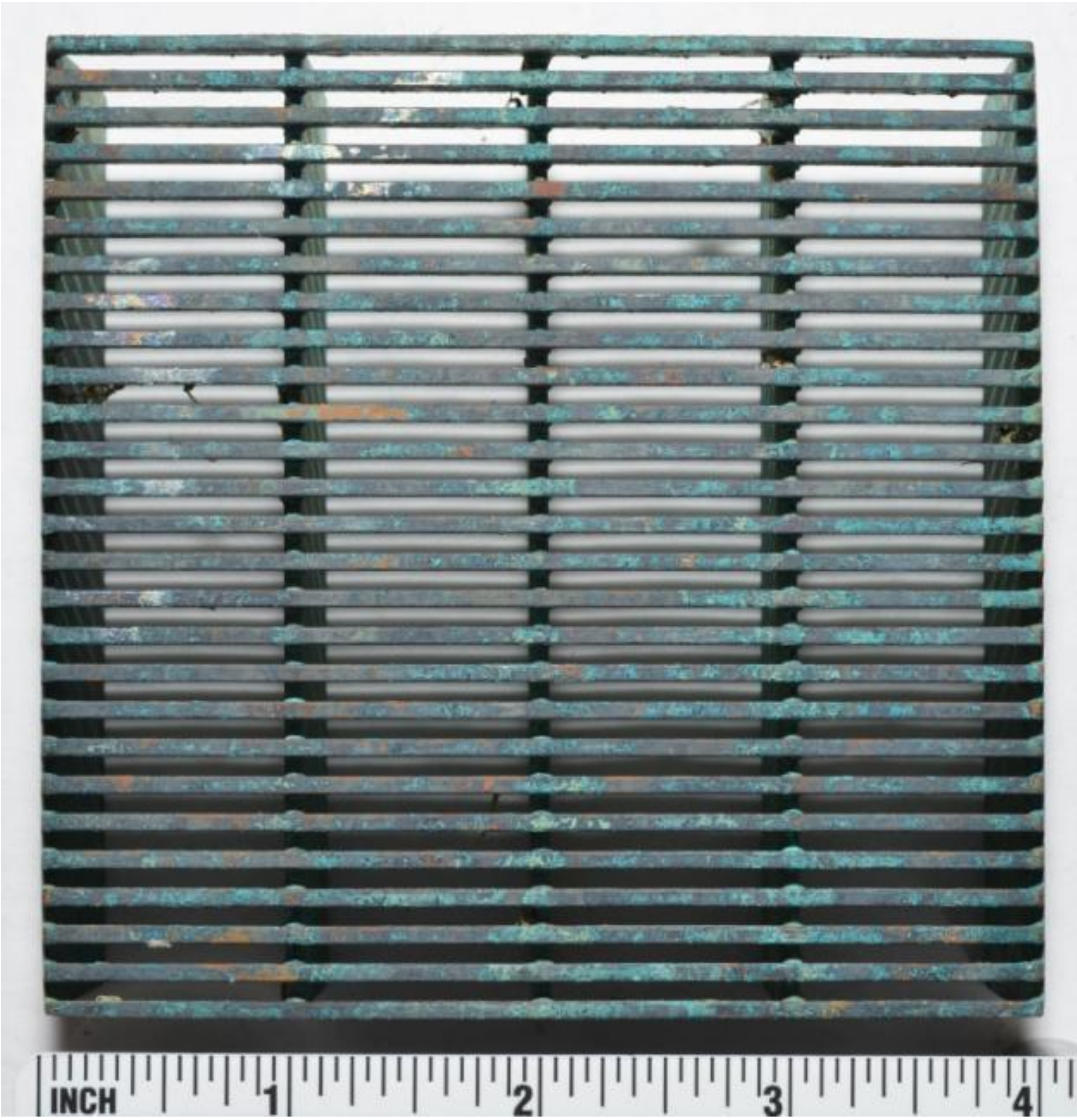
(a) Z-Alloy Coupon 2 Front Side

(b) Z-Alloy Coupon 2 Back Side

Figure 3 Photographs of Z-Alloy coupon 2 (a) front and (b) back side after a 6 month corrosion test.

(a) Z-Alloy Baseline Screen

Figure 4 Photograph of the Z-Alloy baseline screen.



(a) Z-Alloy Screen 1

Figure 5 Photograph of Z-Alloy screen 1 after a 3 month corrosion test.

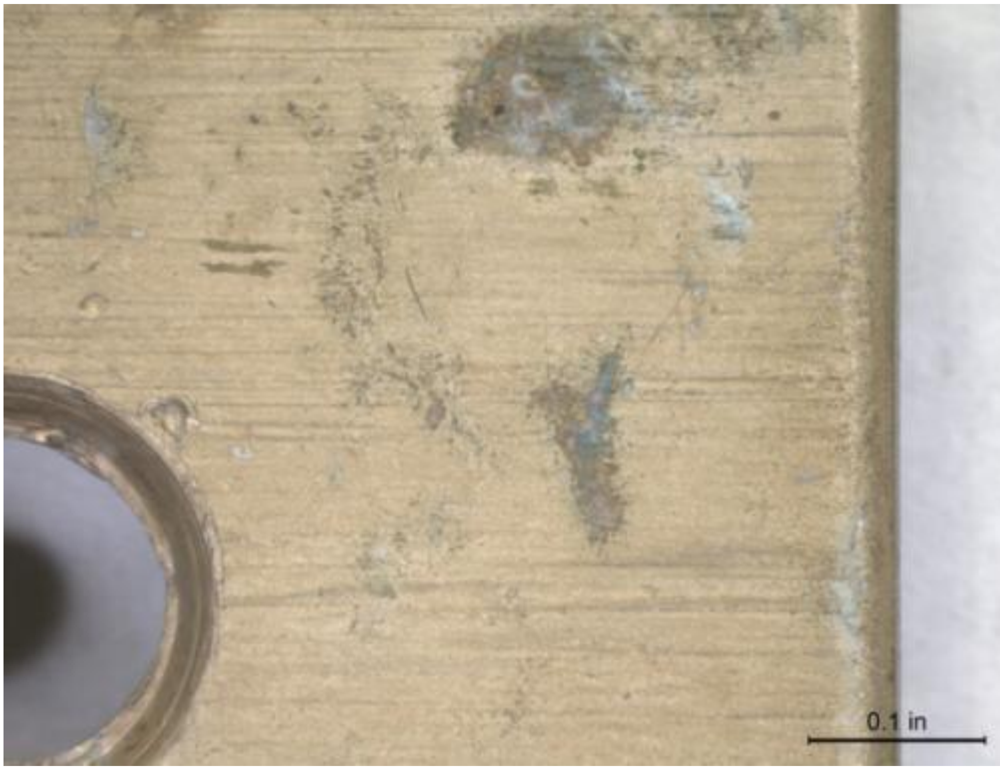
(a) Z-Alloy Screen 2

Figure 6 Photograph of Z-Alloy screen 2 after a 6 month corrosion test.

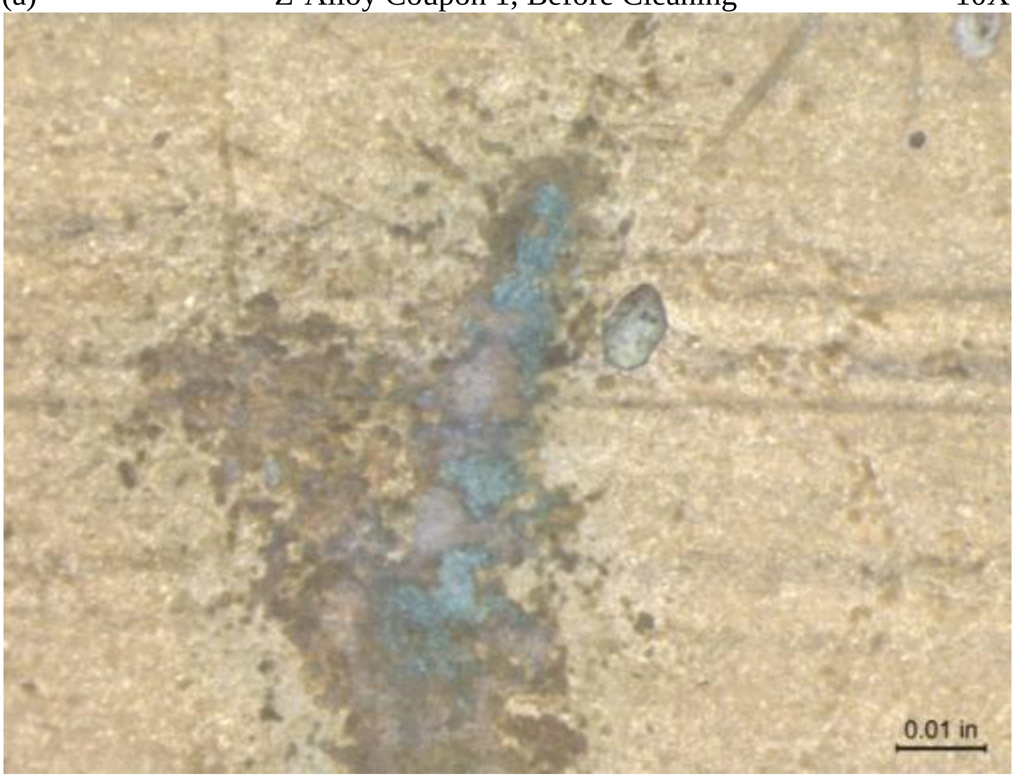
(a) Z-Alloy Baseline Coupon 10X

(b) Z-Alloy Baseline Coupon 50X

Figure 7 Optical macrographs of the Z-Alloy baseline coupon.

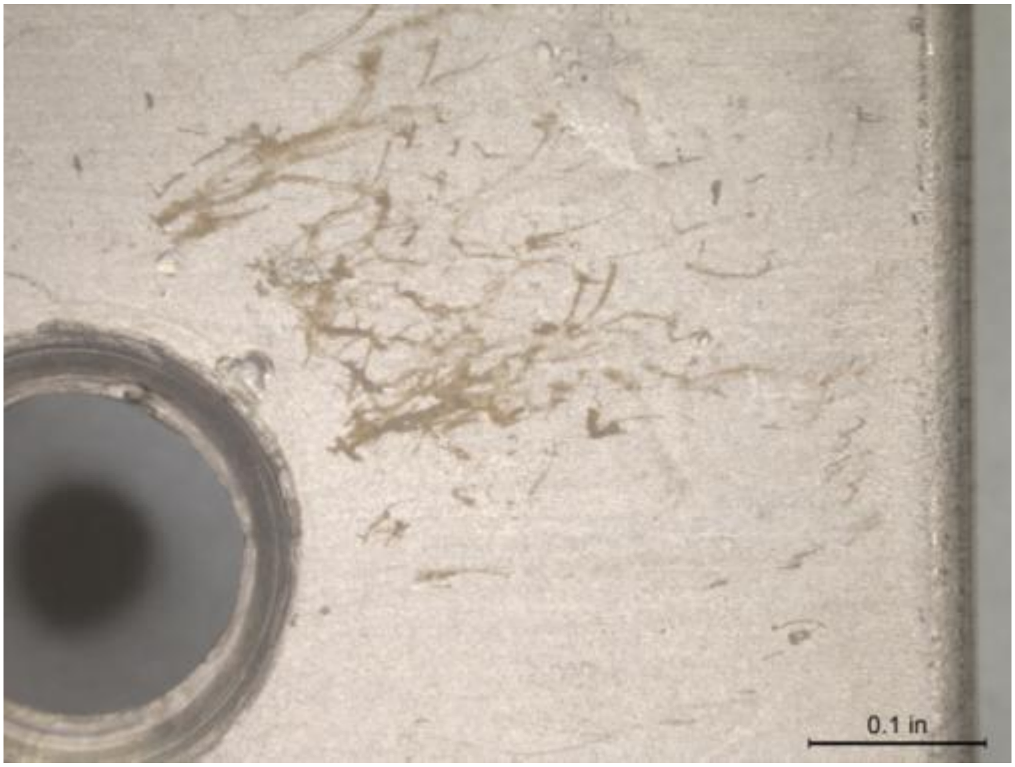


(a) Z-Alloy Coupon 1, Before Cleaning 10X



(b) Z-Alloy Coupon 1, Before Cleaning 50X

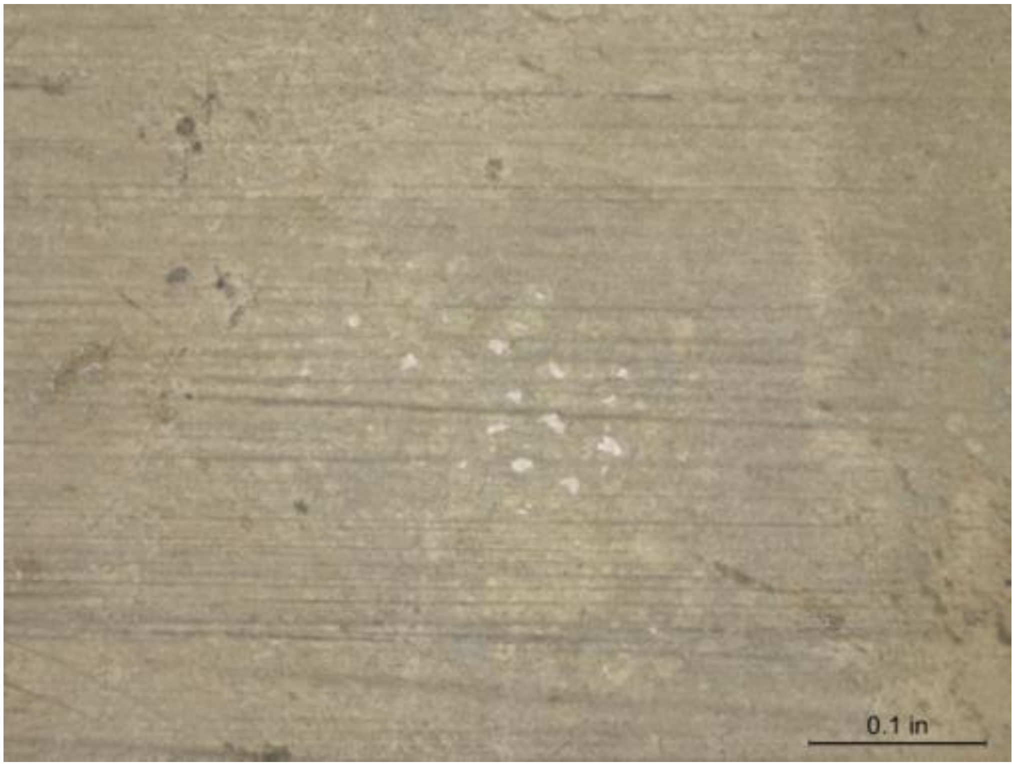
Figure 8 Optical macrographs of Z-Alloy coupon 1 after a 3 month corrosion test, before cleaning.



(a) Z-Alloy Coupon 1, After Cleaning 10X

(b) Z-Alloy Coupon 1, After Cleaning 50X

Figure 9 Optical macrographs of Z-Alloy coupon 1 after a 3 month corrosion test, after cleaning.

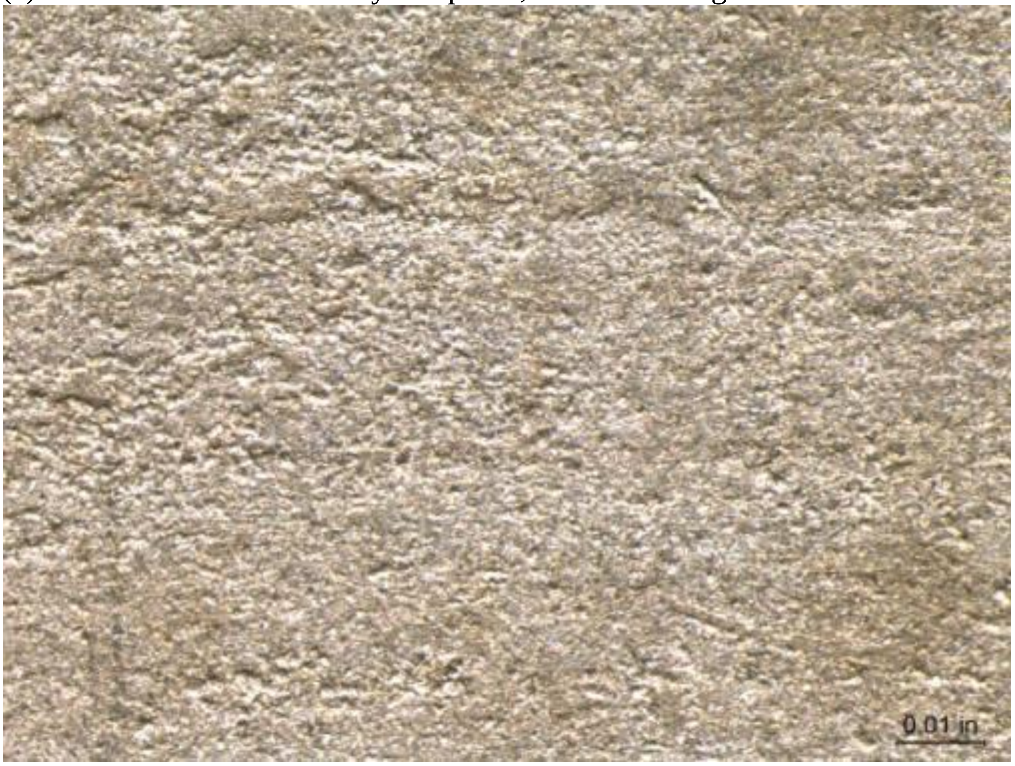


(a) Z-Alloy Coupon 2, Before Cleaning 10X

(b) Z-Alloy Coupon 2, Before Cleaning 50X

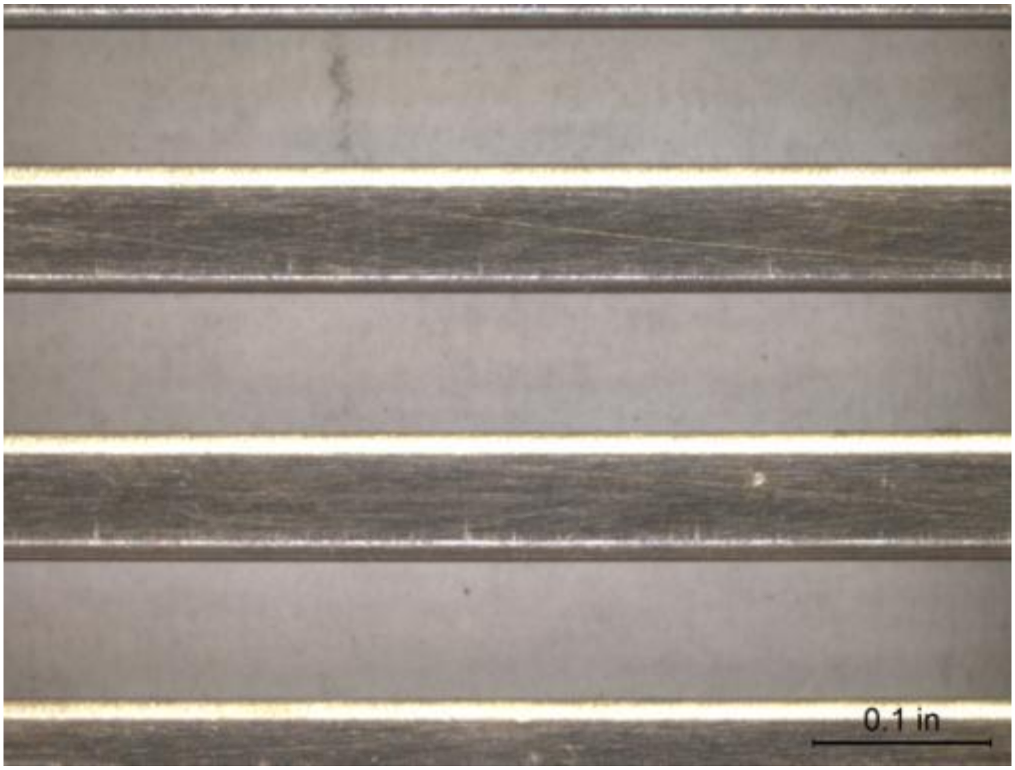
Figure 10 Optical macrographs of Z-Alloy coupon 2 after a 6 month corrosion test, before cleaning.

(a) Z-Alloy Coupon 2, After Cleaning 10X

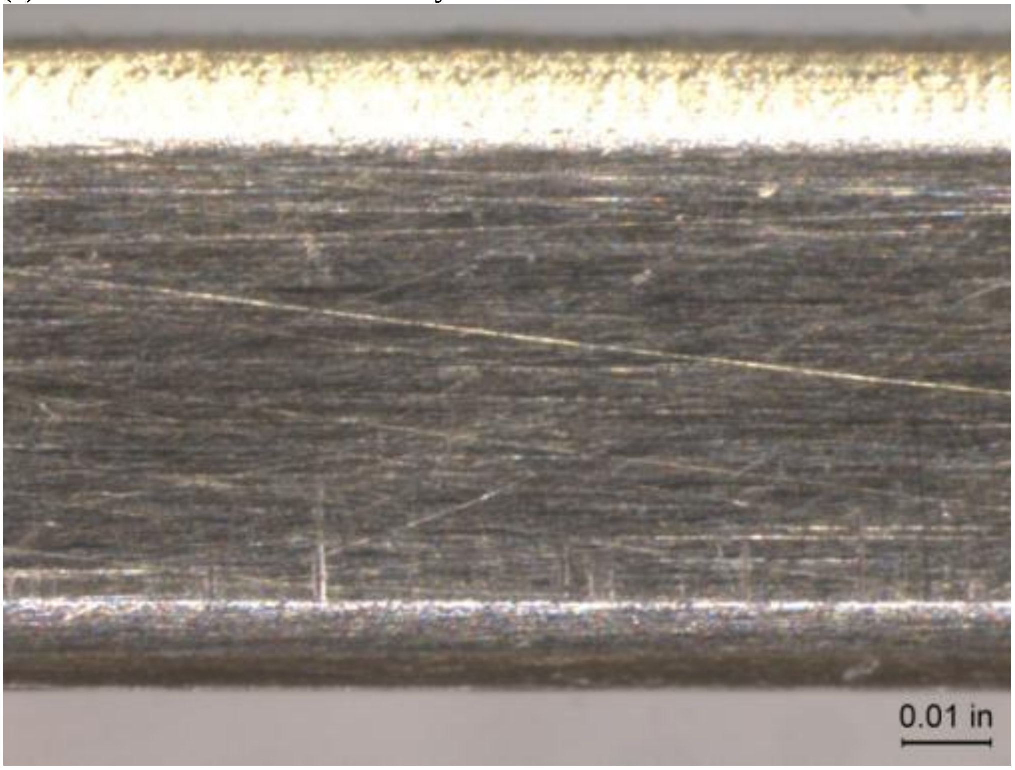


(b) Z-Alloy Coupon 2, After Cleaning 50X

Figure 11 Optical macrographs of Z-Alloy coupon 2 after a 6 month corrosion test, after cleaning.

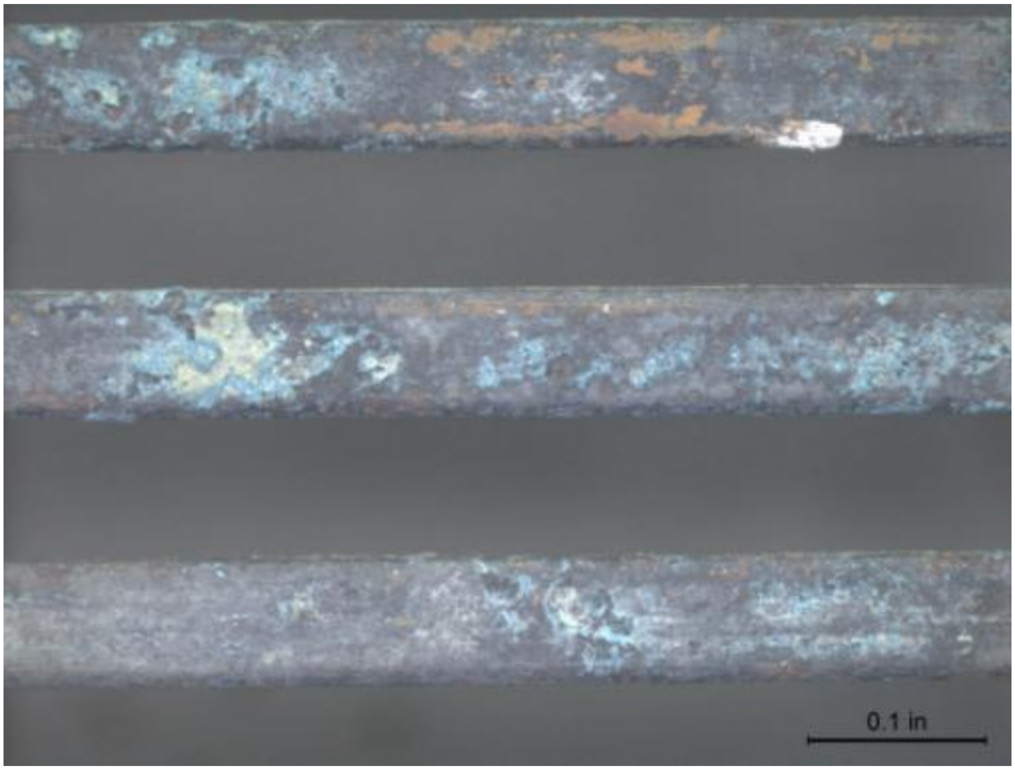


(a) Z-Alloy Baseline Screen 10X

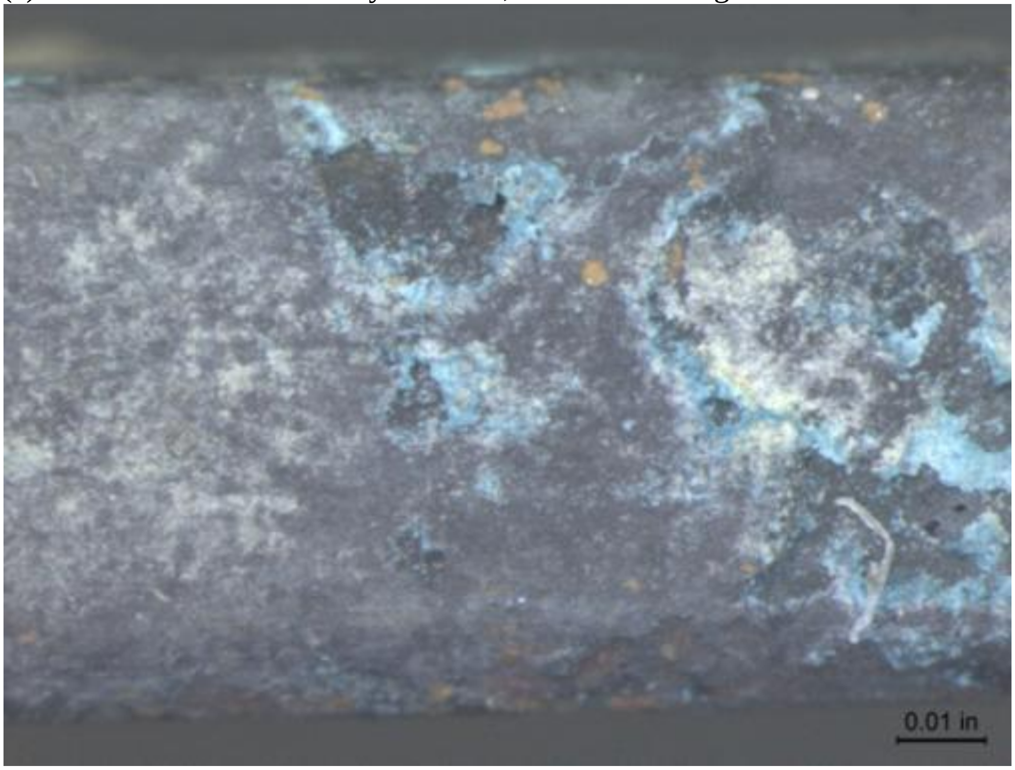


(b) Z-Alloy Baseline Screen 50X

Figure 12 Optical macrographs of the Z-Alloy baseline screen.

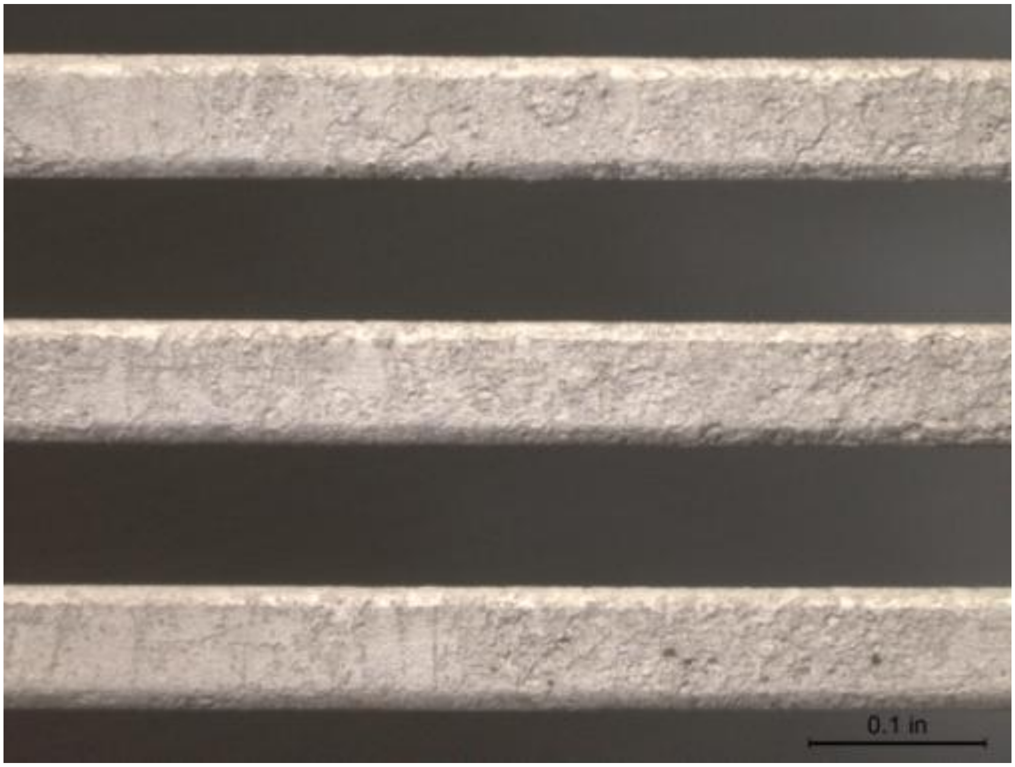


(a) Z-Alloy Screen 1, Before Cleaning 10X

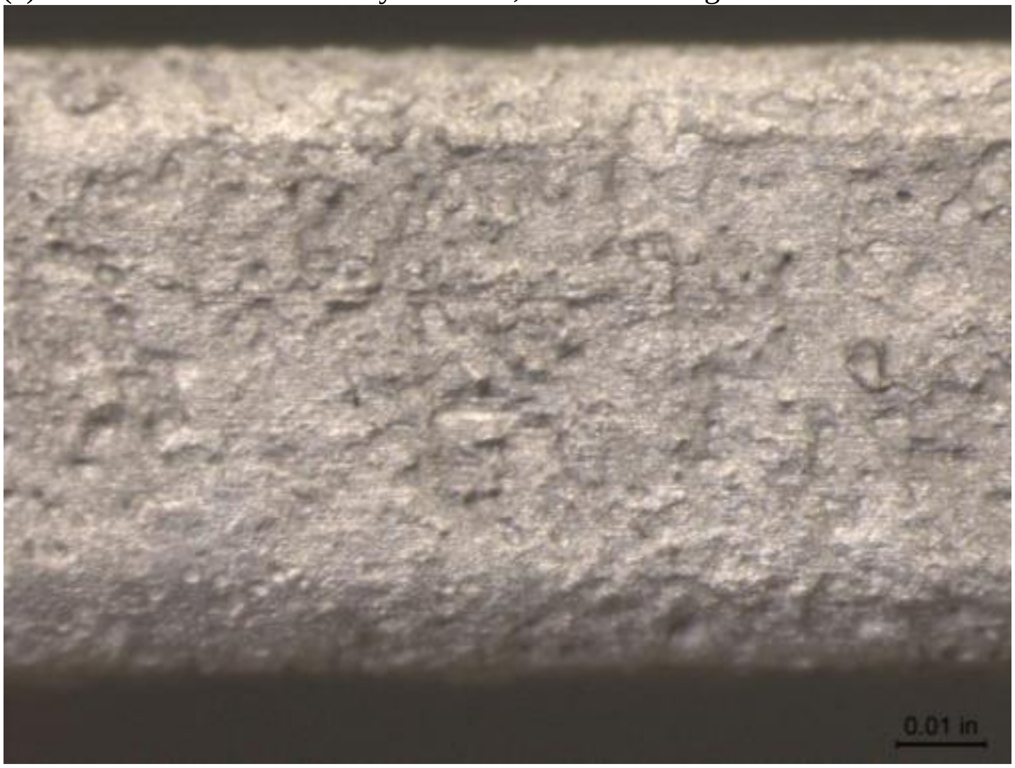


(b) Z-Alloy Screen 1, Before Cleaning 50X

Figure 13 Optical macrographs of Z-Alloy screen 1 after a 3 month corrosion test, before cleaning.

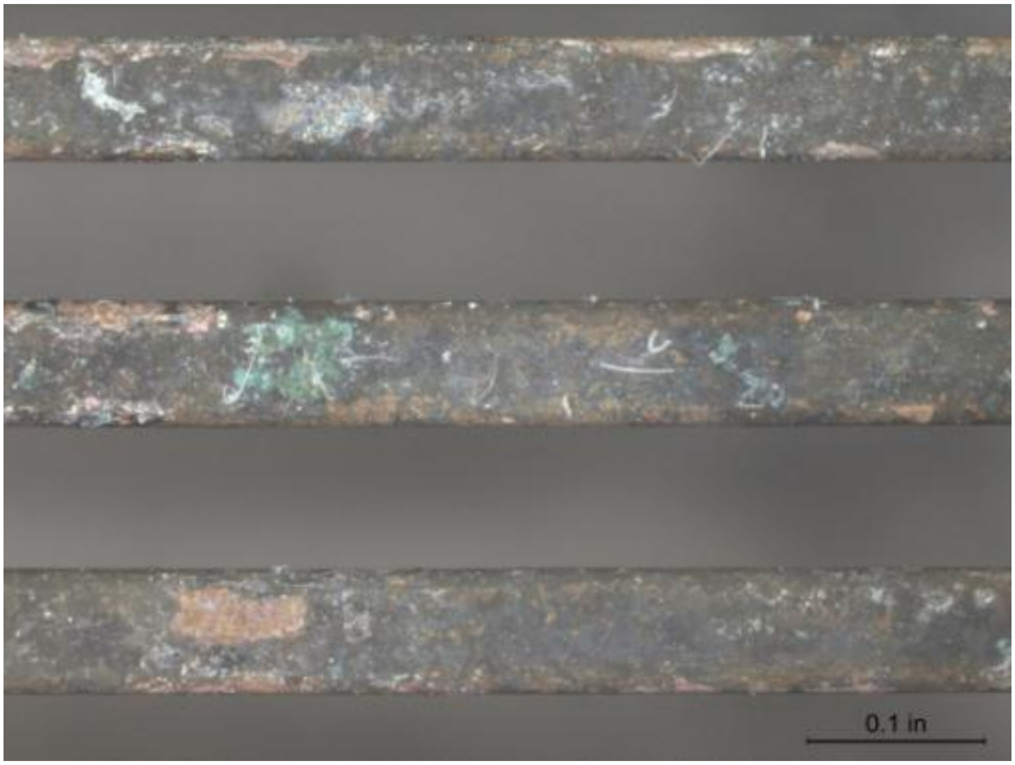


(a) Z-Alloy Screen 1, After Cleaning 10X



(b) Z-Alloy Screen 1, After Cleaning 50X

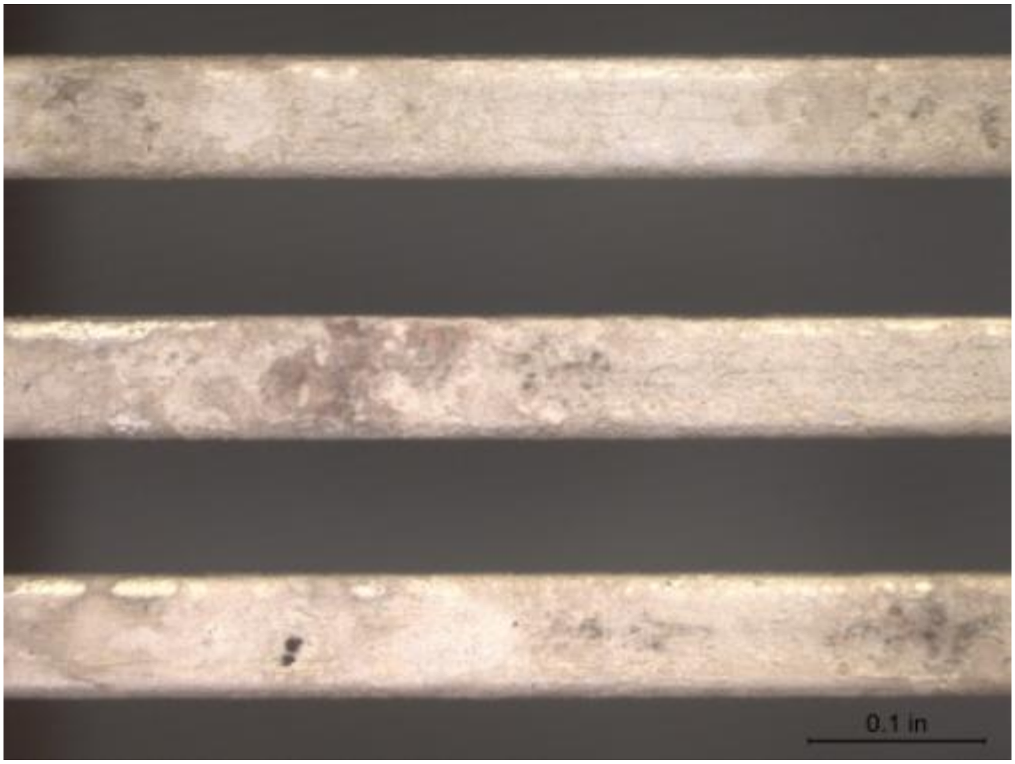
Figure 14 Optical macrographs of Z-Alloy screen 1 after a 3 month corrosion test, after cleaning.



(a) Z-Alloy Screen 2, Before Cleaning 10X

(b) Z-Alloy Screen 2, Before Cleaning 50X

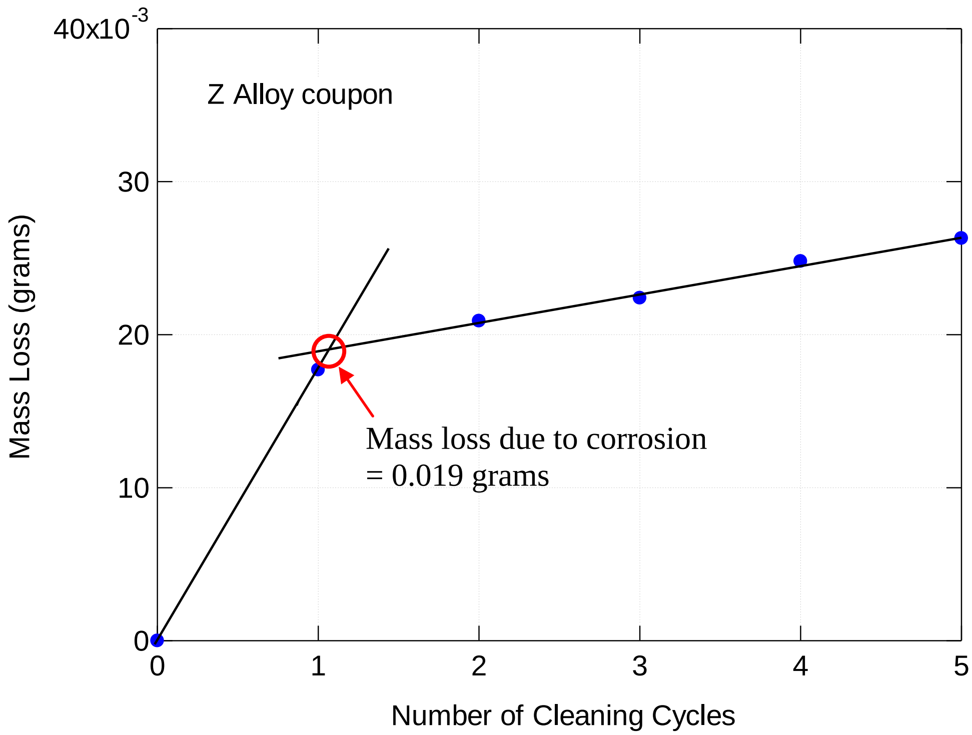
Figure 15 Optical macrographs of Z-Alloy screen 2 after a 6 month corrosion test, before cleaning.



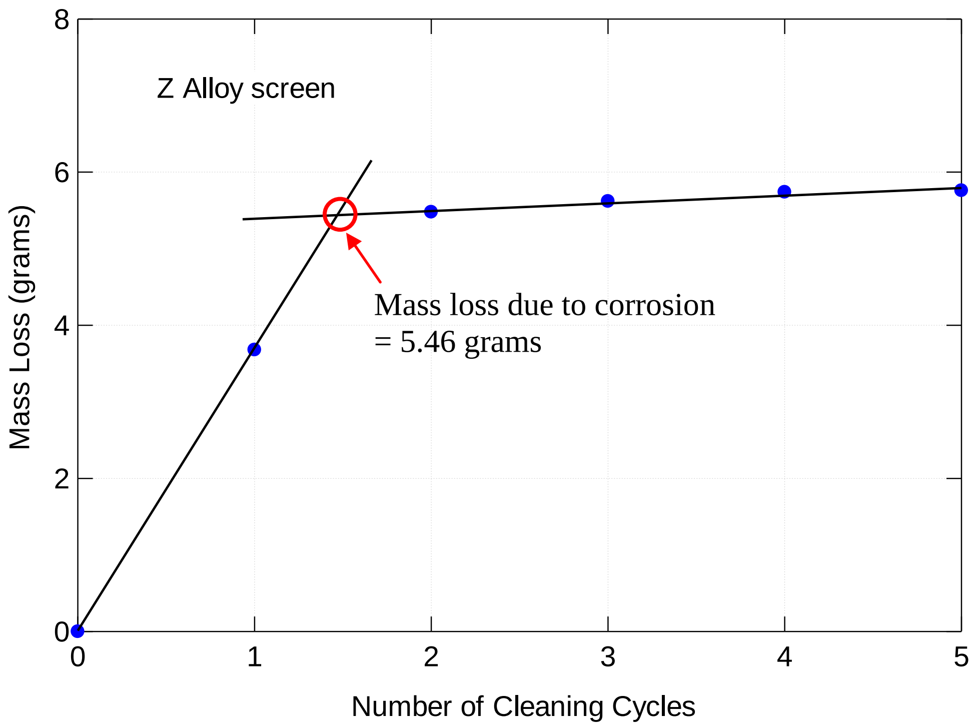
(a) Z-Alloy Screen 2, After Cleaning 10X

(b) Z-Alloy Screen 2, After Cleaning 50X

Figure 16 Optical macrographs of Z-Alloy screen 2 after a 6 month corrosion test, after cleaning.

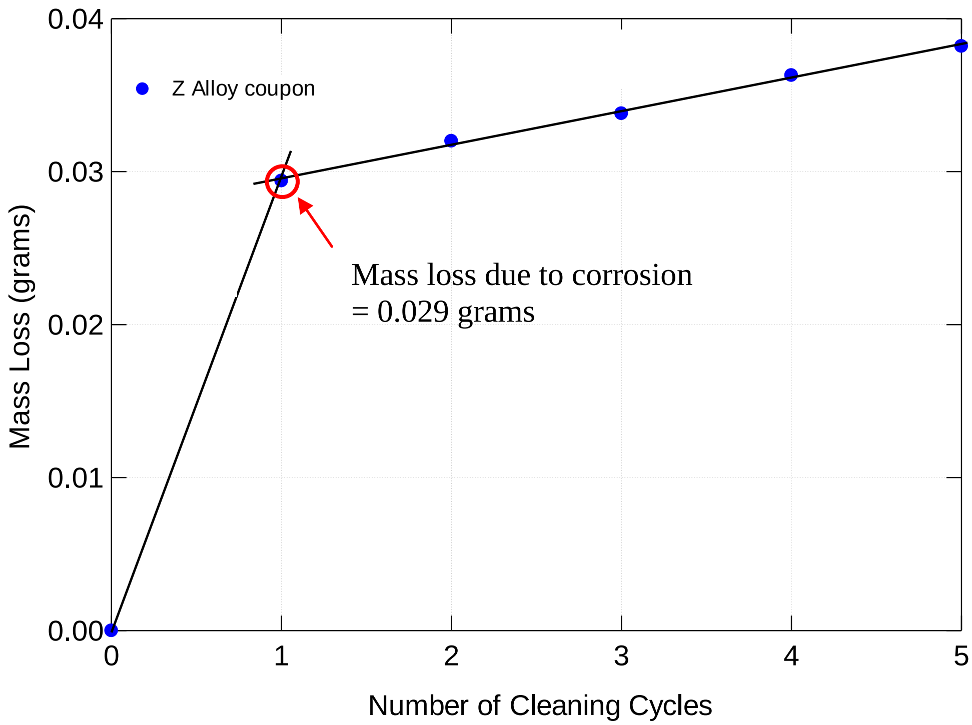


(a)

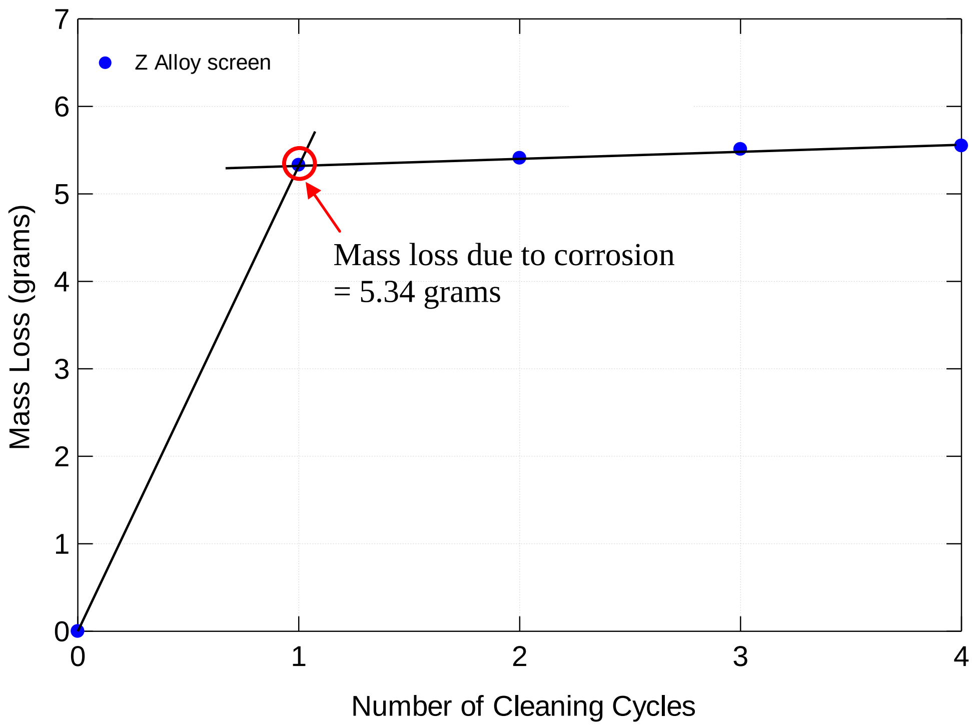


(b)

Figure 17 Mass loss of the Z-Alloy (a) coupon 1 and (b) screen 1 during cleaning.

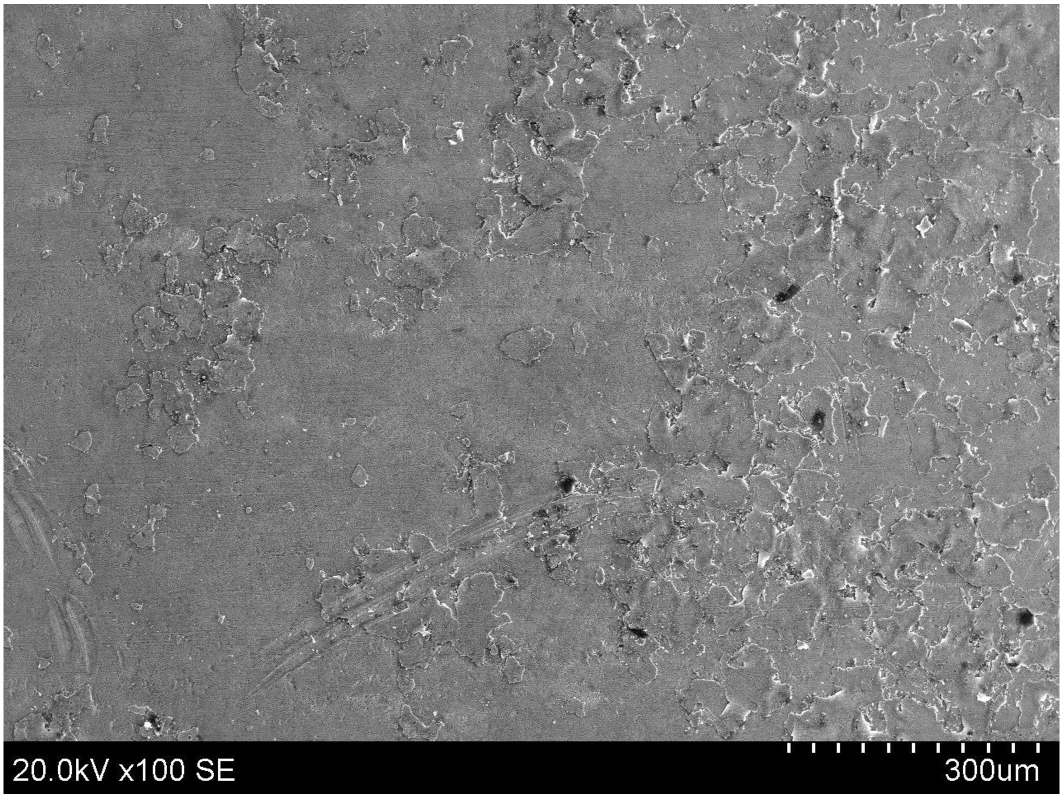


(a)

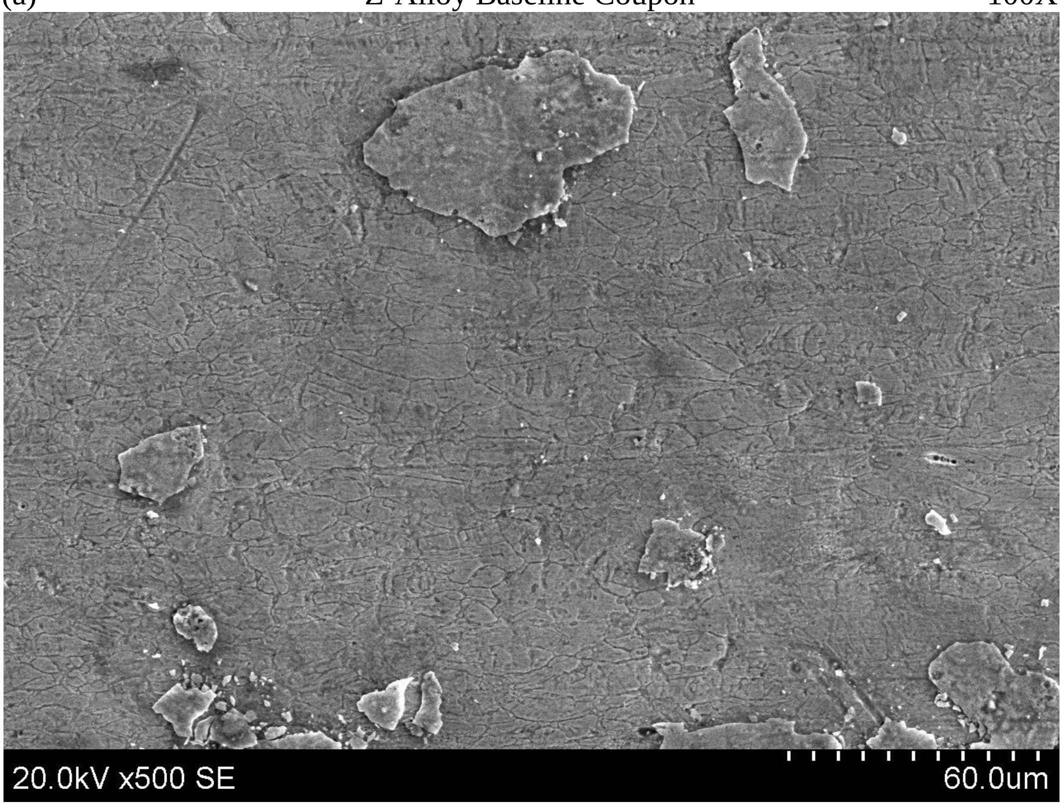


(b)

Figure 18 Mass loss of the Z-Alloy (a) coupon 2 and (b) screen 2 during cleaning.

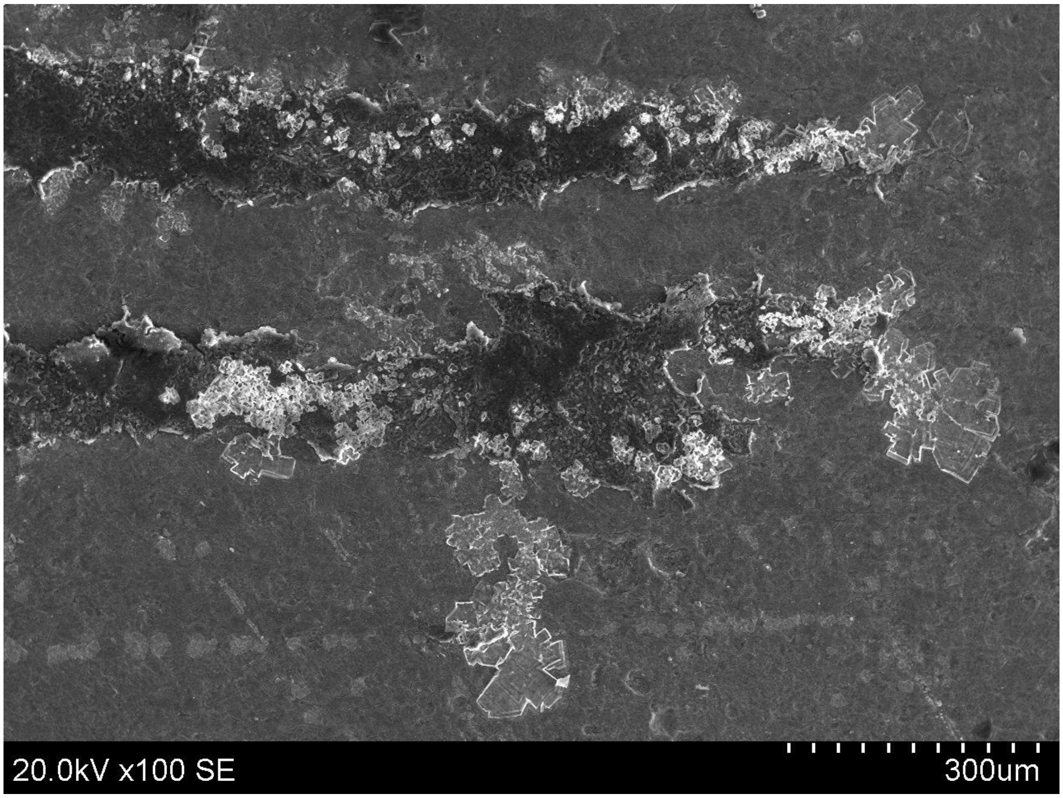


(a) Z-Alloy Baseline Coupon 100X

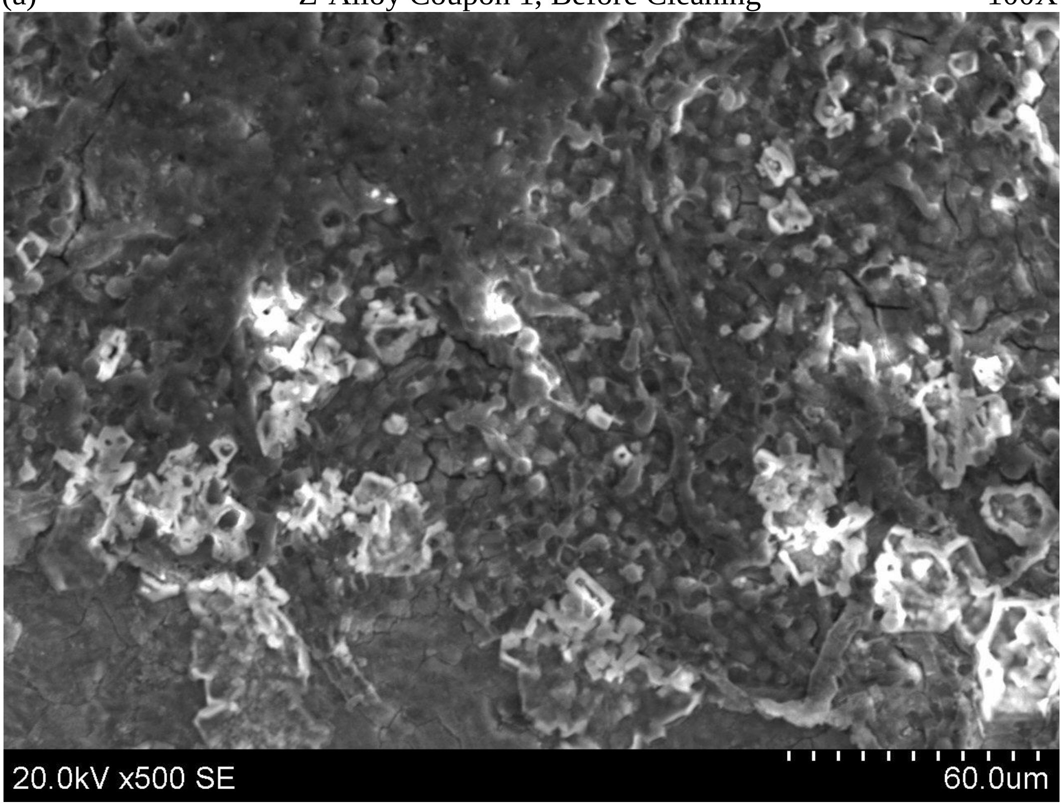


(b) Z-Alloy Baseline Coupon 500X

Figure 19 Scanning electron micrographs of Z-Alloy baseline coupon.



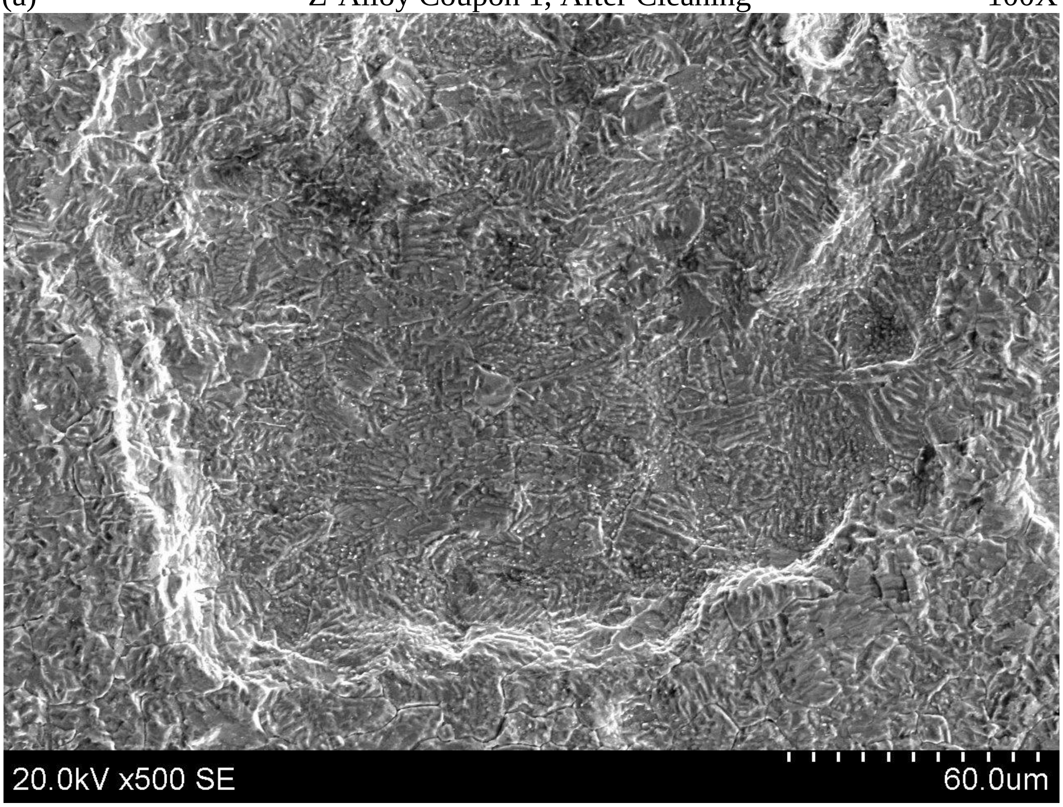
(a) Z-Alloy Coupon 1, Before Cleaning 100X



(b) Z-Alloy Coupon 1, Before Cleaning 500X

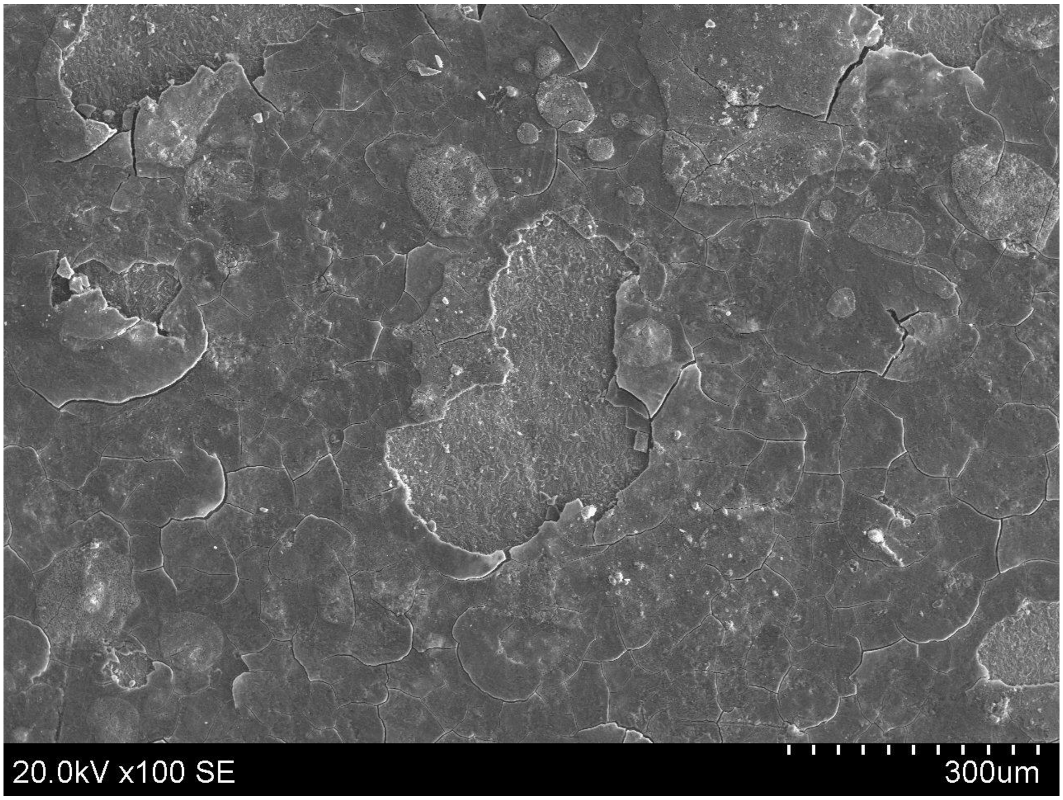
Figure 20 Scanning electron micrographs of Z-Alloy coupon 1 after a 3 month corrosion test, before cleaning.

(a) Z-Alloy Coupon 1, After Cleaning 100X

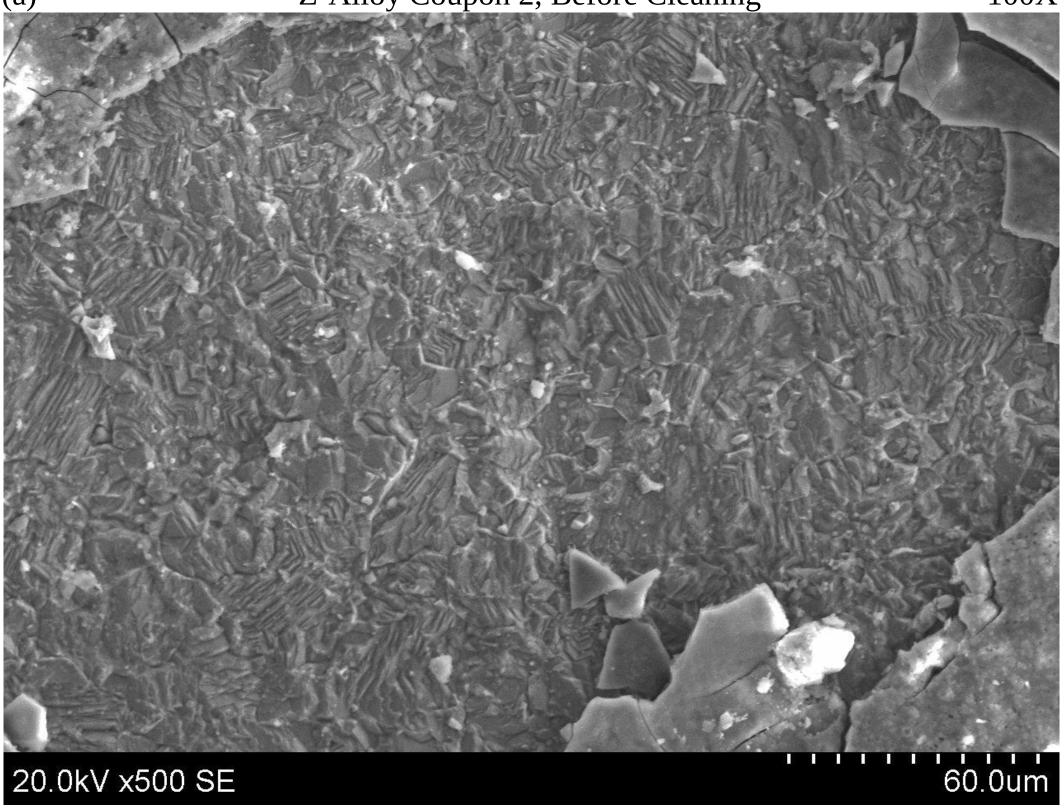


(b) Z-Alloy Coupon 1, After Cleaning 500X

Figure 21 Scanning electron micrographs of Z-Alloy coupon 1 after a 3 month corrosion test, after cleaning.

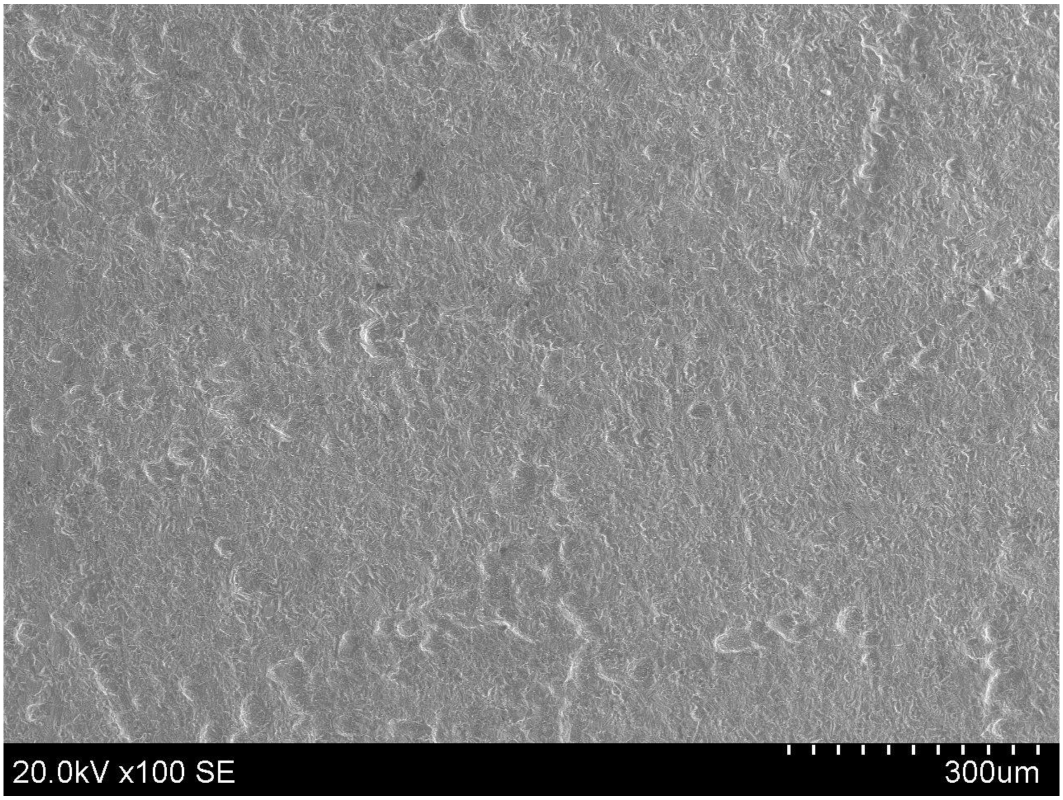


(a) Z-Alloy Coupon 2, Before Cleaning 100X

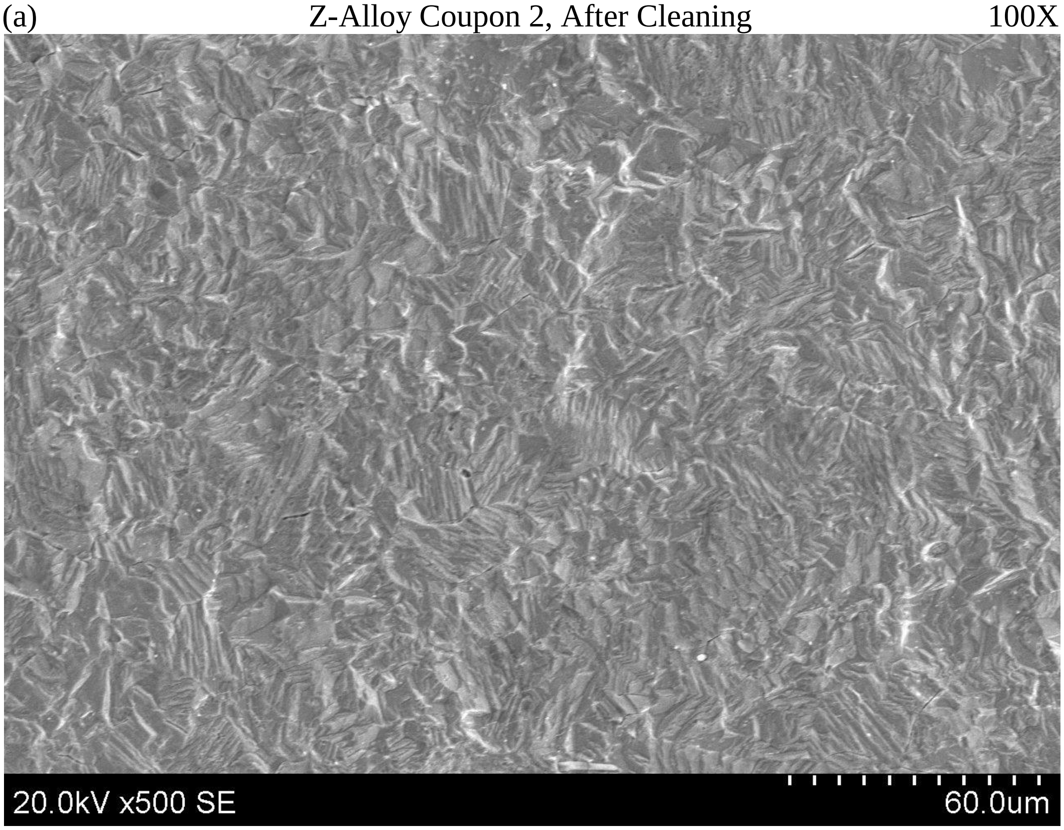


(b) Z-Alloy Coupon 2, Before Cleaning 500X

Figure 22 Scanning electron micrographs of Z-Alloy coupon 2 after a 6 month corrosion test, before cleaning.

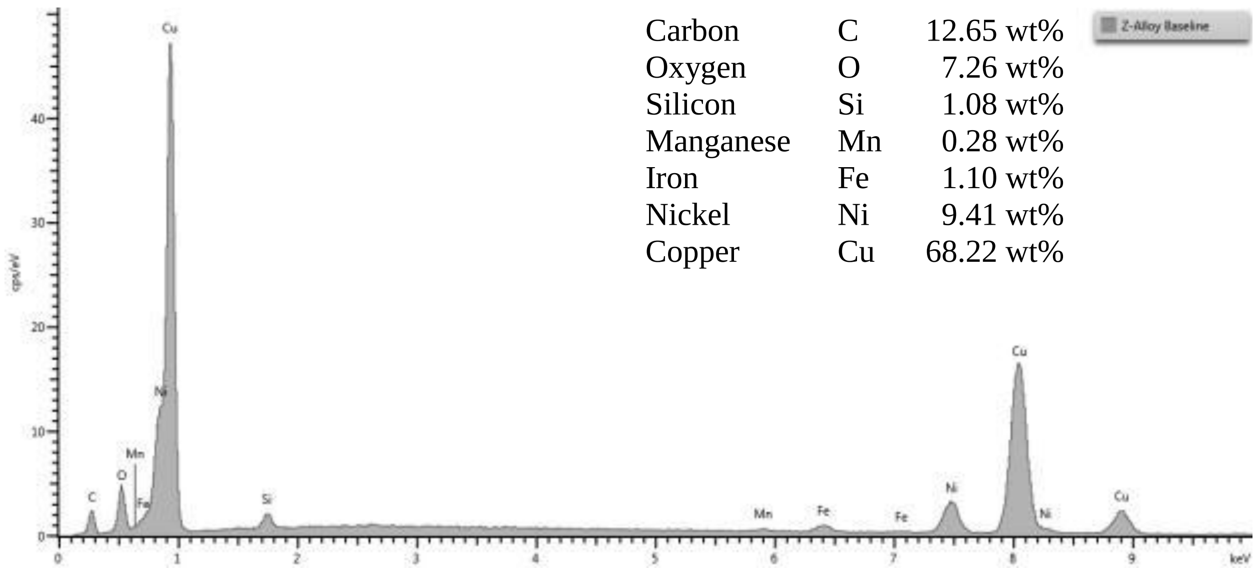


(a) Z-Alloy Coupon 2, After Cleaning 100X



(b) Z-Alloy Coupon 2, After Cleaning 500X

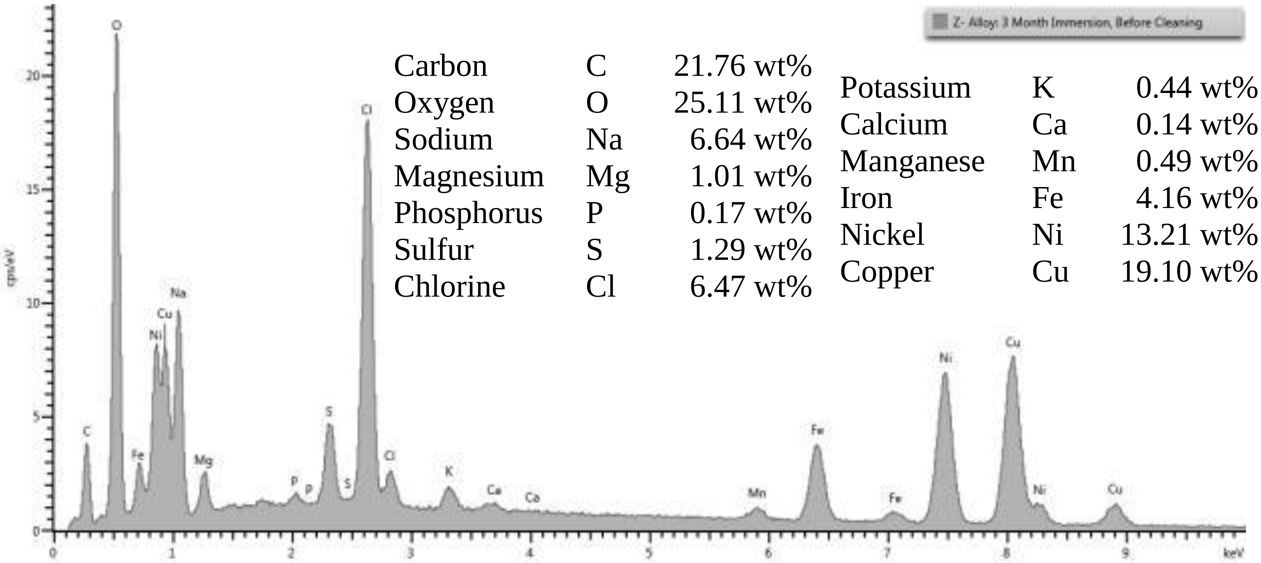
Figure 23 Scanning electron micrographs of Z-Alloy coupon 2 after a 6 month corrosion test, after cleaning.



Carbon	C	12.65 wt%
Oxygen	O	7.26 wt%
Silicon	Si	1.08 wt%
Manganese	Mn	0.28 wt%
Iron	Fe	1.10 wt%
Nickel	Ni	9.41 wt%
Copper	Cu	68.22 wt%

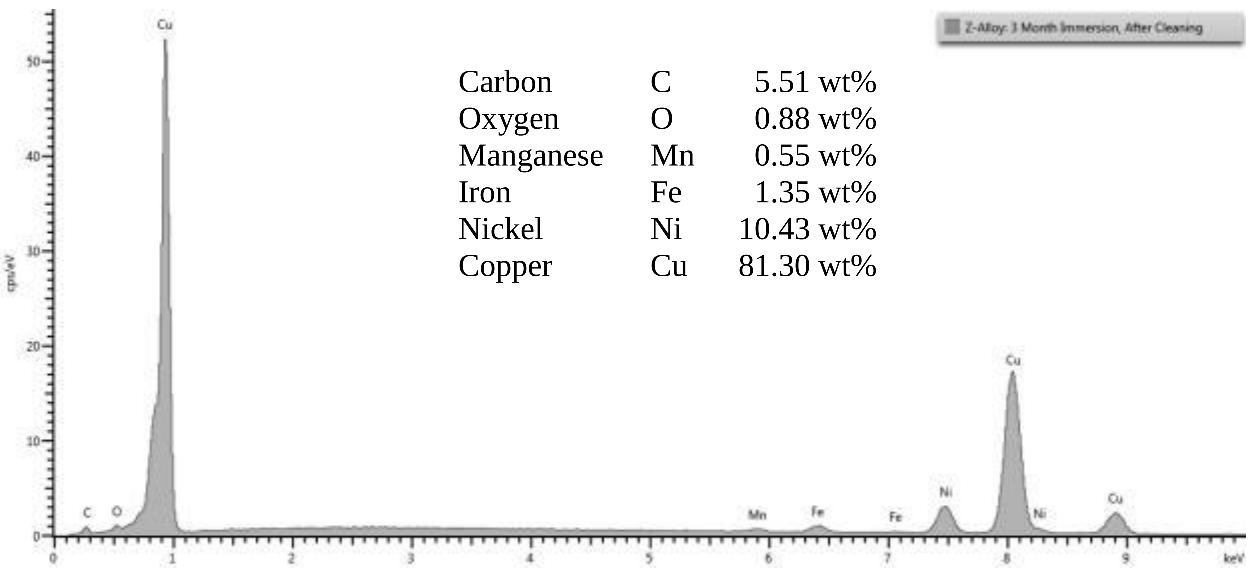
(a) Z-Alloy Baseline Coupon

Figure 24 Energy dispersive x-ray spectra of Z-Alloy baseline coupon 1.



Carbon	C	21.76 wt%
Oxygen	O	25.11 wt%
Sodium	Na	6.64 wt%
Magnesium	Mg	1.01 wt%
Phosphorus	P	0.17 wt%
Sulfur	S	1.29 wt%
Chlorine	Cl	6.47 wt%
Potassium	K	0.44 wt%
Calcium	Ca	0.14 wt%
Manganese	Mn	0.49 wt%
Iron	Fe	4.16 wt%
Nickel	Ni	13.21 wt%
Copper	Cu	19.10 wt%

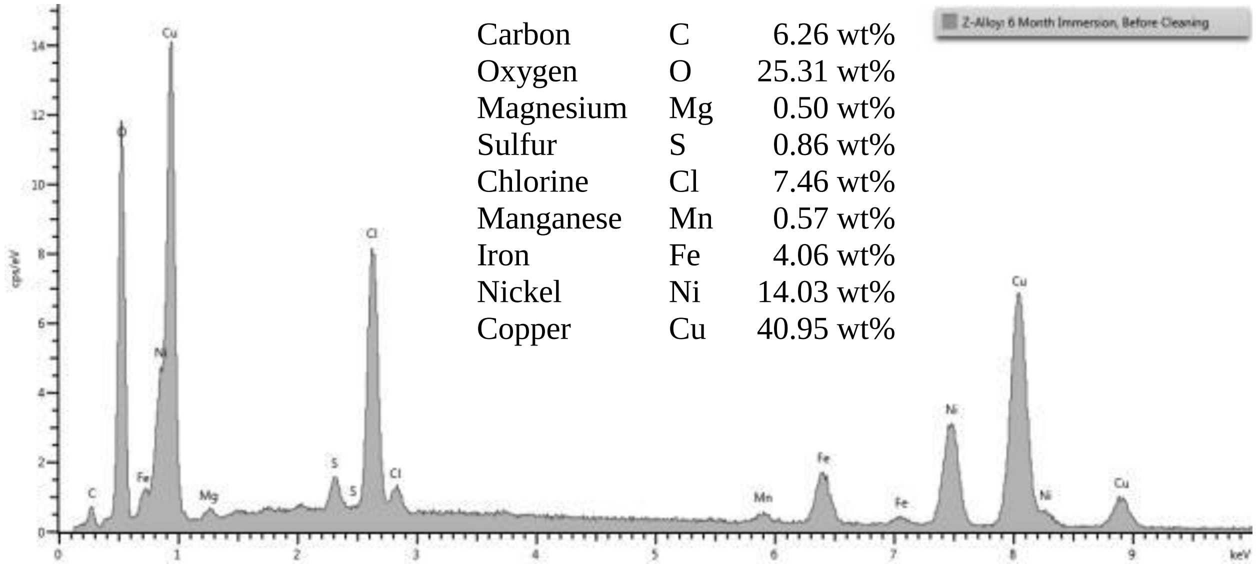
(a) Z-Alloy Coupon 1, Before Cleaning



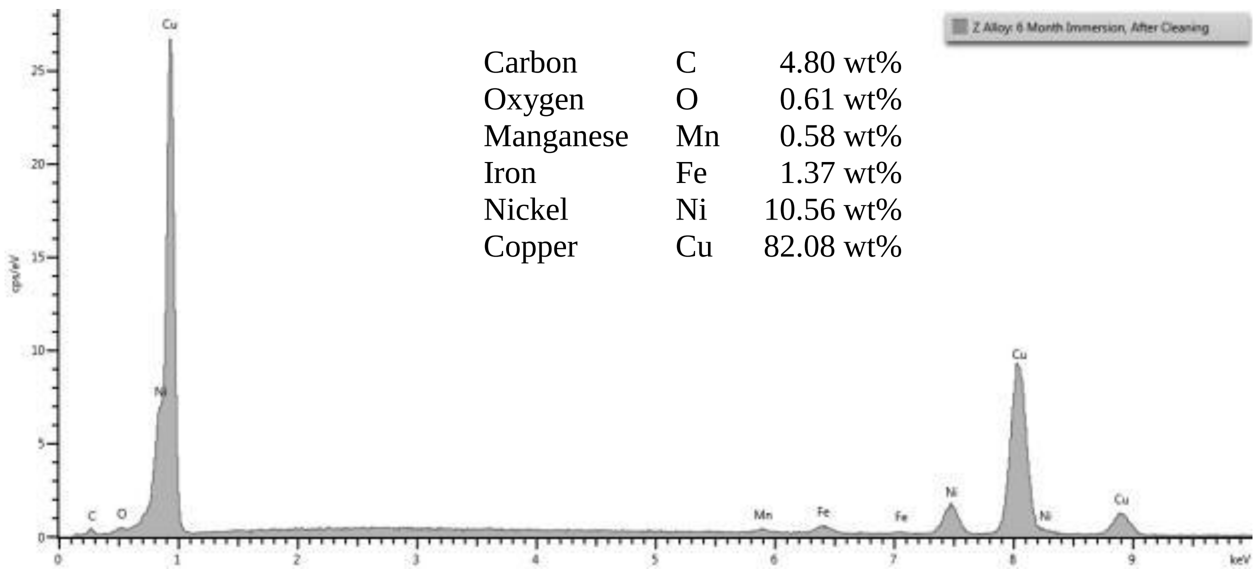
Carbon	C	5.51 wt%
Oxygen	O	0.88 wt%
Manganese	Mn	0.55 wt%
Iron	Fe	1.35 wt%
Nickel	Ni	10.43 wt%
Copper	Cu	81.30 wt%

(b) Z-Alloy Coupon 1, After Cleaning

Figure 25 Energy dispersive x-ray spectra of Z-Alloy coupon 1 after a 3 month corrosion test (a) before cleaning and (b) after cleaning.

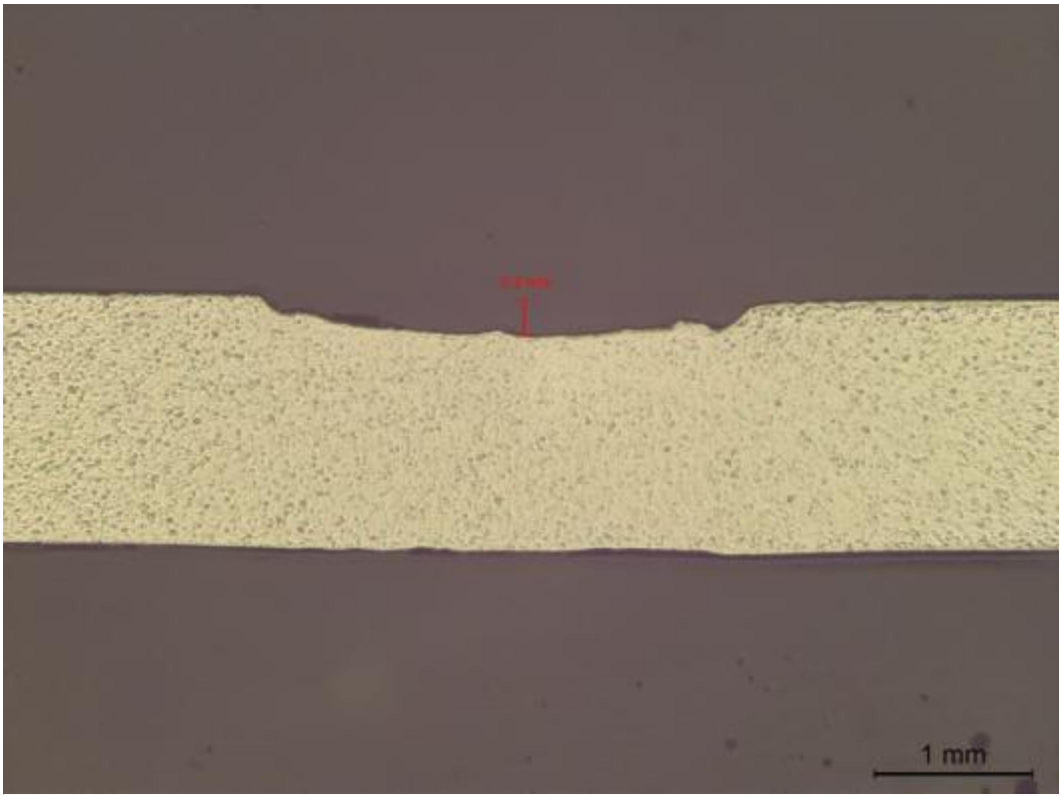


(a) Z-Alloy Coupon 2, Before Cleaning



(b) Z-Alloy Coupon 2, After Cleaning

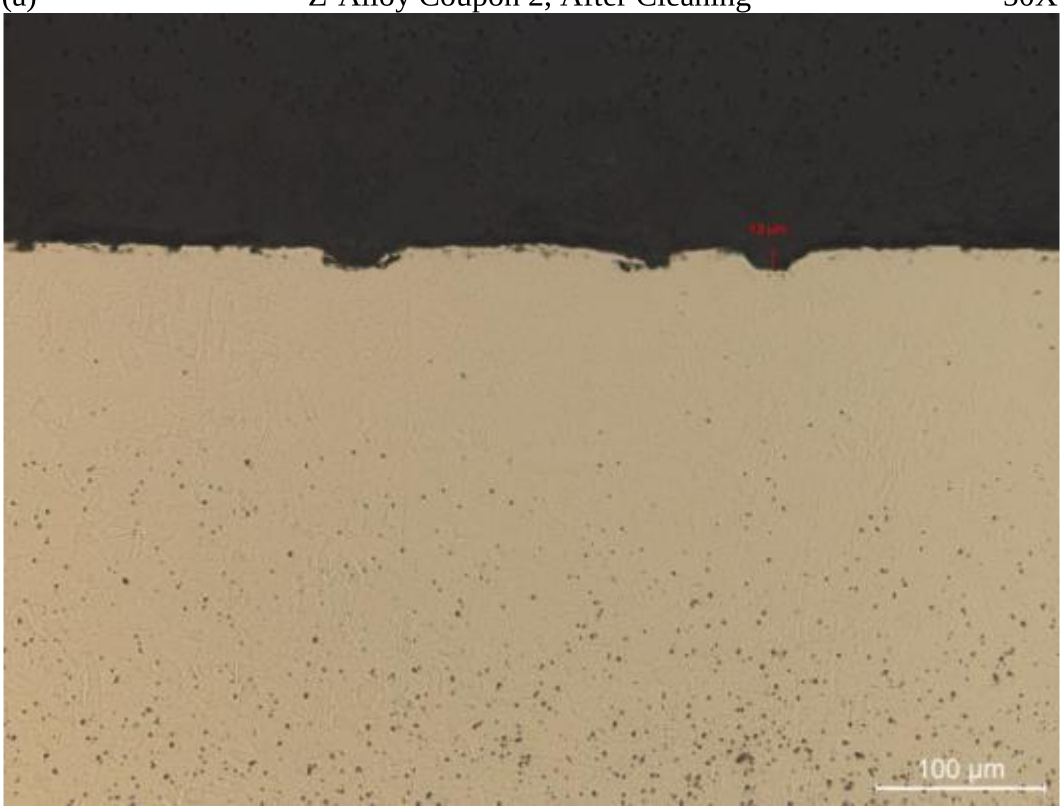
Figure 26 Energy dispersive x-ray spectra of Z-Alloy coupon 2 after a 6 month corrosion test (a) before cleaning and (b) after cleaning.



(a) Z-Alloy Coupon 1, After Cleaning 18.75X

Figure 27 Optical micrograph of Z-Alloy coupon 1.

(a) Z-Alloy Coupon 2, After Cleaning 50X



(a) Z-Alloy Coupon 2, After Cleaning 200X

Figure 28 Optical micrographs of Z-Alloy coupon 2.

WEST BASIN MUNICIPAL WATER DISTRICT OCEAN WATER DESALINATION INTAKE CORROSION STUDY – 10 MONTH RESULTS

Prepared for:

TETRA TECH

Date: May 28, 2015

Prepared by:

V&A

V&A Project No.: 13-0376

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ES EXECUTIVE SUMMARY

West Basin Municipal Water District (West Basin) is pursuing ocean water desalination as an added source of water for its clients. The intent of the study is to measure the extent of corrosion and biofouling on bare and coated metal coupons. Twenty four samples made from four different alloys were identified and installed on a testing apparatus at the West Basin Ocean Water Desalination Intake location near El Segundo, CA. One coupon from each alloy are being removed after 3, 6, 10 and 12 months and are being sent to a laboratory for analysis. The purpose of the corrosion study is the following:

A. To determine the corrosion rates and modes of anticipated corrosion that will occur on the selected materials.
B. To determine the effectiveness of several antifouling control strategies for future design, implementation and operation of intake facilities.
C. To determine the effect that a foul release protective coating will have on biological growth on the test samples.
D. To determine proper material selection, manufacturer quality control, and proper installation of screens.
E. To select materials that are readily available for manufacture of the wedge wire intake screen for use at the full scale West Basin Desalination Plant.
F. To present information with material selection options, showing overall capital cost and O&M costs.

The purpose of this report is to provide the results of the on-site and in-situ testing of metal coupons and wedge wire screen samples after the first 308 days of immersion in the Pacific Ocean seawater. The samples were installed on June 17, 2014 and removed on April 21, 2015. Table ES-1 summarizes the corrosion rate results for four different alloys.

Pitting and general corrosion were the primary mechanisms of corrosion on the coupons. The average corrosion rates of the 10-month samples were all lower than the 6-month samples; which in-turn the corrosion rates were lower than the 3-month samples (except for the 6 and 3-month 90-10 Cu-Ni coupons). The lower average corrosion rates of the 10-month samples are likely due to the continual increase of a passivation layer after 6 months. The passivation layer helps protect the surface from corrosion.

Figure ES-1 and Table ES-1 summarize the results of the testing.

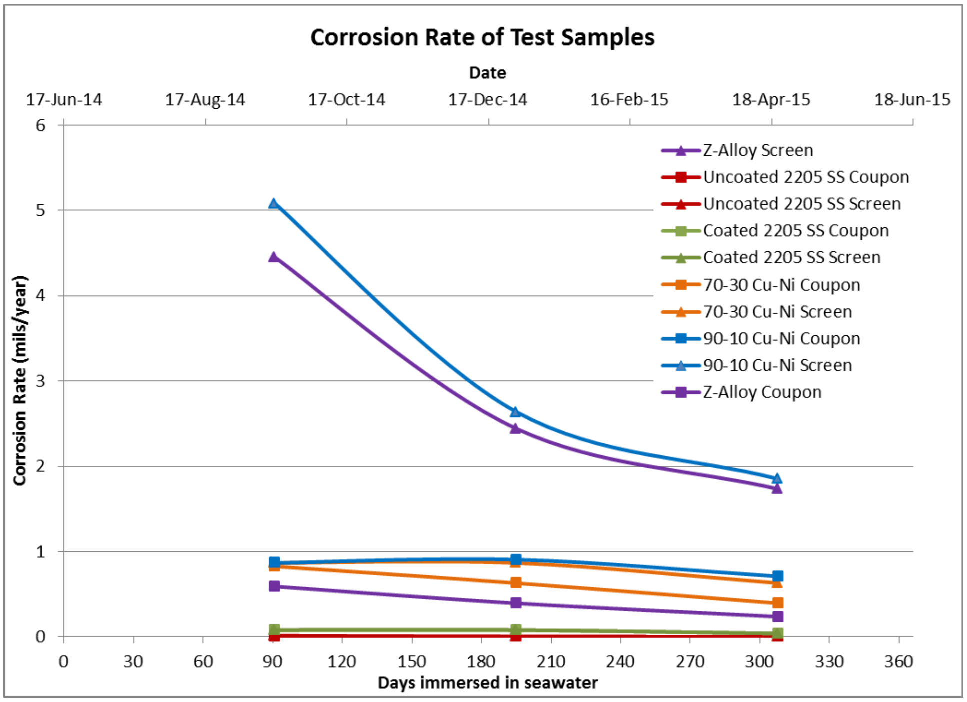


Figure ES-1. Corrosion Rates of Four Alloys after 308 days in Seawater Exposure

Table ES-1. Corrosion Rates of Four Alloys after 308 days in Seawater Exposure

Alloy	Sample Type	Surface Area (sq. in.)	Maximum Pitting Depth over 308 days (mils)	Overall Average Corrosion Rate (mils/year)
2205 Duplex SS Uncoated	1-inch by 3-inch coupon	8.2	0.87	<0.001
	Wedge Wire Screen	96.7	> 20 [A]	0 [A]
2205 Duplex SS with Foul Release Coating	1-inch by 3-inch coupon	8.2	0.94 [B]	0.039 [B]
	Wedge Wire Screen	96.7	> 20 [A]	0.039 [B]
CDA 715 70-30 Cu-Ni	1-inch by 3-inch coupon	8.2	1.46	0.394
	Wedge Wire Screen	65.0	> 20 [A]	0.630
CDA 706 90-10 Cu-Ni	1-inch by 3-inch coupon	8.2	1.34	0.709
	Wedge Wire Screen	79.1	> 20 [A]	1.850
Z Alloy	1-inch by 3-inch coupon	8.2	0.59	0.236
	Wedge Wire Screen	96.3	> 20 [A]	1.732

[A] Less than detectable/measurable. For corrosion rate, the mass loss versus the number of cleaning cycles were plotted to determine the mass loss due to corrosion. For pitting depth of wire screens, the pits were difficult to measure and the screens were not metallographically mounted. Instead a pit depth gauge with detection limit 0.5mm ≈ 20mils was used.

[B] Mass loss and corrosion rate includes metal and coating material

Based on the data over 308 days, coated and uncoated 2205 Duplex Stainless Steel has the lowest overall average corrosion rates of the four metal alloys for both the coupons and screens tested in this study. However, the uncoated 2205 Duplex Stainless Steel samples were the most heavily fouled by marine life.

As can be seen in Table ES-1, the highest overall average corrosion rate was observed on the 90-10 Cu-Ni coupon and screen. The overall average corrosion rates of the 90-10 Cu-Ni and Z Alloy screens were 3 to 7 times higher than the coupons of the same alloy. The 90-10 Cu-Ni coupons were provided from a different vendor than the screens and they may have a different chemical composition. However the same cannot be said for the Z Alloy samples because they were provided from the same vendor. Tenera Environmental indicated that the 70-30 Cu-Ni samples exhibited slightly more green marine life fouling on the coupons and screens than the 90-10 Cu-Ni and Z alloy metals. It is possible that the corrosion rate is reduced by the amount of marine life fouling present on the samples because it limits the exposure of the metal to the seawater. The ability of the metal to create a passivation layer on the surface of each alloy may also affect the corrosion rate.
The highest pitting rate was observed on the 70-30 Cu-Ni coupons. Pits on the small cross sectional areas of the wire screens were difficult to measure, but were all less than 20 mils and probably followed the same trend between the different alloys as the coupons.

Mechanical damage was observed at each corner of the 70-30 Cu-Ni, 90-10 Cu-Ni, and Z Alloy screens where they were secured to the test rack. The mechanical damage may have been caused by the turbulence in the water and abrasion of metal by the zip ties that prevented the passivation of the metal at those locations. The exposed metal was corroded.

1.0 INTRODUCTION

West Basin Municipal Water District (West Basin) is pursuing ocean water desalination as an added source of water for its clients. Four different alloys and one coating system were identified, through review of the literature for similar studies, and installed on a testing apparatus at the West Basin Ocean Water Desalination Intake location near El Segundo, CA. The intent of the study is to measure the extent of corrosion and biofouling on bare and coated metal coupons and wire screens. The samples were installed and a coupon and a wire screen for each material type were removed at 3, 6 and 10 months. The last samples will be removed after 12 months. Once removed, the samples were sent to a lab for analysis. The overall objectives for the study are the following:

- To determine the corrosion rates and modes of anticipated corrosion that will occur on the selected materials.
- To determine the effectiveness of several antifouling control strategies for future design, implementation and operation of intake facilities.
- To determine the effect of a foul release that the protective coating will have on biological growth on the test samples. This will substantiate the ultimate selection of intake screen material and the benefit of providing an anti-fouling coating on the intake screen.
- To determine proper material selection, manufacturer quality control, and proper installation of screens.
- To select materials that are readily available for manufacture of the wedge wire intake screen for use at the full scale West Basin Desalination Plant.
- To present information with material selection options, showing overall capital cost, and O&M costs.

The purpose of this report is to provide the results of the on-site and in-situ testing of metal coupons and wedge wire screen samples after 308 days of immersion in the Pacific Ocean seawater.

2.0 METHODS

The purpose of this section of the report is to describe the testing study procedures for on-site and in-situ testing of metal coupons and wedge wire screen samples in order to assess corrosion impact relative to material selection and operating practices. The results presented in this report are for the samples that were removed after 10 months of seawater exposure.

2.1 Procurement of Materials

Twenty-four (24) testing samples were obtained for testing of the corrosion coupons and 24 testing samples were obtained for the wedge wire screens (4 samples for each material type). The metal coupons are 1 inch wide by 3 inches long by 1/16 of an inch thick and the wedge wire screens are 4 inches by 4 inches with a 2 mm spacing. The 90-10 Cu-Ni screens have 4 mm spacing, between the screen wires.

V&A coordinated with the coupon vendors and screen manufacturers for the procurement of the testing samples. Metal Samples Company of Munford, Alabama, provided the 1-inch by 3-inch long by 1/16-inch thick coupons in 90-10 Copper-Nickel (Cu-Ni), 70-30 Cu-Ni, and the 2205 Duplex Stainless Steel. Metal Samples also provided the 4-inch by 4-inch by 1/8-inch thick flat plate in the same metal alloys. Holes were made on each 1-inch by 3-inch and 4-inch by 4-inch metal sample in order to secure it to the testing rack with plastic zip ties.

Johnson Screens/Bilfinger Water Technologies of New Brighton, Minnesota provided the 4-inch by 4-inch wedge wire screens in the 90-10 Cu-Ni, 2205 Duplex Stainless Steel, and Z alloys. They also provided the 1-inch by 3-inch by 1/16-inch thick coupons and the 4-inch by 4-inch flat plate in the Z alloy.

Hendrick Screen Company of Owensboro, Kentucky, provided the 4-inch by 4-inch wedge wire screens in 70-30 Cu-Ni.

2.2 Coating for Stainless Steel Screens and Coupons

V&A searched for a coating that would provide an NSF Standard 61-approved coating for drinking water contact and was known to prevent the attachment of marine life on hydraulic structures. V&A identified the following foul release coating system for the stainless steel samples from the literature review and discussions with manufacturers:

A. 1st coat - Sherwin Williams Macropoxy 646 PW immersion grade epoxy primer at 6 mils dry film thickness (dft)
B. 2nd coat - Sherwin Williams Seaguard Sher-Release beige silicone Tie Coat at 6 mils dft
C. 3rd coat - Sherwin Williams Seaguard Sher-Release white silicone Surface Coat at 6 mils dft

The coating was applied by Fuji Hunt Smart Surfaces in Davidsonville, Maryland.

2.3 Lab Analysis

2.3.1 Chemical Analysis by EDS

Anamet, Inc. of Hayward, California, performed a quantitative chemical analysis by Energy Dispersive x-ray Spectra (EDS) on a baseline control sample and on the samples after they were immersed in seawater. Anamet's report contains images of the spectra and is included as Appendix A.

2.3.2 Scanning Electron Microscopy

Anamet, Inc. of Hayward, California, performed Scanning Electron Microscopy (SEM) on the samples. The SEM uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. The signals that derive from electron-sample interactions reveal information about the sample including texture, chemical composition, and crystalline structure.

2.3.3 Metallography

Optical macrographs of the samples were also recorded by Anamet, Inc. before and after cleaning of the samples and are attached in Anamet's reports. A metallographic examination of a cross section of each sample was recorded.

2.3.4 Corrosion Rate Analysis

Samples were weighed by Anamet, Inc. Laboratories in Hayward, CA before they were installed. The samples were analyzed by the lab after they were exposed to the seawater environment per ASTM G1 *Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens* and ASTM D2688 *Standard Test Method for Corrosivity of Water in the Absence of Heat Transfer (Weight Loss Method)*. The samples were cleaned with either nitric acid or hydrochloric acid. Plots of mass loss versus cleaning cycles for each sample are attached in Anamet's report. Pitting examination was performed per ASTM G46 *Standard Guide for Examination and Evaluation of Pitting Corrosion*.

2.4 Procedures

After the initial baseline parameters were obtained, the samples were shipped to Tenera Environmental for installation at the project site. Tenera Environmental assembled the testing rack

and affixed the coupons and wedge wire screens prior to immersion in the ocean source water. The wedge wire screens were secured to the testing rack with plastic zip ties. There was one test rack for each set of samples to be removed at each specified interval.

The testing samples consisted of metal coupons, wedge wire screens and flat plates (coated and uncoated) for installation on the in-situ testing apparatus installed by Tenera Environmental divers. Samples and cleaning were performed per ASTM G-1 *Preparing, Cleaning, and Evaluating Corrosion Test Specimens* and ASTM D2688 *Standard Test Method for Corrosivity of Water in the Absence of Heat Transfer (Weight Loss Method)*. ASTM G-1 includes procedures in Sections 14.10 through 14.14 that involve weighing and classifying the types of pits. This test method covers the determination of the corrosivity of water by evaluating pitting and by measuring the weight loss of metal specimens. Pitting is a form of localized corrosion: weight loss is a measure of the average corrosion rate.

A metallographic examination was performed per ASTM E3 *Standard Guide for Preparation of Metallographic Specimens*. The primary objective of metallographic examinations is to reveal the constituents and structure of metals and their alloys by means of a light optical or scanning electron microscope.

Before installation the samples were examined for the following baseline parameters:

1. Weigh all samples per ASTM G1. Samples to be coated will be weighed before and after coating application.
2. Examine samples visually to 40X
3. Color photograph, one of each material type
4. Photomicrograph @ 10X, one of each material type
5. Photomicrograph @ 50X, one of each material type
6. Scanning Electron Micrograph (SEM) @ 100X, one of each material type
7. Energy Dispersive Spectroscopy (EDS), one of each material type

Samples removed after 3, 6, 10 and 12 months of exposure have been and will be examined for the following:

1. Sample cleaning and weighing per ASTM G1 and ASTM D2688
2. Pitting examination per ASTM G46
3. Dimensional inspection (micrometers or NOGO gauge): Wedge wire and gap dimensions.
4. Photomicrograph @ 10X, one of each material type After Cleaning (AC)
5. Photomicrograph @ 50X, one of each material type AC
6. Scanning Electron Micrograph @ 100X, one of each material type AC
7. Elemental analysis with EDS, one of each material type AC
8. Metallographic examination per ASTM E3, one of each material type

2.5 Corrosion Mechanisms

Corrosion is an electrochemical phenomenon that takes place at the interface of the metal and electrolyte, which in this case is seawater. When the metal is in contact with the electrolyte, a difference in potential develops at the electrolyte/metal interface. When corrosion reactions take place, they generate a current between two points on the metal surface with current flow through the electrolyte. Factors that may impact the corrosion rate include the following:

- Presence of inclusions in the metal or a Heat Affected Zone due to welding
- Mechanical stresses caused by welding, forming or temperature
- Water velocity and tidal fluctuations at the surface of the coupon (not possible to simulate in a lab)
- Alloy resistance to corrosion due to high chloride concentrations in seawater
- Water temperature, dissolved oxygen, sulfates, and chlorides. Water temperature data was collected at the intake to better understand and account for how temperature may impact the corrosion rate.

The following sections explain some possible corrosion mechanisms for the metals based on V&A's research.

2.5.1 Uniform Corrosion

If all metal surfaces are attacked via corrosion at an equal rate, the corrosion is termed uniform. As far as failure rate, the uniform corrosion rate is expressed in terms of pipe penetrating rates (rate of pipe wall loss) in thousandths of inches (mils) per year (mpy).

2.5.2 Localized and Pitting Corrosion

When corrosion of the metal surface is localized, the surface under the most aggressive attack becomes recessed with respect to the rest of the pipe surface and visible pits are formed. In such instances, the attack is said to be non-uniform, localized, or pitting corrosion. Theoretically, corrosion pitting in metals is divided into two phases: pit initiation and propagation.

2.5.3 Stress Corrosion Cracking

The occurrence of stress corrosion cracking (SCC) depends on the simultaneous achievement of three requirements: 1) a susceptible material; 2) a chemical environment that causes SCC for that material and 3) sufficient tensile (mechanical) stress within the material. The mechanical stresses may be caused by welding, forming, applied loads, and temperature.

Photo 2-1 and Photo 2-2 show samples of the cracking that might occur for copper alloys and duplex stainless steel under mechanical and chemical stresses. These photos are not of the metal samples that are part of this study and are presented for demonstrative purposes only.

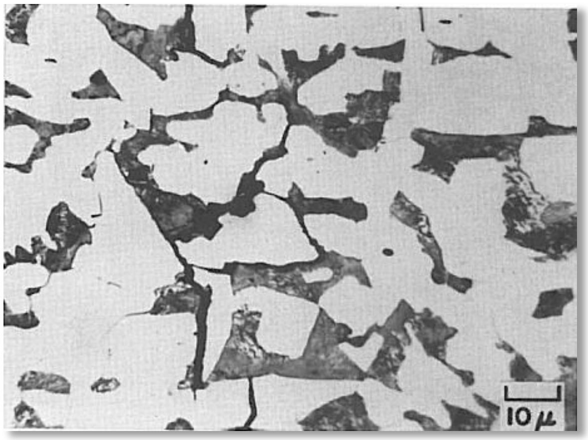


Photo 2-1. Intergranular Stress Corrosion Cracking in a Steel Pipe.[1]

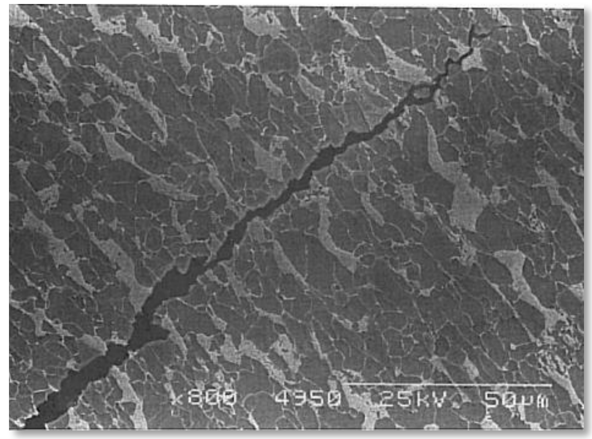


Photo 2-2. Transgranular Stress Corrosion Cracking in a Steel Pipe.[2]

2.6 Reference Corrosion Rates from Studies Performed by Others

V&A researched seawater corrosion rates for the alloys in this study to compare the corrosion rate of the alloys with the results of this study. Table 2-1 summarizes the information found in corrosion control literature.

Table 2-1. Average Corrosion Rates from Literature Review for Alloys in Seawater

Material	UNS	Corrosion Rate (mils/yr.)	Reference
2205 duplex stainless steel	S32205	0.03	McGuire, Stainless Steels for Design Engineers, p. 101, 2008
70-30 Cu-Ni	C71500	0.13	ASM Volume 13B p. 140 Fig 14 (Efird & Anderson, Mater. Perform., 1975)
90-10 Cu-Ni	C70600	0.15	ASM Volume 13B p.140, Fig 13 (Efird & Anderson, Mater. Perform., 1975)

[1] Revie, R. Winston. Uhlig's Corrosion Handbook. 2nd Edition, John Wiley and Sons, Inc. New York, 2000, p. 194.
[2] Ibid.

Figure 2-1 shows a graph of the average corrosion rates for several metal alloys in seawater. As seen in the graph, 70-30 Cu-Ni and 90-10 Cu-Ni have a corrosion rate of 0.15 to 0.5 mils per year.

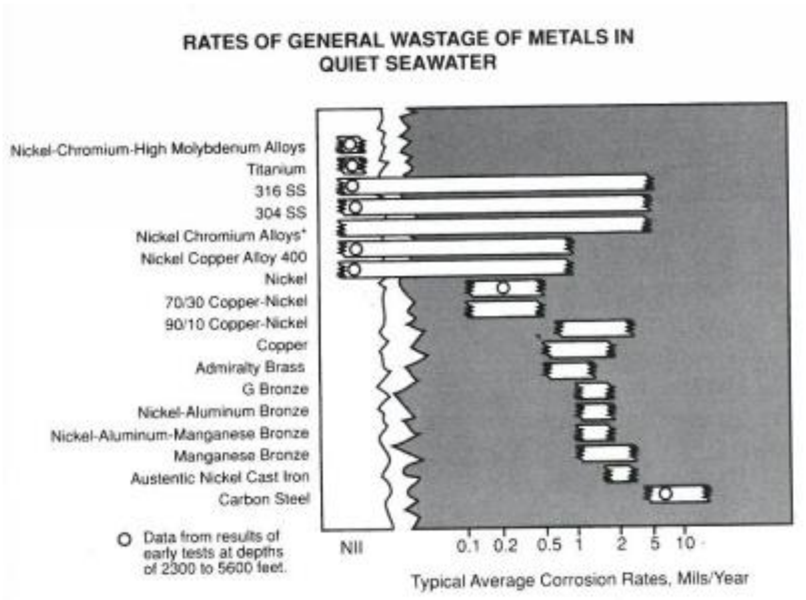


Figure 2-1. Graph of Average Corrosion Rates of Different Alloys in Seawater[3]

[3] NACE Corrosion Engineer's Reference Book, 2nd Ed. (1991) R.S. Treseder (editor)

3.0 FINDINGS

The third set of ten coupons and screens was installed on Tuesday, June 17, 2014, and retrieved after 308 days on Tuesday, April 21, 2015. Photographic documentation and lab results and analysis are presented below.

3.1 Photos of Samples after 10 Months of Exposure

Photo 3-1 through Photo 3-14 show the samples before they were cleaned or analyzed. Photo 3-6, Photo 3-10, and Photo 3-14 show some typical mechanical damage to the screen wires that was observed on the 70-30 Cu-Ni, 90-10 Cu-Ni, and Z Alloy screens. The damage was observed at each corner of the screen where the screens were secured to the test rack. The mechanical damage may have been caused by the turbulence in the water and the abrasion by the zip ties that prevented the passivation of the metal at those locations. The exposed metal was corroded.

Some photos are courtesy of Anamet, Inc. and are included in the reports in Appendix A.

Photo 3-1. Marine life attached to uncoated 2205 Duplex stainless steel coupon with a weld.

Photo 3-2. Marine life attached to uncoated 2205 Duplex stainless steel wedge wire screen.

Photo 3-3. Minor damage to coating on edge of 2205 Duplex stainless steel coupon.

Photo 3-4. Coating damage to 2205 Duplex Stainless Steel wedge wire sample.

Photo 3-5. Detail view of weld on 70-30 Cu-Ni coupon.

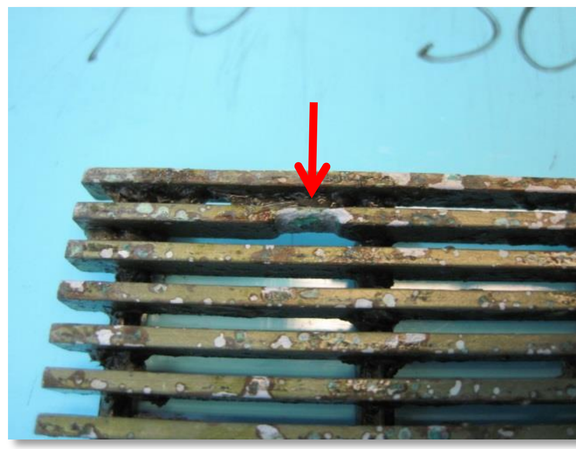


Photo 3-6. Mechanical damage to 70-30 Cu-Ni wedge wire screen.

Photo 3-7. 70-30 Cu-Ni coupon at 10x magnification.

Photo 3-8. 70-30 Cu-Ni wire screen at 10x magnification.

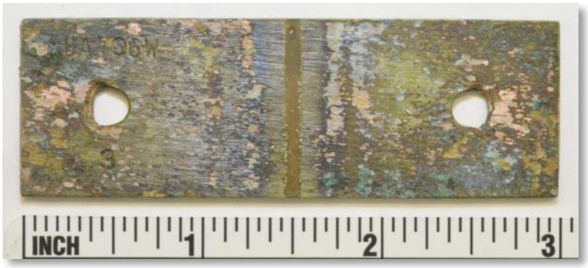


Photo 3-9. 90-10 Cu-Ni 1-inch by 3-inch coupon with weld.

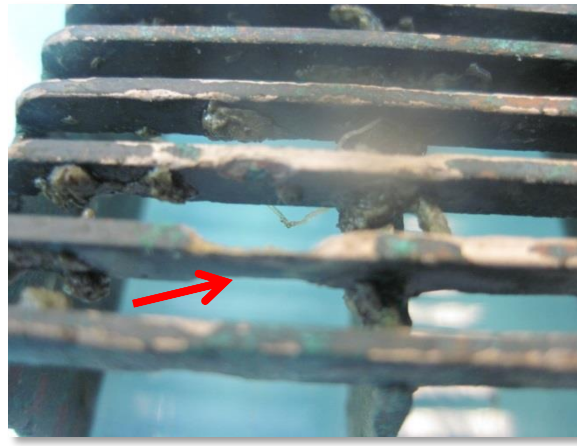


Photo 3-10. Mechanical damage to 90-10 Cu-Ni wedge wire screen.

Photo 3-11. 90-10 Cu-Ni coupon at 10x magnification.

Photo 3-12. 90-10 Cu-Ni wire screen at 10x magnification.

Photo 3-13. Z alloy 1-inch by 3-inch coupon with weld.

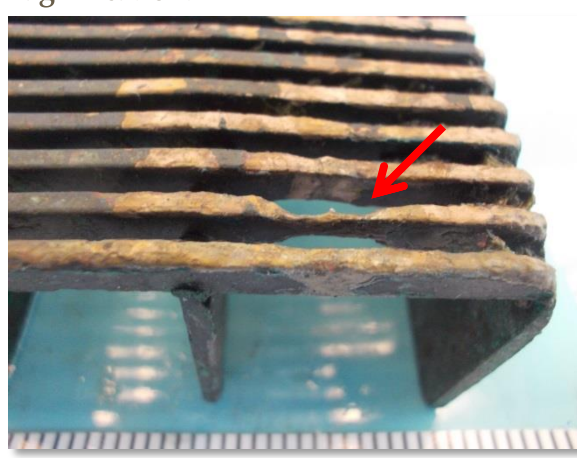


Photo 3-14. Mechanical damage to Z alloy wedge wire screen.

Photo 3-15. Z alloy coupon at 10x magnification.

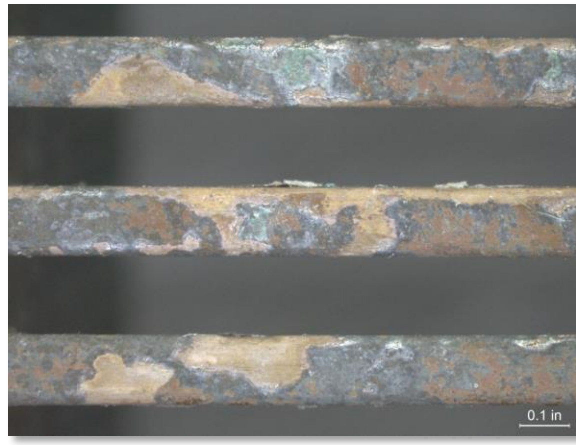


Photo 3-16. Z alloy wire screen at 10x magnification.

3.2 Corrosion Rates after 308 Days

Table 3-1 summarizes the results of the corrosion rate analysis conducted by Anamet, Inc. after the samples were exposed to seawater for 308 days starting on June 17, 2014.

Table 3-1. Corrosion Rates of Four Alloys after 308 days in Seawater Exposure

Alloy	Sample Type	Surface Area (sq. in.)	Maximum Pitting Depth over 308 days (mils)	Overall Average Corrosion Rate (mils/year)
2205 Duplex SS Uncoated	1-inch by 3-inch coupon	8.2	0.87	< 0.001
	Wedge Wire Screen	96.7	< 20 [A]	0 [A]
2205 Duplex SS with Foul Release Coating	1-inch by 3-inch coupon	8.2	0.94 [B]	0.039 [B]
	Wedge Wire Screen	96.7	< 20 [A]	0.039 [B]
CDA 715 70-30 Cu-Ni	1-inch by 3-inch coupon	8.2	1.46	0.394
	Wedge Wire Screen	65.0	< 20 [A]	0.630
CDA 706 90-10 Cu-Ni	1-inch by 3-inch coupon	8.2	1.34	0.709
	Wedge Wire Screen	79.1	< 20 [A]	1.850
Z Alloy	1-inch by 3-inch coupon	8.2	0.59	0.236
	Wedge Wire Screen	96.3	< 20 [A]	1.732

[A] Less than detectable/measurable. For corrosion rate, the mass loss versus the number of cleaning cycles were plotted to determine the mass loss due to corrosion. For pitting depth of wire screens, the pits were difficult to measure and the screens were not metallographically mounted. Instead a pit depth gauge with detection limit 0.5mm ≈ 20mils was used.
[B] Mass loss and corrosion rate includes metal and coating material

3.2.1 Corrosion Rate over Time

Figure 3-1 summarizes the results of the corrosion rate analysis over 10 months of testing.

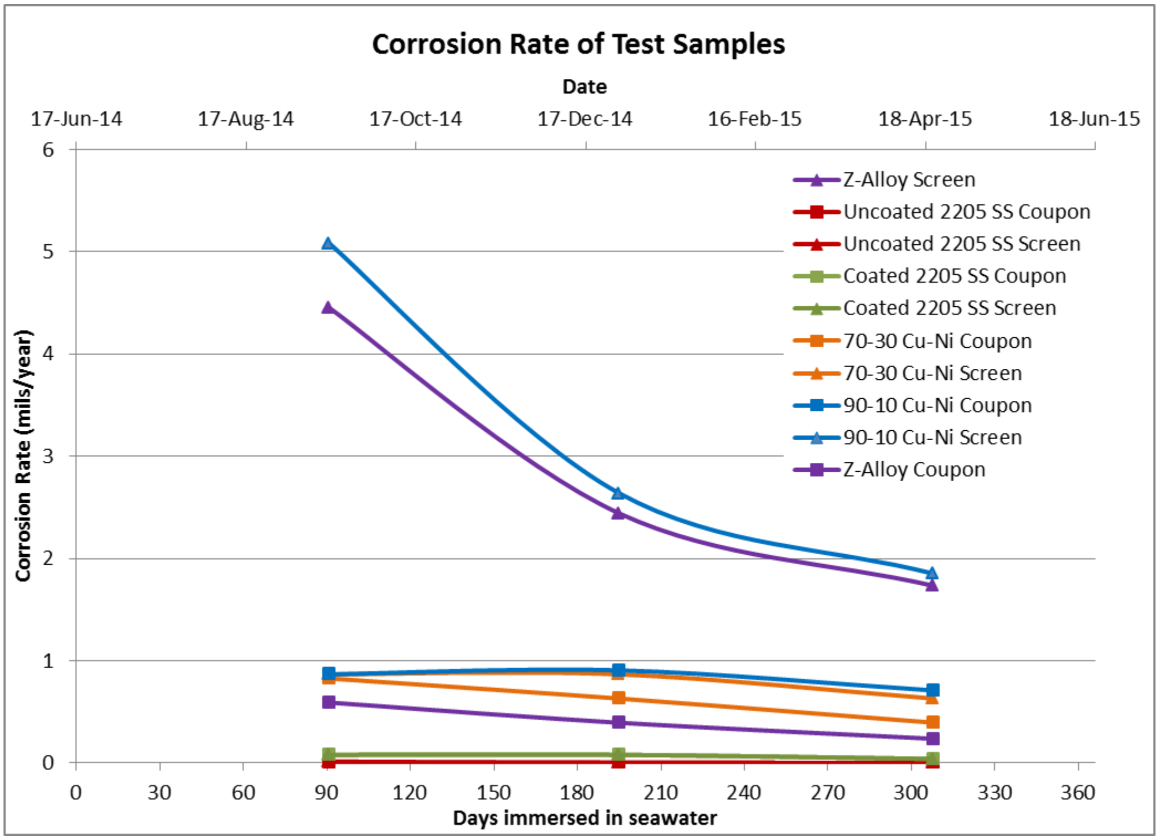
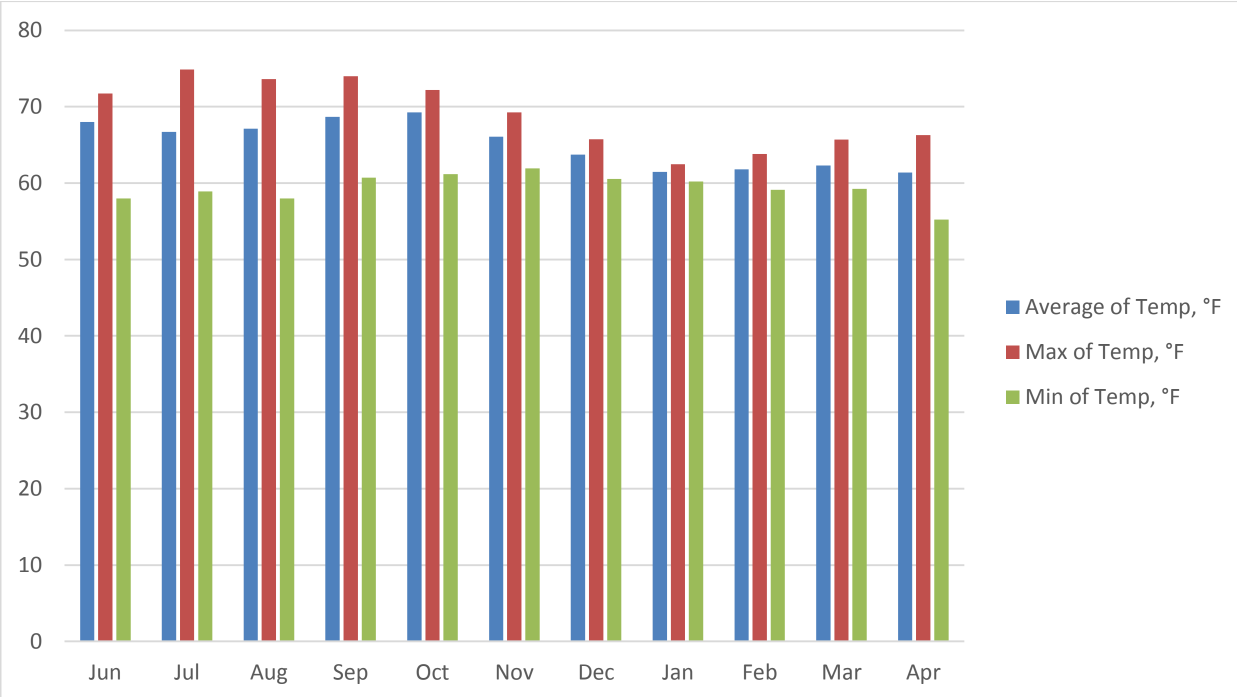


Figure 3-1. Corrosion Rates of Four Alloys over 10 months in Seawater Exposure

The average corrosion rates of the 10-month samples were all lower than the 6-month samples; which in turn had lower corrosion rates than the 3-month samples (except for the 3 and 6- month 90-10 Cu-Ni coupons). The lower average corrosion rates of the 10-month samples are likely due to the continual increase of a surface passivation layer after 6 months. The passivation layer helps protect the surface from corrosion.

3.2.2 Water Temperature

The corrosion rates may have also been affected by the seasonal water temperature changes. Figure 3-2 graphs the water temperature data collected at the intake throughout the course of the study.



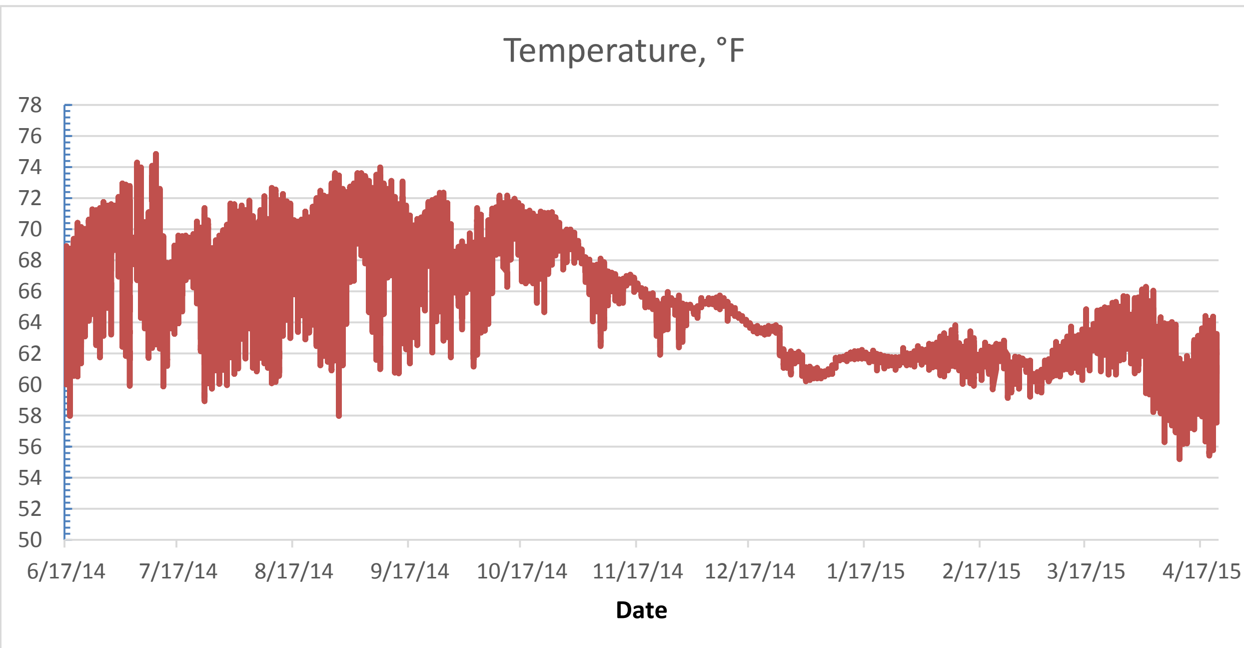


Figure 3-2. Water Temperature at Intake

The water temperature for all the months was an average of 64 degrees Fahrenheit, minimum 55 degrees Fahrenheit and maximum 75 degrees Fahrenheit. The lower corrosion rate appears to coincide with lower water temperatures and smaller temperature fluctuations, however the decrease in temperature and temperature fluctuations were minimal compared to the passivated layer that protects the metal surface.

3.2.3 Comparison between the Different Material Types

Based on the data over 308 days, coated and uncoated 2205 Duplex Stainless Steel has the lowest average corrosion rates of the four metal alloy coupons and screens tested in this study. However, the uncoated 2205 Duplex Stainless Steel samples were the most heavily fouled by marine life.

Of the copper alloy coupon samples, the Z alloy 1-inch by 3-inch coupon indicated the lowest overall average corrosion rate and the 90-10 Cu-Ni coupon had the highest corrosion rate. The 90-10 Cu-Ni screen had the highest corrosion rate of all of the screens after 308 days of exposure. The overall average corrosion rates of the 90-10 Cu-Ni and Z Alloy screens were 3 to 7 times higher than the coupons of the same alloy. The 90-10 Cu-Ni coupons were provided from a different vendor than the screens and they may have a different chemical composition. However the same cannot be said for the Z Alloy samples because they were provided by the same vendor. Tenera Environmental indicated that the 70-30 Cu-Ni samples exhibited slightly more green marine life fouling on the coupons and screens than the 90-10 Cu-Ni and Z alloy metals (see Photo 3-5 through Photo 3-16). It is possible that the corrosion rate is reduced by the amount of marine life fouling present on the samples because it limits the exposure of the metal to the seawater. The ability of the metal to create a passivation layer on the surface of each alloy may also affect the corrosion rate.

The highest pitting rate was observed on the 70-30 Cu-Ni coupons. Pits on the small cross sectional areas of the wire screens were difficult to measure, but were all less than 20 mils and appeared to the same trend between the different alloys as the coupons.

Photo 3-17 through Photo 3-26 show the surfaces of the samples under magnification. Photos are courtesy of Anamet, Inc. and are included in the reports in Appendix A.

Photo 3-17. Uncoated 2205 Duplex SS coupon surface after cleaning at 50X magnification.

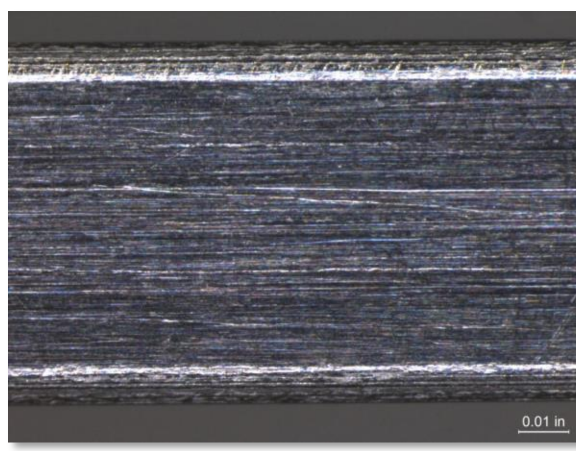


Photo 3-18. Uncoated 2205 Duplex SS screen surface after cleaning at 50X magnification.

Photo 3-19. 2205 Duplex SS coupon surface exposed at an area of coating damage.

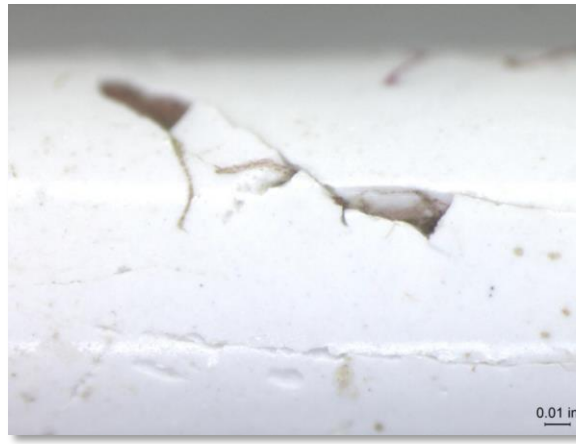


Photo 3-20. 2205 Duplex SS wedge wire screen surface at an area of coating damage.

Photo 3-21. CDA 715 coupon at 50x magnification after cleaning

Photo 3-22. CDA 715 Screen at 50X magnification after cleaning.

Photo 3-23. CDA 706 coupon at 50x magnification after cleaning.

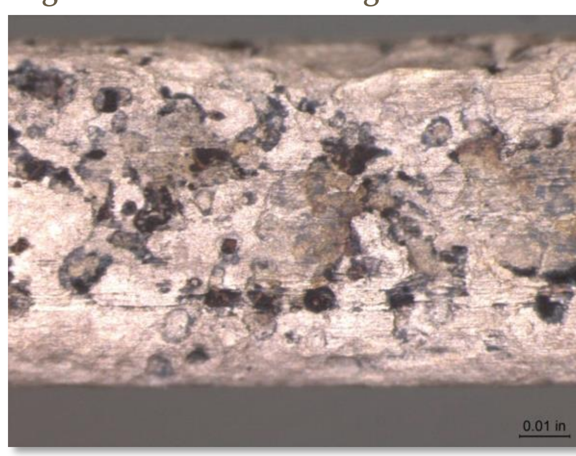


Photo 3-24. CDA 706 screen at 50X magnification after cleaning.

Photo 3-25. Z Alloy coupon at 50X magnification after cleaning.

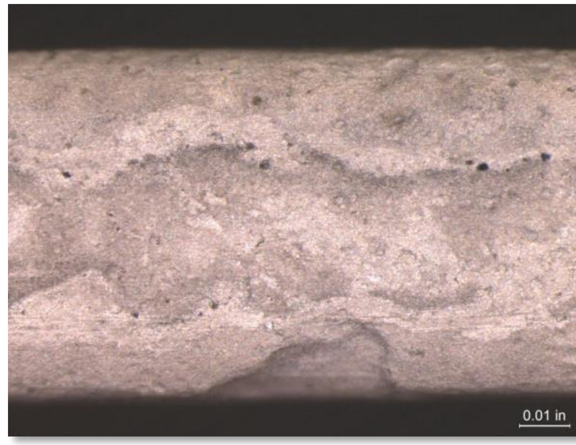


Photo 3-26. Z Alloy Screen at 50X magnification after cleaning.

4.0 CONCLUSIONS

Based on the literature research and the lab analysis, V&A presents the following conclusions.

4.1 Coupons

1. The average corrosion rates of the 10-month samples are lower than the 6-month samples. The passivation layer has continued to protect the metal surfaces as indicated by the decrease in the corrosion rate over 10-month samples have a protective passivation layer.
2. The average corrosion rate of the uncoated and coated 2205 Duplex Stainless Steel coupons was the lowest of the four alloys that were included in this study.
3. The greatest amount of biofouling was observed on the uncoated 2205 Duplex Stainless Steel coupons.
4. The average corrosion rate of the 90-10 Cu-Ni coupons was the highest of the four alloys that were included in this study.
5. The lowest coupon pitting depth was measured on the Z Alloy coupons after 308 days of exposure in seawater.
6. The highest pitting depth was measured on the70-30 Cu-Ni coupons after 308 days of exposure in seawater.
7. Pitting and general corrosion were the primary modes of corrosion on the coupons.
8. There is a large difference in the overall corrosion rate between the coupons and screens for the 90-10Cu-Ni and Z Alloy samples.
9. The overall average corrosion rates of the 90-10Cu-Ni and Z Alloy screens were 3 to 7 times higher than the coupons of the same alloy.
10. The overall average corrosion rates were higher than the data found in the literature summarized in Table 2-1.

4.2 Screens

1. The average corrosion rate of the uncoated 2205 Duplex Stainless Steel screens was the lowest of the four alloys after 308 days of exposure.
2. The greatest amount of biofouling was observed on the uncoated 2205 Duplex Stainless Steel wedge wire screens.
3. The average corrosion rate of the 90-10 Cu-Ni screens was the highest of the four alloys that were included in this study.
4. Pitting and general corrosion were the primary modes of corrosion on the screens.

5. The maximum pitting depth of the screens appears to follow the same trend between the different alloys as the coupons, but was difficult to measure due to the clearance between the wires.
6. The overall average corrosion rates of the 90-10Cu-Ni and Z Alloy screens were 3 to 7 times higher than the coupons of the same alloy.
7. The overall average corrosion rates were higher than the data found in the literature summarized in Table 2-1.
8. Mechanical damage was observed at each corner of the 70-30 Cu-Ni, 90-10 Cu-Ni, and Z Alloy screens where they were secured to the test rack. The mechanical damage may have been caused by the turbulence in the water and abrasion of metal by the zip ties that prevented the passivation of the metal at those locations. The exposed metal was corroded.

APPENDIX A. LAB ANALYSIS REPORTS

Report No. 5005.0361A **May 19, 2015**

CORROSION EVALUATION OF 2205 DUPLEX STAINLESS STEEL COUPONS AND SCREENS WITH ANTI-BIOFOULING COATING

Customer Authorization: Verbal

Report To: V & A Engineering
Attn: Manuel Najar
155 Grand Avenue, Suite 700
Oakland, CA 94612

1.0 INTRODUCTION

Five coupons, five wedge wire screens, and one plate of 2205 duplex stainless steel with a bio-fouling coating were submitted by V&A Engineering for corrosion evaluation. The coupons were 1-inch by 3-inches by ¼-inch thick. The wedge wire screens were 4-inches by 4-inches by 1-inch tall with 2 mm spacing. The plate was 4-inches by 4-inches by 1/8-inch thick.

Four coupons and four screens were to be placed in seawater for a period up to one year. After every 3 month interval, one coupon and one screen were to be removed from the test system and examined for corrosion. The purpose of this evaluation was to document the samples in the baseline as-received condition, then again after 3, 6, 10, and 12 months of water exposure, record any loss in mass, examine for any pitting corrosion, and estimate the corrosion rate.

The samples were evaluated by the following laboratory procedures:

1) Visual examination and weighing
2) Cleaning per ASTM G1[1]
3) Scanning electron microscopy
4) Metallography

The results of the evaluation showed minimal mass loss and corrosion for the coupon and screen after 3, 6, and 10 months of corrosion testing. The coupon and the screen, after 3 months and 6 months of corrosion testing, had a corrosion rate of approximately 0.002 millimeters per year. The coupon and screen, after 10 months of corrosion testing, had a corrosion rate of 0.001 millimeters per year.

[1] G1: Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

2.0 EVALUATION[2]

2.1 Visual Examination

The sample identifications for the coupons and wedge wire screens and their corresponding immersion times are shown in Table 1. The coupons had identification numbers stamped on the front face by V&A Engineering. A number of notches, corresponding to the sample number, were sawed at the edge of each screen for identification after the corrosion test. The weights of the samples were recorded. Coupons 6 – 9 and screens 1 – 5 were sent back to V&A for corrosion testing. Coupon 10 was the baseline sample and documented by photography, optical stereoscopy and scanning electron microscopy for comparison to the tested samples. Screen 5 was documented as a baseline by photography and optical stereoscopy, and then sent to V&A for testing.

Photographs of the baseline coupon are shown in Figure 1. Photographs of coupon 1, after 3 months of corrosion testing, are shown in Figure 2. Photographs of coupon 2, after 6 months of corrosion testing, are shown in Figure 3. Photographs of coupon 3, after 10 months of corrosion testing, are shown in Figure 4.

A photograph of the baseline screen is shown in Figure 5. A photograph of screen 1, after 3 months of corrosion testing, is shown in Figure 6. A photograph of screen 2, after 6 months of corrosion testing, is shown in Figure 7. A photograph of screen 3, after 10 months of corrosion testing, is shown in Figure 8.

2.2 Cleaning

The coupon and screen were cleaned with solution C.7.1 per ASTM G1.[3] One cleaning cycle was approximately 5 minutes. After each cleaning cycle, the samples were rinsed in water, dried, and weighed. The cleaning and weighing cycle was completed five times for the coupon and screen. The weights of the samples as-received, after corrosion testing but before cleaning, and after each cleaning cycle are presented in Table 2.

Optical macrographs of the baseline coupon and screen are shown in Figures 9 and 16, respectively. Representative optical macrographs of the samples after a 3 month corrosion test, before and after cleaning, are shown in Figures 10 – 11 and 17 – 18. Representative optical macrographs of the sample after a 6 month corrosion test, before and after cleaning, are shown in Figures 12 – 13 and 19 – 20. Representative optical macrographs of the sample after a 10 month corrosion test, before and after cleaning, are shown in Figures 14 – 15 and 21 – 22.

The mass loss versus the number of cleaning cycles was plotted, shown in Figure 23 – 25. The equations for best fit lines AB and BC, calculated using IGOR Pro, are listed in Table 3. Point B, indicated by the red circle in each plot, corresponds to the mass loss due to corrosion during the cleaning process for each sample. This mass loss was subtracted from the weight of the sample before cleaning and from the weight of the sample as-received to determine the total

[2] The magnifications of the optical and scanning electron micrographs in this report are approximate and should not be used as a basis for dimensional analyses unless otherwise indicated.
[3] 100 mL nitric acid + 900 ml reagent water.

mass loss from corrosion. The corrosion rate of each sample was determined by the formula specified in Section 8.1 of ASTM G1:

$$Corrosion\ Rate = \frac{K\ x\ W}{A\ x\ T\ x\ D}$$

where K = 8.76 x 10^4, T = time of exposure in hours, A = area in cm^2, W = mass loss in grams, and D = density in g/cm^3. The total mass loss from corrosion and the calculated corrosion rate of each sample is shown in Table 4.

2.3 Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy

The baseline coupon, coupon 1, and coupon 2 were examined with a scanning electron microscope. Representative scanning electron micrographs of the baseline coupon are shown in Figure 26. Representative scanning electron micrographs of coupon 1 before and after cleaning are shown in Figures 27 – 28. Representative scanning electron micrographs of coupon 2 before and after cleaning are shown in Figures 29 – 30. Representative scanning electron micrographs of coupon 3 before and after cleaning are shown in Figures 31 – 32. Energy dispersive x-ray spectra of the baseline coupon and coupons 1 – 3 before and after cleaning are shown in Figures 33 – 36.

2.4 Metallography

Cross sections were taken from the coupon and prepared for a metallographic examination. Optical micrographs of the surface for coupons 1 – 3 are shown in Figures 37 – 39. Small, shallow pits were observed in coupon 1 and 3, the deepest of which measured 24 µm, as shown in Figure 39. Sharp narrow pits were observed in coupon 2, the deepest measured 34 µm.

3.0 DISCUSSION

The coupons and screens showed minimal mass loss and pitting overall after 3, 6, and 9 months of corrosion testing. The coupons and screens had more material loss over time but maintained a consistent corrosion rate.

4.0 CONCLUSIONS[4]

The following conclusions are based upon the submitted samples and the evidence gathered:

1. The coupon, after 3 months of corrosion testing, had a mass loss of 0.023 grams and a corrosion rate of 0.002 mm / year.

[4] The conclusions in this report are based upon the available information and evidence provided by the client and gathered by Anamet, within the scope of work authorized by the client, and they are hereby presented by Anamet to a reasonable degree of engineering and scientific certainty. Anamet reserves the right to amend or supplement its conclusions or opinions presented in this report should additional data or information become available, or further work be approved by the client.

2. The screen, after 3 months of corrosion testing, had a mass loss of 0.25 grams and a corrosion rate of 0.002 mm / year.
3. The coupon, after 6 months of corrosion testing, had a mass loss of 0.031 grams and a corrosion rate of 0.002 mm / year.
4. The screen, after 6 months of corrosion testing, had a mass loss of 0.43 grams and a corrosion rate of 0.002 mm / year.
5. The coupon, after 10 months of corrosion testing, had a mass loss of 0.035 grams and a corrosion rate of 0.001 mm / year.
6. The screen, after 10 months of corrosion testing, had a mass loss of 0.60 grams and a corrosion rate of 0.001 mm / year.

Prepared by:

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Materials Engineer

Reviewed by:

Audrey A. Fasching

Audrey A. Fasching, Ph.D., P.E.
Senior Materials Engineer

Table 1
Sample Identifications

Description		V&A Engineering Identification (As-Received)	Anamet Identification (in report)	Notes
Alloy	Part			
2205 Duplex Stainless Steel with anti-biofouling coating	**Flat Plate** 4-inch x 4-inch x 1/8-inch	None	Plate	None
	Coupon 1-inch x 3-inch x 1/8-inch with autogenous weld bead	2205 SS 1	Coupon 1*	3 Month Immersion
		2205 SS 2	Coupon 2*	6 Month Immersion
		2205 SS 3	Coupon 3*	10 Month Immersion
		2205 SS 4	Coupon 4*	12 Month Immersion
		2205 SS 5	Coupon 5	Baseline Sample (no exposure)
	Wedge Wire Screen 4-inch x 4-inch x 1-inch with 2 mm spacing	None	Screen 1*	3 Month Immersion
		None	Screen 2*	6 Month Immersion
		None	Screen 3*	10 Month Immersion
		None	Screen 4*	12 Month Immersion
		None	Screen 5*	12 Month Immersion

* Cable ties were attached to each sample to designate sample identification. The number of cable ties per sample corresponded to the sample number.

Table 2
Sample Weights

Sample	Baseline Measurement	Measurements after 3 Months Corrosion Testing				
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)
Coupon 1	24.1892	24.1683	24.1668	24.1666	24.1665	-
Screen 1	339.91	340.03	339.70	339.66	339.63	339.63

Sample	Baseline Measurement	Measurements after 6 Months Corrosion Testing				
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)
Coupon 2	24.2019	24.1714	24.1711	24.1701	24.1694	24.1691
Screen 2	341.67	341.34	341.24	341.24	341.25	-

Sample	Baseline Measurement	Measurements after 10 Months Corrosion Testing				
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)
Coupon 3	24.2035	24.1681	24.1675	24.1668	24.1661	-
Screen 3	338.80	338.24	338.20	338.20	338.21	-

Table 3
Equations of Lines AB and BC for Corrosion Testing Samples

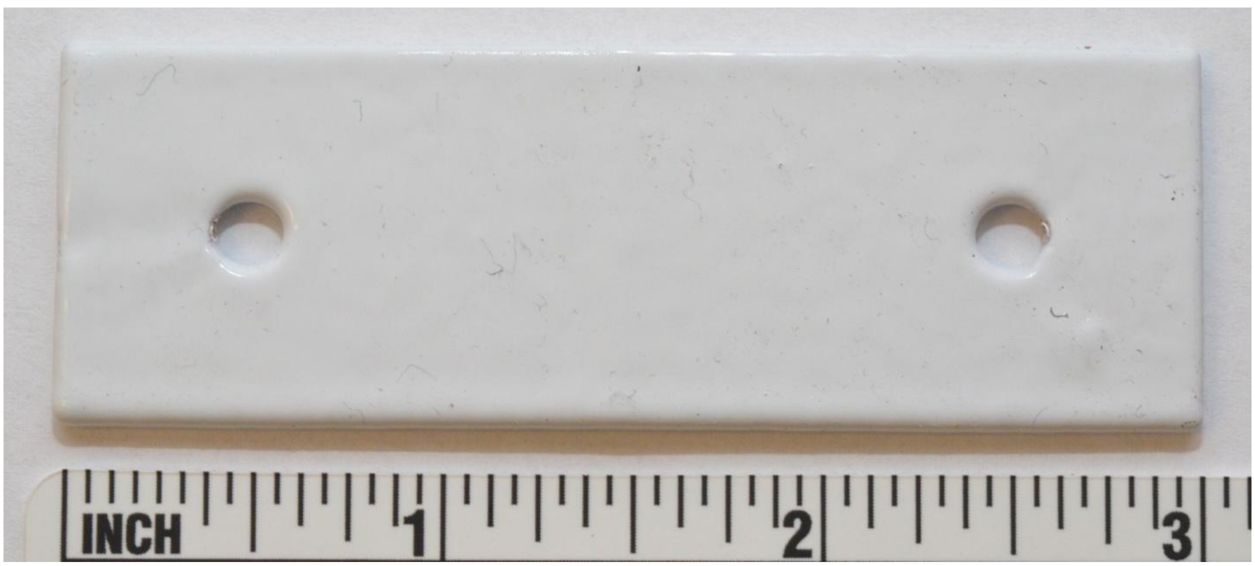
Sample	Line AB	Line BC	Point B (Approximate Mass Loss from Corrosion During Cleaning)
Coupon 1	y = 0.0015x	y = 0.0001x + 0.0015	0.0016 grams
Coupon 2	N/A	y = 0.0006x	0 grams
Coupon 3	N/A	y = 0.0006x	0 grams
Screen 1	y = 0.33x	y = 0.02x + 0.35	0.37 grams
Screen 2	y = 0.10x	y = 0.10	0.10 grams
Screen 3	y = 0.02x	y = 0.04	0.04 grams

Table 4
Total Mass Loss from Corrosion and Corrosion Rate

Sample	Total Mass Loss from Corrosion*	Corrosion Rate
Coupon 1	0.023 grams	0.002 mm / year
Coupon 2	0.031 grams	0.002 mm / year
Coupon 3	0.035 grams	0.001 mm / year
Screen 1	0.25 grams	0.002 mm / year
Screen 2	0.43 grams	0.002 mm / year
Screen 3	0.60 grams	0.001 mm / year

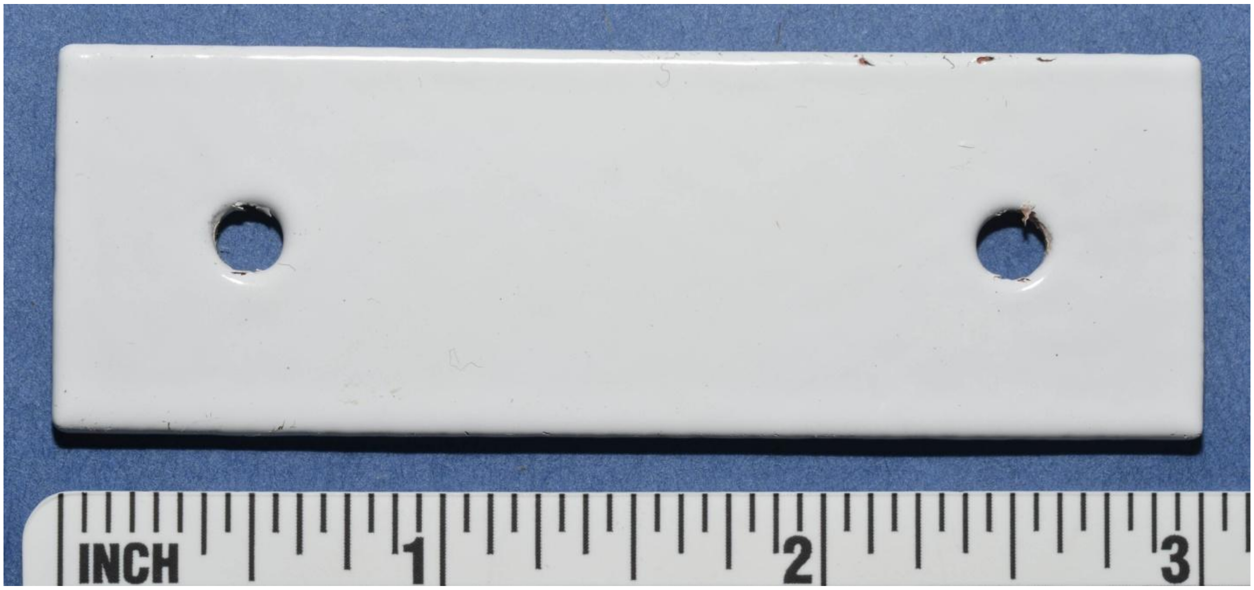
* Weight As-Received – (Weight Before Cleaning – Mass Loss from Corrosion During Cleaning)

(a) Coated Duplex 2205 Stainless Steel Baseline Coupon, Front Side

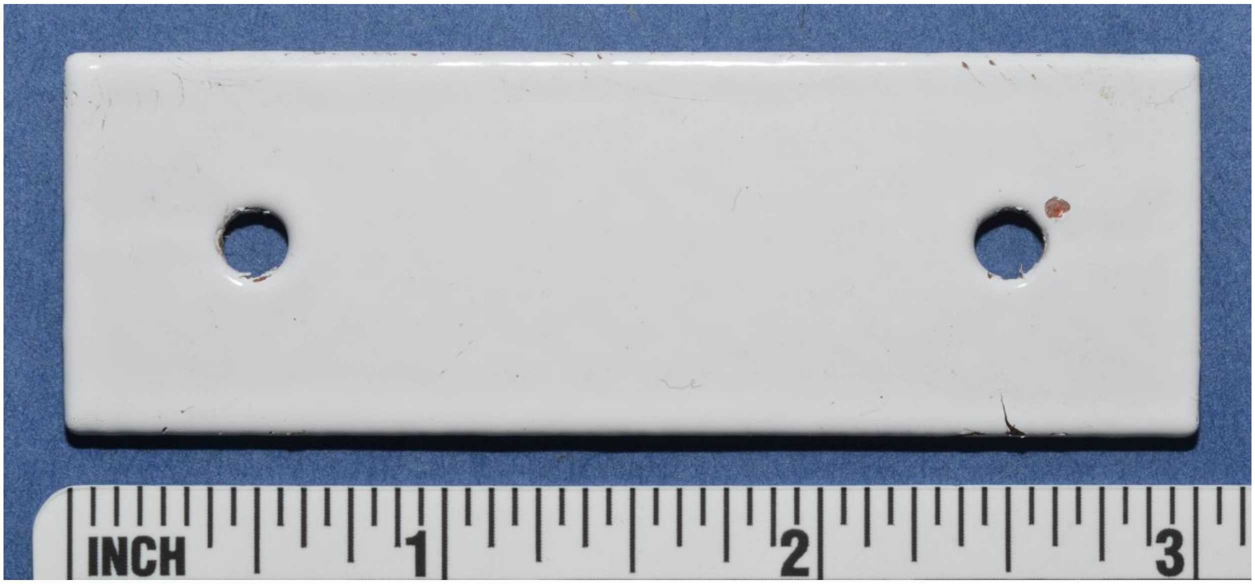


(b) Coated Duplex 2205 Stainless Steel Baseline Coupon, Back Side

Figure 1 Photographs of the duplex 2205 stainless steel with anti-biofouling coating baseline coupon (a) front and (b) back side.



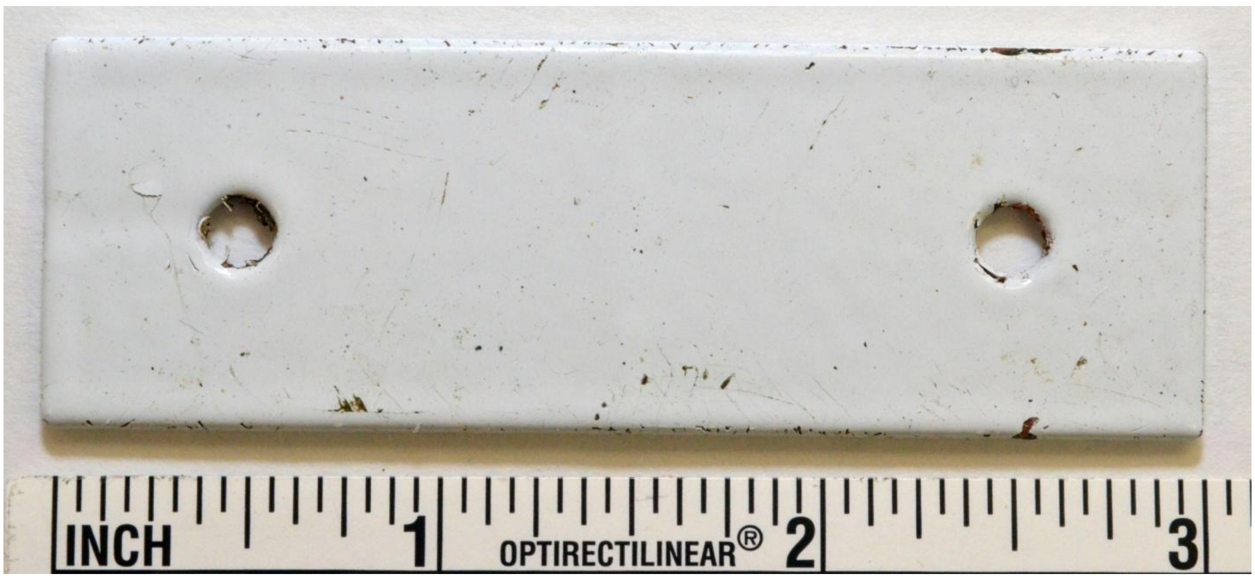
(a) Coated Duplex 2205 Stainless Steel Coupon 1, Front Side



(b) Coated Duplex 2205 Stainless Steel Coupon 1, Back Side

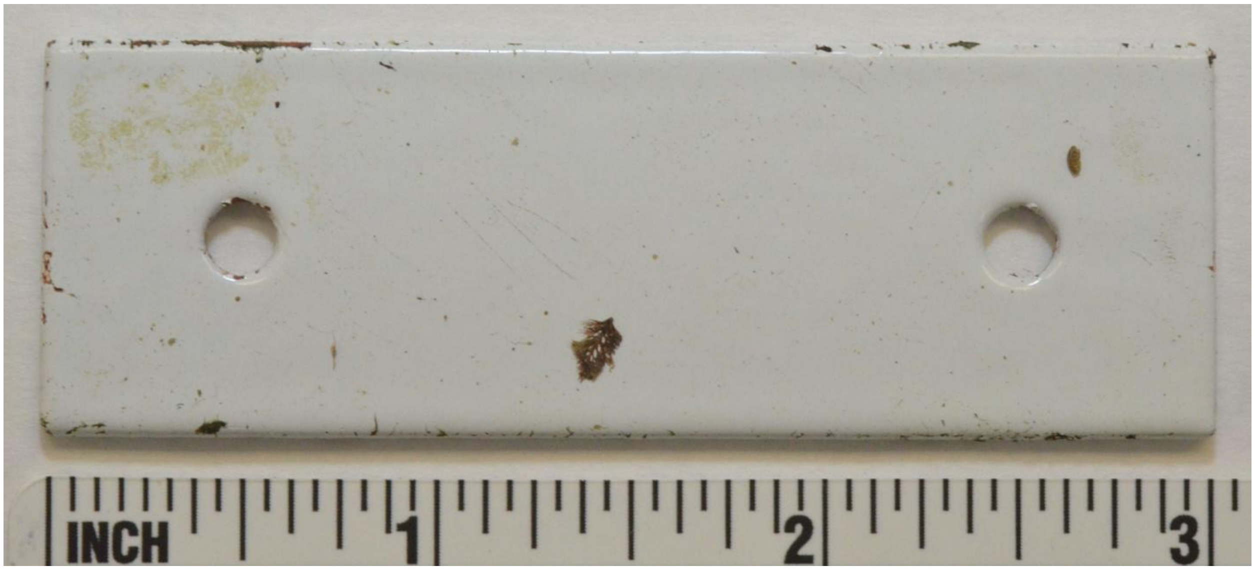
Figure 2 Photographs of duplex 2205 stainless steel with anti-biofouling coating coupon 1 (a) front and (b) back side after a 3 month corrosion test.

(a) Coated Duplex 2205 Stainless Steel Coupon 2, Front Side



(b) Coated Duplex 2205 Stainless Steel Coupon 2, Back Side

Figure 3 Photographs of duplex 2205 stainless steel with anti-biofouling coating coupon 2 (a) front and (b) back side after a 6 month corrosion test.



(a) Coated Duplex 2205 Stainless Steel Coupon 3, Front Side

(b) Coated Duplex 2205 Stainless Steel Coupon 3, Back Side

Figure 4 Photographs of duplex 2205 stainless steel with anti-biofouling coating coupon 3 (a) front and (b) back side after a 10 month corrosion test.

(a) Coated Duplex 2205 Stainless Steel Baseline Screen

Figure 5 Photograph of the duplex 2205 stainless steel with anti-biofouling coating baseline screen.

(a) Coated Duplex 2205 Stainless Steel Screen 1

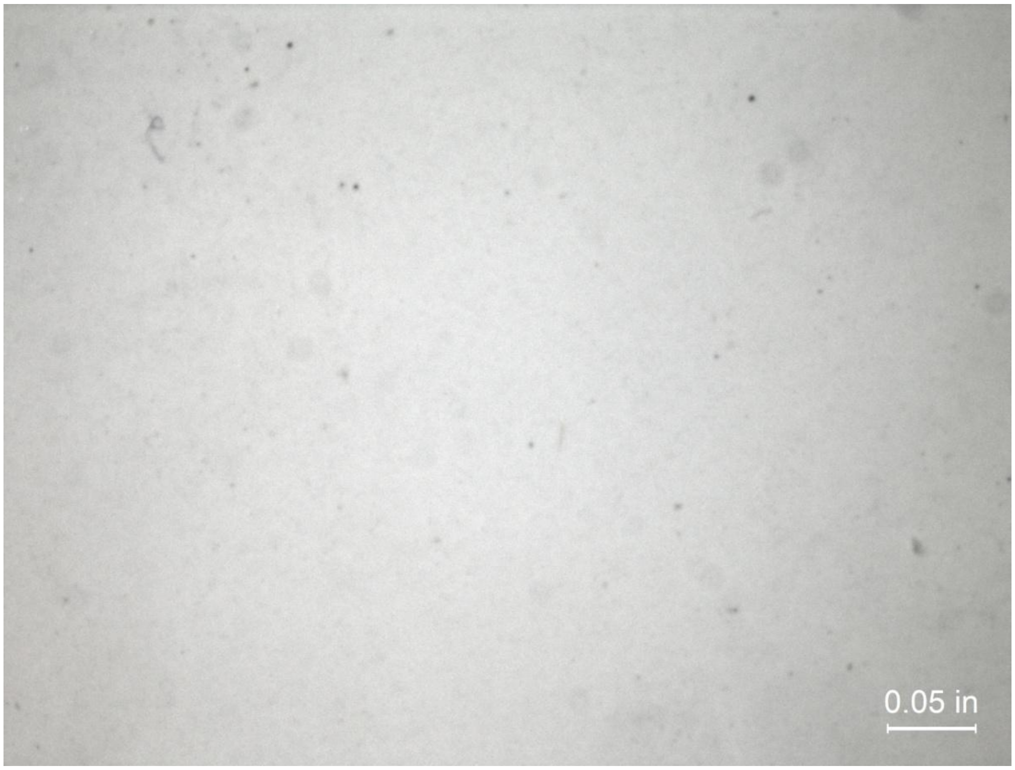
Figure 6 Photograph of duplex 2205 stainless steel with anti-biofouling coating screen 1 after a 3 month corrosion test.

(a) Coated Duplex 2205 Stainless Steel Screen 2

Figure 7 Photograph of duplex 2205 stainless steel with anti-biofouling coating screen 2 after a 6 month corrosion test.

(a) Coated Duplex 2205 Stainless Steel Screen 3

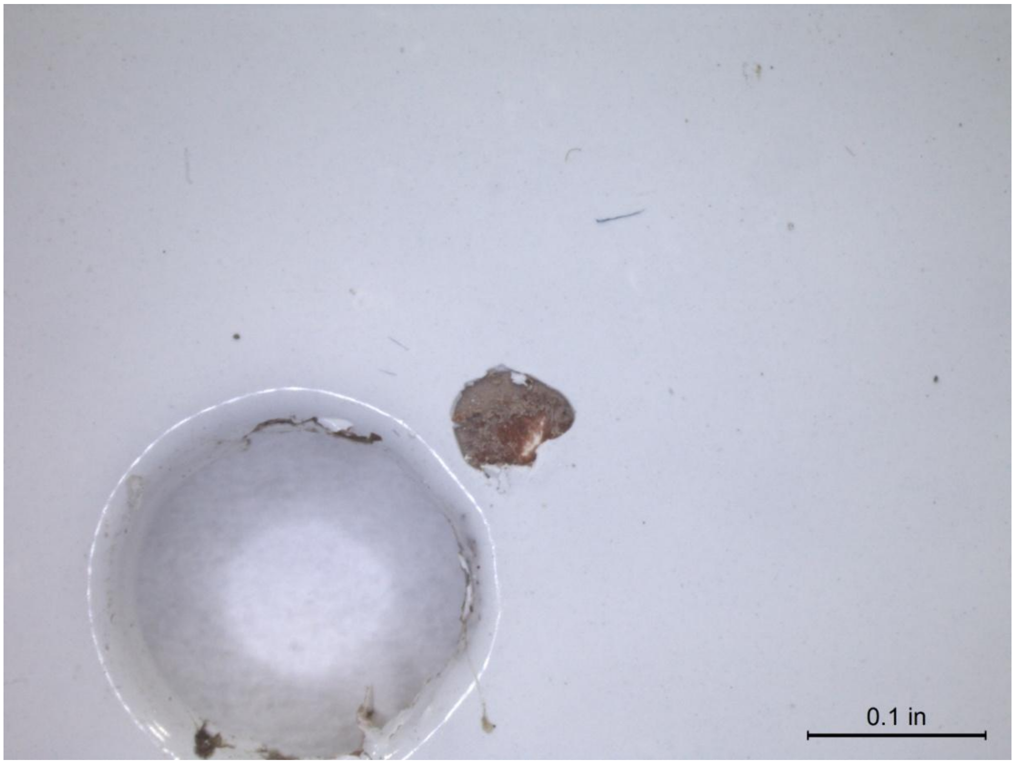
Figure 8 Photograph of duplex 2205 stainless steel with anti-biofouling coating screen 3 after a 10 month corrosion test.



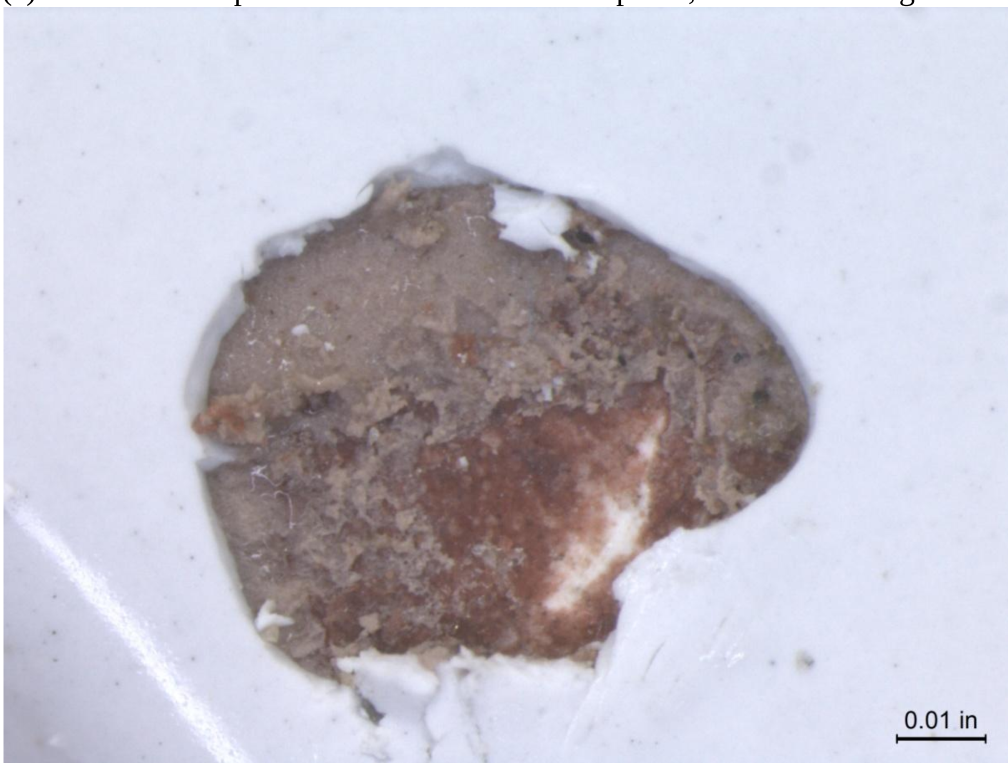
(a) Coated Duplex 2205 Stainless Steel Baseline Coupon 10X

(b) Coated Duplex 2205 Stainless Steel Baseline Coupon 40X

Figure 9 Optical macrographs of the duplex 2205 stainless steel with anti-biofouling coating baseline coupon.

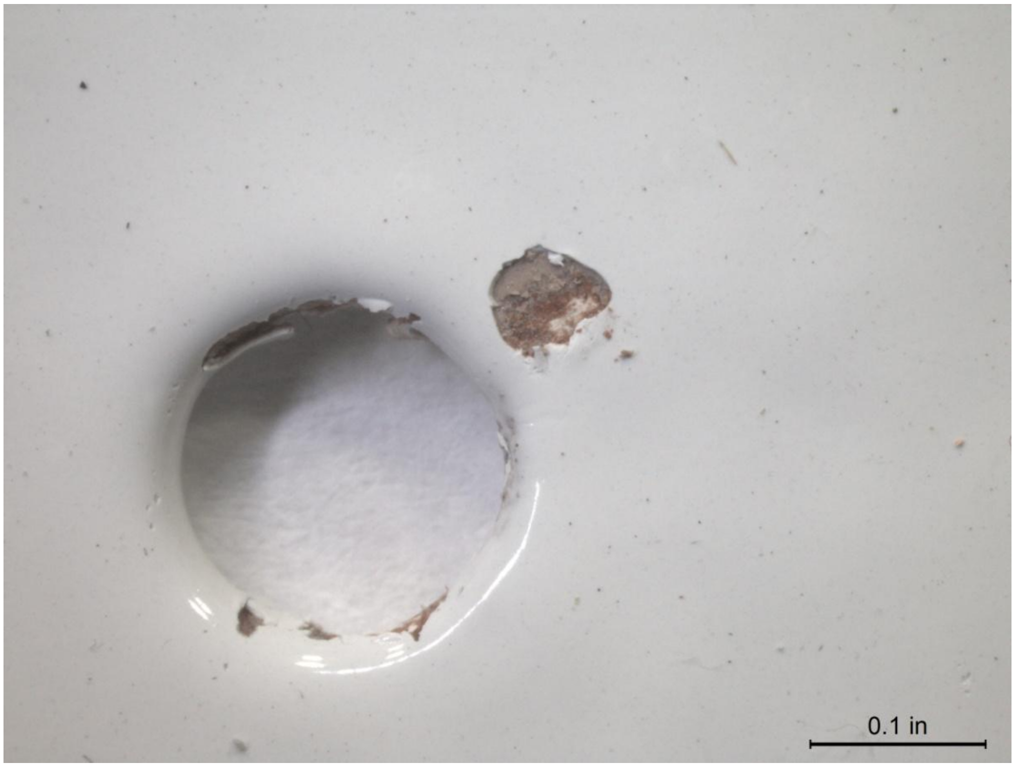


(a) Coated Duplex 2205 Stainless Steel Coupon 1, Before Cleaning 10X

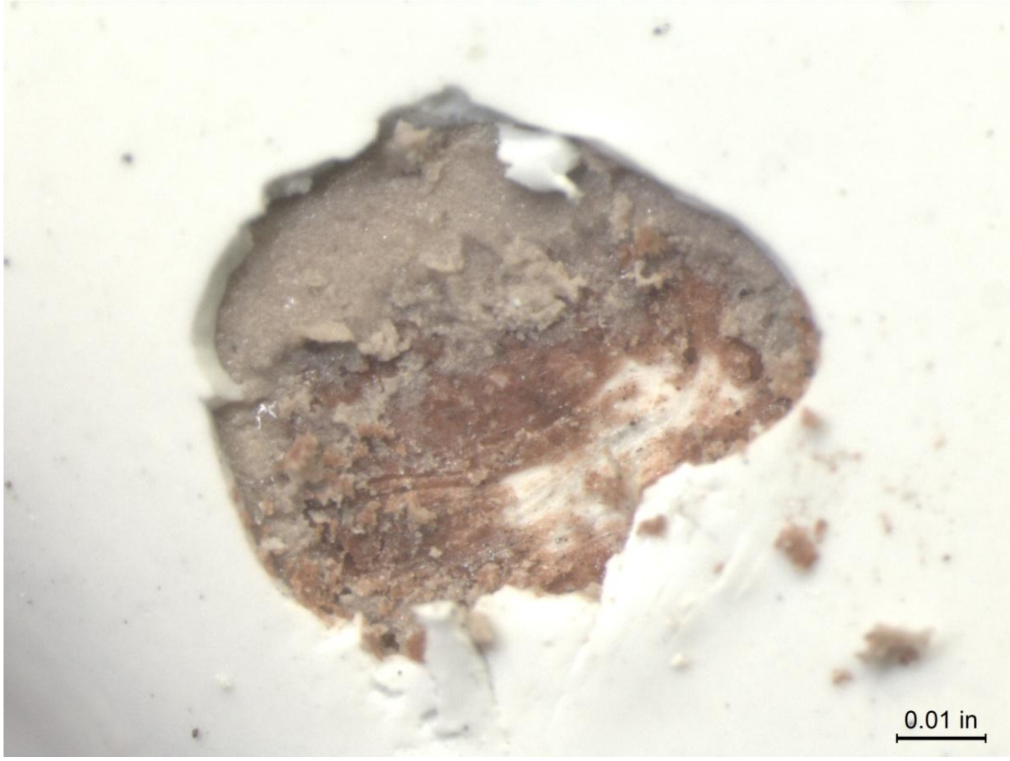


(b) Coated Duplex 2205 Stainless Steel Coupon 1, Before Cleaning 50X

Figure 10 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 1 after a 3 month corrosion test, before cleaning.

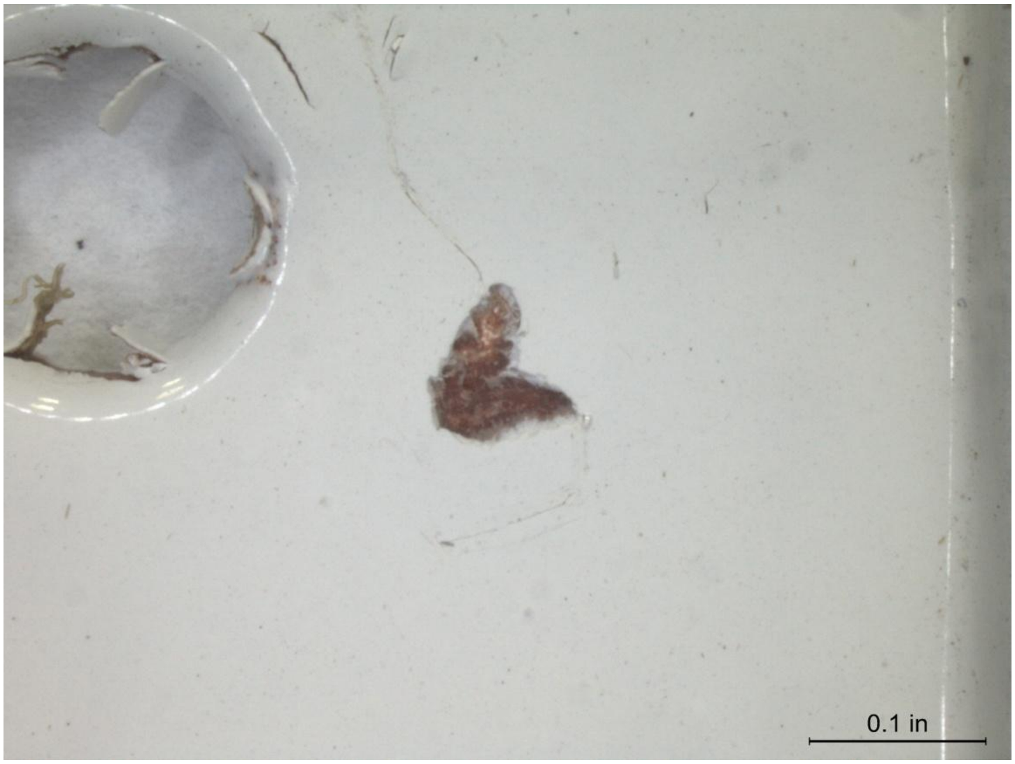


(a) Coated Duplex 2205 Stainless Steel Coupon 1, After Cleaning 10X



(b) Coated Duplex 2205 Stainless Steel Coupon 1, After Cleaning 50X

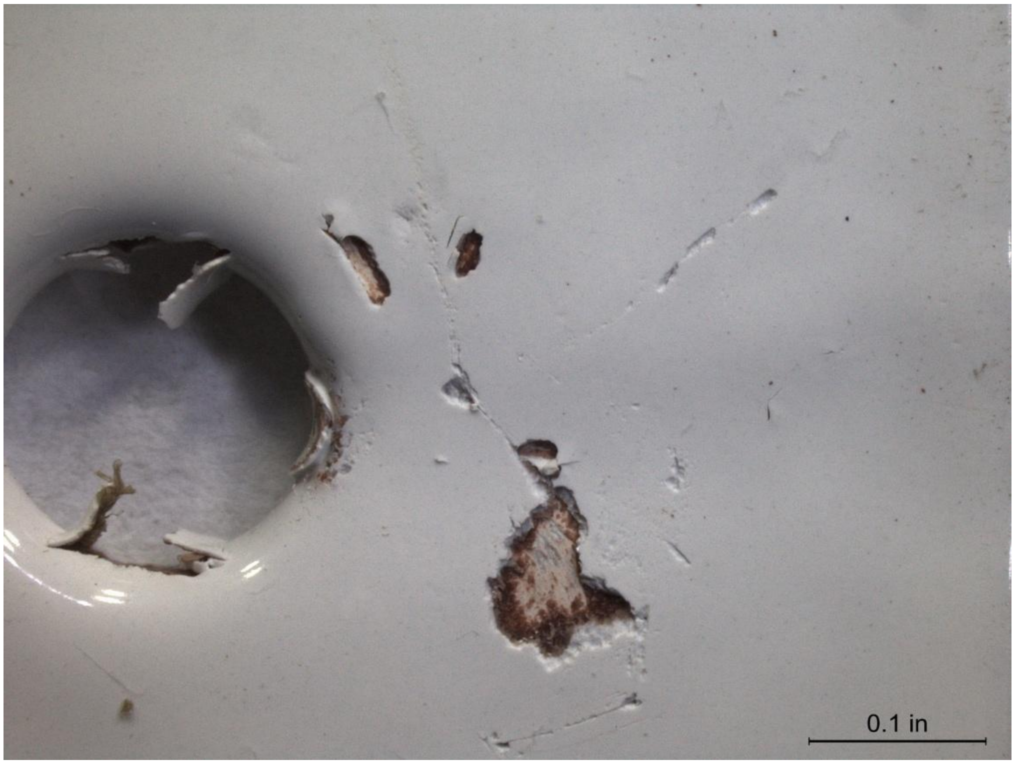
Figure 11 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 1 after a 3 month corrosion test, after cleaning.



(a) Coated Duplex 2205 Stainless Steel Coupon 2, Before Cleaning 10X

(b) Coated Duplex 2205 Stainless Steel Coupon 2, Before Cleaning 50X

Figure 12 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 2 after a 6 month corrosion test, before cleaning.

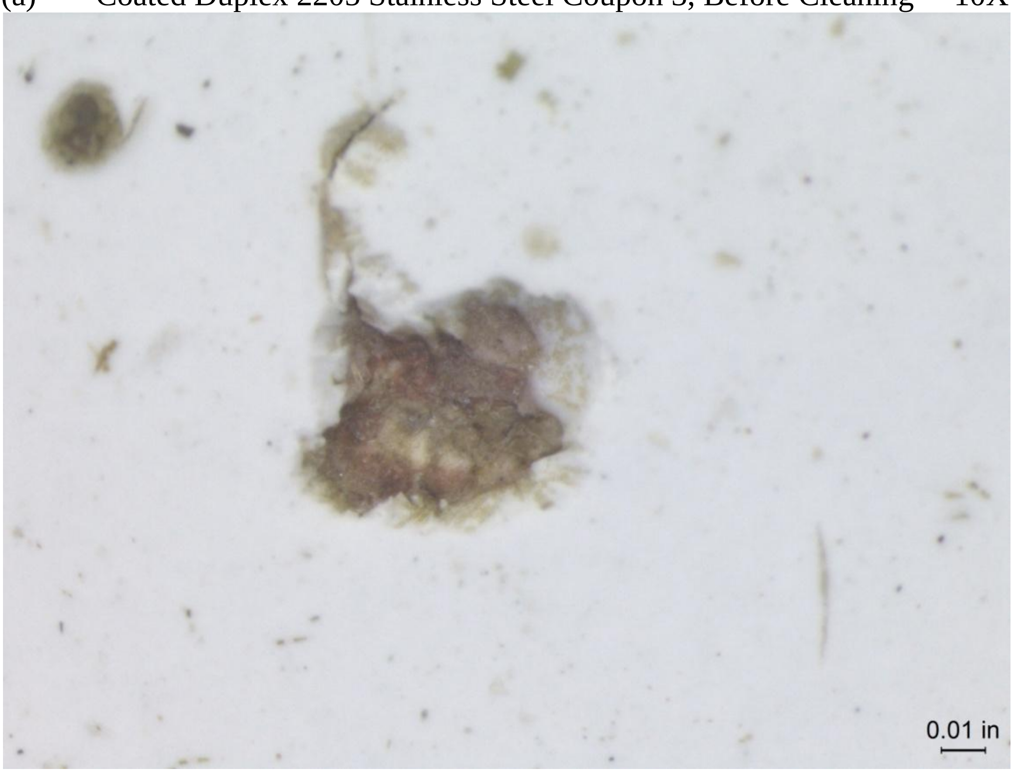


(a) Coated Duplex 2205 Stainless Steel Coupon 2, After Cleaning 10X

(b) Coated Duplex 2205 Stainless Steel Coupon 2, After Cleaning 50X

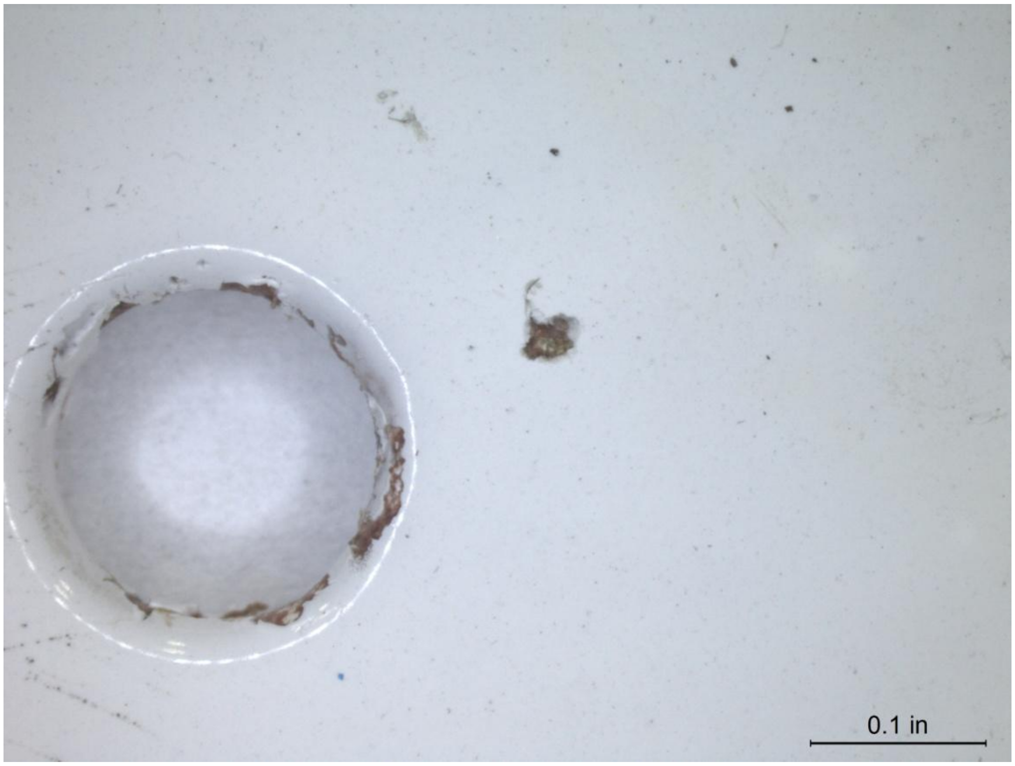
Figure 13 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 2 after a 6 month corrosion test, after cleaning.

(a) Coated Duplex 2205 Stainless Steel Coupon 3, Before Cleaning 10X



(b) Coated Duplex 2205 Stainless Steel Coupon 3, Before Cleaning 50X

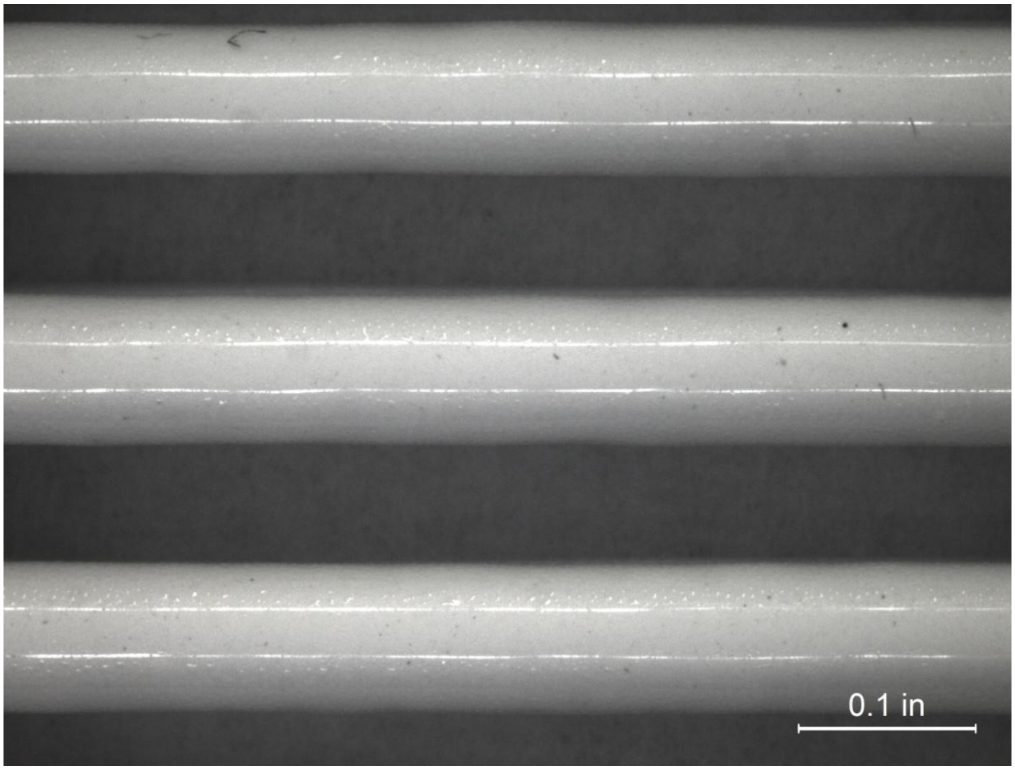
Figure 14 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 3 after a 10 month corrosion test, before cleaning.



(a) Coated Duplex 2205 Stainless Steel Coupon 3, After Cleaning 10X

(b) Coated Duplex 2205 Stainless Steel Coupon 3, After Cleaning 50X

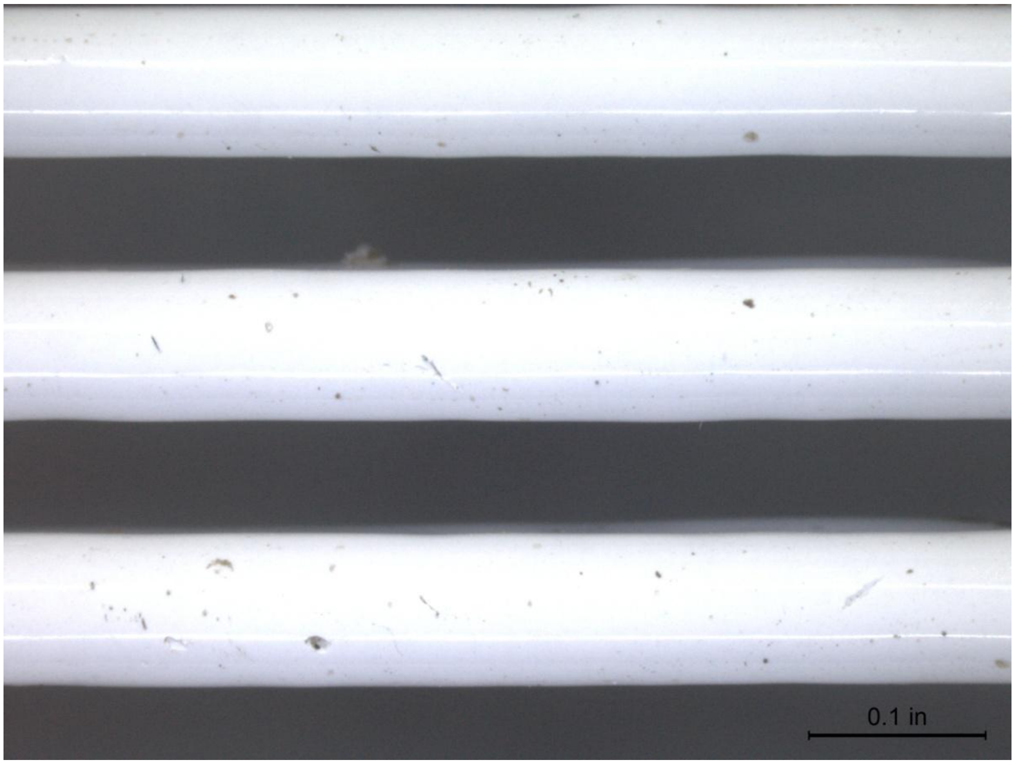
Figure 15 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 3 after a 10 month corrosion test, after cleaning.



(a) Coated Duplex 2205 Stainless Steel Baseline Screen 10X

(b) Coated Duplex 2205 Stainless Steel Baseline Screen 50X

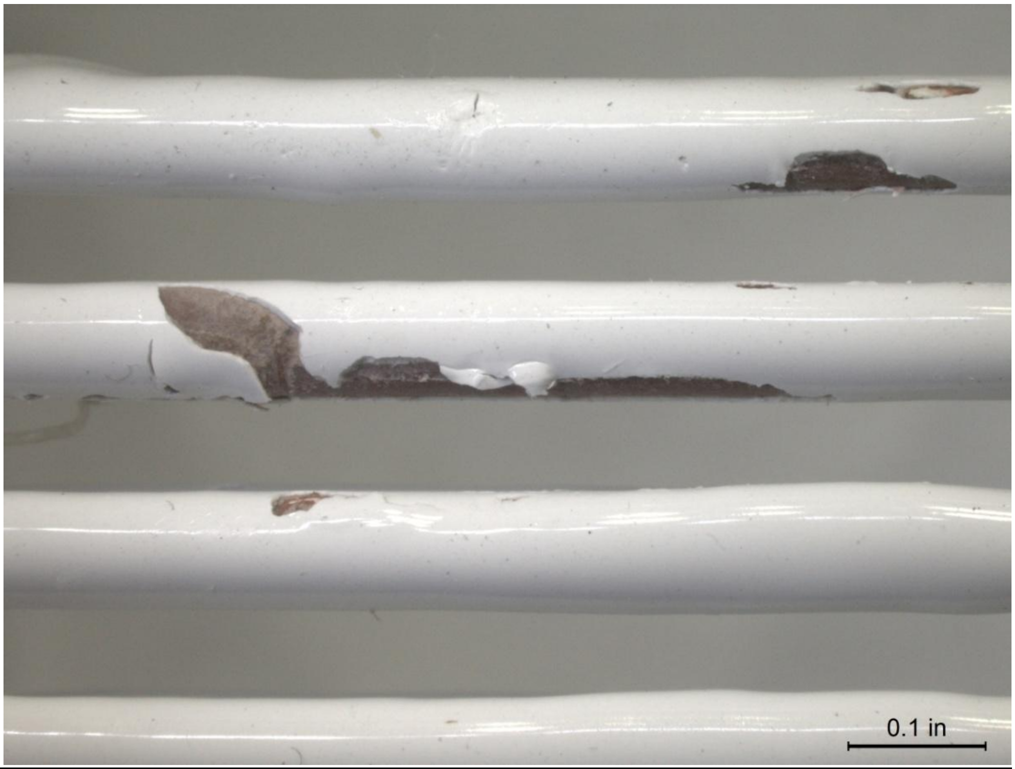
Figure 16 Optical macrographs of the duplex 2205 stainless steel with anti-biofouling coating baseline screen.



(a) Coated Duplex 2205 Stainless Steel Screen 1, Before Cleaning 10X

(b) Coated Duplex 2205 Stainless Steel Screen 1, Before Cleaning 50X

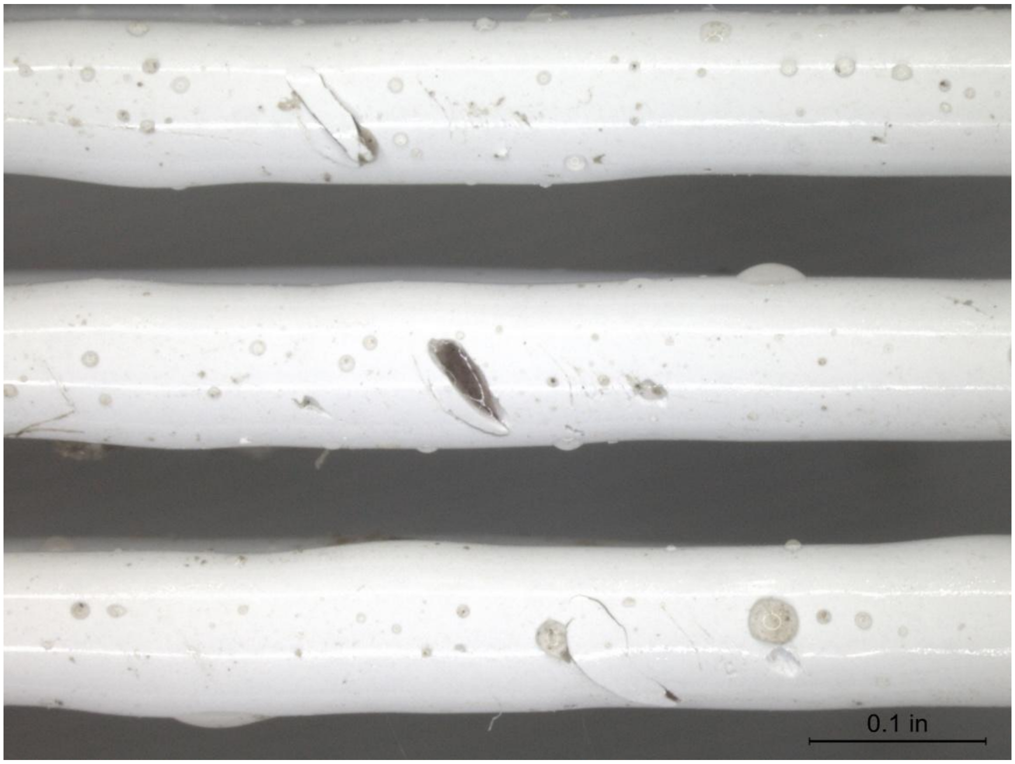
Figure 17 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating screen 1 after a 3 month corrosion test, before cleaning.



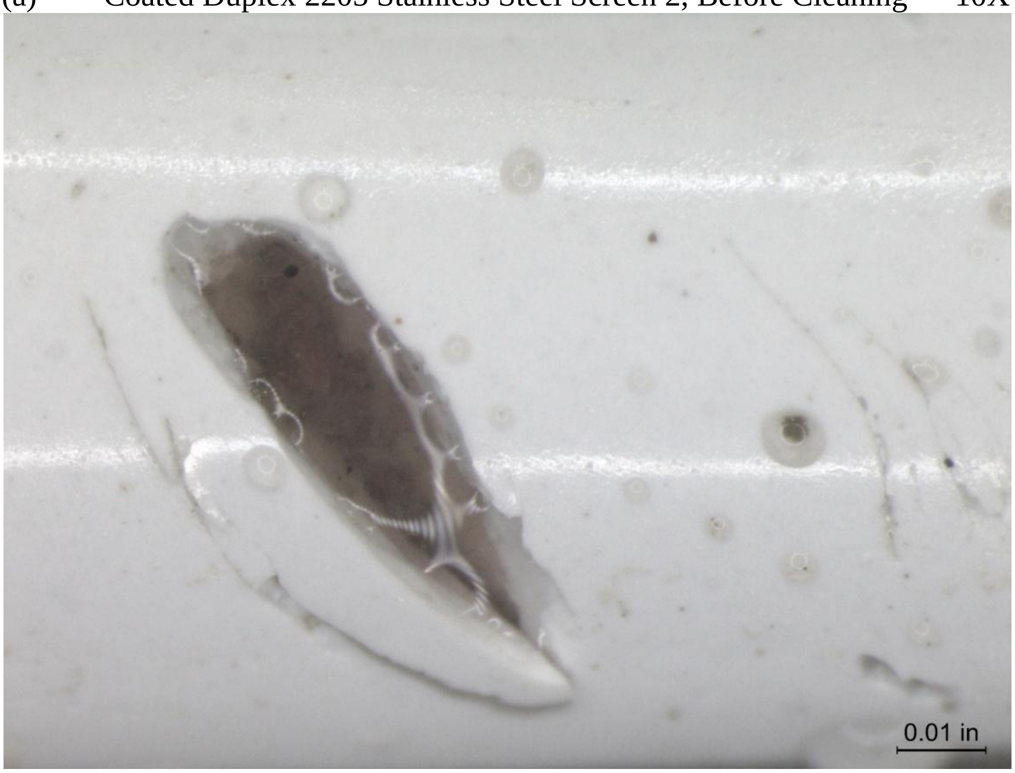
(a) Coated Duplex 2205 Stainless Steel Screen 1, After Cleaning 10X

(b) Coated Duplex 2205 Stainless Steel Screen 1, After Cleaning 50X

Figure 18 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating screen 1 after a 3 month corrosion test, after cleaning.

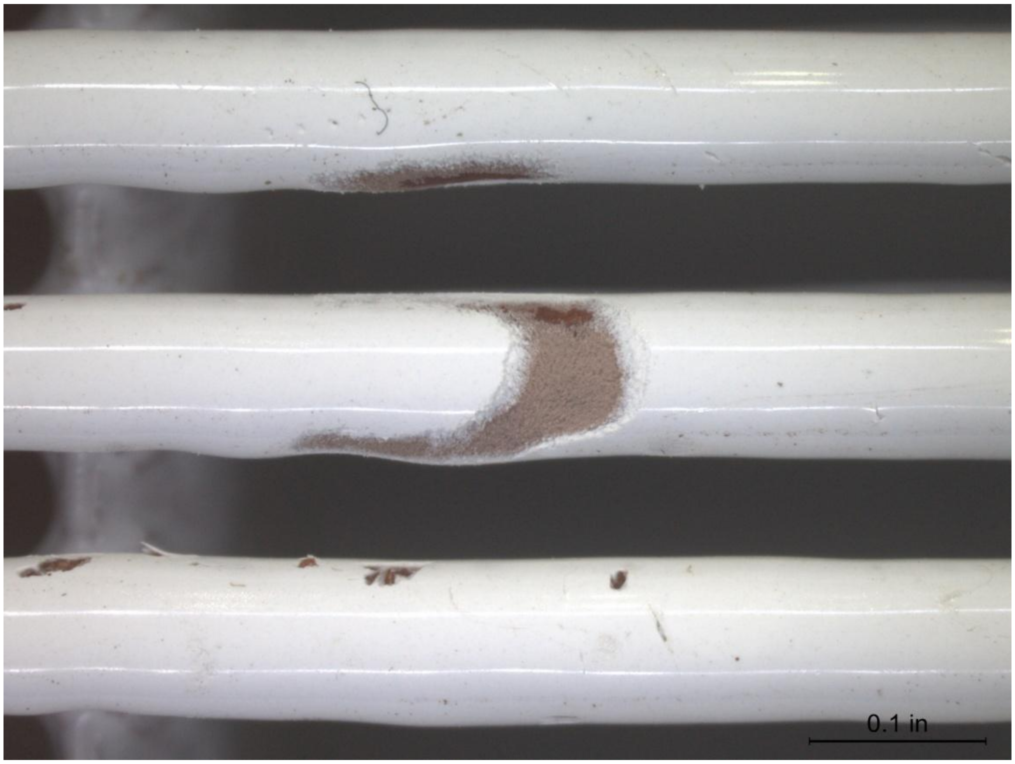


(a) Coated Duplex 2205 Stainless Steel Screen 2, Before Cleaning 10X



(b) Coated Duplex 2205 Stainless Steel Screen 2, Before Cleaning 50X

Figure 19 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating screen 2 after a 6 month corrosion test, before cleaning.



(a) Coated Duplex 2205 Stainless Steel Screen 2, After Cleaning 10X

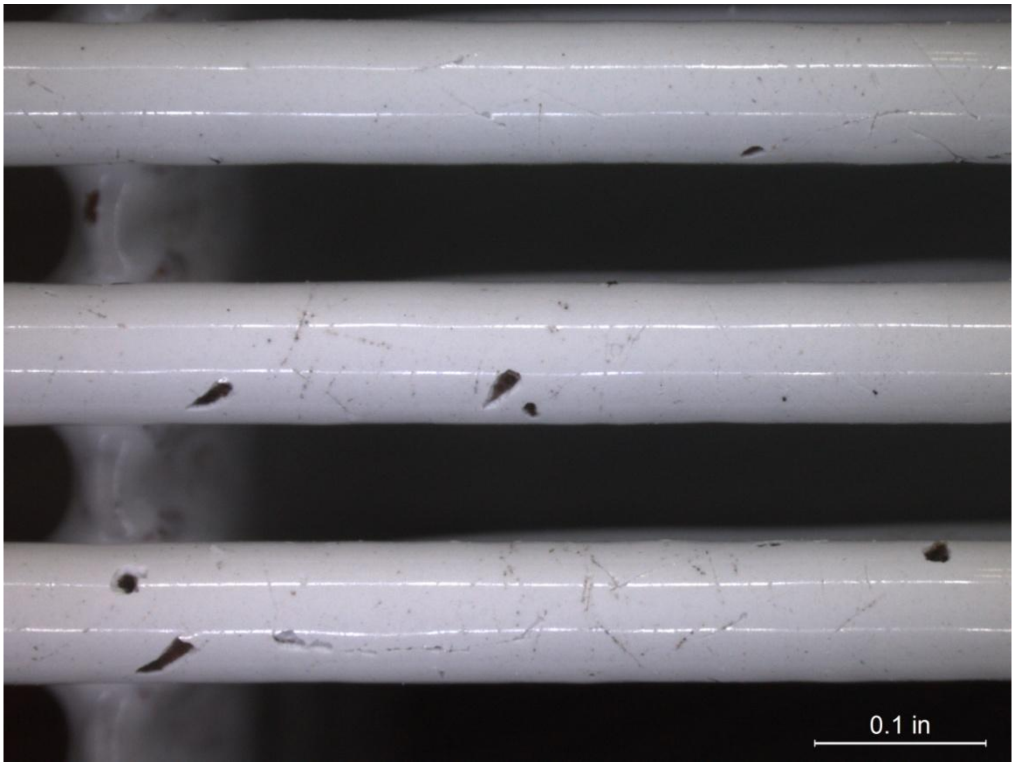
(b) Coated Duplex 2205 Stainless Steel Screen 2, After Cleaning 50X

Figure 20 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating screen 2 after a 6 month corrosion test, after cleaning.

(a) Coated Duplex 2205 Stainless Steel Screen 3, Before Cleaning 10X

(b) Coated Duplex 2205 Stainless Steel Screen 3, Before Cleaning 50X

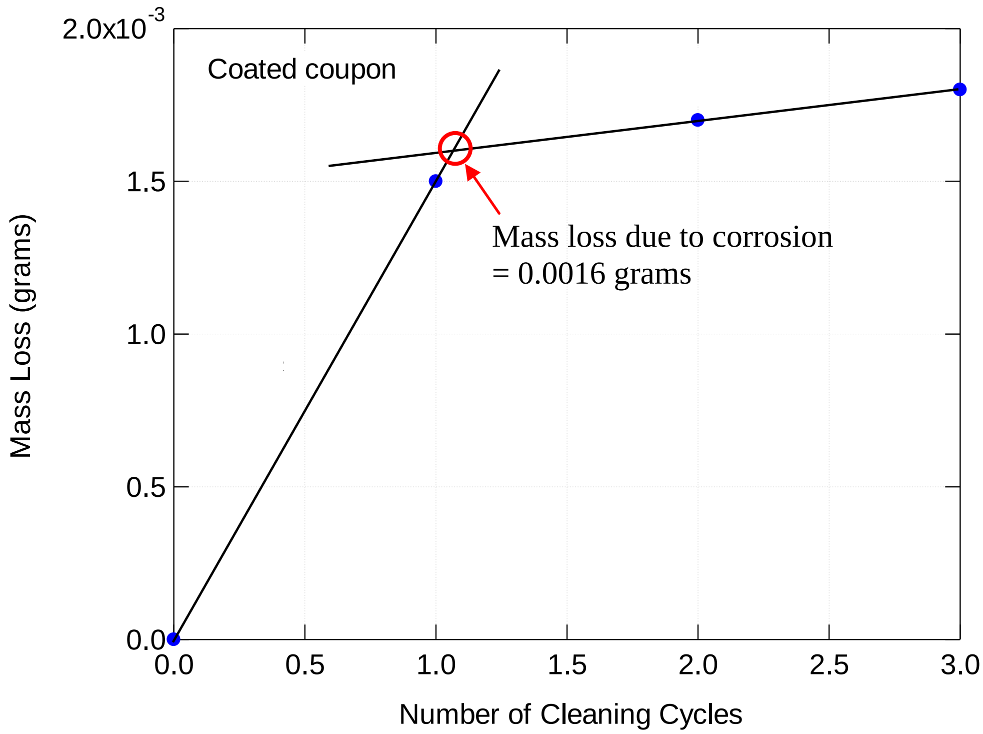
Figure 21 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating screen 3 after a 10 month corrosion test, before cleaning.



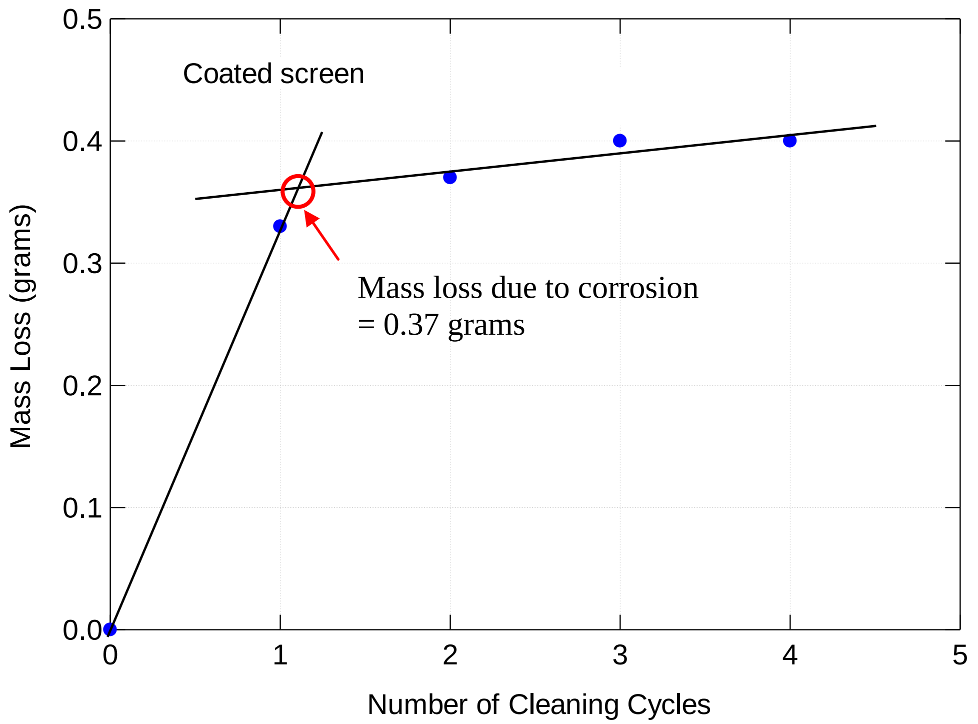
(a) Coated Duplex 2205 Stainless Steel Screen 3, After Cleaning 10X

(b) Coated Duplex 2205 Stainless Steel Screen 3, After Cleaning 50X

Figure 22 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating screen 3 after a 10 month corrosion test, after cleaning.

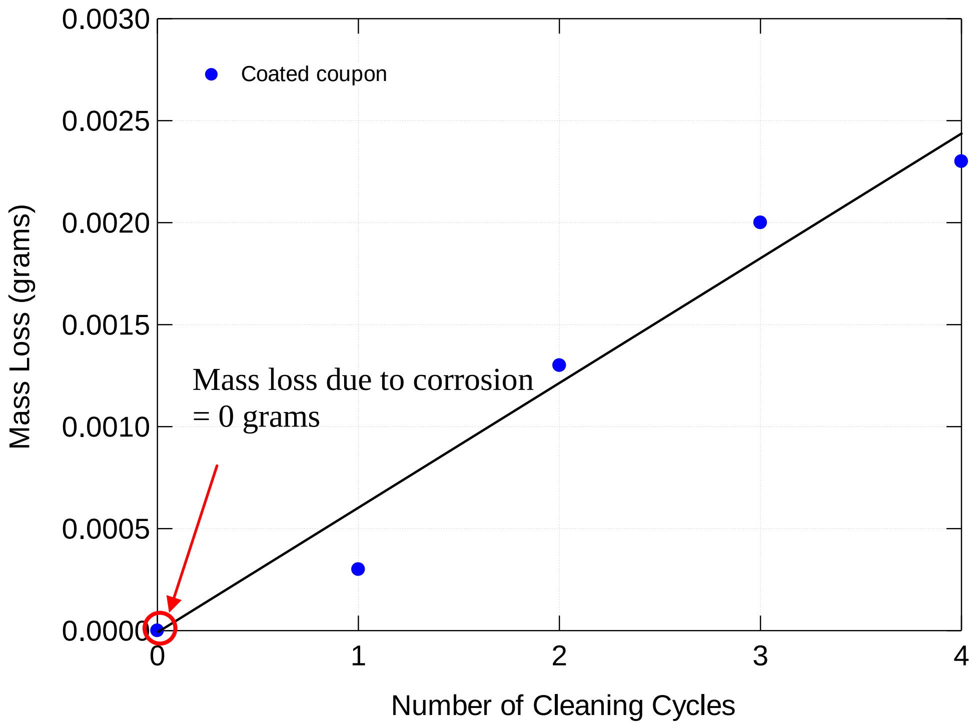


(a)

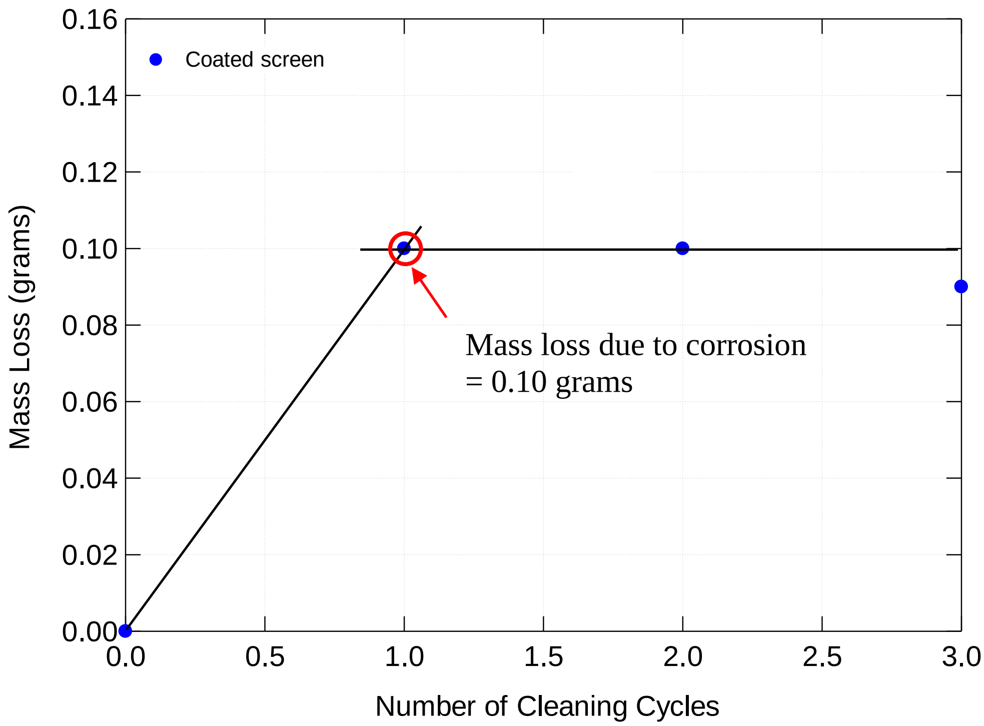


(b)

Figure 23 Mass loss of the duplex 2205 stainless steel with anti-biofouling coating (a) coupon 1 and (b) screen 1 during cleaning.

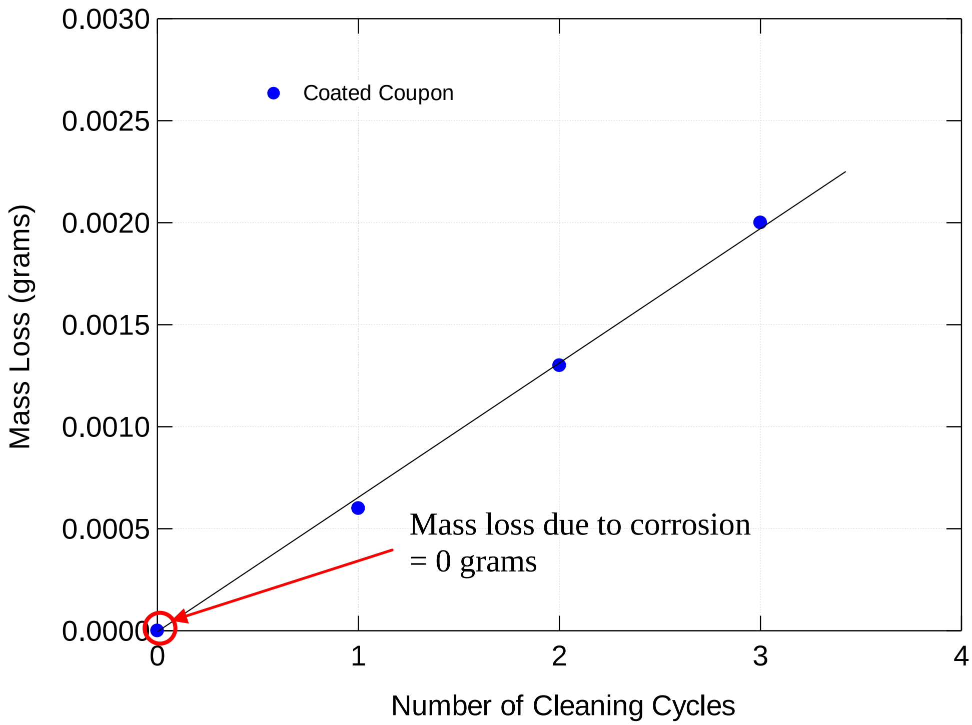


(a)

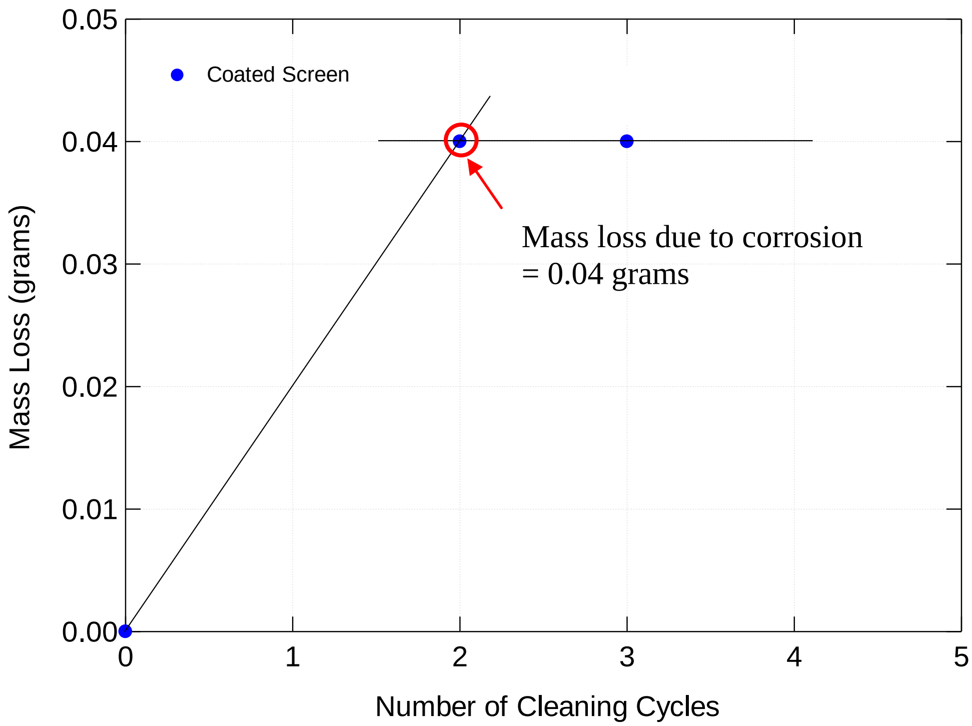


(b)

Figure 24 Mass loss of the duplex 2205 stainless steel with anti-biofouling coating (a) coupon 2 and (b) screen 2 during cleaning.

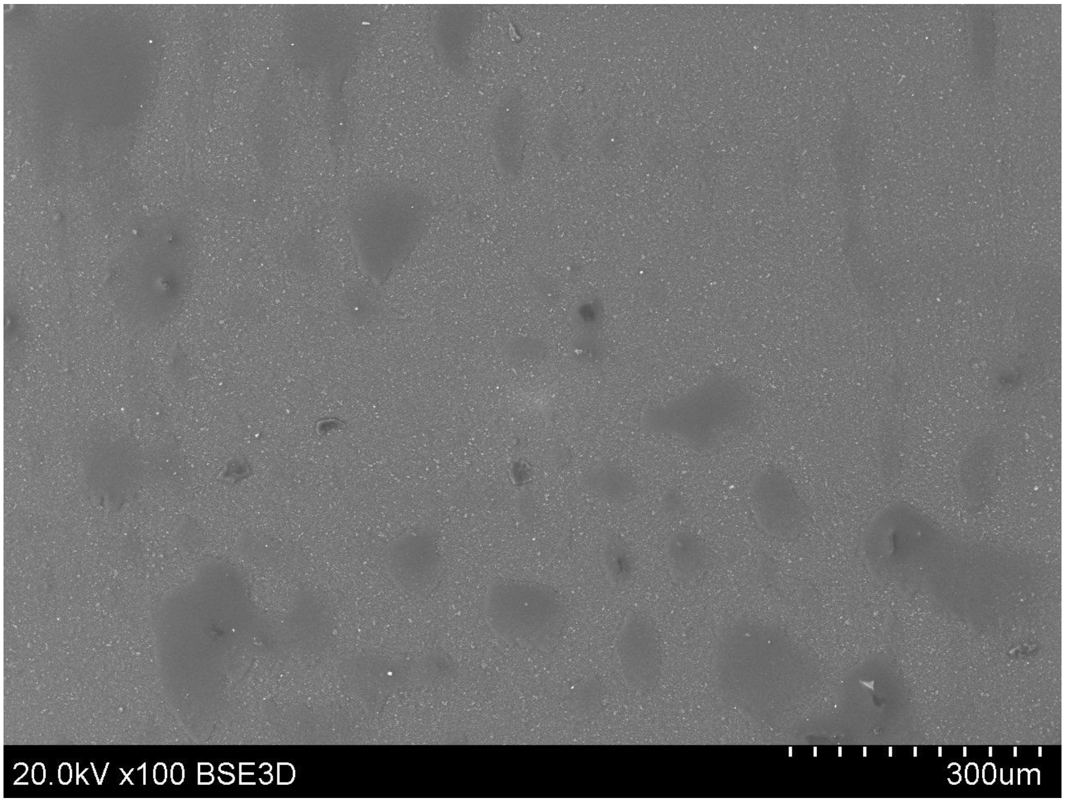


(a)

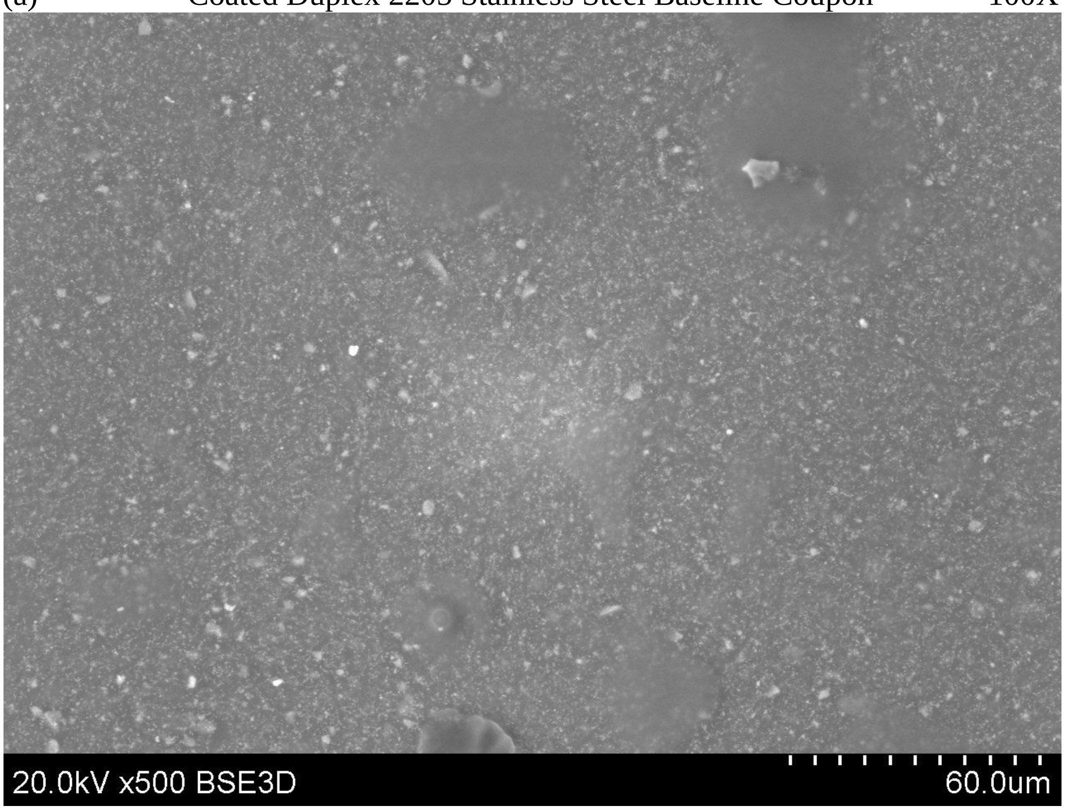


(b)

Figure 25 Mass loss of the duplex 2205 stainless steel with anti-biofouling coating (a) coupon 3 and (b) screen 3 during cleaning.

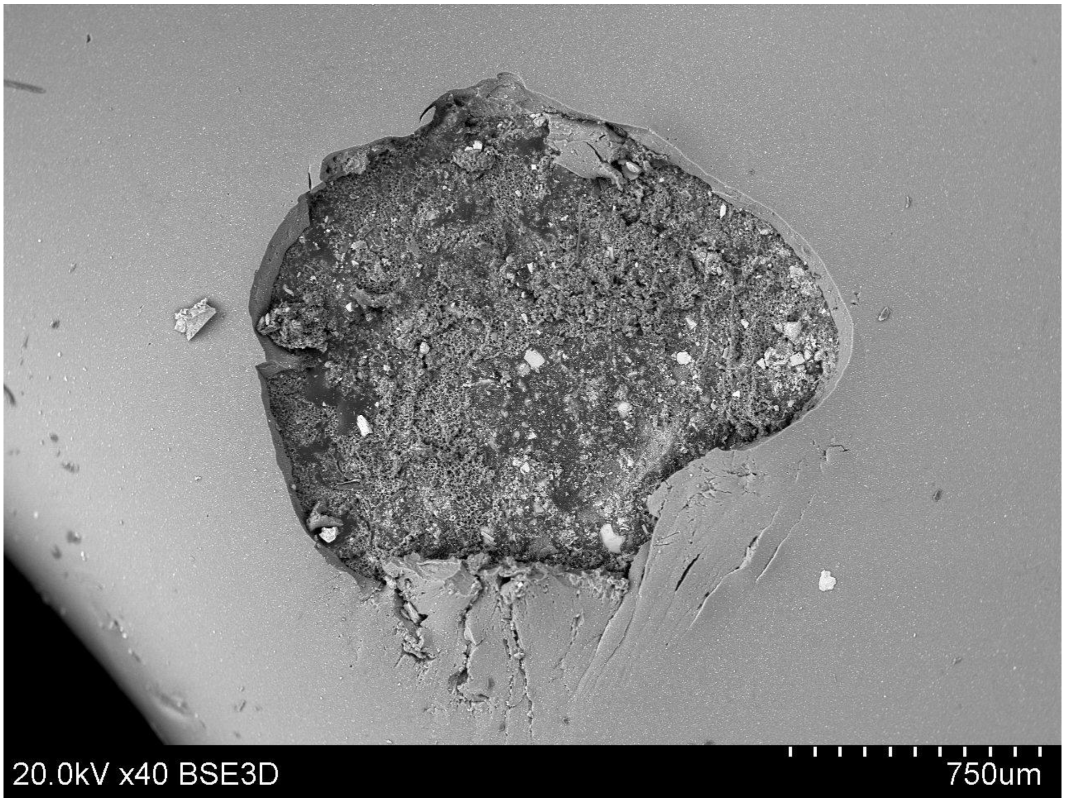


(a) Coated Duplex 2205 Stainless Steel Baseline Coupon 100X

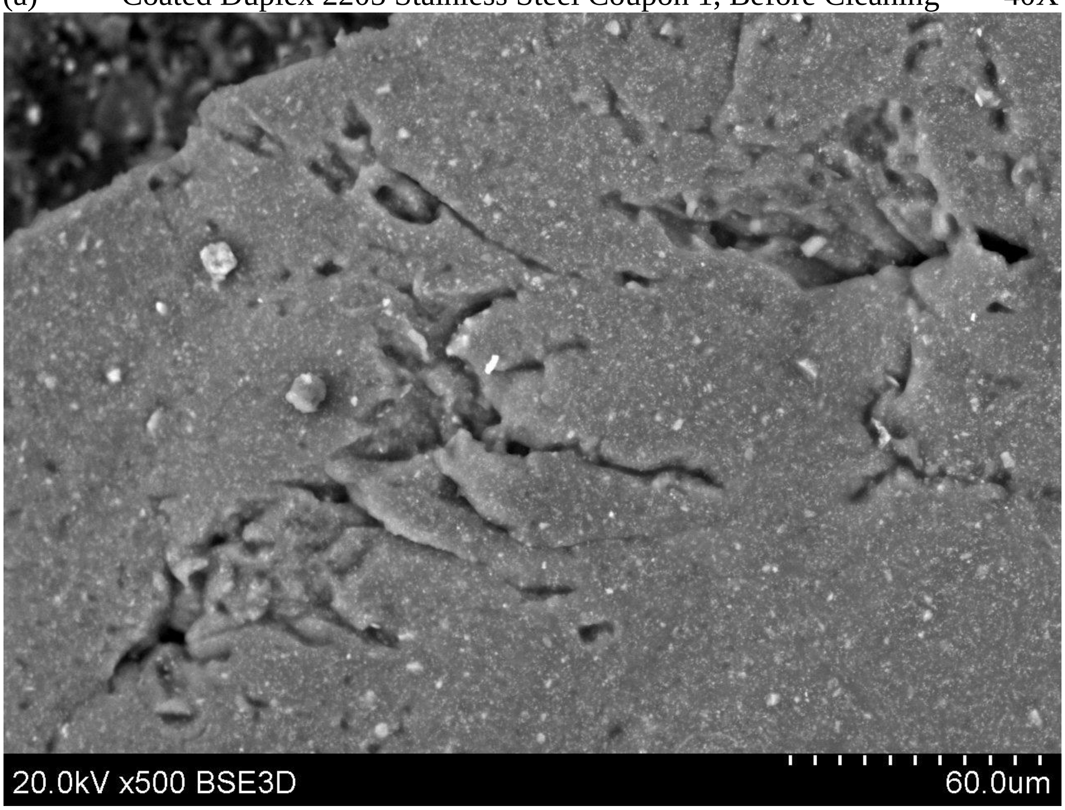


(b) Coated Duplex 2205 Stainless Steel Baseline Coupon 500X

Figure 26 Scanning electron micrographs of the duplex 2205 stainless steel with anti-biofouling coating baseline coupon.

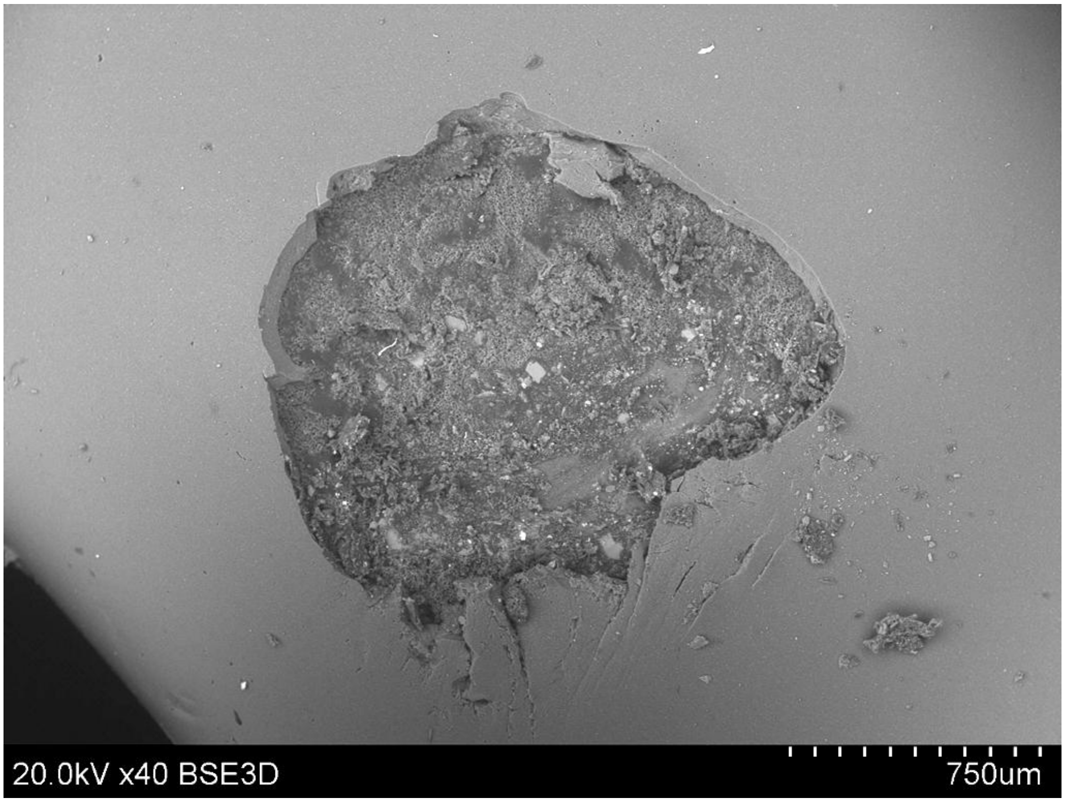


(a) Coated Duplex 2205 Stainless Steel Coupon 1, Before Cleaning 40X

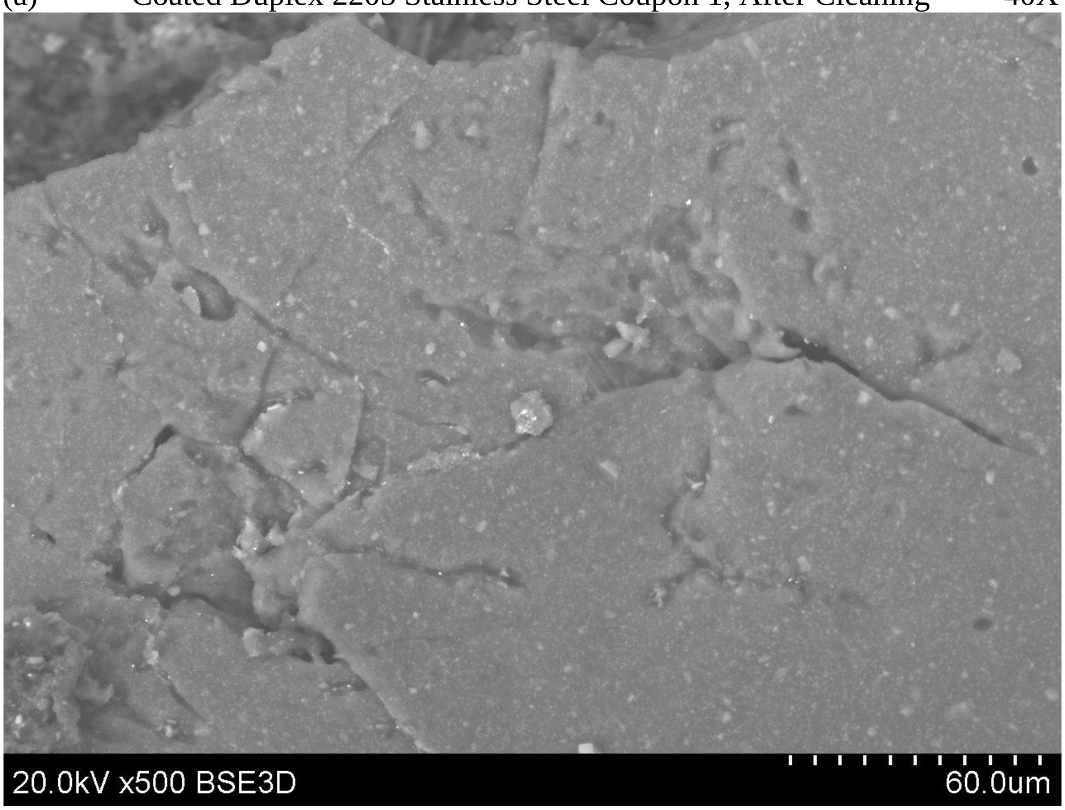


(b) Coated Duplex 2205 Stainless Steel Coupon 1, Before Cleaning 500X

Figure 27 Scanning electron micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 1 after a 3 month corrosion test, before cleaning.

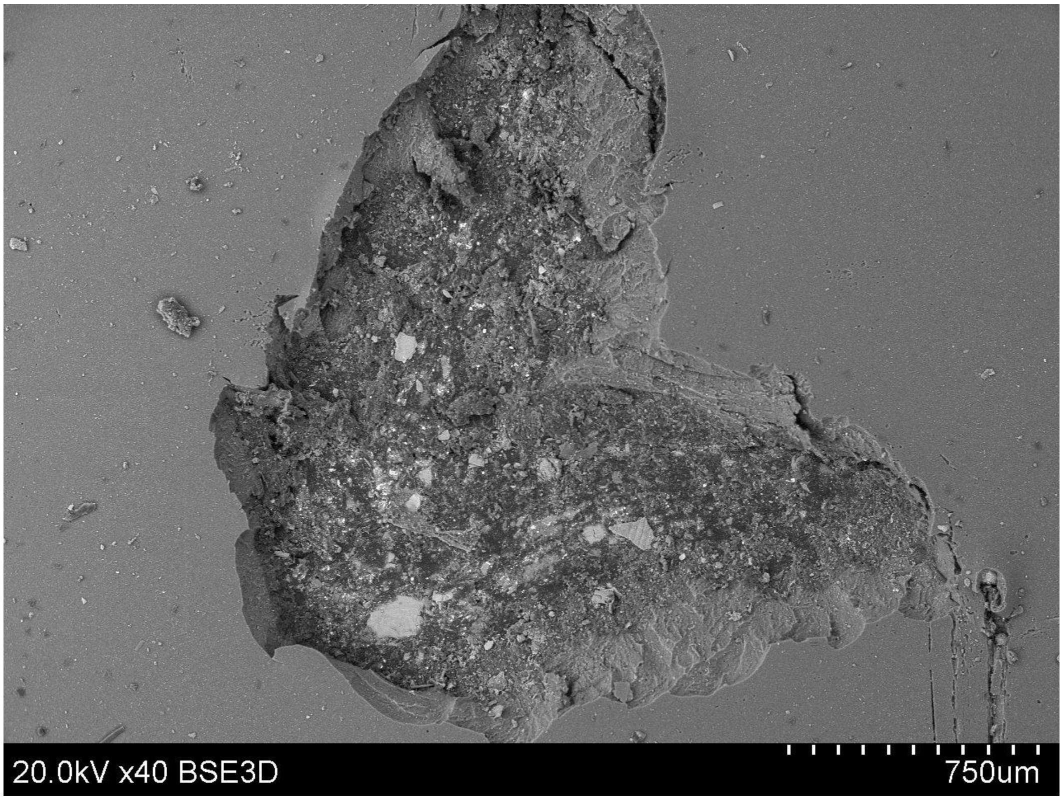


(a) Coated Duplex 2205 Stainless Steel Coupon 1, After Cleaning 40X

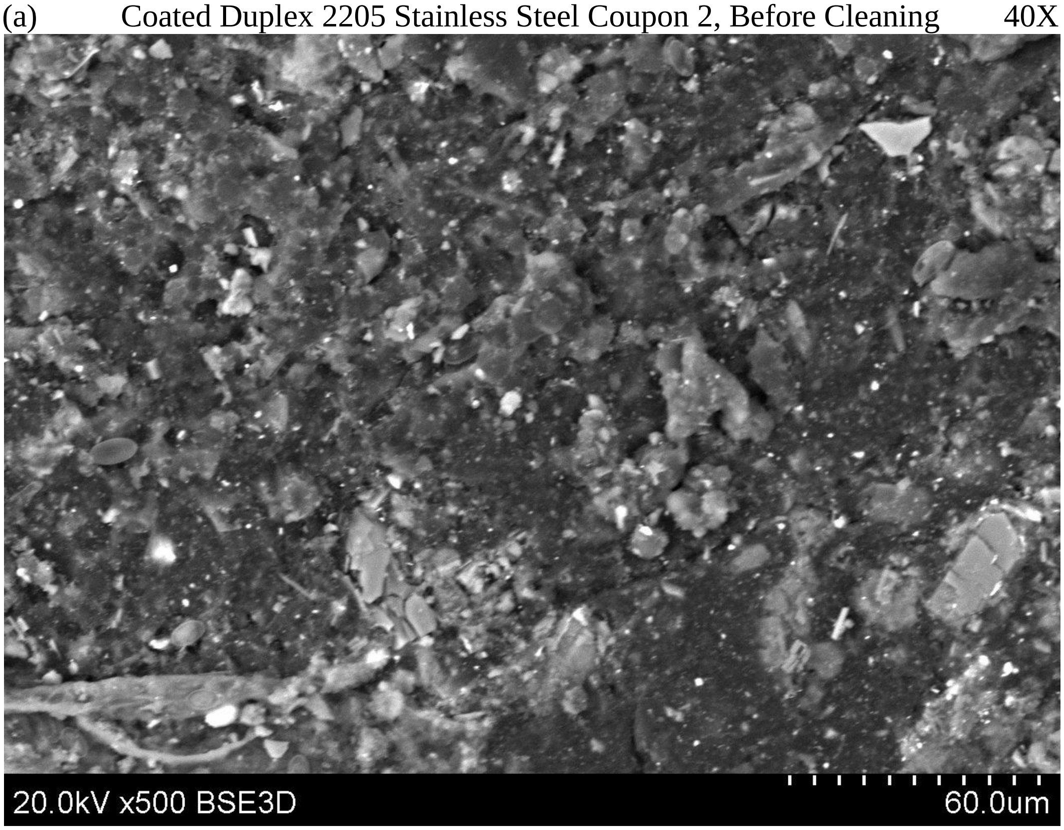


(b) Coated Duplex 2205 Stainless Steel Coupon 1, After Cleaning 500X

Figure 28 Scanning electron micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 1 after a 3 month corrosion test, after cleaning.

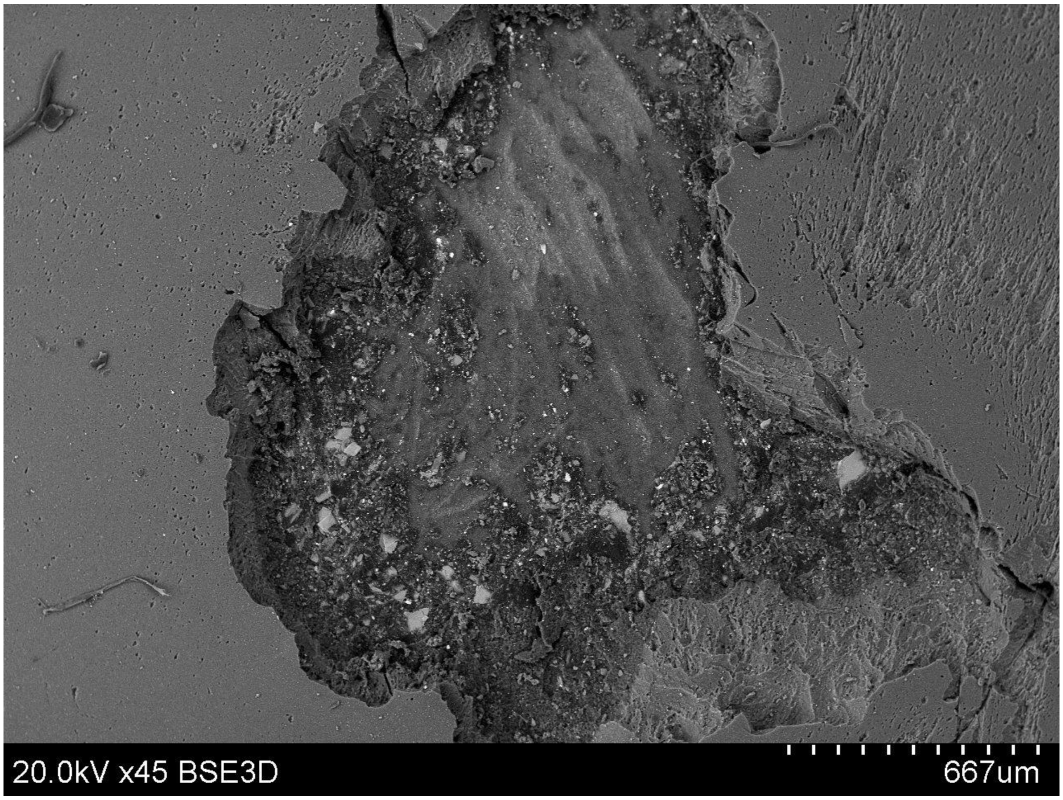


(a) Coated Duplex 2205 Stainless Steel Coupon 2, Before Cleaning 40X

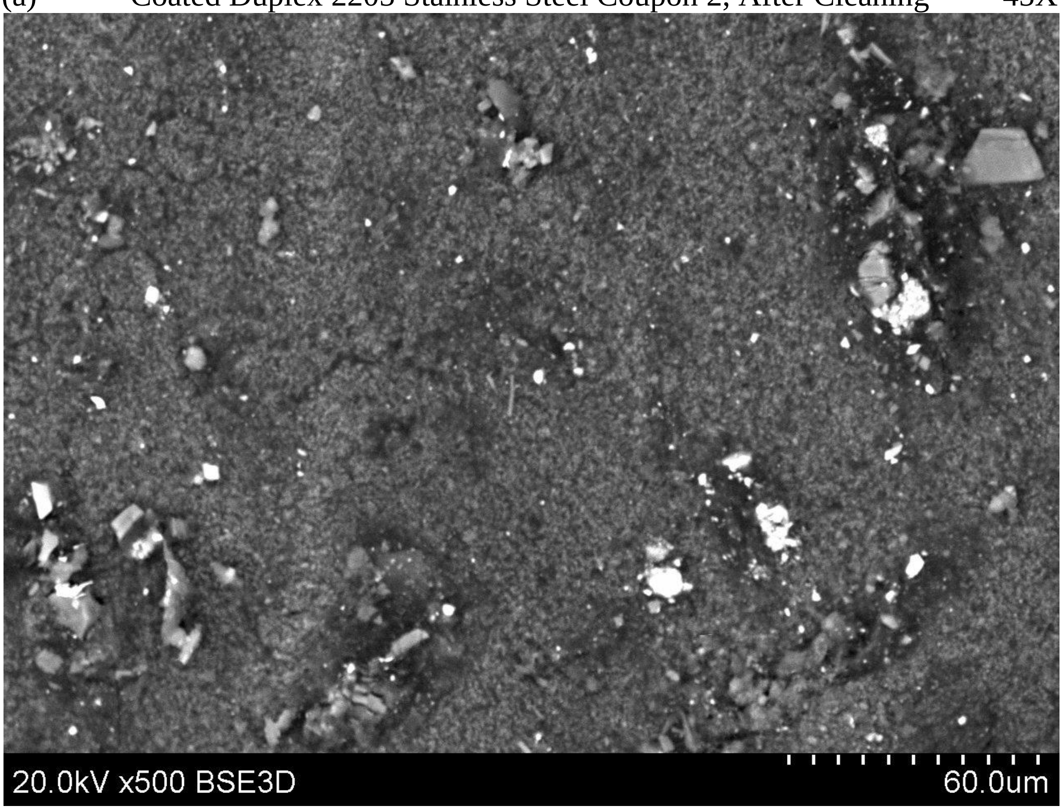


(b) Coated Duplex 2205 Stainless Steel Coupon 2, Before Cleaning 500X

Figure 29 Scanning electron micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 2 after a 6 month corrosion test, before cleaning.

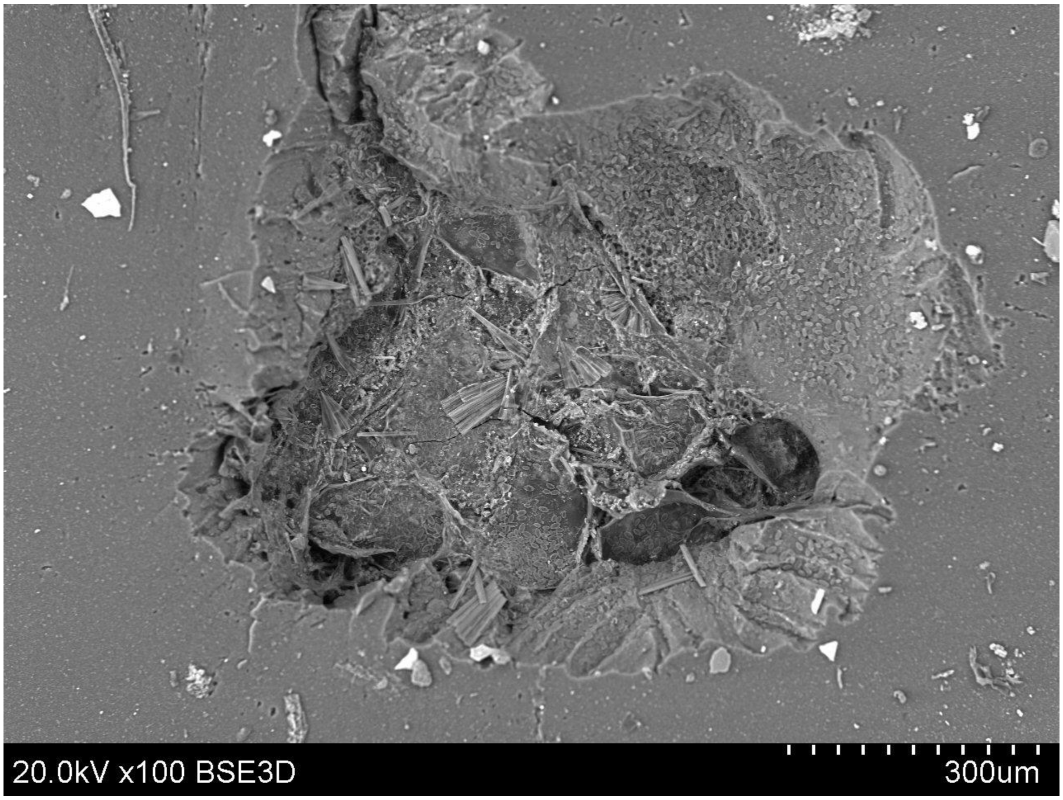


(a) Coated Duplex 2205 Stainless Steel Coupon 2, After Cleaning 45X

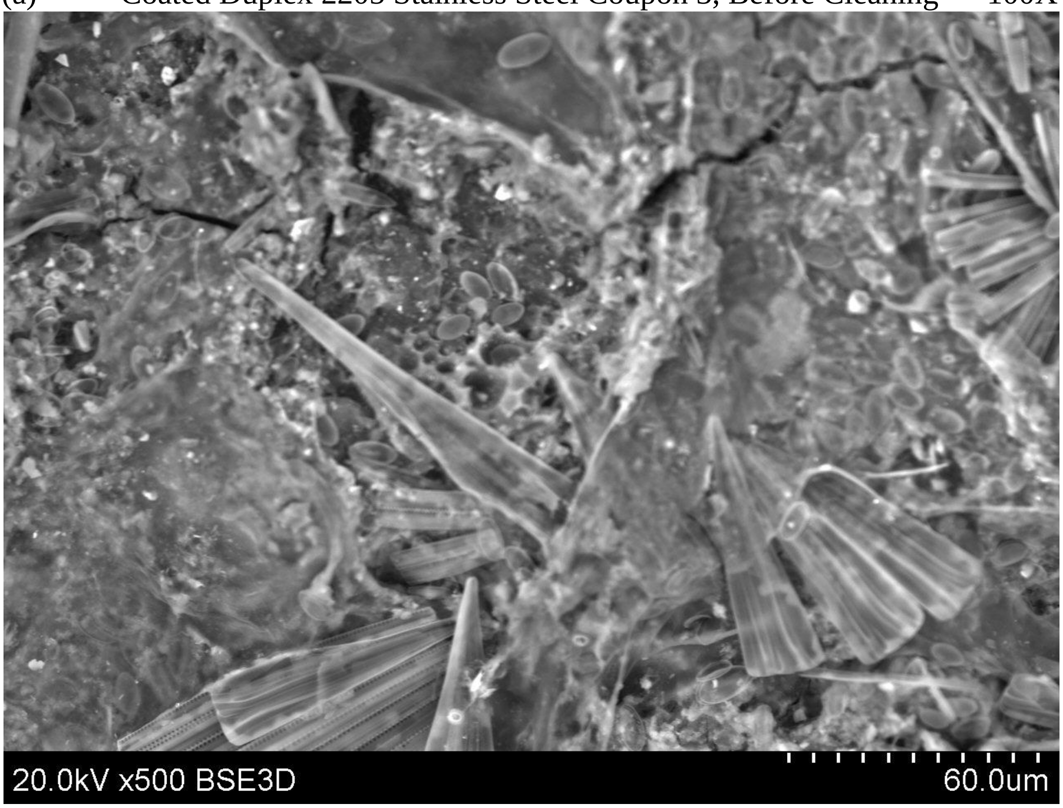


(b) Coated Duplex 2205 Stainless Steel Coupon 2, After Cleaning 500X

Figure 30 Scanning electron micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 2 after a 6 month corrosion test, after cleaning.

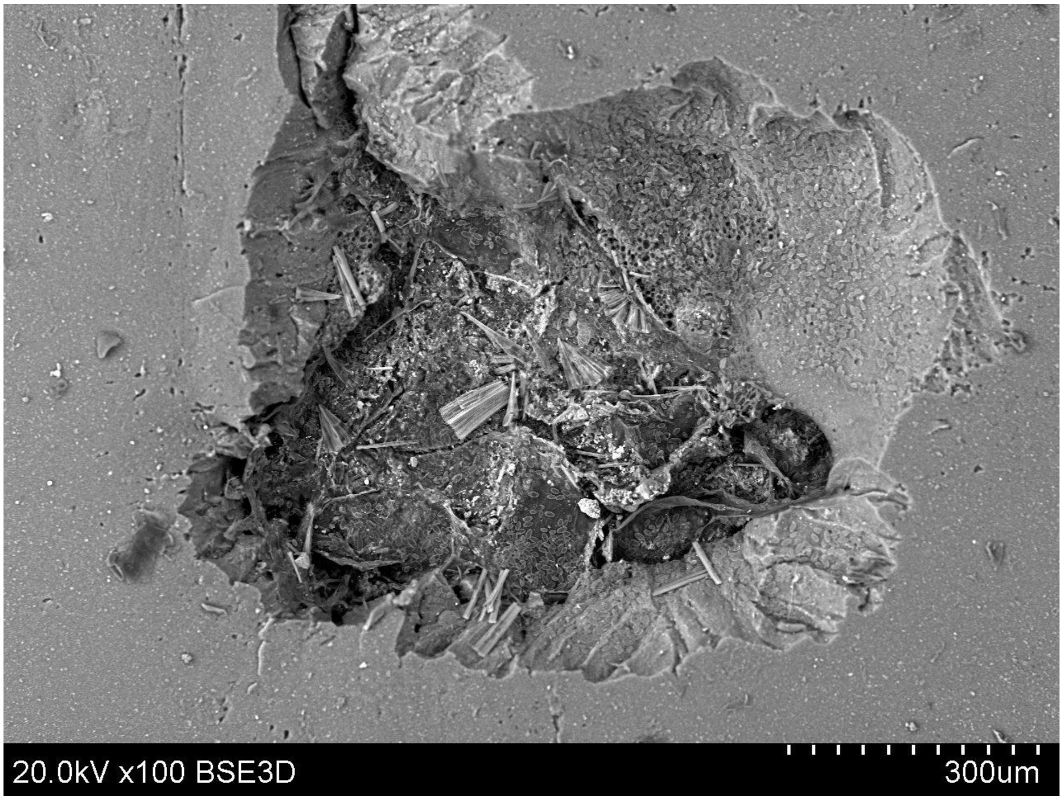


(a) Coated Duplex 2205 Stainless Steel Coupon 3, Before Cleaning 100X

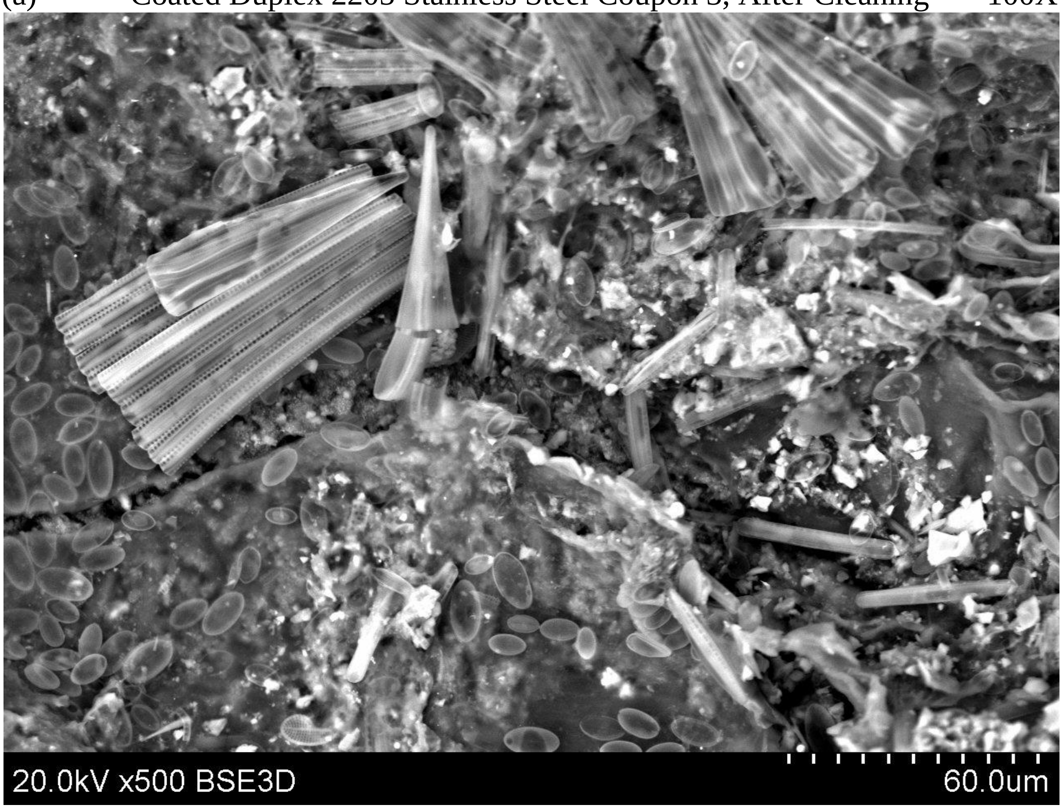


(b) Coated Duplex 2205 Stainless Steel Coupon 3, Before Cleaning 500X

Figure 31 Scanning electron micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 3 after a 10 month corrosion test, before cleaning.

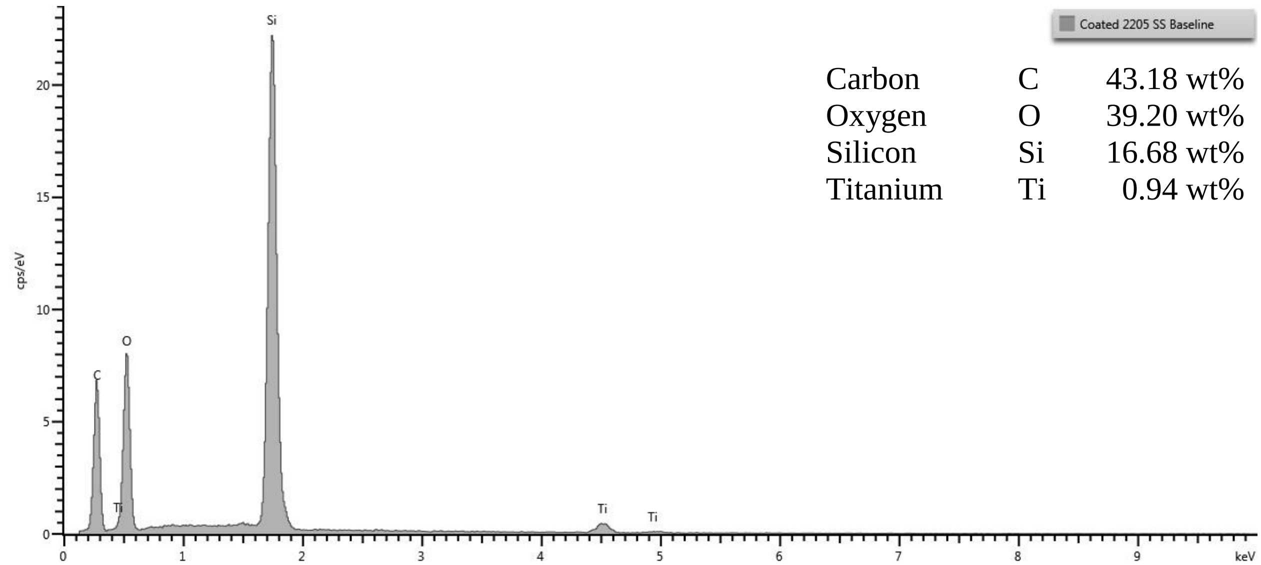


(a) Coated Duplex 2205 Stainless Steel Coupon 3, After Cleaning 100X



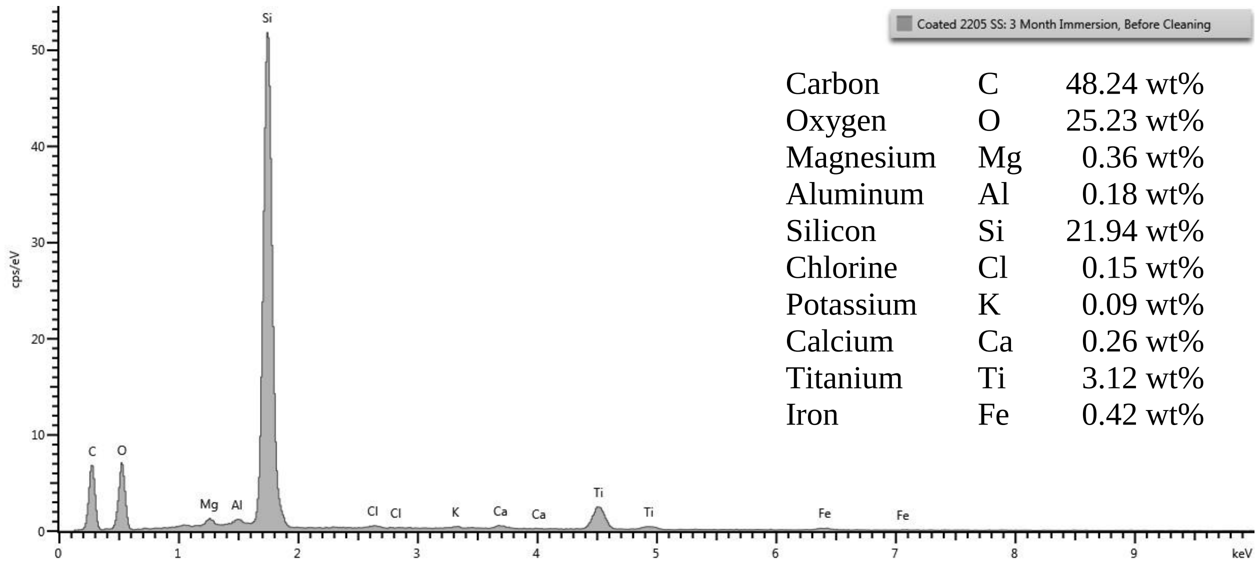
(b) Coated Duplex 2205 Stainless Steel Coupon 3, After Cleaning 500X

Figure 32 Scanning electron micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 3 after a 10 month corrosion test, after cleaning.

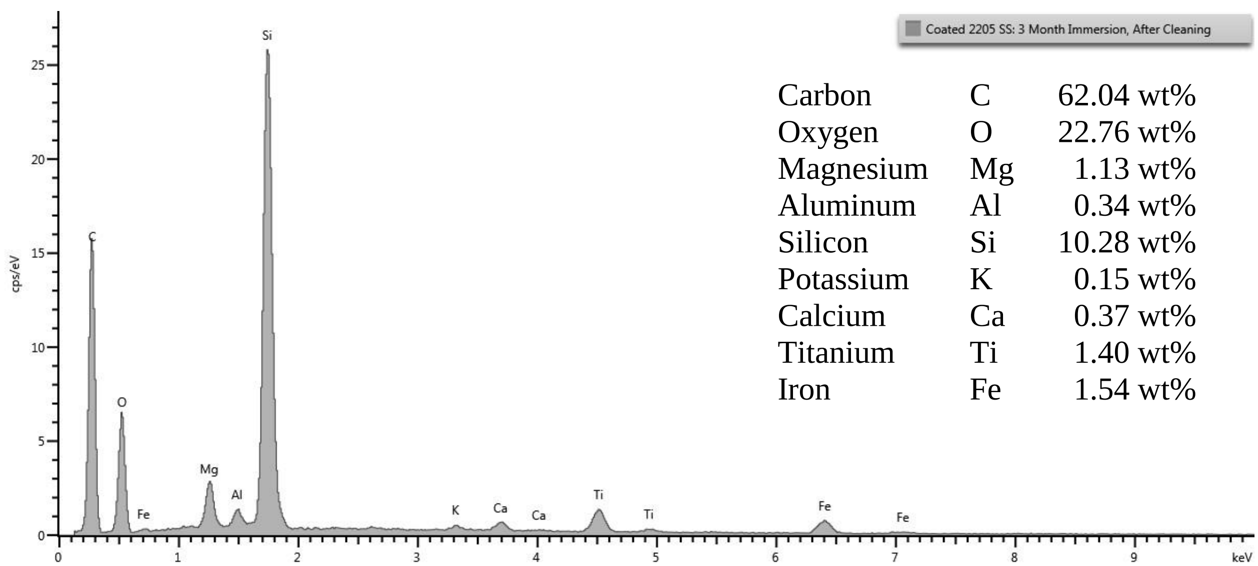


(a) Coated Duplex 2205 Stainless Steel Baseline Coupon

Figure 33 Energy dispersive x-ray spectra of the duplex 2205 stainless steel with anti-biofouling coating baseline coupon.

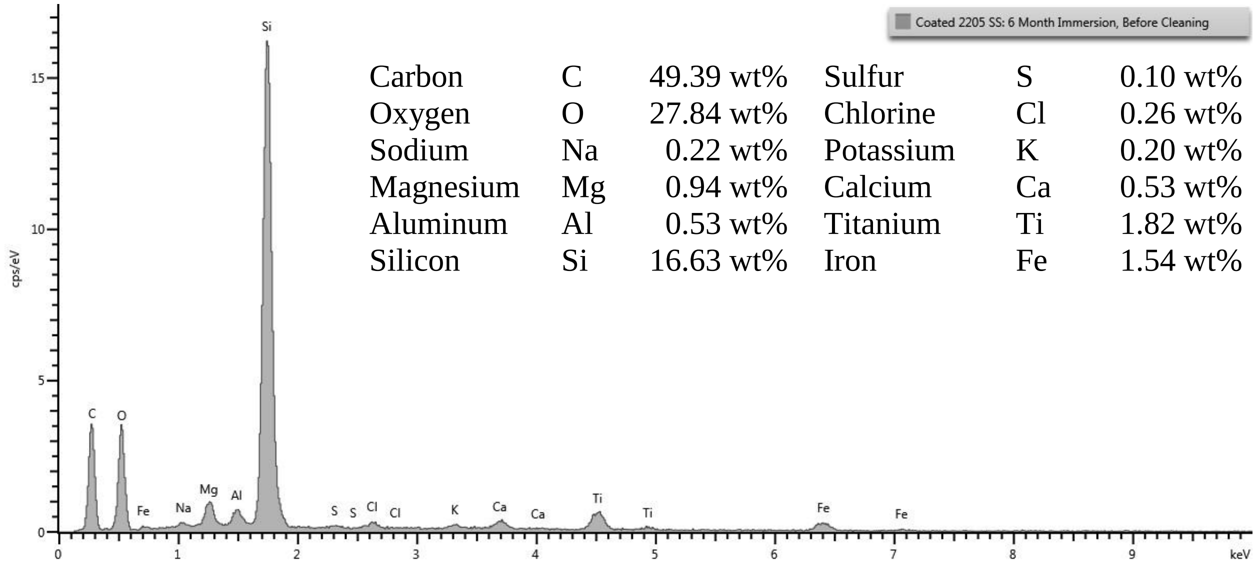


(a) Coated Duplex 2205 Stainless Steel Coupon 1, Before Cleaning

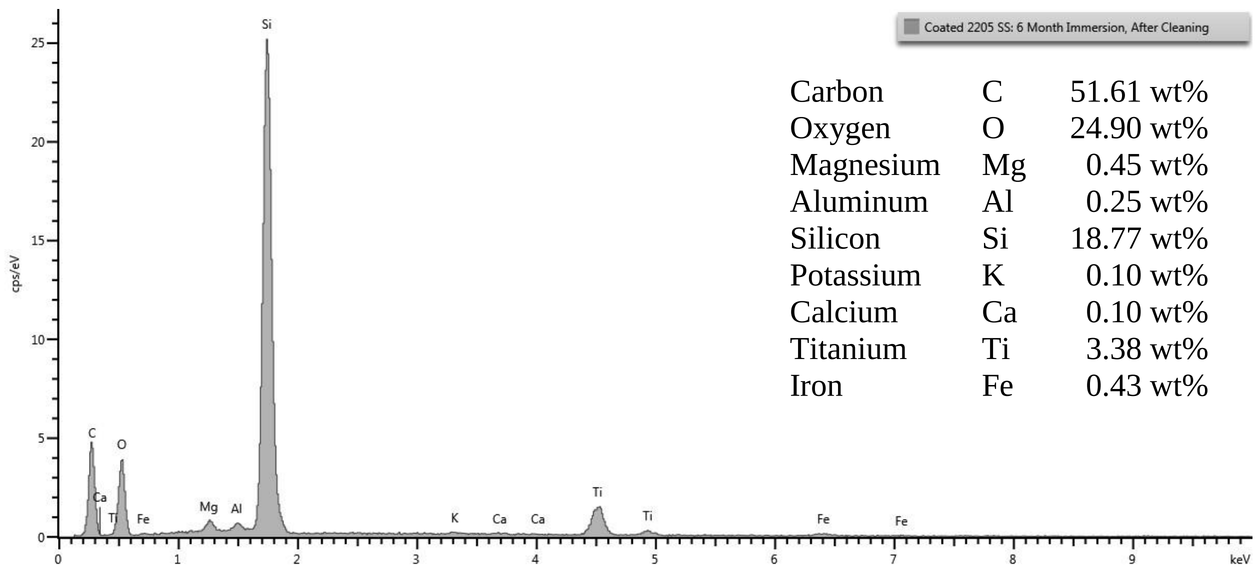


(b) Coated Duplex 2205 Stainless Steel Coupon 1, After Cleaning

Figure 34 Energy dispersive x-ray spectra of duplex 2205 stainless steel with anti-biofouling coating coupon 1 after a 3 month corrosion test (a) before cleaning and (b) after cleaning.

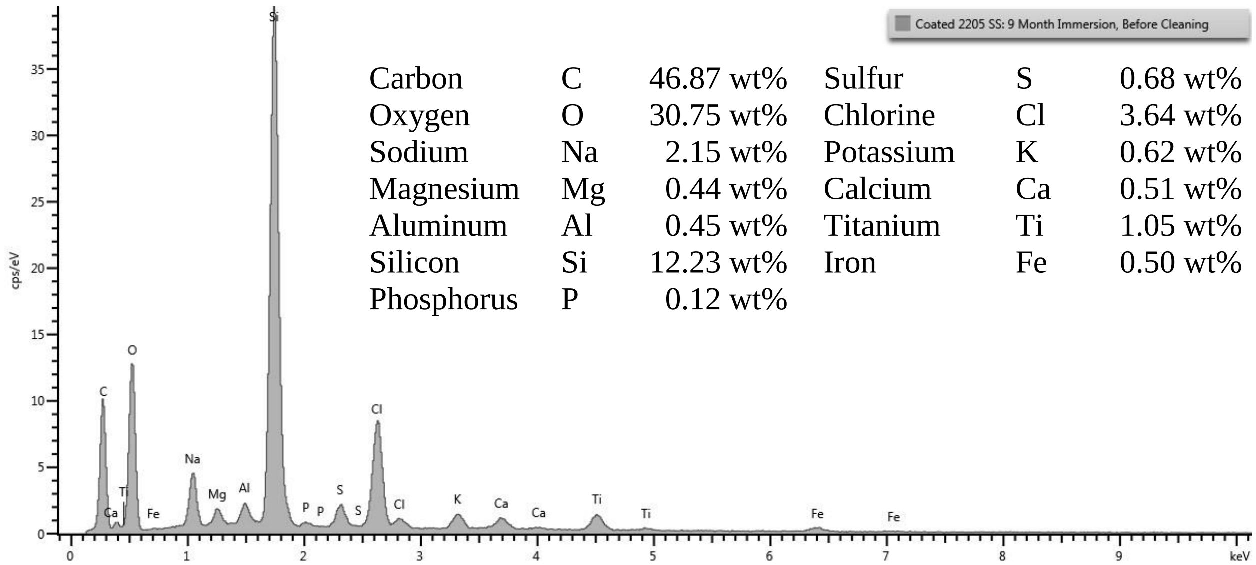


(a) Coated Duplex 2205 Stainless Steel Coupon 2, Before Cleaning

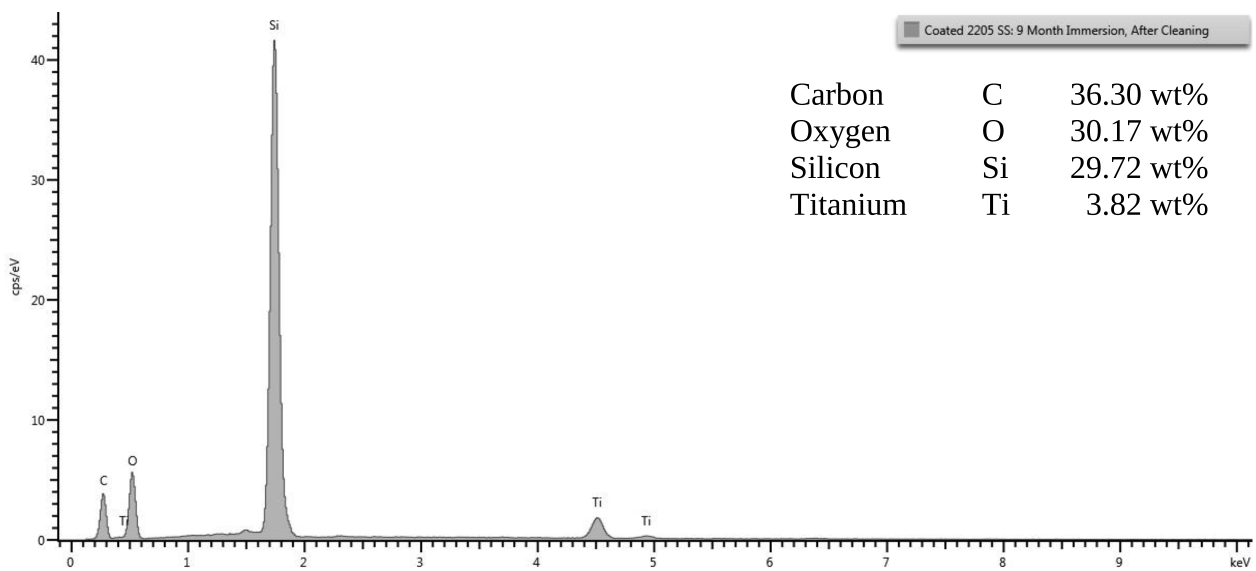


(b) Coated Duplex 2205 Stainless Steel Coupon 2, After Cleaning

Figure 35 Energy dispersive x-ray spectra of duplex 2205 stainless steel with anti-biofouling coating coupon 2 after a 6 month corrosion test (a) before cleaning and (b) after cleaning.

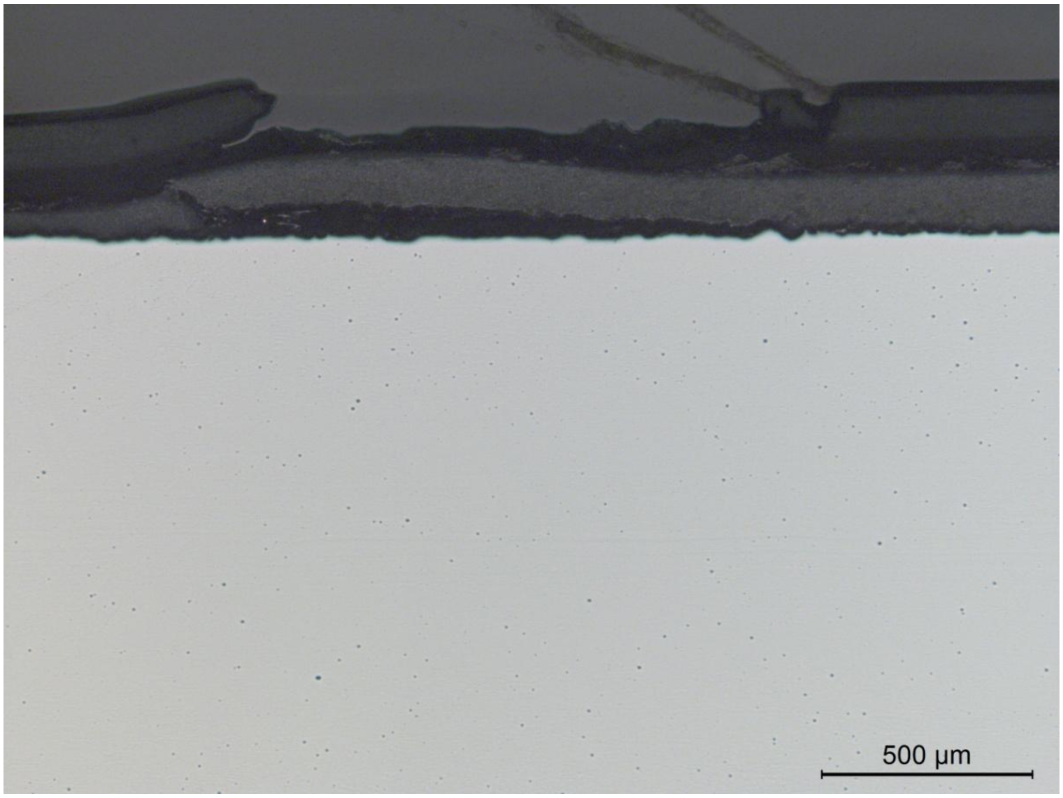


(a) Coated Duplex 2205 Stainless Steel Coupon 3, Before Cleaning

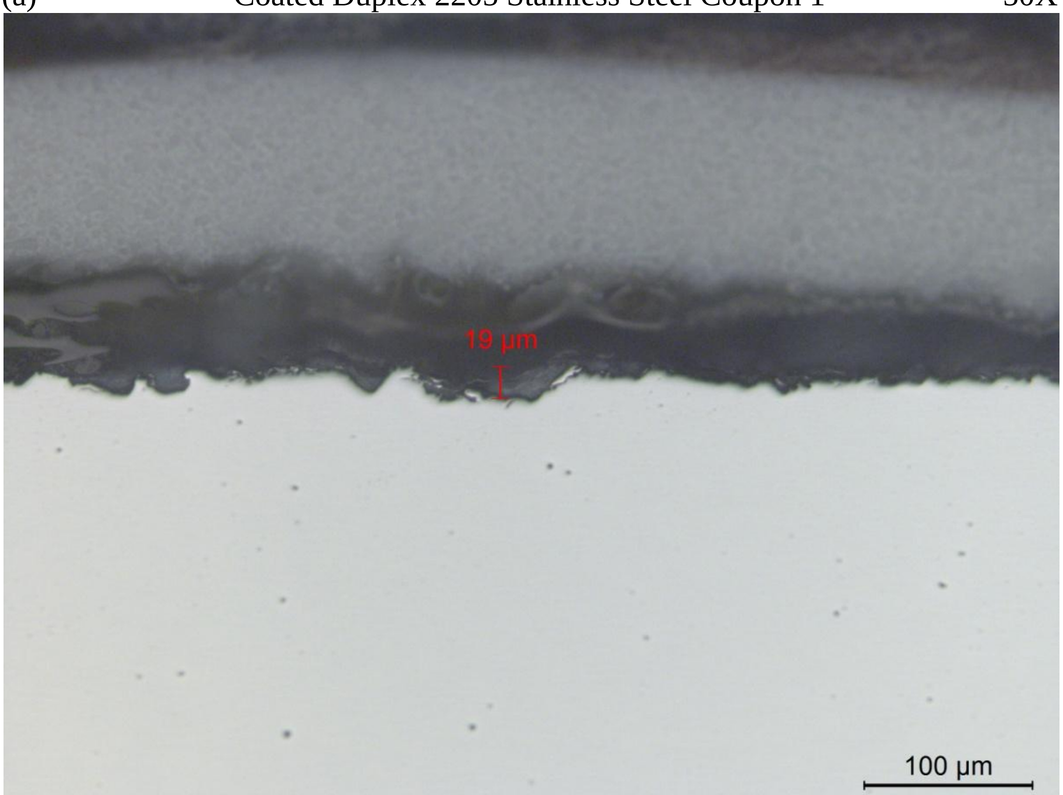


(b) Coated Duplex 2205 Stainless Steel Coupon 3, After Cleaning

Figure 36 Energy dispersive x-ray spectra of duplex 2205 stainless steel with anti-biofouling coating coupon 3 after a 10 month corrosion test (a) before cleaning and (b) after cleaning.



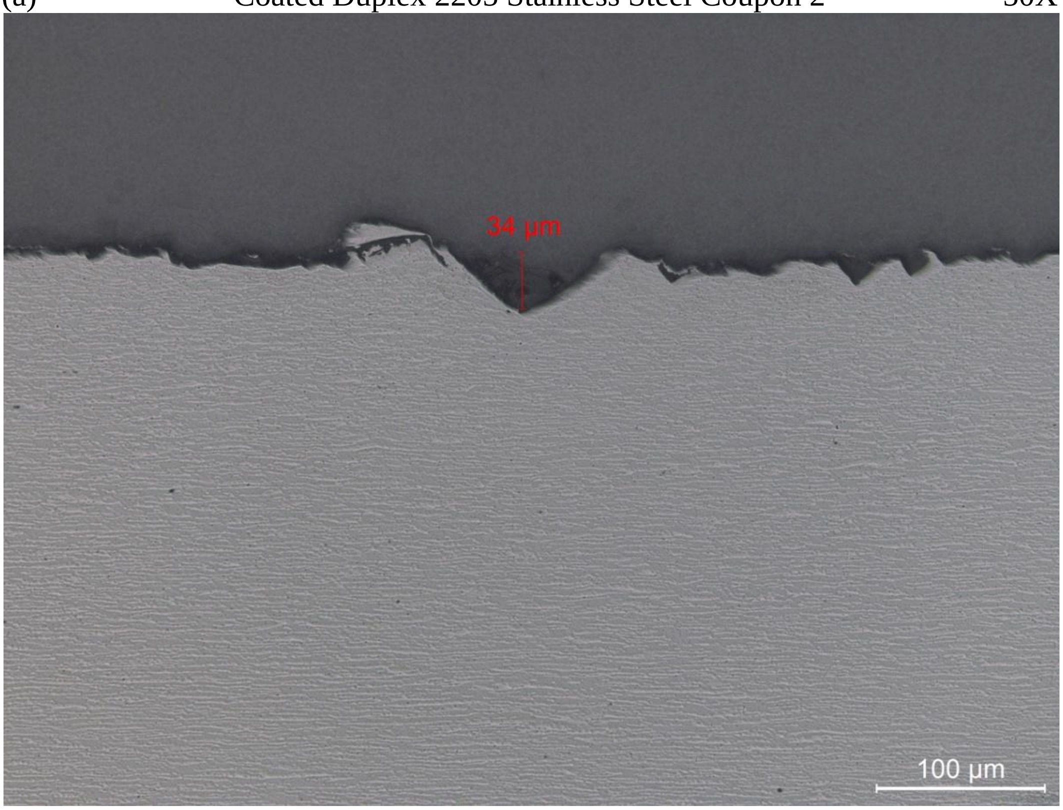
(a) Coated Duplex 2205 Stainless Steel Coupon 1 50X



(b) Coated Duplex 2205 Stainless Steel Coupon 1 200X

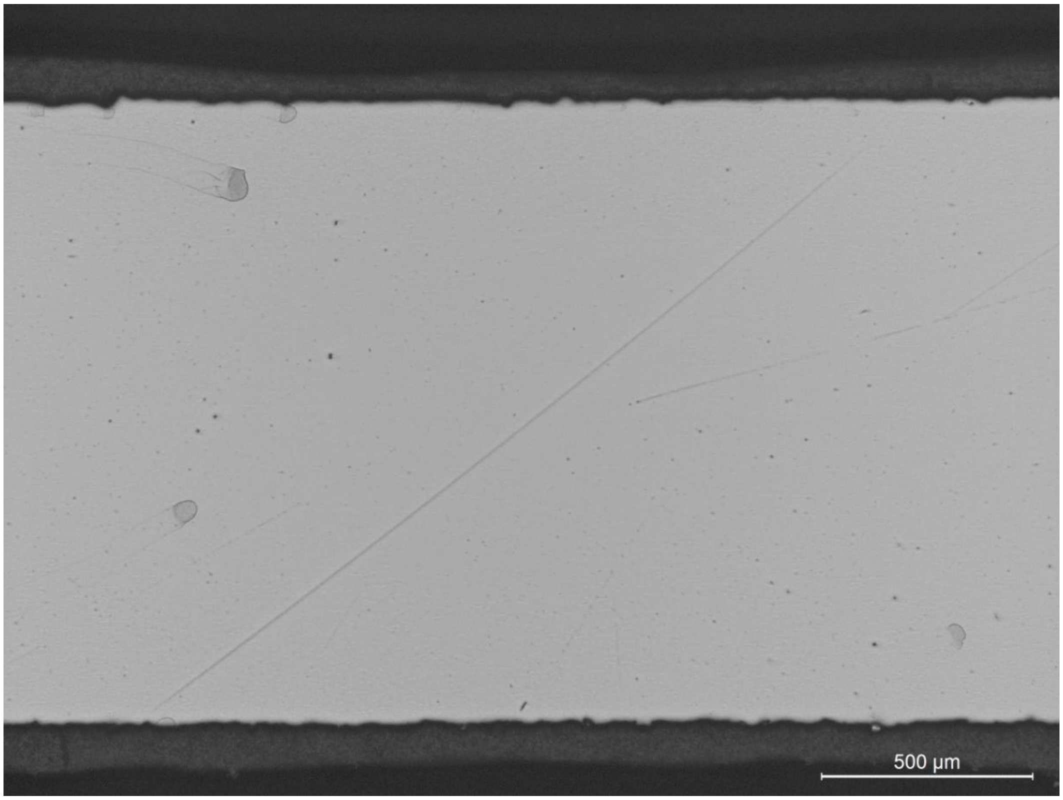
Figure 37 Optical micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 1.

(a) Coated Duplex 2205 Stainless Steel Coupon 2 50X

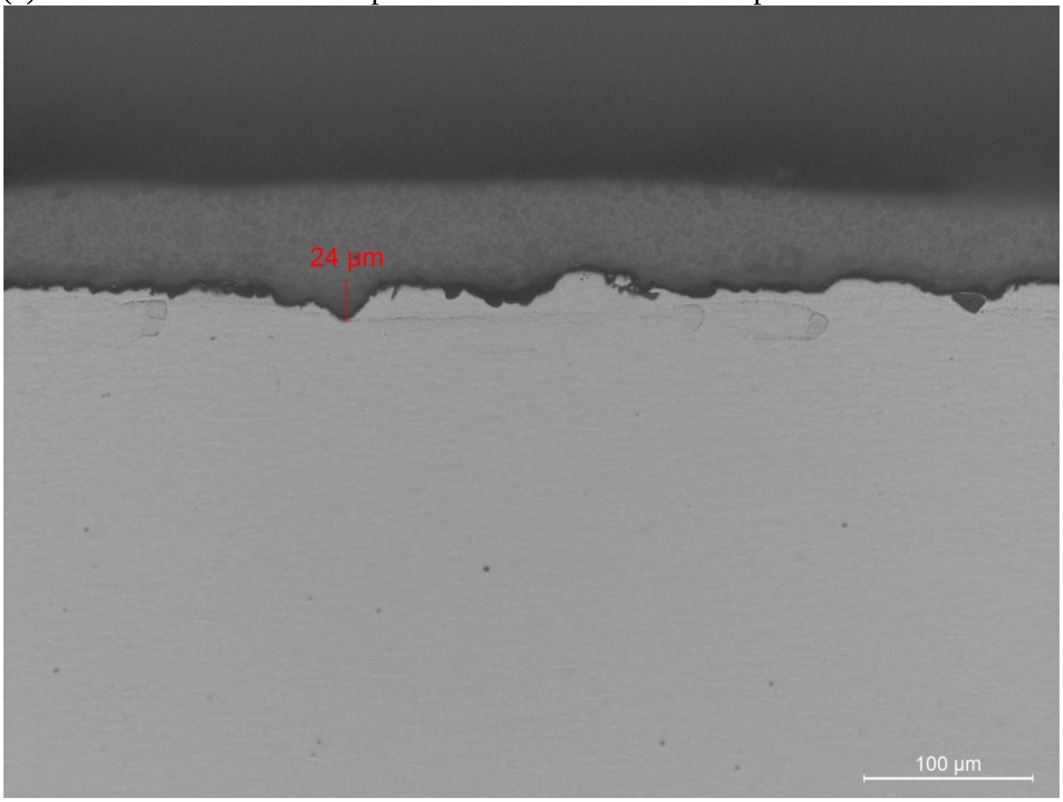


(b) Coated Duplex 2205 Stainless Steel Coupon 2 200X

Figure 38 Optical micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 2.



(a) Coated Duplex 2205 Stainless Steel Coupon 3 50X



(b) Coated Duplex 2205 Stainless Steel Coupon 3 200X

Figure 39 Optical micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 3.

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Report No. 5005.0361B **May 19, 2015**

CORROSION EVALUATION OF 2205 DUPLEX STAINLESS STEEL COUPONS AND SCREENS

Customer Authorization: Verbal

Report To: V & A Engineering
Attn: Manuel Najar
155 Grand Avenue, Suite 700
Oakland, CA 94612

1.0 INTRODUCTION

Five coupons, five wedge wire screens, and one plate made from a 2205 duplex stainless steel alloy were submitted by V&A Engineering for corrosion evaluation. The coupons were 1-inch by 3-inches by ¼-inch thick. The wedge wire screens were 4-inches by 4-inches by 1-inch tall with 4 mm spacing. The plate was 4-inches by 4-inches by 1/8-inch thick.

Four coupons and four screens were to be placed in seawater for a period up to one year. After every 3 month interval, one coupon and one screen were to be removed from the test system and examined for corrosion. The purpose of this evaluation was to document the samples in the baseline as-received condition, then again after 3, 6, 10, and 12 months of water exposure, record any loss in mass, examine for any pitting corrosion, and estimate the corrosion rate.

The samples were evaluated by the following laboratory procedures:

1) Visual examination and weighing
2) Cleaning per ASTM G1[1]
3) Scanning electron microscopy
4) Metallography

The results of the evaluation showed minimal mass loss and corrosion for the coupon and screen after 3, 6, and 10 months of corrosion testing. Both the coupon and screen, after a 3 month corrosion test, had a corrosion rate less than 0.0005 millimeters per year. Both the coupon and screen, after a 6 month corrosion test, had a corrosion rate less than 0.0005 millimeters per year. Both the coupon and screen, after a 10 month corrosion test, had a corrosion rate less than 0.0005 millimeters per year.

[1] G1: Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

2.0 EVALUATION[2]

2.1 Visual Examination

The sample identifications for the coupons and wedge wire screens and their corresponding immersion times are shown in Table 1. The coupons had identification numbers stamped on the front face by V&A Engineering. A number of notches, corresponding to the sample number, were sawed at the edge of each screen for identification after the corrosion test. The weights of the samples were recorded. Coupons 6 – 9 and screens 1 – 5 were sent back to V&A for corrosion testing. Coupon 10 was the baseline sample and documented by photography, optical stereoscopy and scanning electron microscopy for comparison to the tested samples. Screen 5 was documented as a baseline by photography and optical stereoscopy, and then sent to V&A for testing.

Photographs of the baseline coupon are shown in Figure 1. Photographs of coupon 1, after 3 months of corrosion testing, are shown in Figure 2. Photographs of coupon 2, after 6 months of corrosion testing, are shown in Figure 3. Photographs of coupon 2, after 10 months of corrosion testing, are shown in Figure 4.

A photograph of the baseline screen is shown in Figure 5. A photograph of screen 1, after 3 months of corrosion testing, is shown in Figure 6. A photograph of screen 2, after 6 months of corrosion testing, is shown in Figure 7. A photograph of screen 2, after 10 months of corrosion testing, is shown in Figure 8.

2.2 Cleaning

The coupon and screen were cleaned with solution C.7.1 per ASTM G1.[3] One cleaning cycle was approximately 10 minutes. After each cleaning cycle, the samples were rinsed in water, dried, and weighed. The cleaning and weighing cycle was completed five times for the coupon and screen. The weights of the samples as-received, after corrosion testing but before cleaning, and after each cleaning cycle are presented in Table 2.

Optical macrographs of the baseline coupon and screen are shown in Figures 9 and 16, respectively. Representative optical macrographs of the samples after a 3 month corrosion test, before and after cleaning are shown in Figures 10 – 11 and 17 – 18. Representative optical macrographs of the samples after a 6 month corrosion test, before and after cleaning are shown in Figures 12 – 13 and 19 – 20. Representative optical macrographs of the samples after a 10 month corrosion test, before and after cleaning are shown in Figures 14 – 15 and 21 – 22.

The mass loss versus the number of cleaning cycles were plotted to determine the mass loss of the samples due to corrosion, shown in Figures 23 – 25. The equations for best fit lines AB and BC, calculated using IGOR Pro, are listed in Table 3. Point B, indicated by the red circle in each plot, corresponds to the mass loss due to corrosion for each sample. This mass loss was subtracted from the weight of the sample before cleaning and from the weight of the sample as-

[2] The magnifications of the optical and scanning electron micrographs in this report are approximate and should not be used as a basis for dimensional analyses unless otherwise indicated.
[3] 100 mL nitric acid + 900 ml reagent water.

received to determine the total mass loss from corrosion. The corrosion rate of each sample was determined by the formula specified in Section 8.1 of ASTM G1:

$$Corrosion\ Rate = \frac{K\ x\ W}{A\ x\ T\ x\ D}$$

where K = 8.76 x 10^4, T = time of exposure in hours, A = area in cm^2, W = mass loss in grams, and D = density in g/cm^3. The density of the Z-Alloy was determined by cutting a section out of the baseline coupon, measuring the length, width, and thickness, and weighing the section with a balance. The total mass loss from corrosion and the calculated corrosion rate of each sample is shown in Table 4.

2.3 Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy

The baseline coupon, coupon 6, and coupon 7 were examined with a scanning electron microscope. Representative scanning electron micrographs of the baseline coupon are shown in Figure 26. Representative scanning electron micrographs of coupon 1 after cleaning are shown in Figure 27. Representative scanning electron micrographs of coupon 2 after cleaning are shown in Figure 28. Representative scanning electron micrographs of coupon 3 after cleaning are shown in Figure 29. Energy dispersive x-ray spectra of the baseline coupon and coupons 6 – 8 are shown in Figures 30 – 32a. The coupons were not analyzed by scanning electron microscopy and energy dispersive x-ray spectroscopy before cleaning due to the amount of biological products on it.

2.4 Metallography

Cross sections were taken from the coupon and prepared for a metallographic examination. Optical micrographs of the surfaces for coupons 6 – 8 are shown in Figures 33 – 35. Small, narrow pits were observed in all samples, the deepest of which measured 27 µm.

3.0 DISCUSSION

The coupon and screen showed minimal mass loss and pitting overall after 3, 6, and 10 months of corrosion testing. The weight loss of the coupons was beyond the measurement capabilities of the balance; the calculated corrosion rate was consistent over the duration of the corrosion test. The screens had less material loss over time but maintained a consistent corrosion rate.

4.0 CONCLUSIONS[4]

The following conclusions are based upon the submitted samples and the evidence gathered:

1. The coupon, after 3 months of corrosion testing, had a mass loss less than 0.001 grams and a corrosion rate less than 0.0005 mm / year.
2. The screen, after 3 months of corrosion testing, had a mass loss of 0.04 grams and a corrosion rate less than 0.0005 mm / year.
3. The coupon, after 6 months of corrosion testing, had a mass loss less than 0.001 grams and a corrosion rate less than 0.0005 mm / year.
4. The screen, after 6 months of corrosion testing, had a mass loss of 0.02 grams and a corrosion rate less than 0.0005 mm / year.
5. The coupon, after 10 months of corrosion testing, had a mass loss less than 0.001 grams and a corrosion rate less than 0.0005 mm / year.
6. The screen, after 10 months of corrosion testing, had a mass loss less than 0.001 grams and a corrosion rate less than 0.0005 mm / year.

Prepared by:	Reviewed by:
Norman Yuen	Audrey A. Fasching
Norman Yuen Materials Engineer	Audrey A. Fasching, Ph.D., P.E. Senior Materials Engineer

[4] The conclusions in this report are based upon the available information and evidence provided by the client and gathered by Anamet, within the scope of work authorized by the client, and they are hereby presented by Anamet to a reasonable degree of engineering and scientific certainty. Anamet reserves the right to amend or supplement its conclusions or opinions presented in this report should additional data or information become available, or further work be approved by the client.

Table 1
Sample Identifications

Description		V&A Engineering Identification (As-Received)	Anamet Identification (in report)	Notes
Alloy	Part			
2205 Duplex Stainless Steel	**Flat Plate** 4-inch x 4-inch x 1/8-inch	2205 2	Plate	None
	Coupon 1-inch x 3-inch x 1/8-inch with autogenous weld bead	2205W 6	Coupon 6	3 Month Immersion
		2205W 7	Coupon 7	6 Month Immersion
		2205W 8	Coupon 8	10 Month Immersion
		2205W 9	Coupon 9	12 Month Immersion
		2205W 10	Coupon 10	Baseline Sample (no exposure)
	Wedge Wire Screen 4-inch x 4-inch x 1-inch with 2 mm spacing	None	Screen 1	3 Month Immersion
		None	Screen 2	6 Month Immersion
		None	Screen 3	10 Month Immersion
		None	Screen 4	12 Month Immersion
		None	Screen 5	12 Month Immersion

Table 2
Sample Weights

Sample	Baseline Measurement	Measurements after 3 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 6	22.1525	22.1531	22.1529	22.1527	22.1515	22.1514	22.1513
Screen 1	311.70	311.78	311.66	311.66	311.66	311.67	311.67

Sample	Baseline Measurement	Measurements after 6 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 7	22.0018	22.0018	22.0017	22.0015	22.0016	-	-
Screen 2	313.62	313.60	313.59	313.60	313.58	-	-

Sample	Baseline Measurement	Measurements after 10 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 8	22.0012	22.0010	22.0011	22.0008	22.0006	-	-
Screen 3	312.36	312.36	312.36	312.35	312.34	-	-

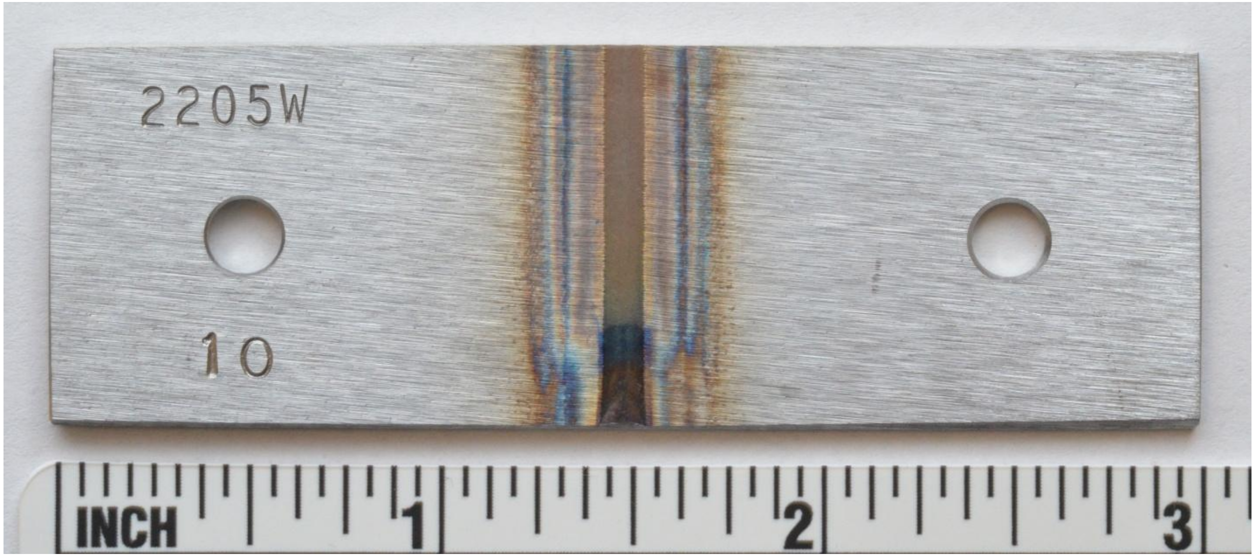
Table 3
Equations of Lines AB and BC for Corrosion Testing Samples

Sample	Line AB	Line BC	Point B (Approximate Mass Loss from Corrosion)
Coupon 6	y = 0.0004x	N/A	0 grams
Coupon 7	N/A	y = 0.0001x	0 grams
Coupon 8	N/A	y = 0.0001x	0 grams
Screen 1	y = 0.12x	y = 0.120	0.12 grams
Screen 2	N/A	y = 0.007x	0 grams
Screen 3	N/A	y = 0.010x	0 grams

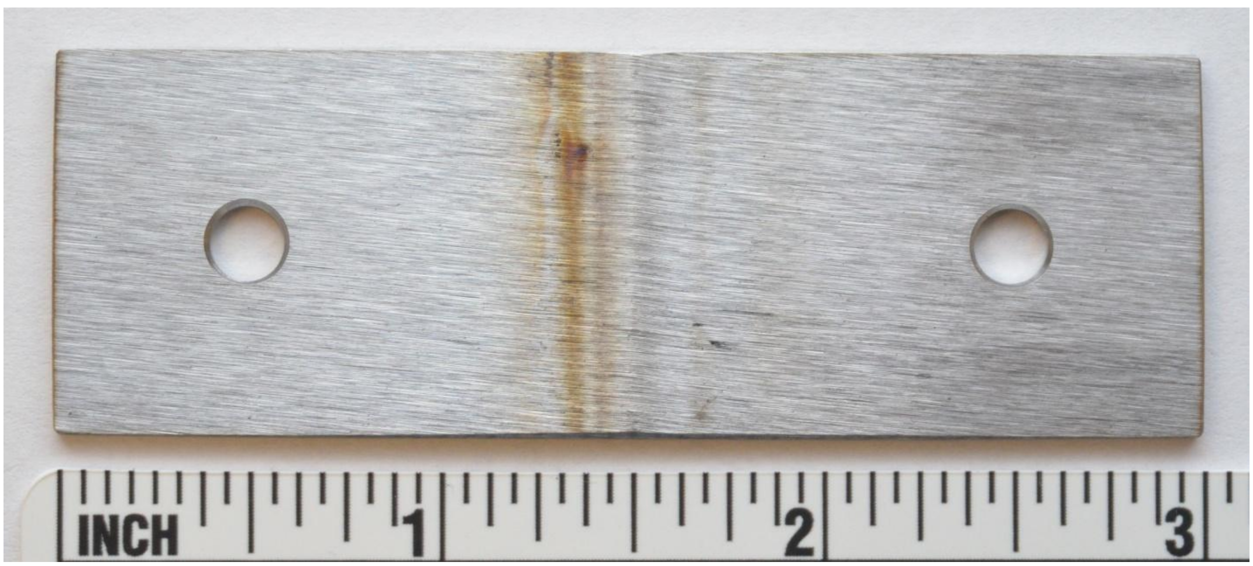
Table 4
Total Mass Loss from Corrosion and Corrosion Rate

Sample	Total Mass Loss from Corrosion*	Corrosion Rate
Coupon 6	< 0.001 grams	< 0.0005 mm / year
Coupon 7	< 0.001 grams	< 0.0005 mm / year
Coupon 8	< 0.001 grams	< 0.0005 mm / year
Screen 1	0.04 grams	< 0.0005 mm / year
Screen 2	0.02 grams	< 0.0005 mm / year
Screen 3	0.00 grams	< 0.0005 mm / year

* Weight As-Received – (Weight Before Cleaning – Mass Loss from Corrosion During Cleaning)



(a) Duplex 2205 Stainless Steel Baseline Coupon, Front Side



(b) Duplex 2205 Stainless Steel Baseline Coupon, Back Side

Figure 1 Photographs of the duplex 2205 stainless steel baseline coupon (a) front and (b) back side.

(a) Duplex 2205 Stainless Steel Coupon 6, Front Side

(b) Duplex 2205 Stainless Steel Coupon 6, Back Side

Figure 2 Photographs of duplex 2205 stainless steel coupon 6 (a) front and (b) back side after a 3 month corrosion test.

(a) Duplex 2205 Stainless Steel Coupon 7, Front Side

(b) Duplex 2205 Stainless Steel Coupon 7, Back Side

Figure 3 Photographs of duplex 2205 stainless steel coupon 7 (a) front and (b) back side after a 6 month corrosion test.

(a) Duplex 2205 Stainless Steel Coupon 8, Front Side

(b) Duplex 2205 Stainless Steel Coupon 8, Back Side

Figure 4 Photographs of duplex 2205 stainless steel coupon 8 (a) front and (b) back side after a 10 month corrosion test.

(a) Duplex 2205 Stainless Steel Baseline Screen

Figure 5 Photograph of the duplex 2205 stainless steel baseline screen.

(a) Duplex 2205 Stainless Steel Screen 1

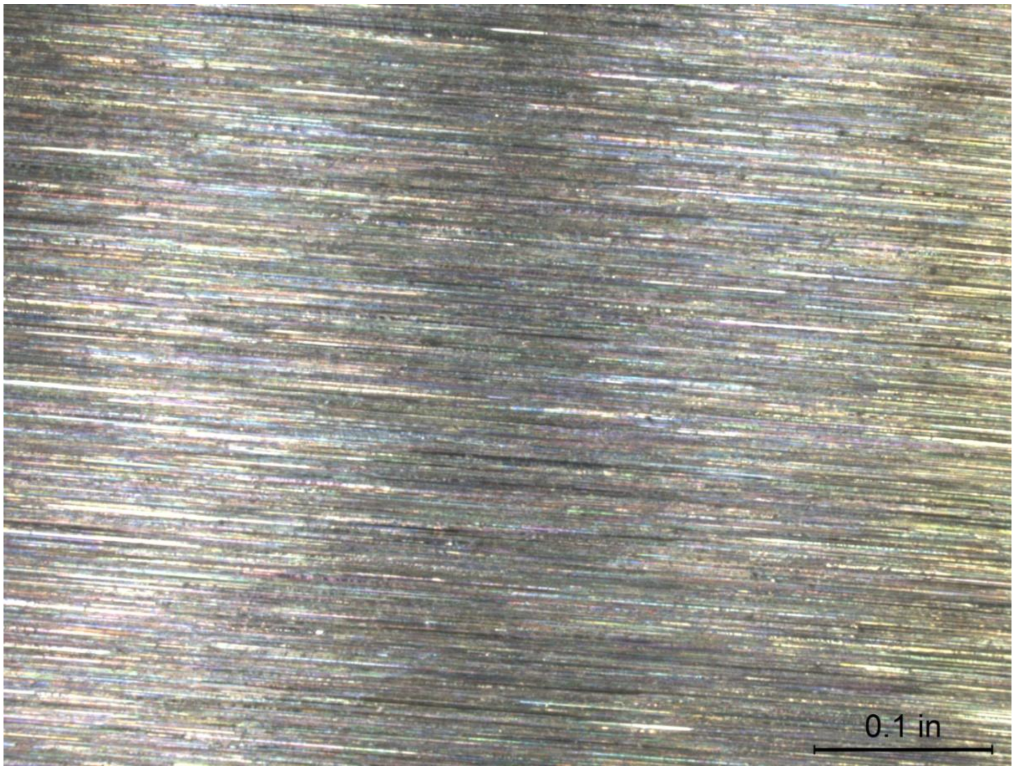
Figure 6 Photograph of duplex 2205 stainless steel screen 1 after a 3 month corrosion test.

(a) Duplex 2205 Stainless Steel Screen 2

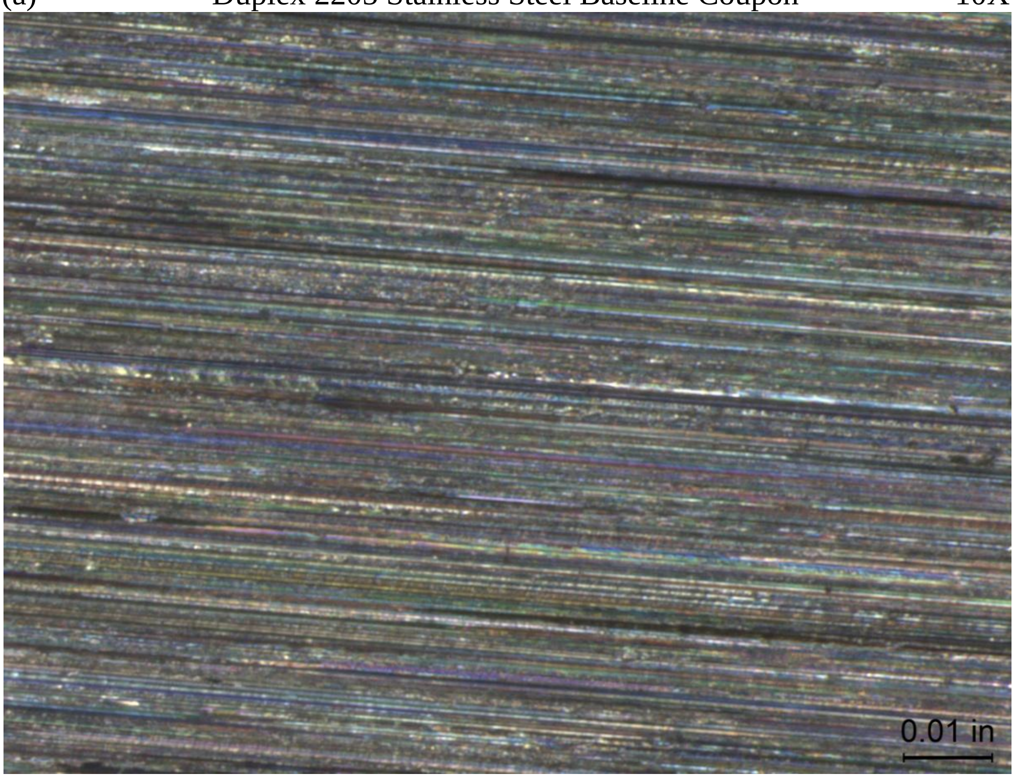
Figure 7 Photograph of duplex 2205 stainless steel screen 2 after a 6 month corrosion test.

(a) Duplex 2205 Stainless Steel Screen 3

Figure 8 Photograph of duplex 2205 stainless steel screen 3 after a 10 month corrosion test.



(a) Duplex 2205 Stainless Steel Baseline Coupon 10X



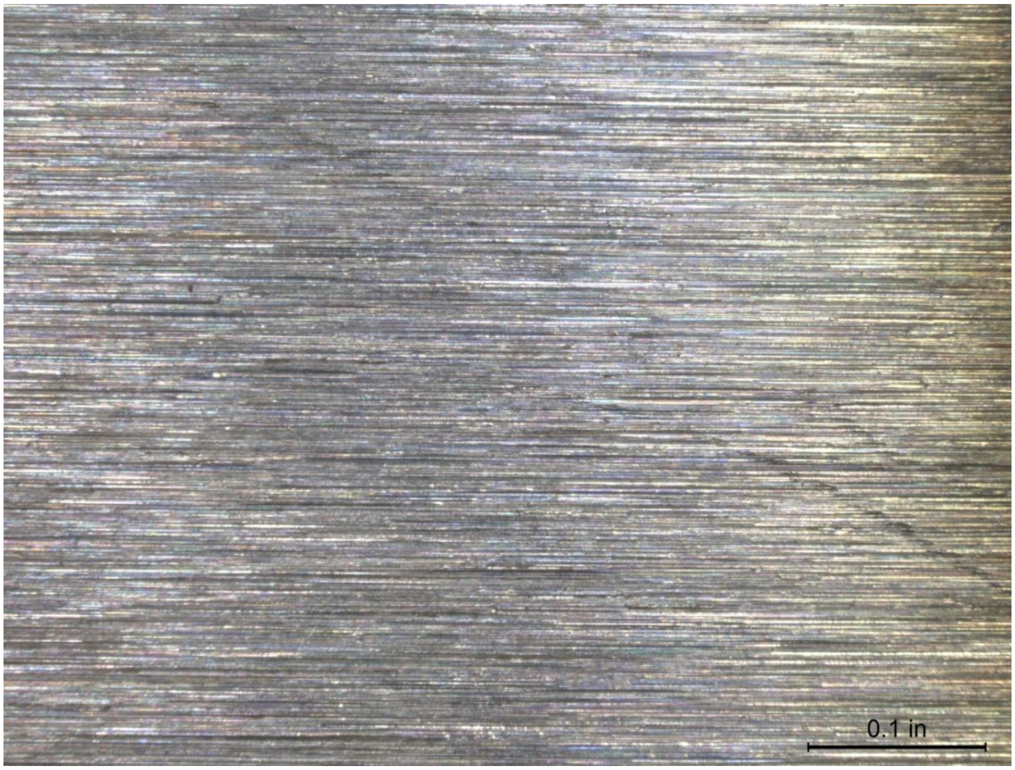
(b) Duplex 2205 Stainless Steel Baseline Coupon 50X

Figure 9 Optical macrographs of the duplex 2205 stainless steel baseline coupon.

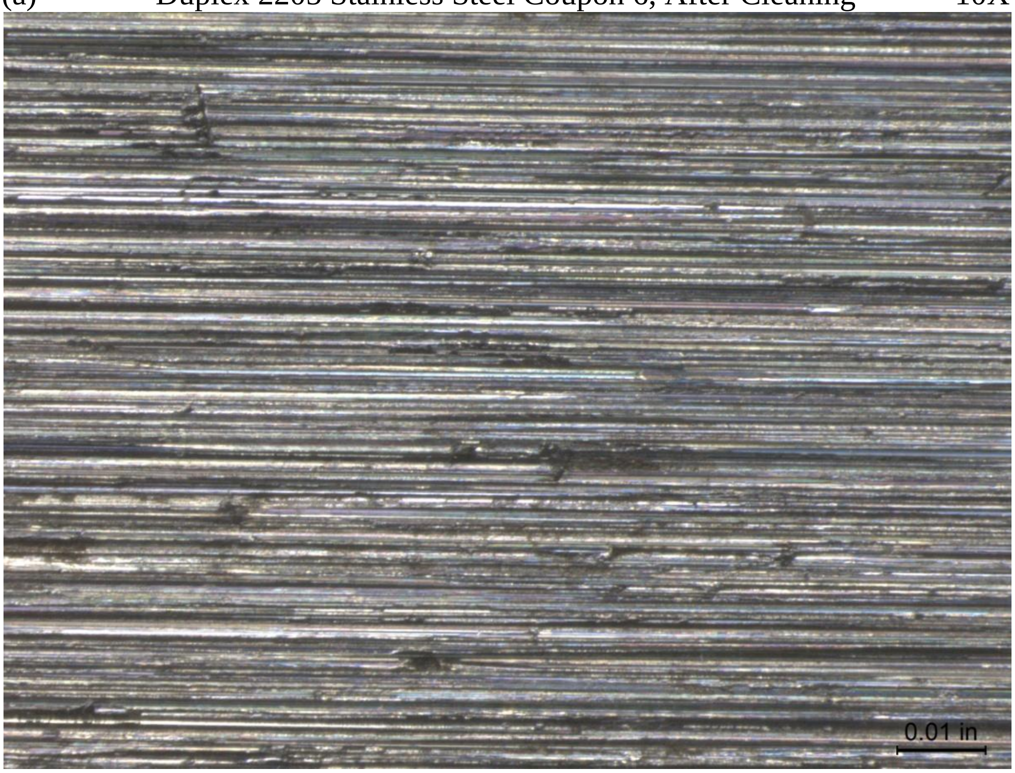
(a) Duplex 2205 Stainless Steel Coupon 6, Before Cleaning 10X

(b) Duplex 2205 Stainless Steel Coupon 6, Before Cleaning 50X

Figure 10 Optical macrographs of duplex 2205 stainless steel coupon 6 after a 3 month corrosion test, before cleaning.



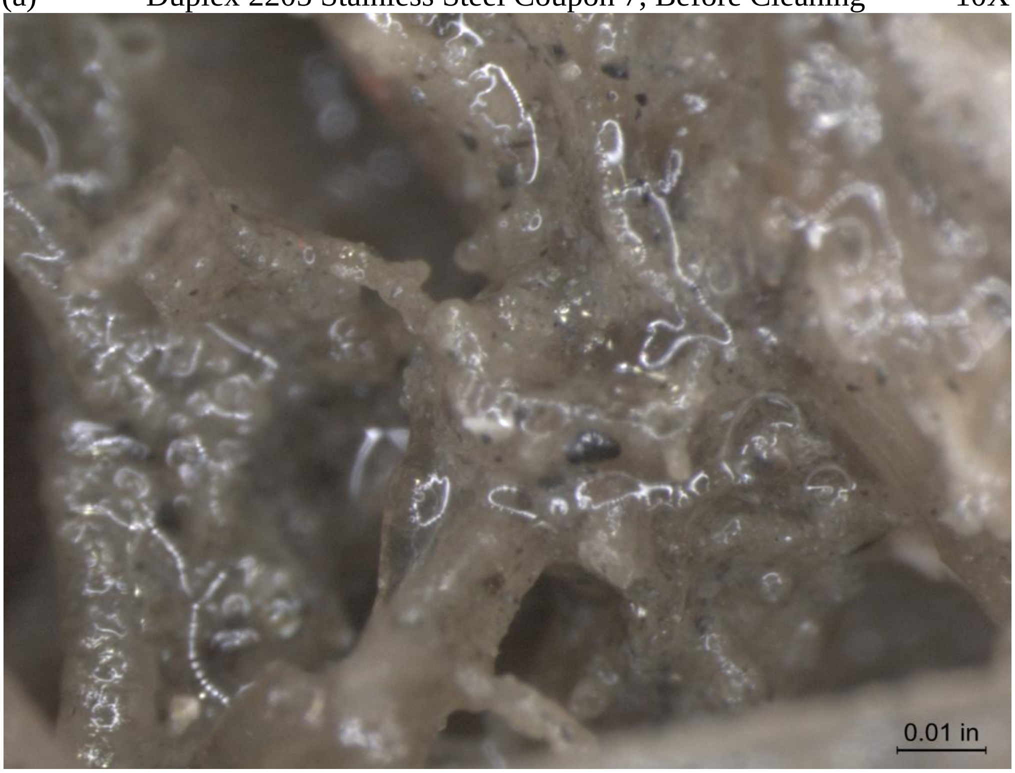
(a) Duplex 2205 Stainless Steel Coupon 6, After Cleaning 10X



(b) Duplex 2205 Stainless Steel Coupon 6, After Cleaning 50X

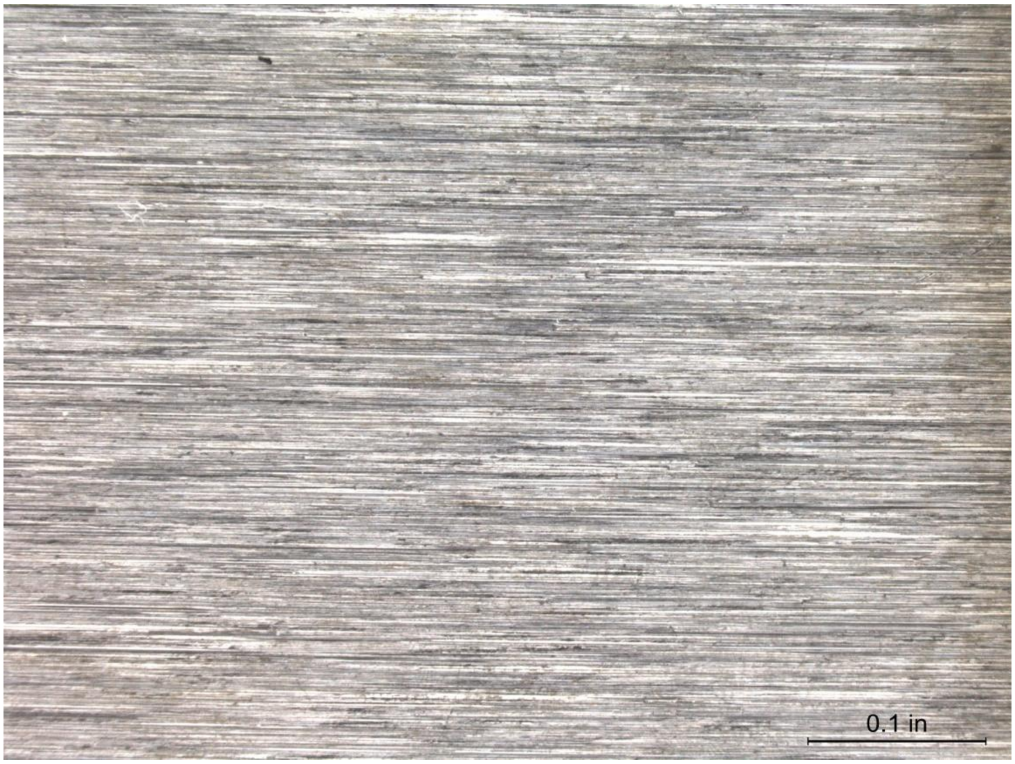
Figure 11 Optical macrographs of duplex 2205 stainless steel coupon 6 after a 3 month corrosion test, after cleaning.

(a) Duplex 2205 Stainless Steel Coupon 7, Before Cleaning 10X



(b) Duplex 2205 Stainless Steel Coupon 7, Before Cleaning 50X

Figure 12 Optical macrographs of duplex 2205 stainless steel coupon 7 after a 6 month corrosion test, before cleaning.



(a) Duplex 2205 Stainless Steel Coupon 7, After Cleaning 10X

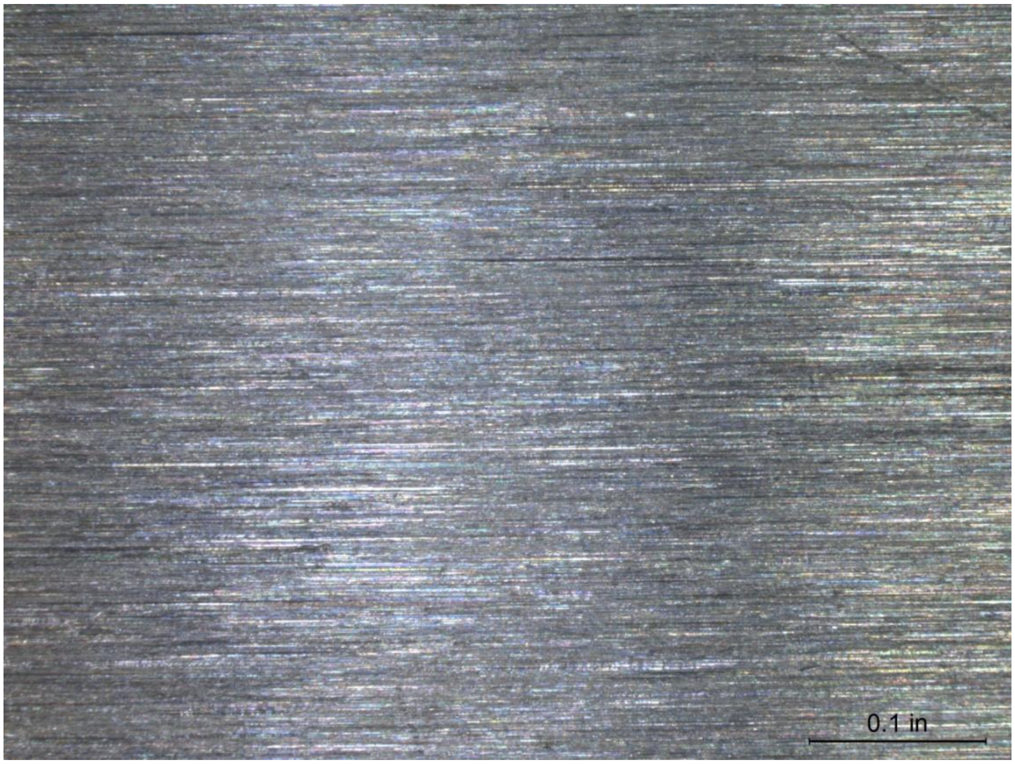
(b) Duplex 2205 Stainless Steel Coupon 7, After Cleaning 50X

Figure 13 Optical macrographs of duplex 2205 stainless steel coupon 7 after a 6 month corrosion test, after cleaning.

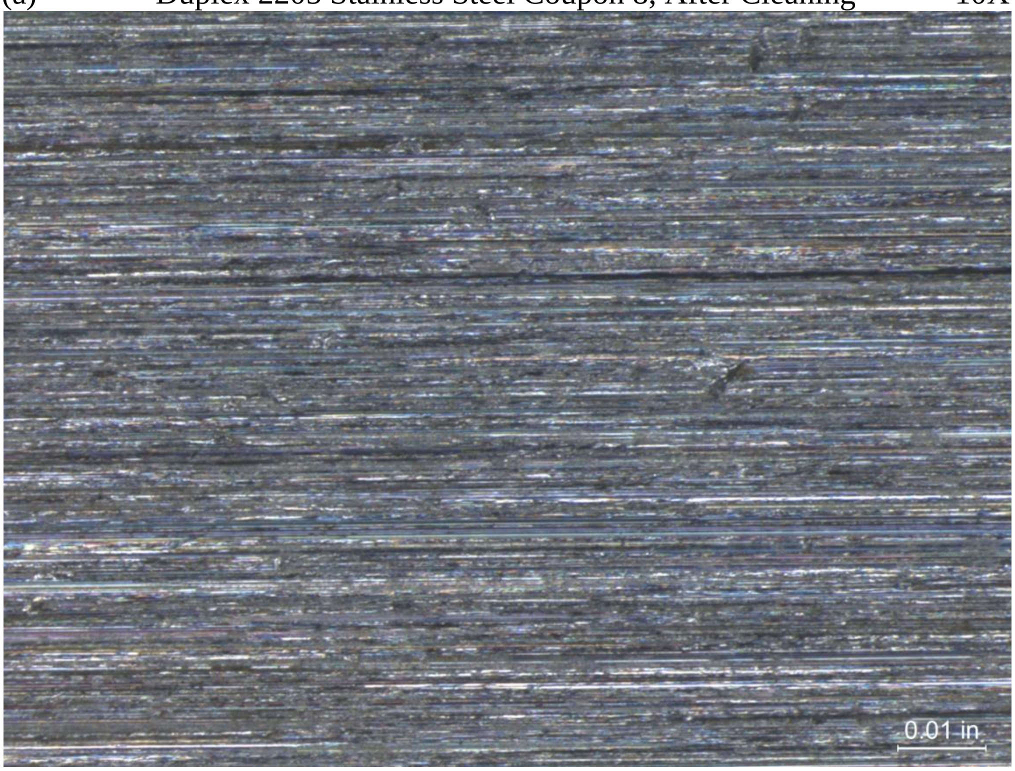
(a) Duplex 2205 Stainless Steel Coupon 8, Before Cleaning 10X

(b) Duplex 2205 Stainless Steel Coupon 8, Before Cleaning 50X

Figure 14 Optical macrographs of duplex 2205 stainless steel coupon 8 after a 10 month corrosion test, before cleaning.

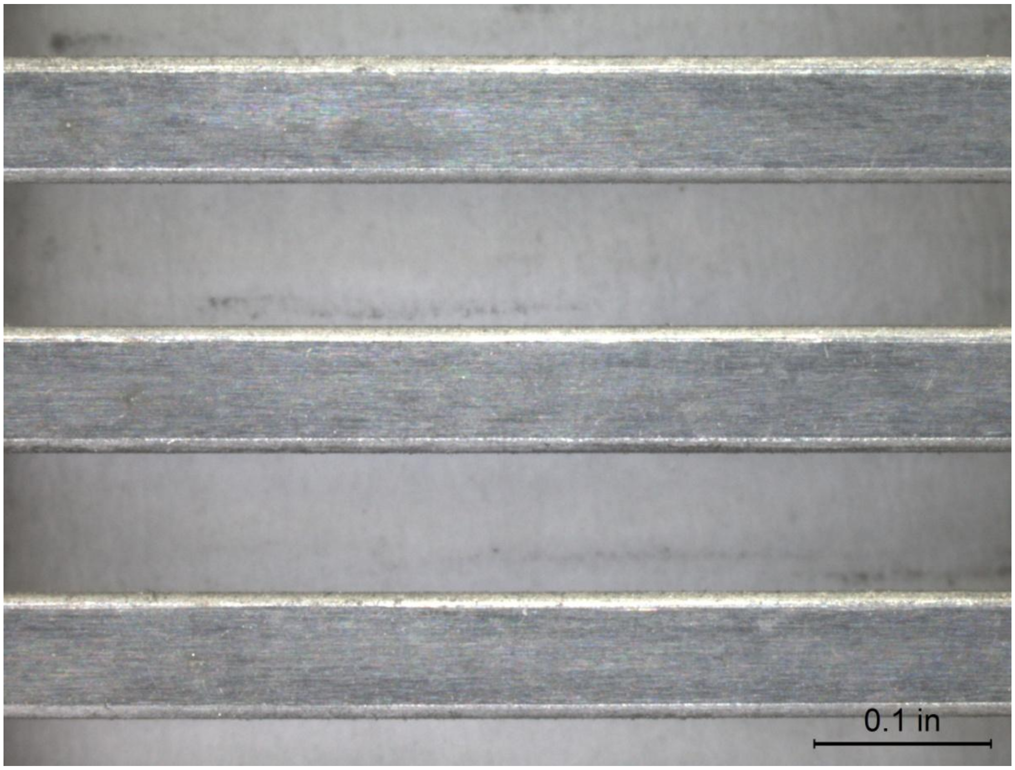


(a) Duplex 2205 Stainless Steel Coupon 8, After Cleaning 10X

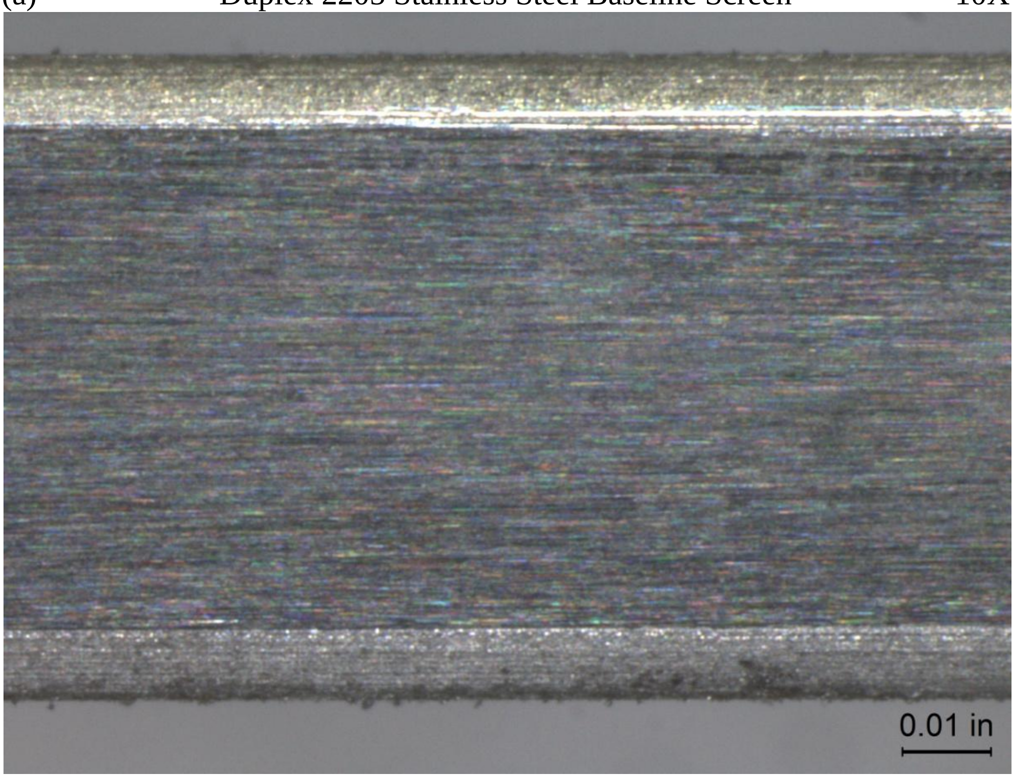


(b) Duplex 2205 Stainless Steel Coupon 8, After Cleaning 50X

Figure 15 Optical macrographs of duplex 2205 stainless steel coupon 8 after a 10 month corrosion test, after cleaning.

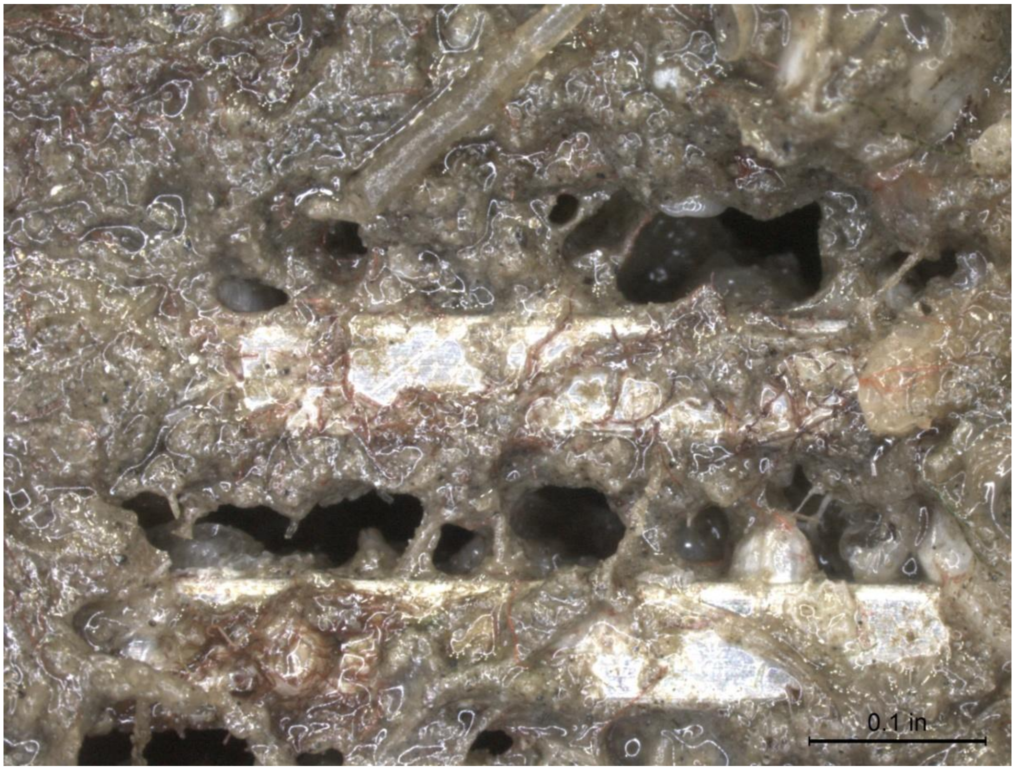


(a) Duplex 2205 Stainless Steel Baseline Screen 10X

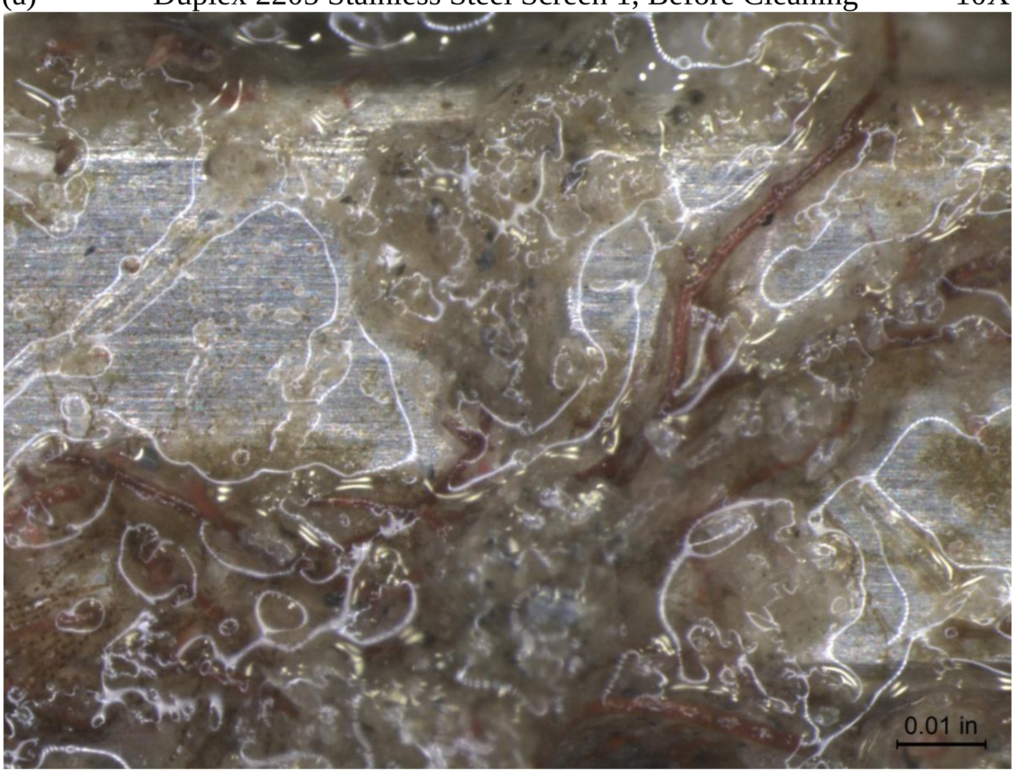


(b) Duplex 2205 Stainless Steel Baseline Screen 50X

Figure 16 Optical macrographs of the duplex 2205 stainless steel baseline screen.

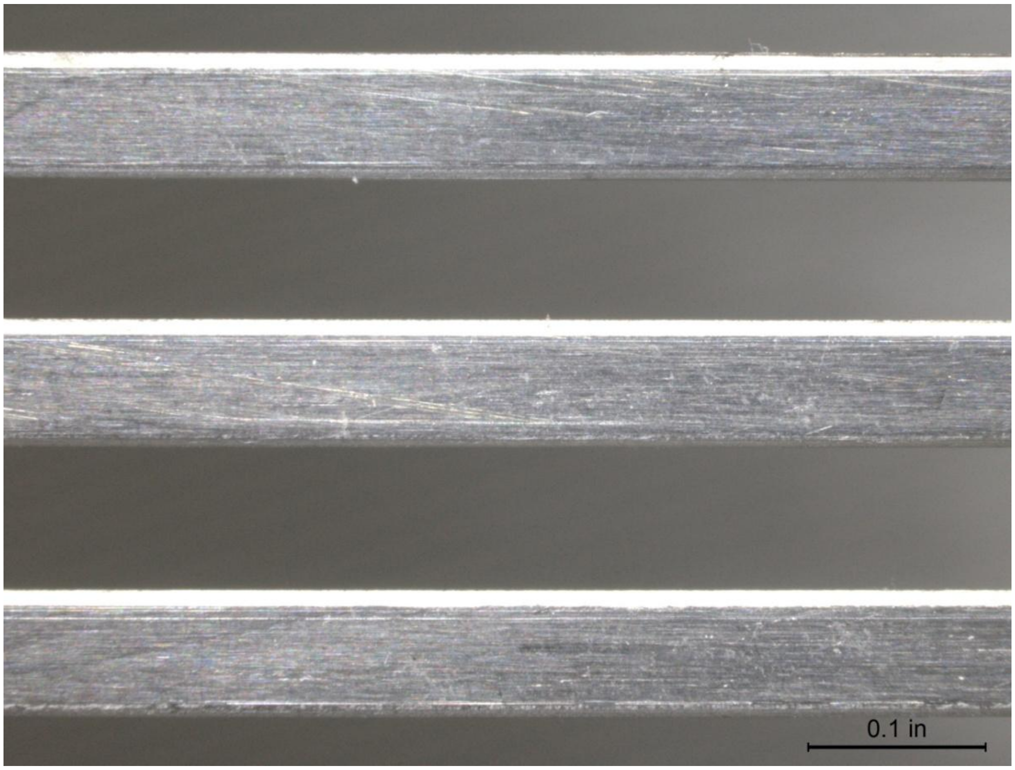


(a) Duplex 2205 Stainless Steel Screen 1, Before Cleaning 10X

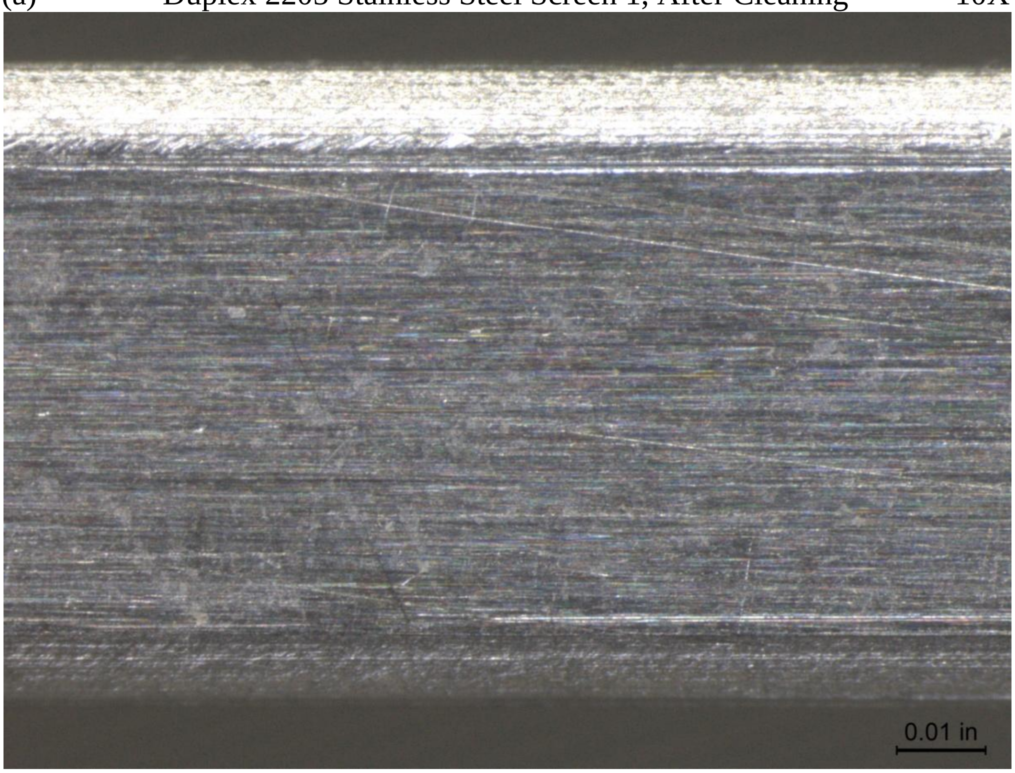


(b) Duplex 2205 Stainless Steel Screen 1, Before Cleaning 50X

Figure 17 Optical macrographs of duplex 2205 stainless steel screen 1 after a 3 month corrosion test, before cleaning.



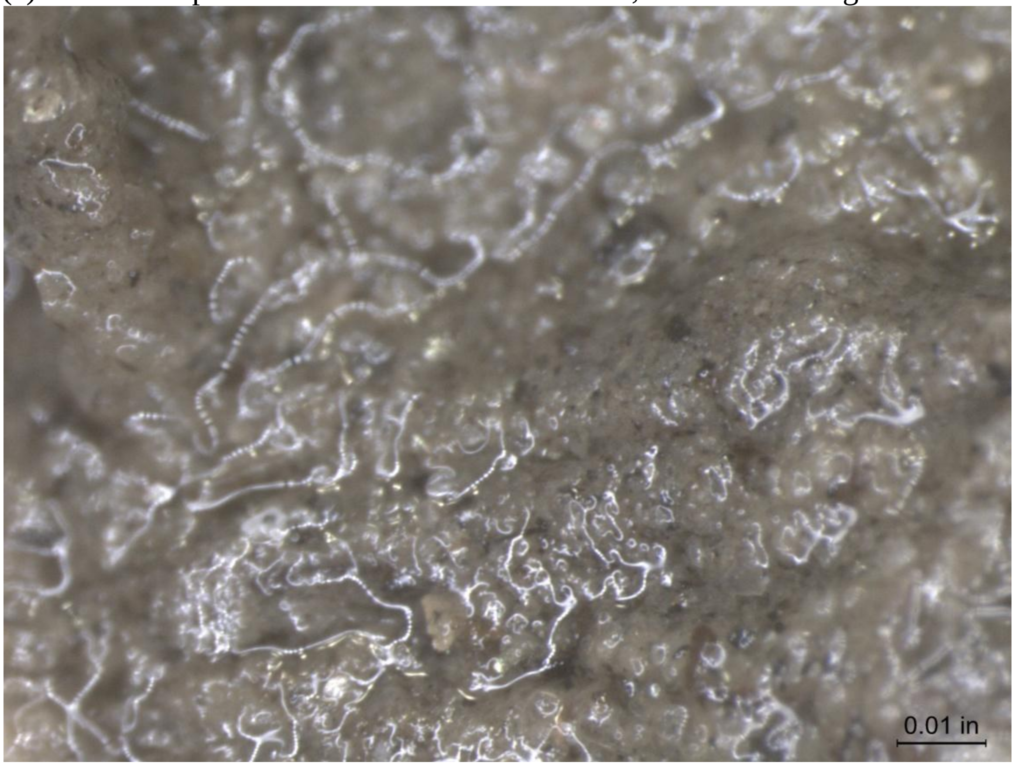
(a) Duplex 2205 Stainless Steel Screen 1, After Cleaning 10X



(b) Duplex 2205 Stainless Steel Screen 1, After Cleaning 50X

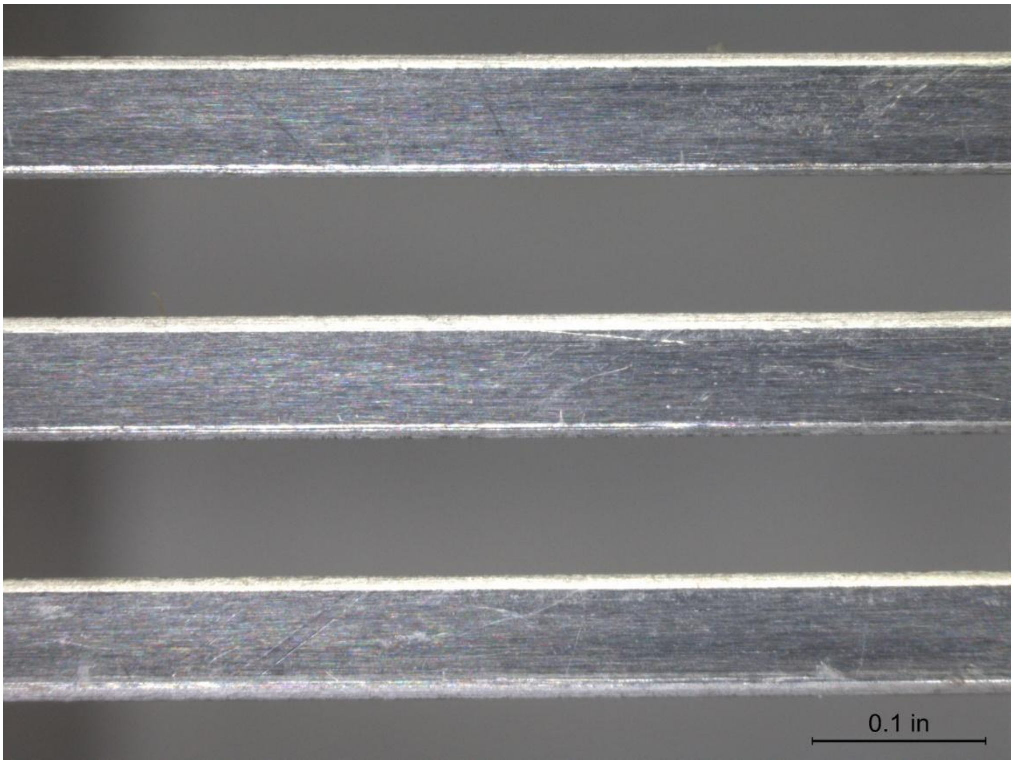
Figure 18 Optical macrographs of duplex 2205 stainless steel screen 1 after a 3 month corrosion test, after cleaning.

(a) Duplex 2205 Stainless Steel Screen 2, Before Cleaning 10X

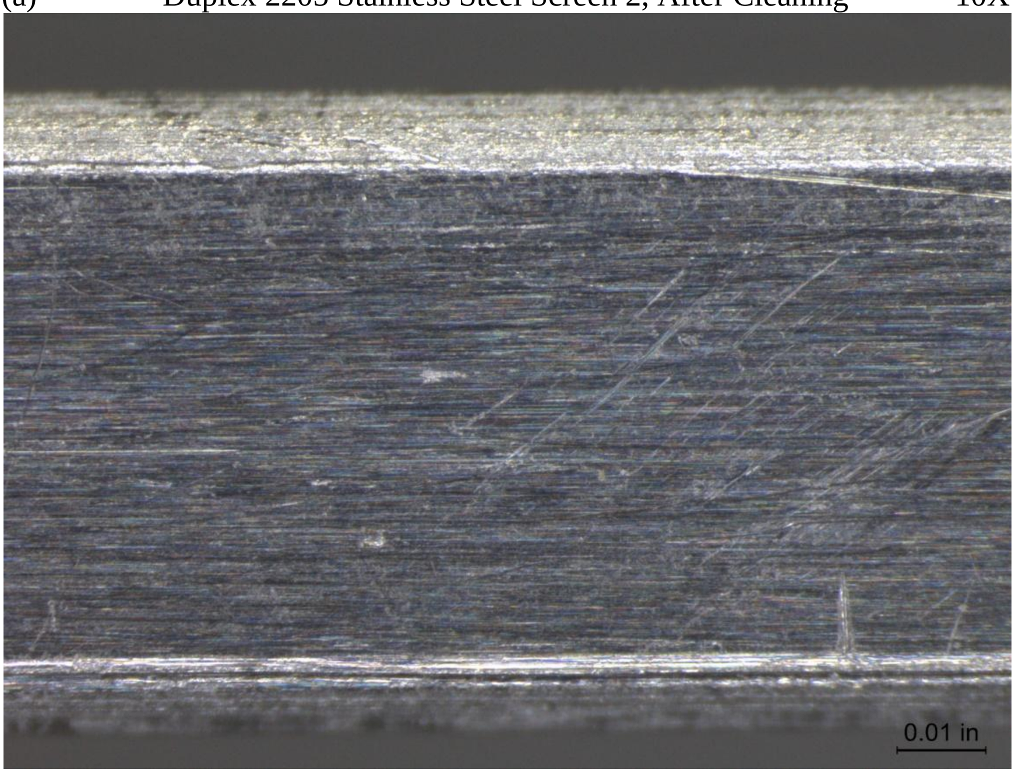


(b) Duplex 2205 Stainless Steel Screen 2, Before Cleaning 50X

Figure 19 Optical macrographs of duplex 2205 stainless steel screen 2 after a 6 month corrosion test, before cleaning.

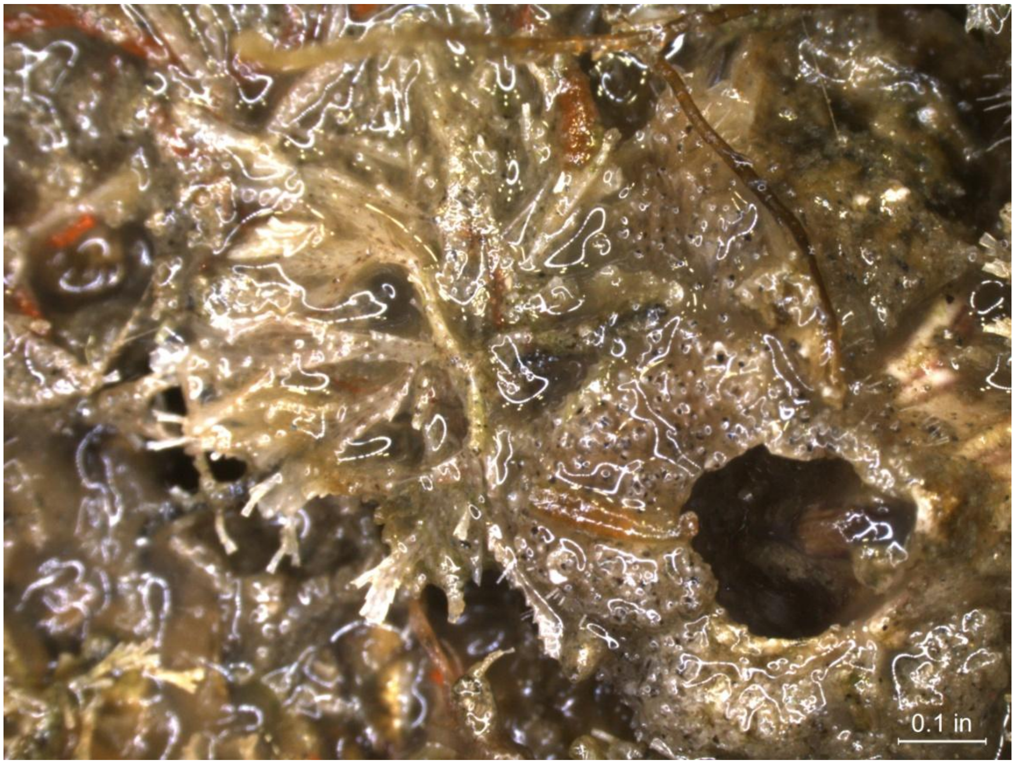


(a) Duplex 2205 Stainless Steel Screen 2, After Cleaning 10X

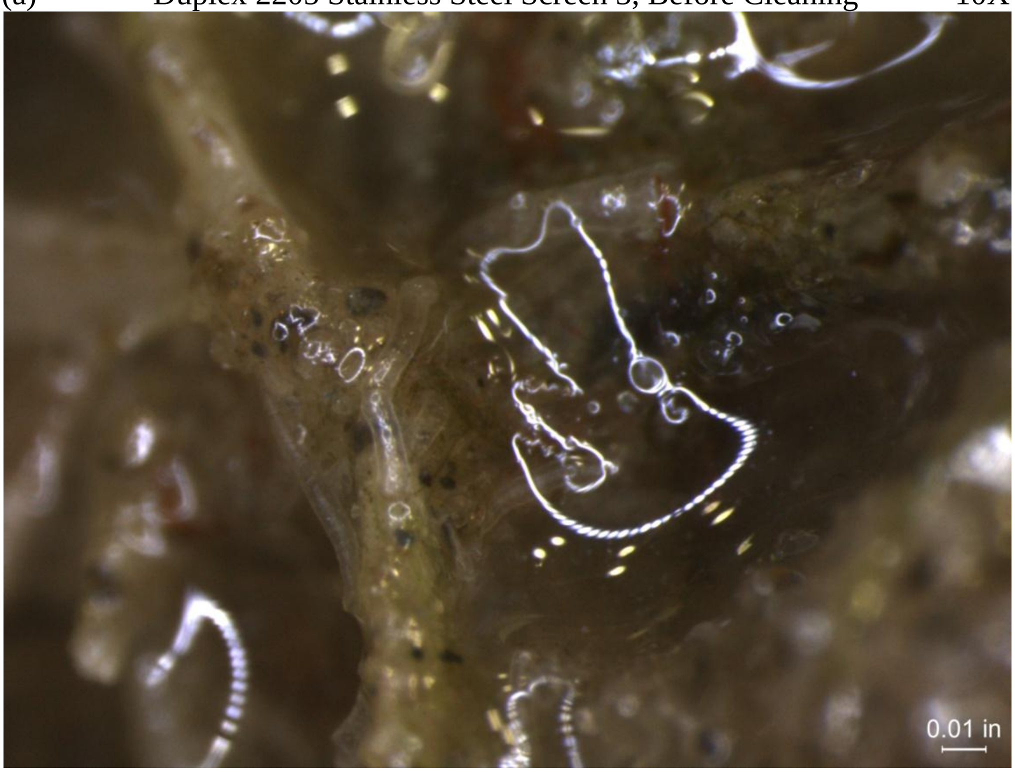


(b) Duplex 2205 Stainless Steel Screen 2, After Cleaning 50X

Figure 20 Optical macrographs of duplex 2205 stainless steel screen 2 after a 6 month corrosion test, after cleaning.

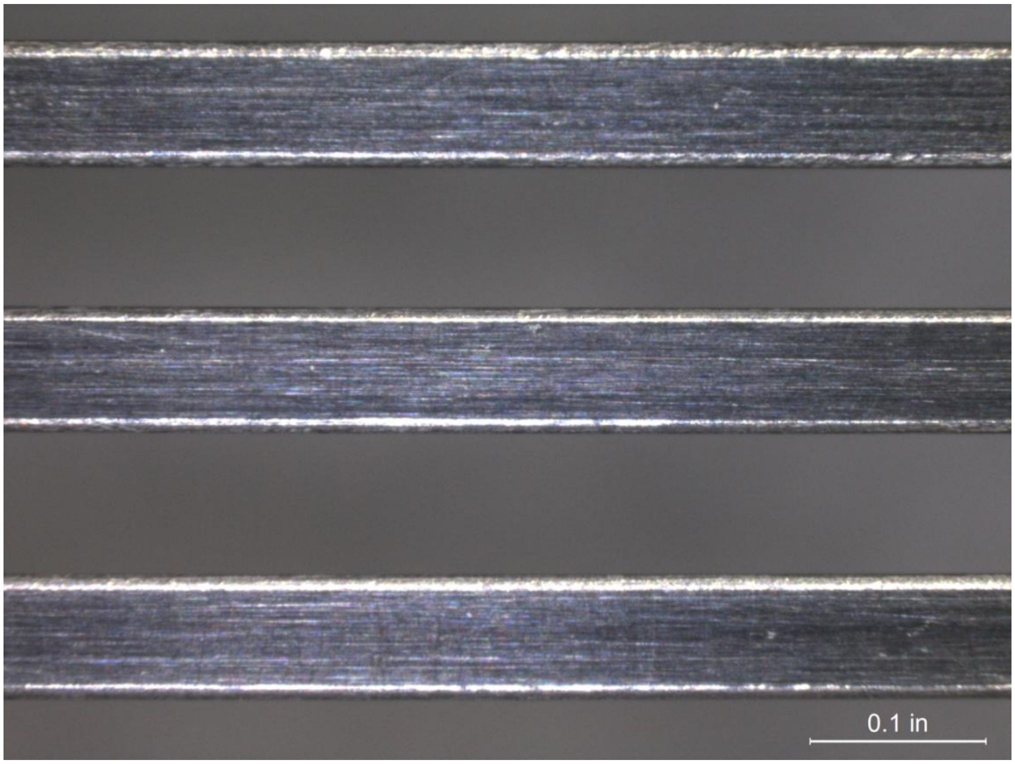


(a) Duplex 2205 Stainless Steel Screen 3, Before Cleaning 10X

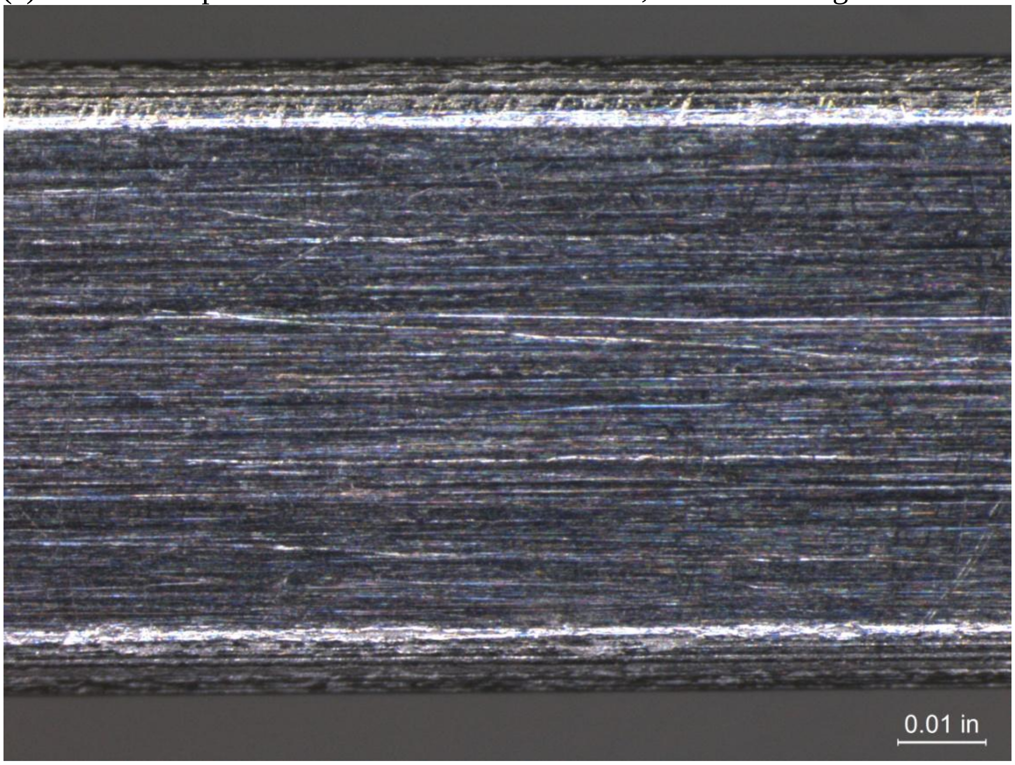


(b) Duplex 2205 Stainless Steel Screen 3, Before Cleaning 50X

Figure 21 Optical macrographs of duplex 2205 stainless steel screen 3 after a 10 month corrosion test, before cleaning.

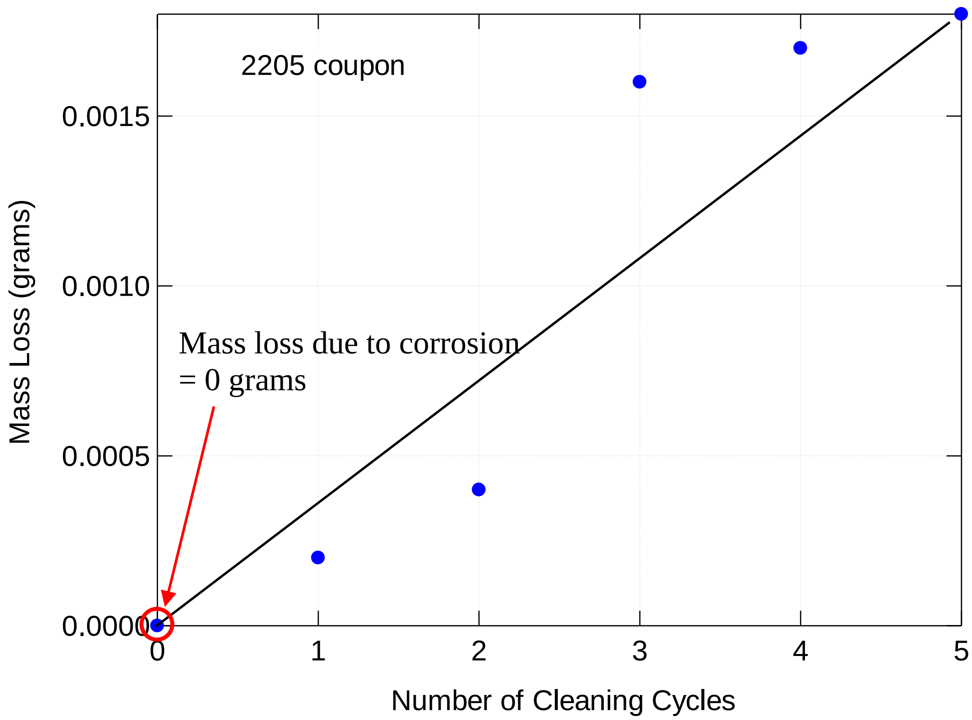


(a) Duplex 2205 Stainless Steel Screen 3, After Cleaning 10X

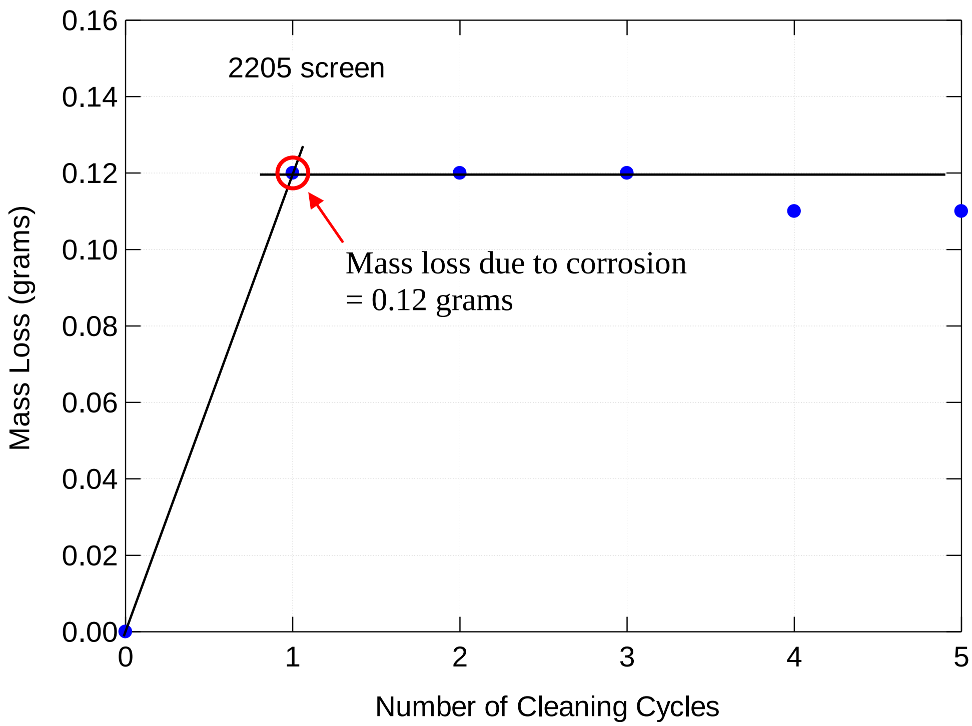


(b) Duplex 2205 Stainless Steel Screen 3, After Cleaning 50X

Figure 22 Optical macrographs of duplex 2205 stainless steel screen 3 after a 10 month corrosion test, after cleaning.

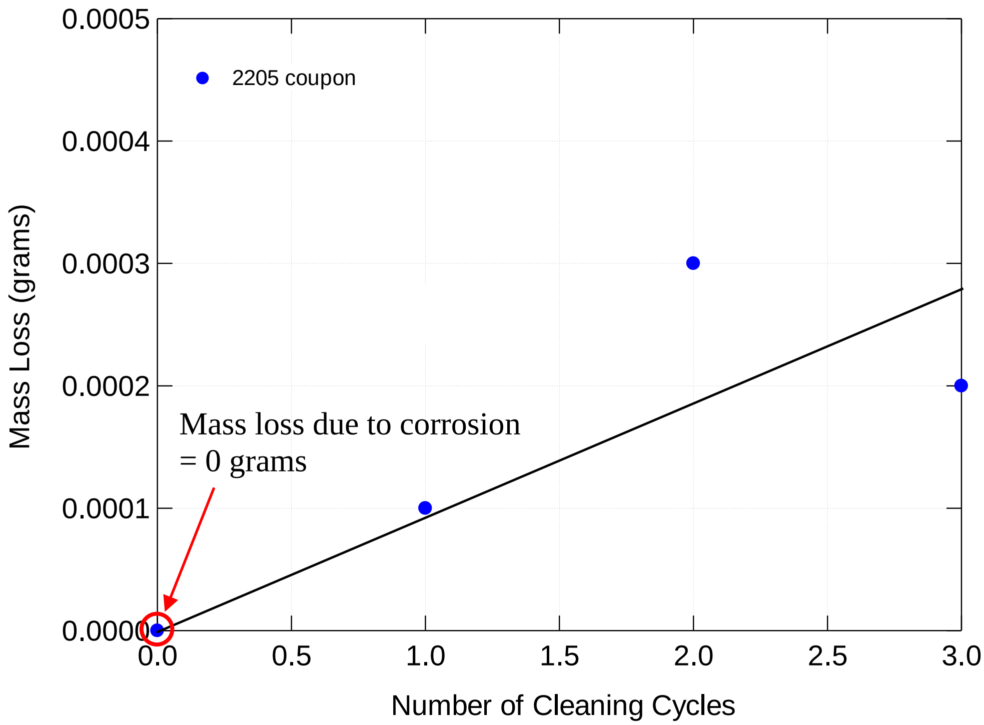


(a)

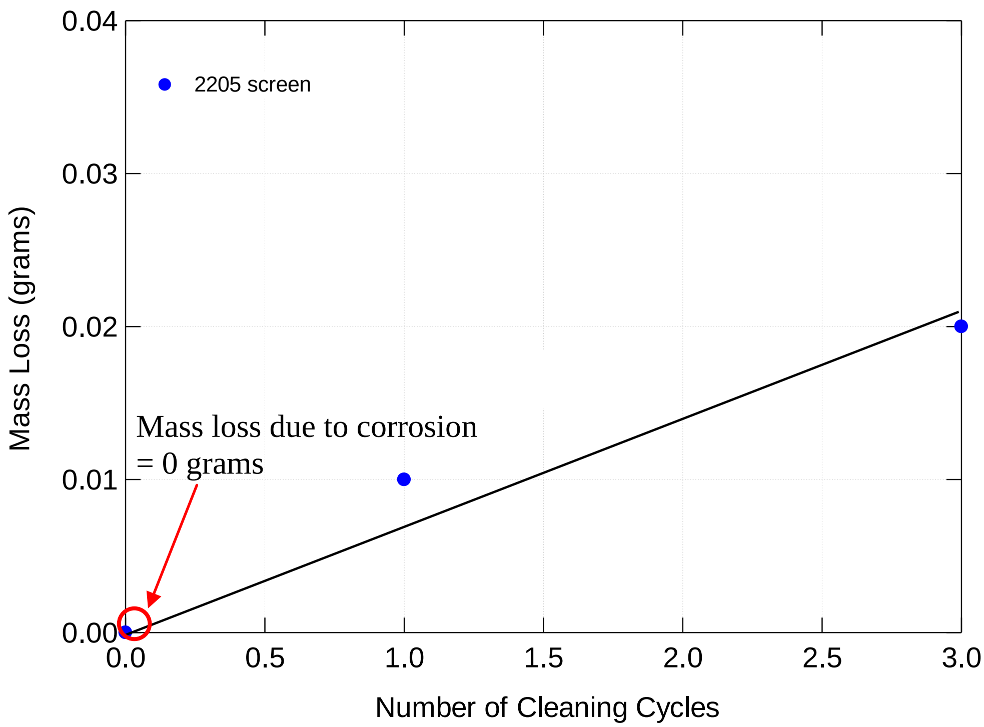


(b)

Figure 23 Mass loss of the duplex 2205 stainless steel (a) coupon 6 and (b) screen 1 during cleaning.

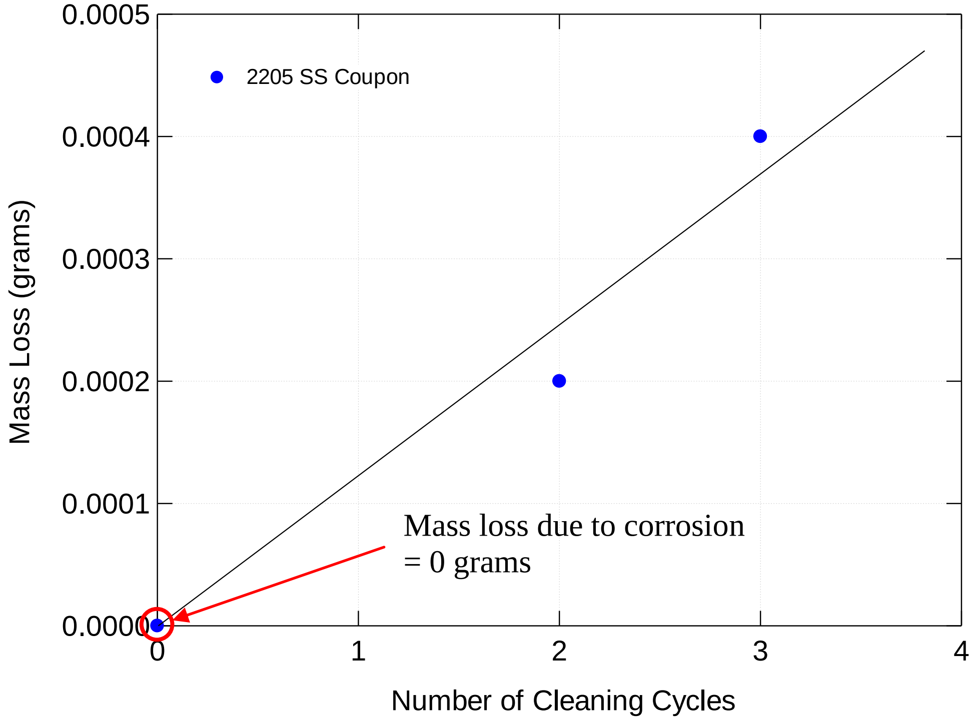


(a)

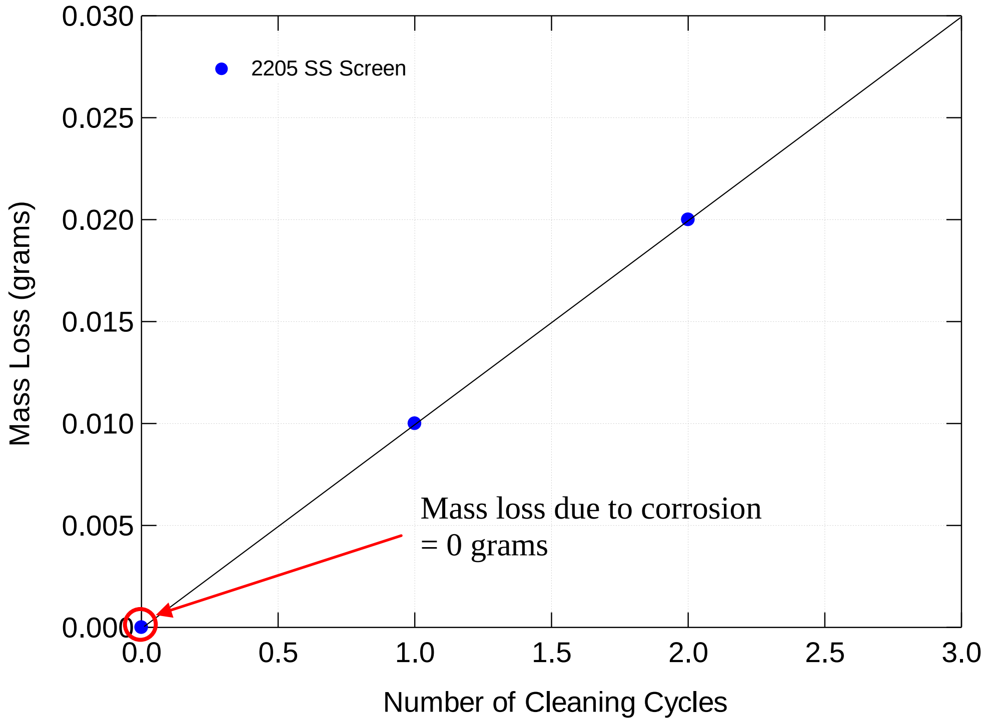


(b)

Figure 24 Mass loss of the duplex 2205 stainless steel (a) coupon 7 and (b) screen 2 during cleaning.

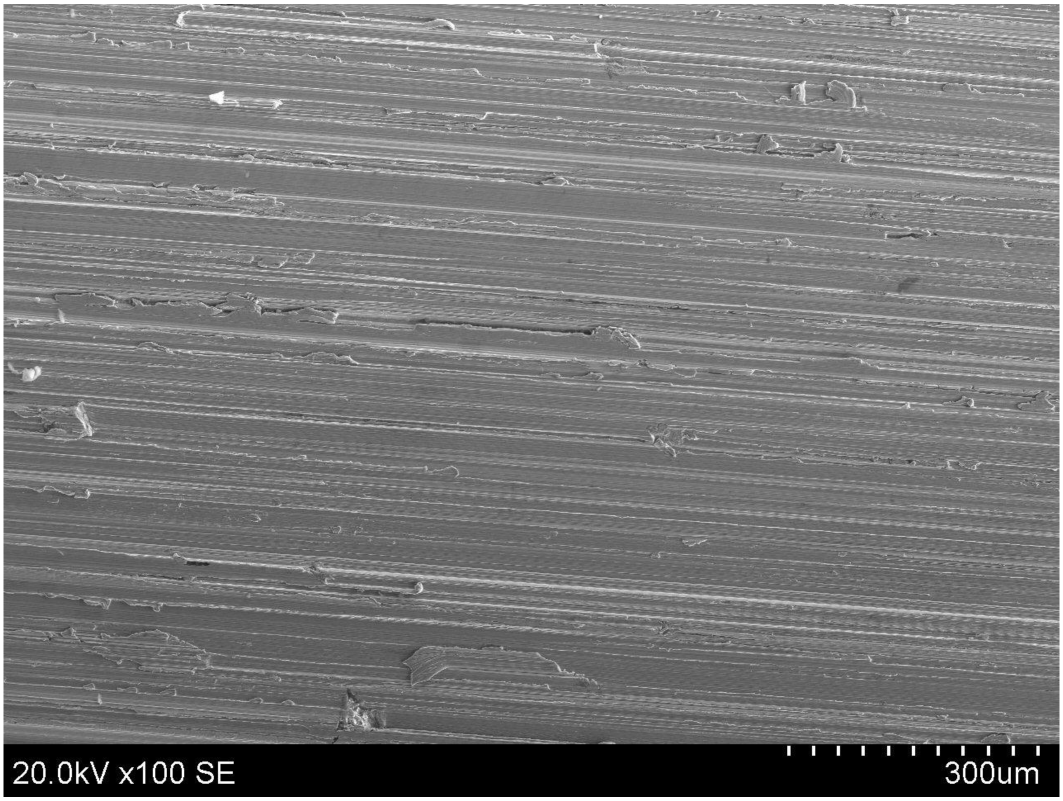


(a)

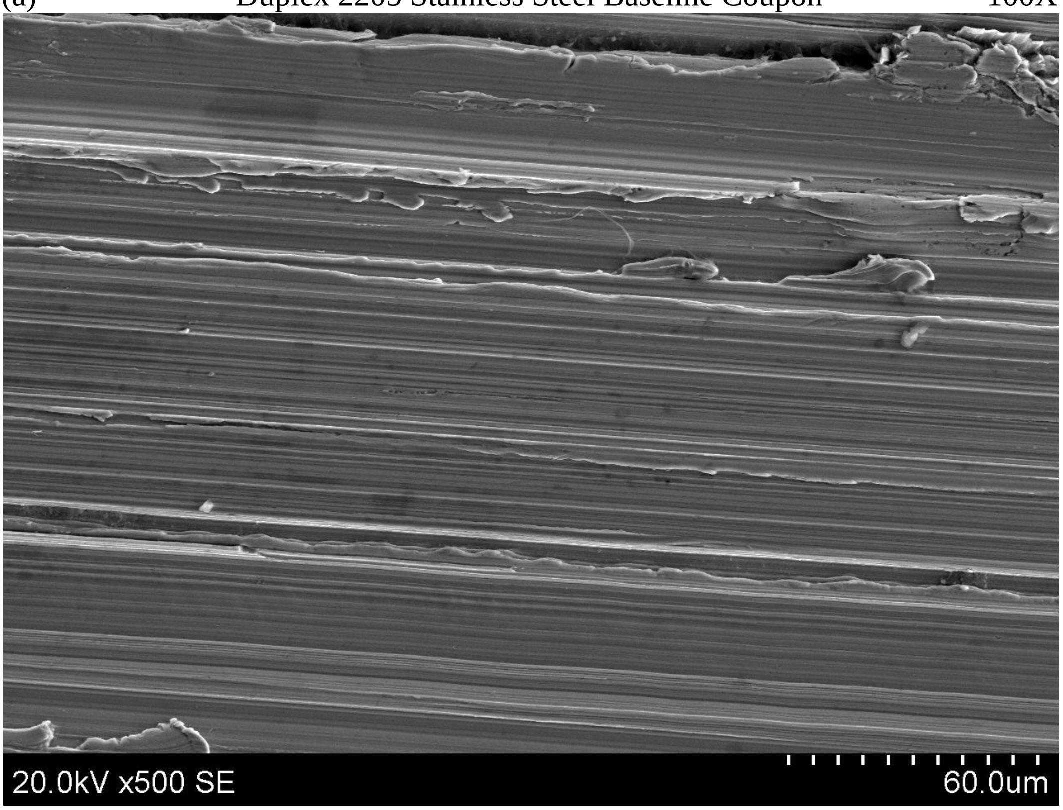


(b)

Figure 25 Mass loss of the duplex 2205 stainless steel (a) coupon 8 and (b) screen 3 during cleaning.

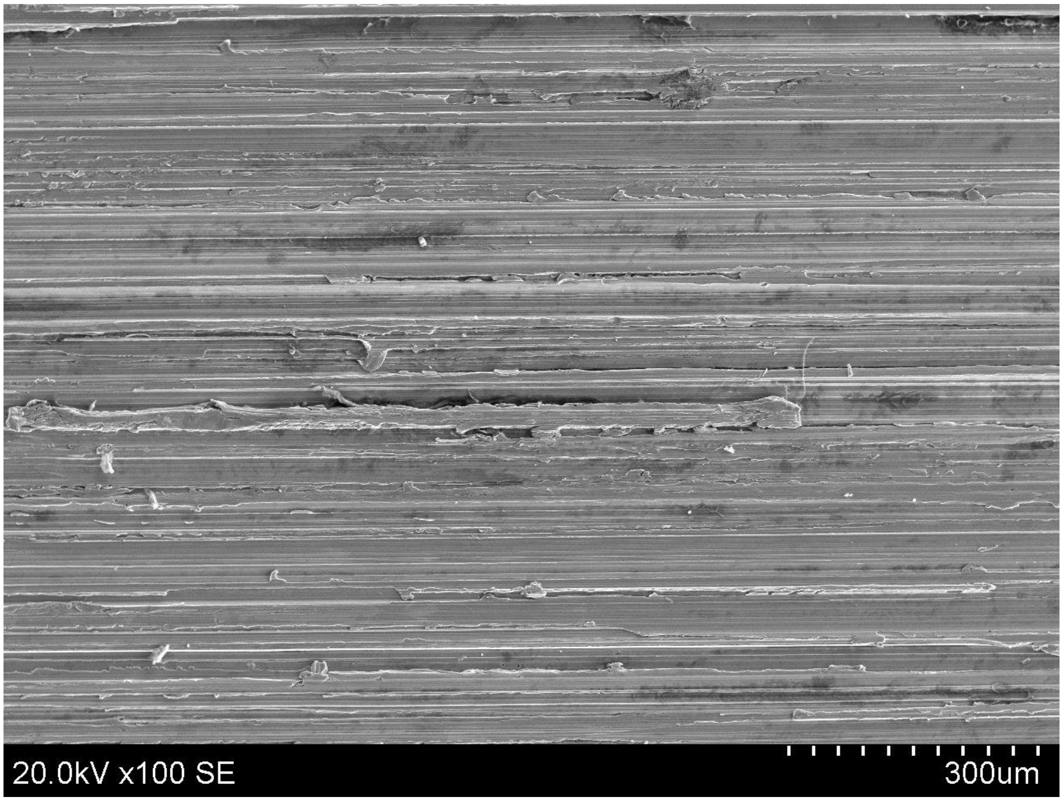


(a) Duplex 2205 Stainless Steel Baseline Coupon 100X

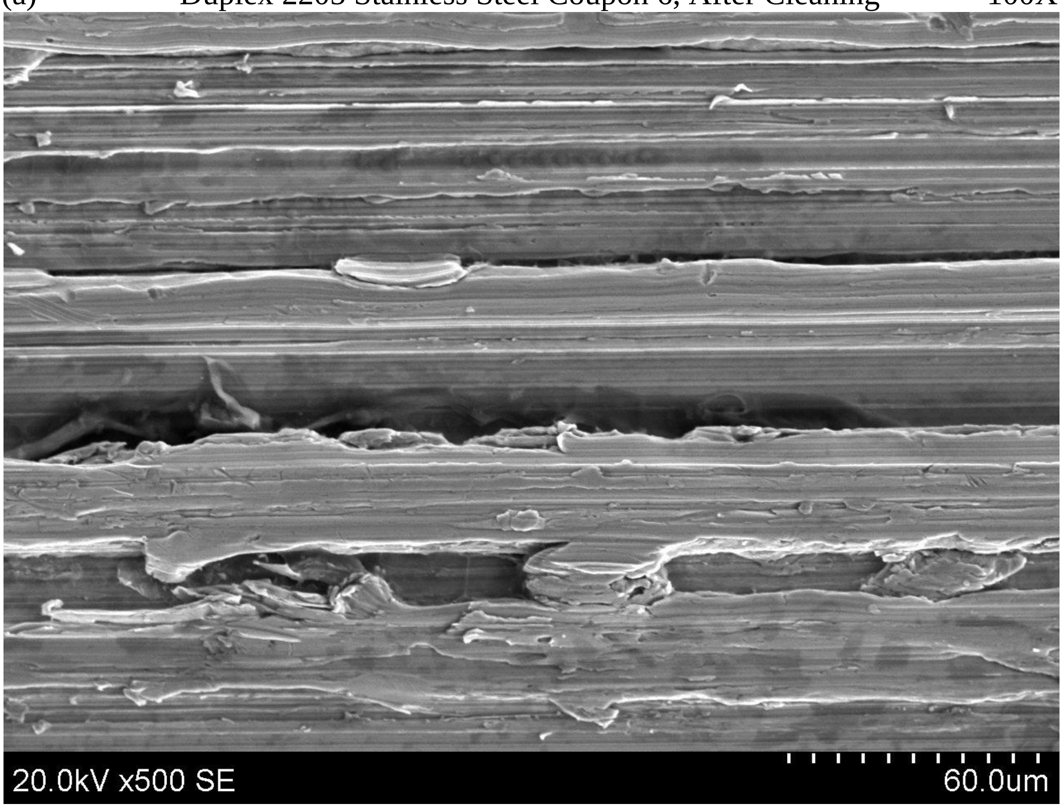


(b) Duplex 2205 Stainless Steel Baseline Coupon 500X

Figure 26 Scanning electron micrographs of the duplex 2205 stainless steel baseline coupon.

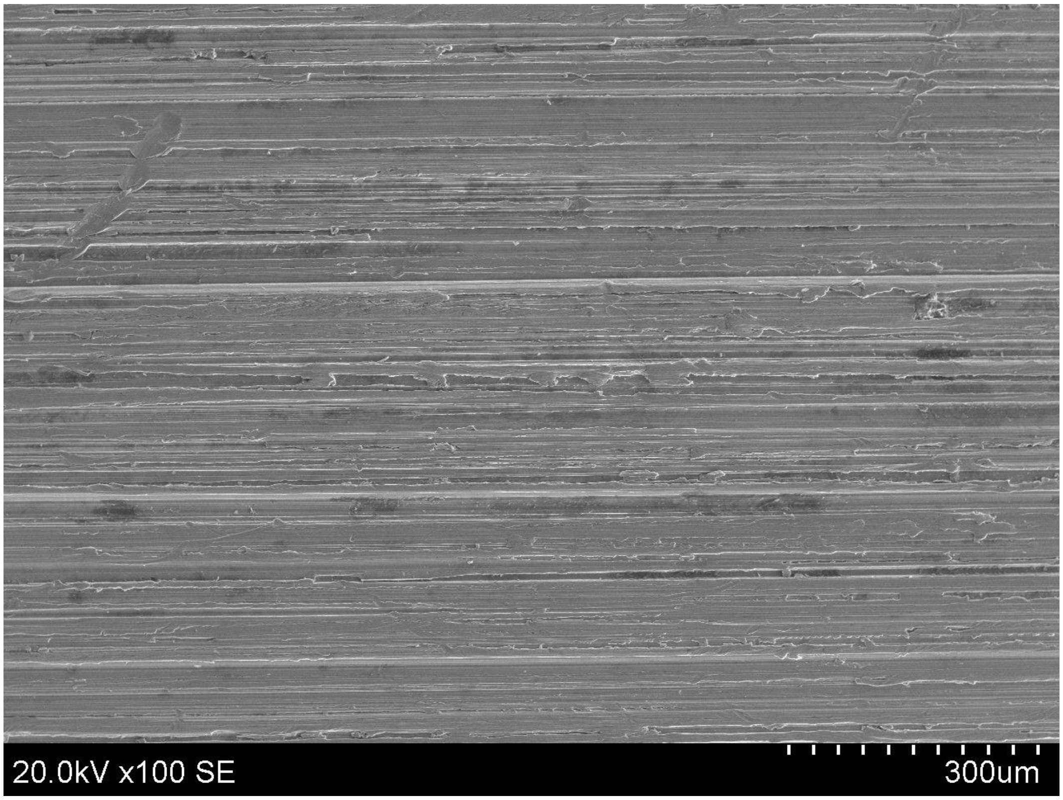


(a) Duplex 2205 Stainless Steel Coupon 6, After Cleaning 100X

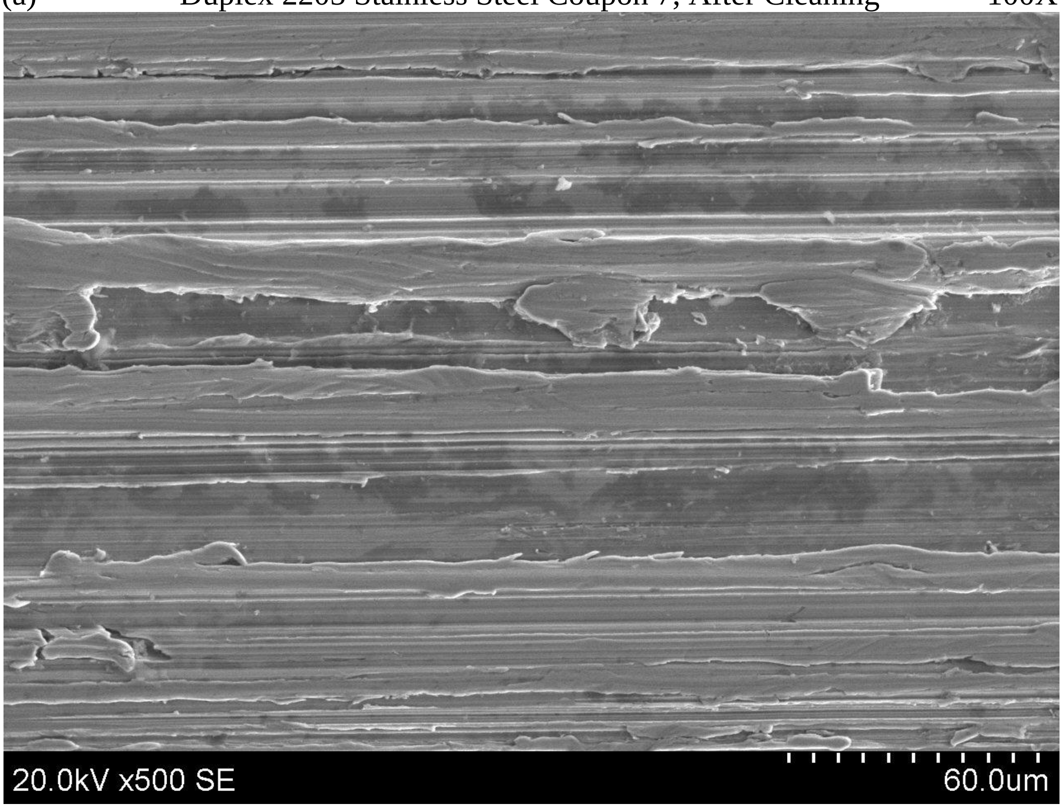


(b) Duplex 2205 Stainless Steel Coupon 6, After Cleaning 500X

Figure 27 Scanning electron micrographs of duplex stainless steel coupon 6 after a 3 month corrosion test, after cleaning.

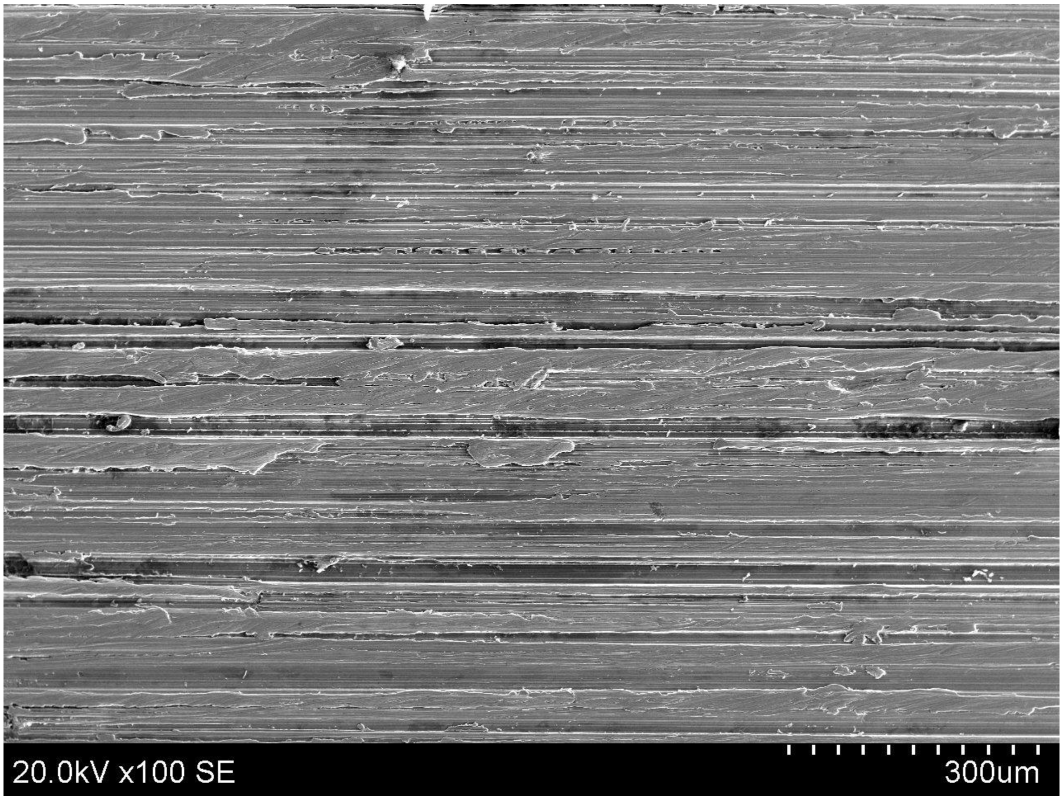


(a) Duplex 2205 Stainless Steel Coupon 7, After Cleaning 100X

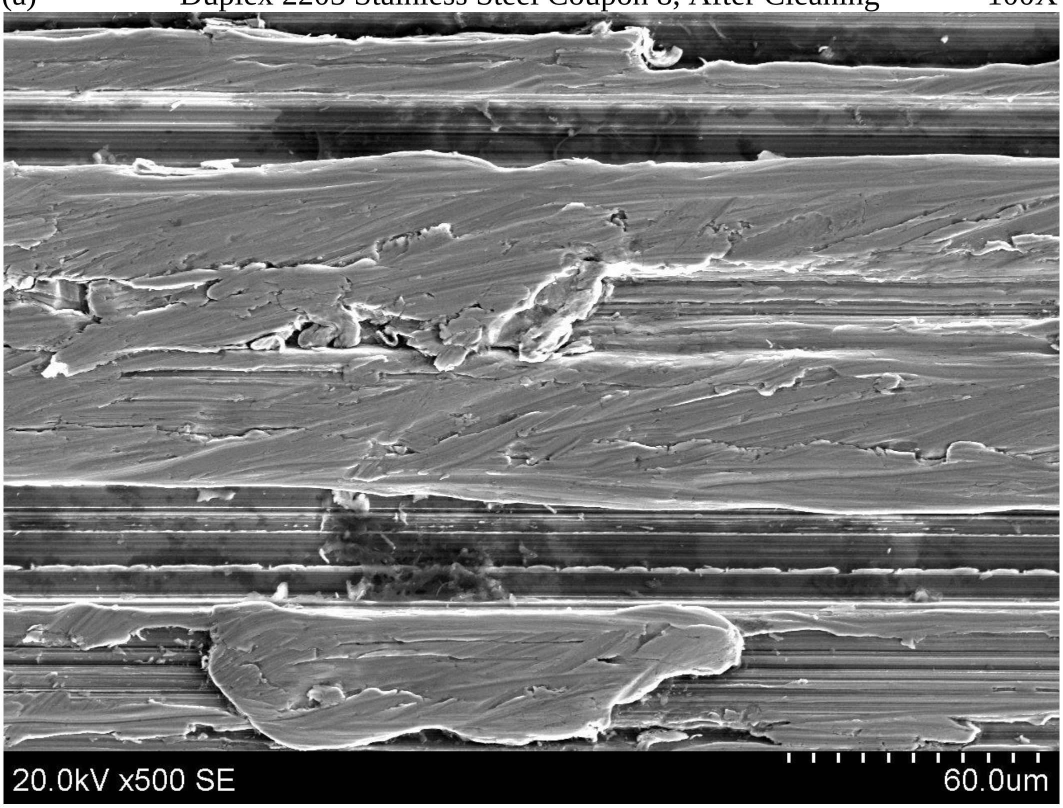


(b) Duplex 2205 Stainless Steel Coupon 7, After Cleaning 500X

Figure 28 Scanning electron micrographs of duplex stainless steel coupon 7 after a 6 month corrosion test, after cleaning.

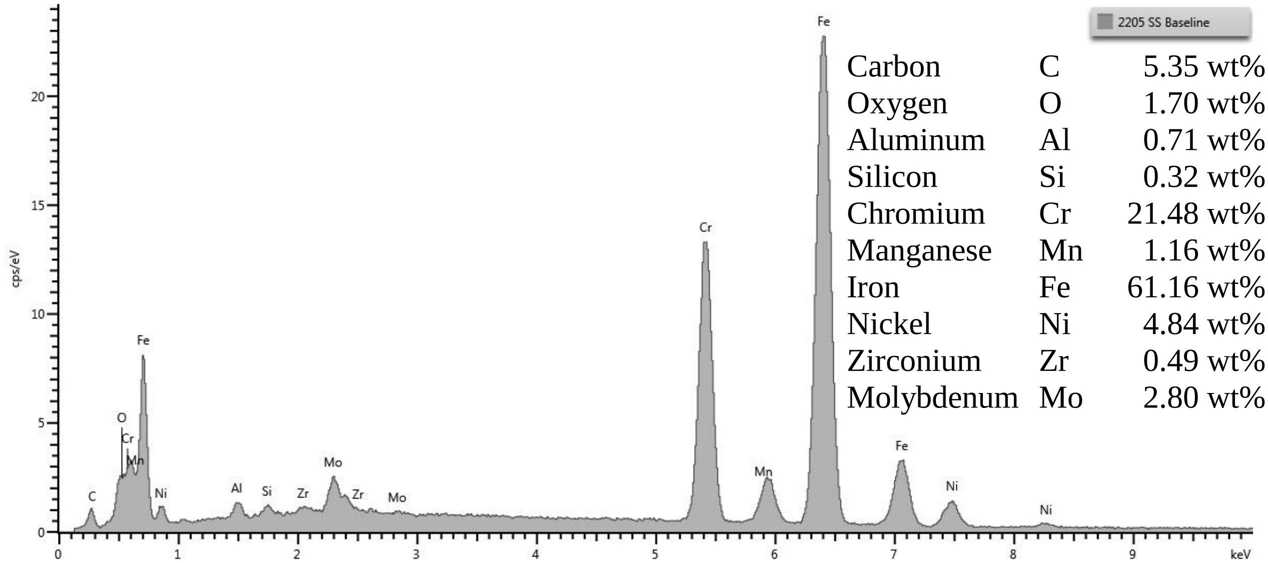


(a) Duplex 2205 Stainless Steel Coupon 8, After Cleaning 100X



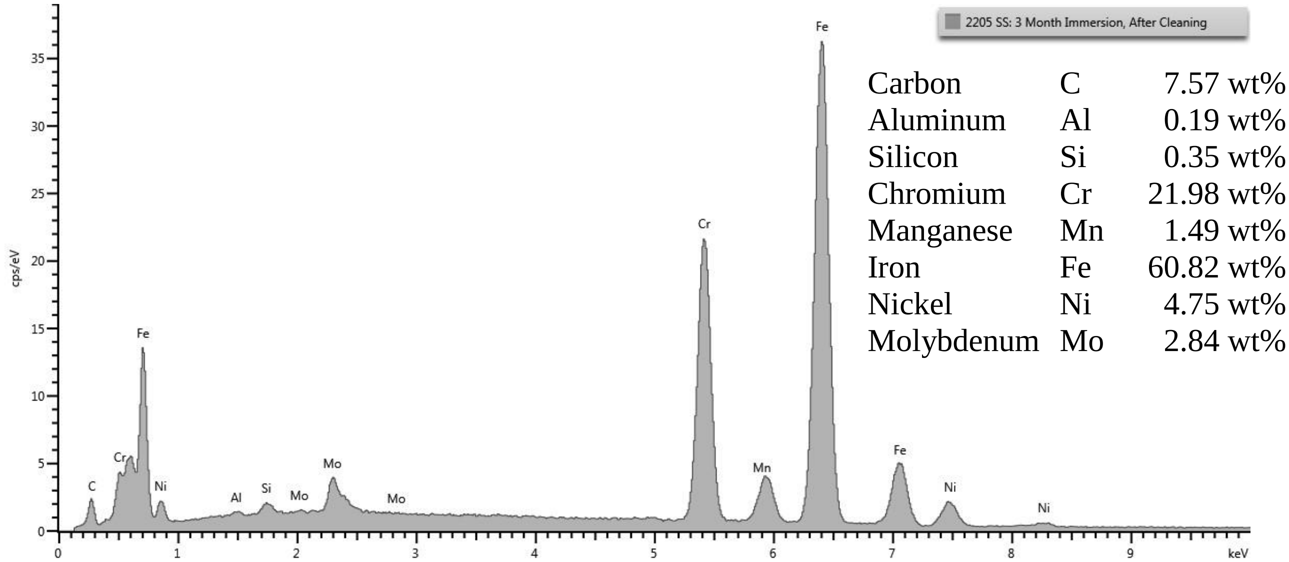
(b) Duplex 2205 Stainless Steel Coupon 8, After Cleaning 500X

Figure 29 Scanning electron micrographs of duplex stainless steel coupon 8 after a 10 month corrosion test, after cleaning.

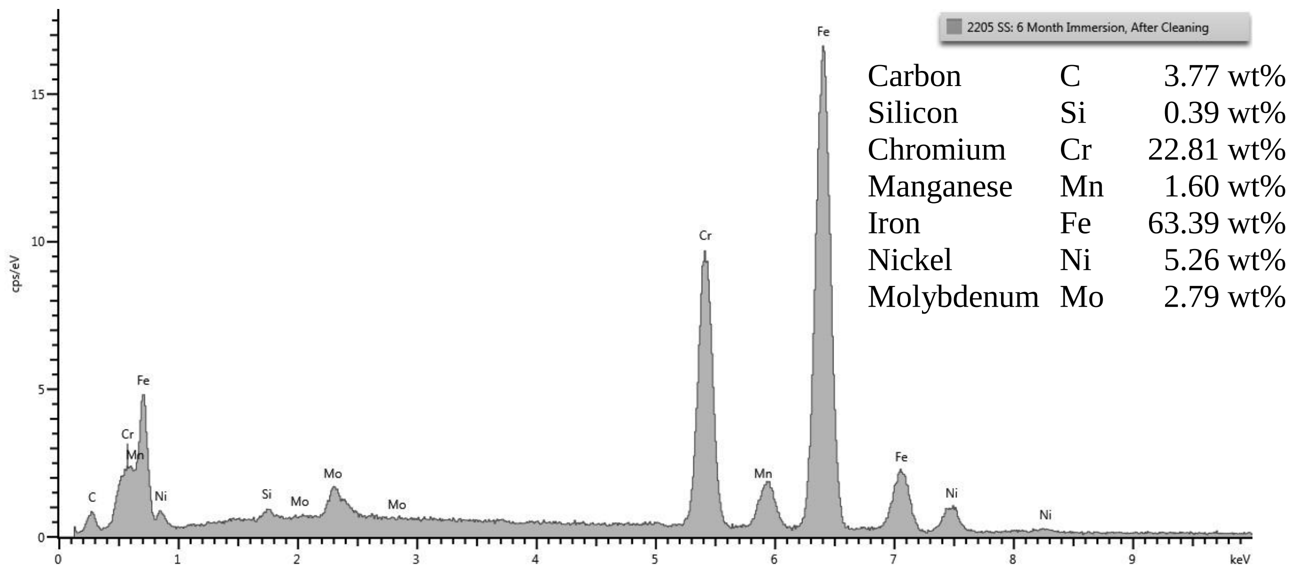


(a) Duplex 2205 Stainless Steel Baseline Coupon

Figure 30 Energy dispersive x-ray spectra of the duplex 2205 stainless steel baseline coupon.

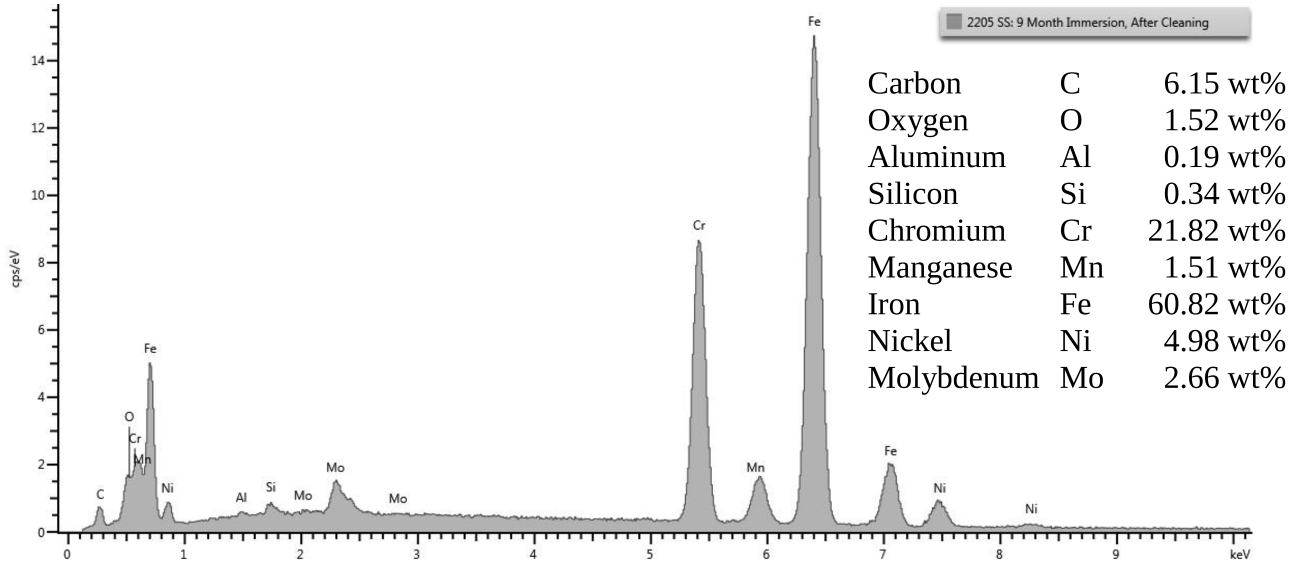


(a) Duplex 2205 Stainless Steel Coupon 6, After Cleaning



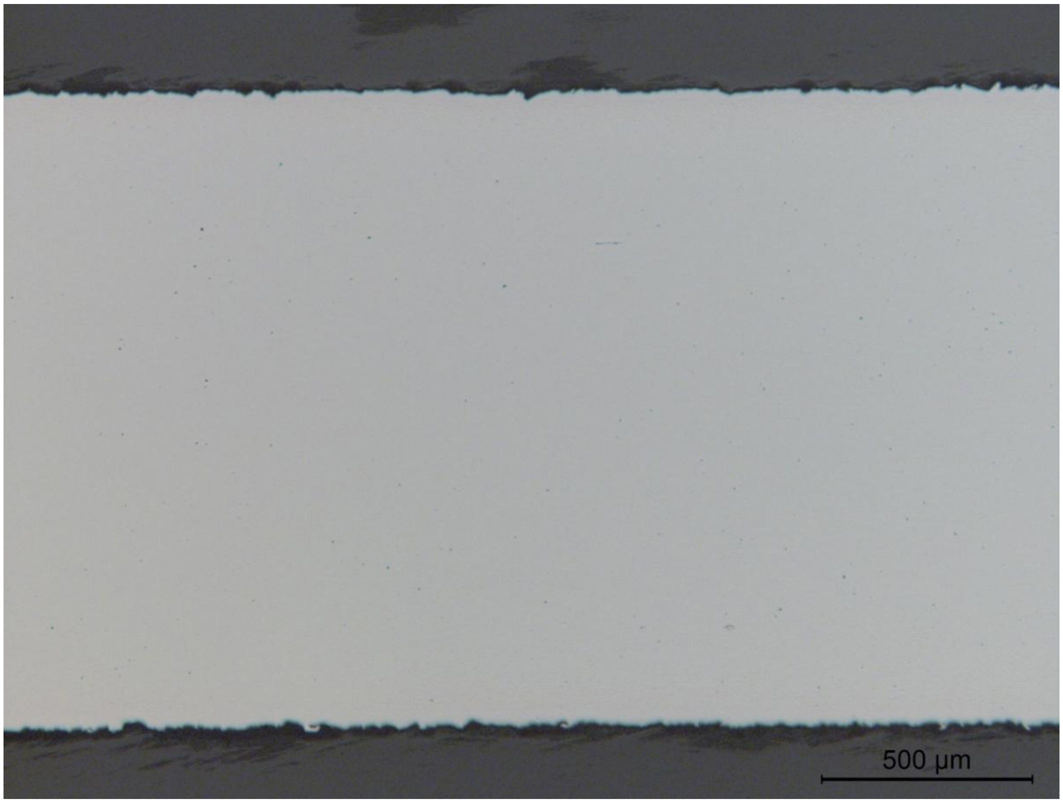
(b) Duplex 2205 Stainless Steel Coupon 7, After Cleaning

Figure 31 Energy dispersive x-ray spectra of (a) coupon 6 after a 3 month corrosion test and (b) coupon 7 after a 6 month corrosion test, after cleaning. Both coupons were not analyzed by energy dispersive x-ray spectroscopy before cleaning due to the marine life on the surface of the coupon.



(a) Duplex 2205 Stainless Steel Coupon 8, After Cleaning

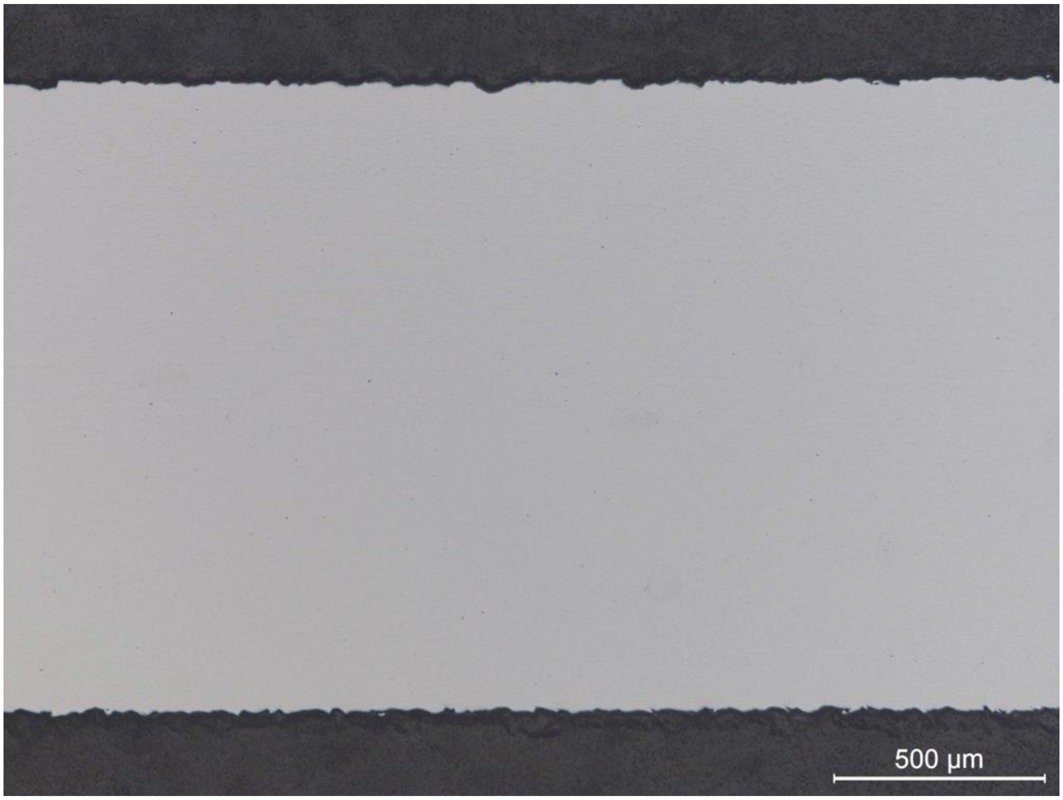
Figure 32 Energy dispersive x-ray spectra of coupon 8 after a 10 month corrosion test, after cleaning. The coupon was not analyzed by energy dispersive x-ray spectroscopy before cleaning due to the marine life on the surface of the coupon.



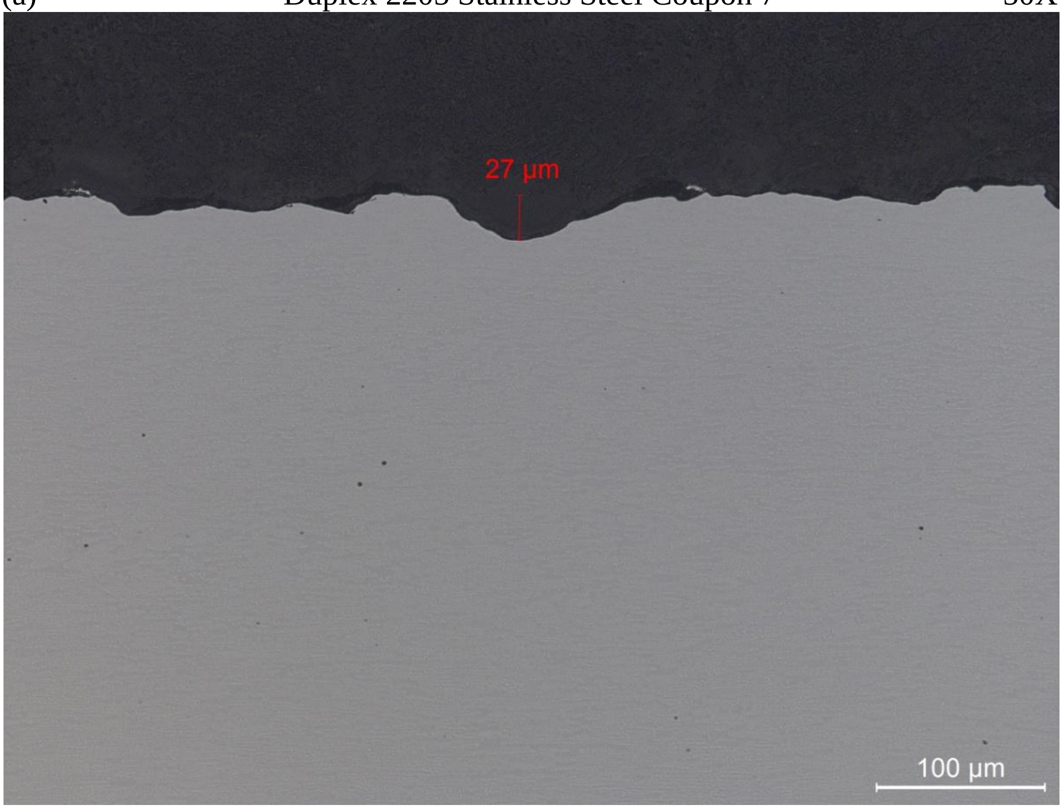
(a) Duplex 2205 Stainless Steel Coupon 6 50X

(b) Duplex 2205 Stainless Steel Coupon 6 200X

Figure 33 Optical micrographs of duplex stainless steel coupon 6.

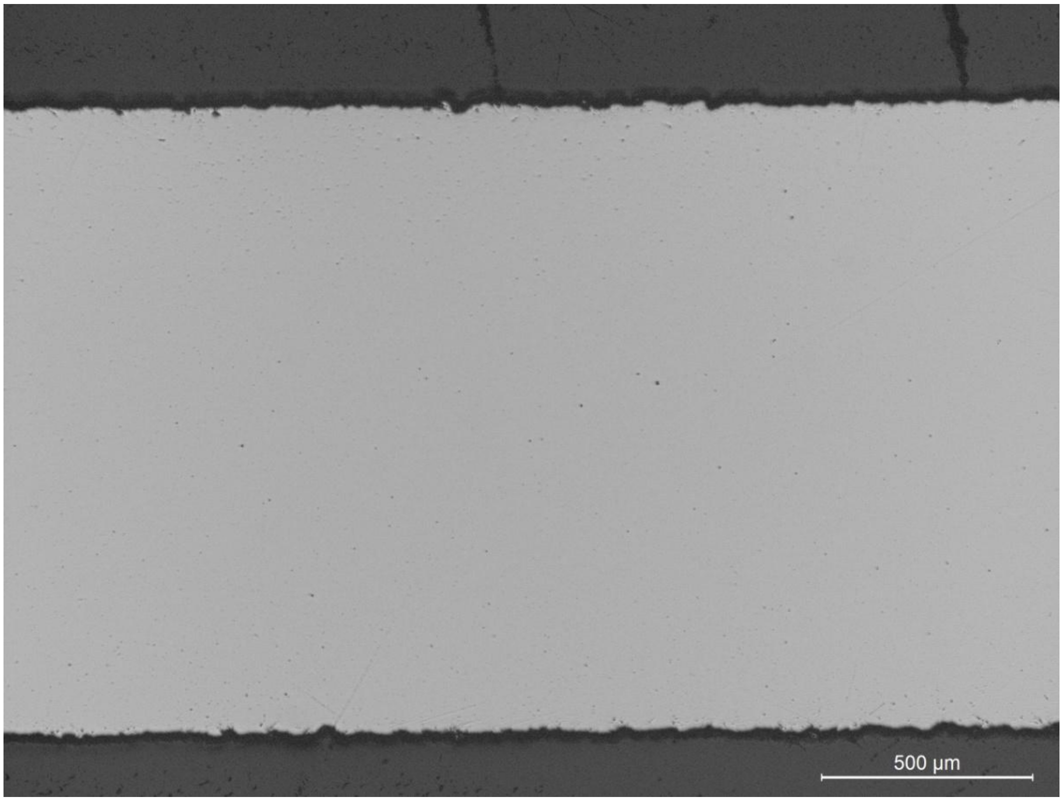


(a) Duplex 2205 Stainless Steel Coupon 7 50X

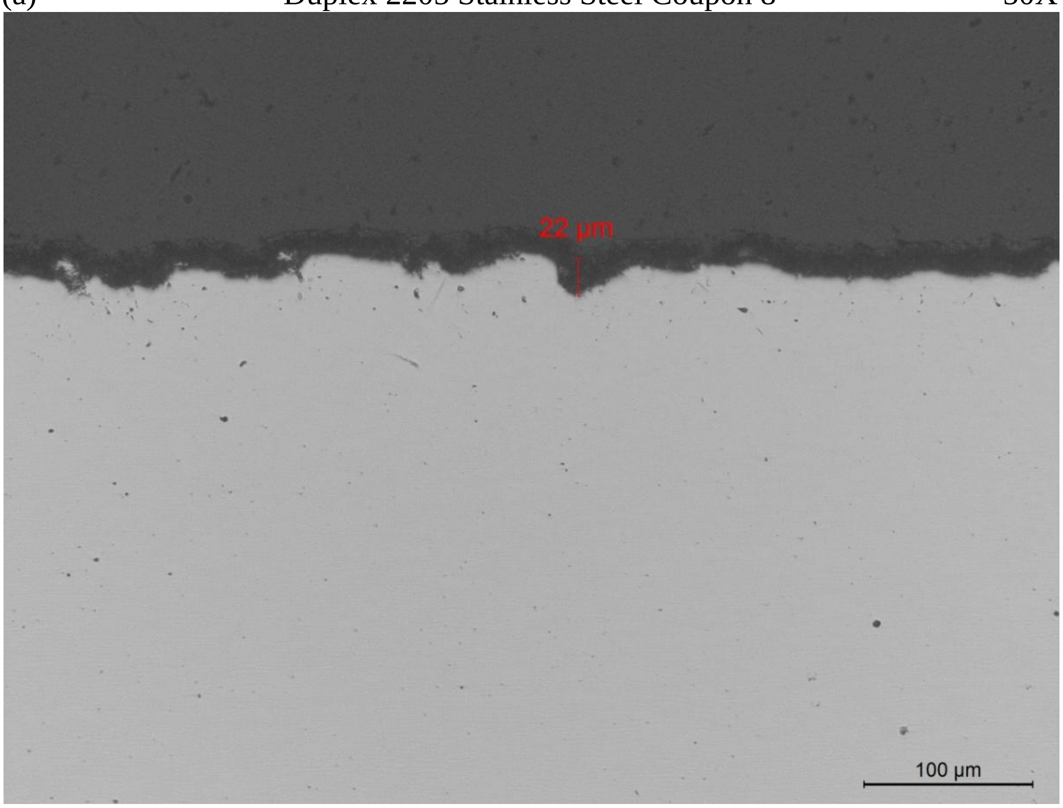


(b) Duplex 2205 Stainless Steel Coupon 7 200X

Figure 34 Optical micrographs of duplex stainless steel coupon 7.



(a) Duplex 2205 Stainless Steel Coupon 8 50X



(b) Duplex 2205 Stainless Steel Coupon 8 200X

Figure 35 Optical micrographs of duplex stainless steel coupon 8.

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Report No. 5005.0361C **May 19, 2015**

CORROSION EVALUATION OF CDA 706 COUPONS AND SCREENS

Customer Authorization: Verbal

Report To: V & A Engineering
Attn: Manuel Najar
155 Grand Avenue, Suite 700
Oakland, CA 94612

1.0 INTRODUCTION

Five coupons, five wedge wire screens, and one plate made from CDA 706, a 90-Copper, 10-Nickel alloy, were submitted by V&A Engineering for corrosion evaluation. The coupons were 1-inch by 3-inches by ¼-inch thick. The wedge wire screens were 4-inches by 4-inches by 1-inch tall with 4 mm spacing. The plate was 4-inches by 4-inches by 1/8-inch thick.

Four coupons and four screens were to be placed in seawater for a period up to one year. After every 3 month interval, one coupon and one screen were to be removed from the test system and examined for corrosion. The purpose of this evaluation was to document the samples in the baseline as-received condition, then again after 3, 6, 10, and 12 months of water exposure, record any loss in mass, examine for any pitting corrosion, and estimate the corrosion rate.

The samples were evaluated by the following laboratory procedures:

1) Visual examination and weighing
2) Cleaning per ASTM G1[1]
3) Scanning electron microscopy
4) Metallography

The results of the evaluation showed minimal mass loss and corrosion for the coupon and screen after 3, 6, and 10 months of corrosion testing. The coupon and screen, after 3 months of corrosion testing, had a corrosion rate of approximately 0.022 millimeters per year and 0.129 millimeters per year, respectively. The coupon and screen, after 6 months of corrosion testing, had a corrosion rate of approximately 0.023 millimeters per year and 0.067 millimeters per year, respectively. The coupon and screen, after 10 months of corrosion testing, had a corrosion rate of approximately 0.018 millimeters per year and 0.047 millimeters per year, respectively.

[1] G1: Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

2.0 EVALUATION[2]

2.1 Visual Examination

The sample identifications for the coupons and wedge wire screens and their corresponding immersion times are shown in Table 1. The coupons had identification numbers stamped on the front face by V&A Engineering. A number of notches, corresponding to the sample number, were sawed at the edge of each screen for identification after the corrosion test. The weights of the samples were recorded. Coupons 1 – 4 and screens 1 – 5 were sent back to V&A for corrosion testing. Coupon 5 was the baseline sample and documented by photography, optical stereoscopy and scanning electron microscopy for comparison to the tested samples. Screen 5 was documented as a baseline by photography and optical stereoscopy, and then sent to V&A for testing.

Photographs of the baseline coupon are shown in Figure 1. Photographs of coupon 1, after 3 months of corrosion testing, are shown in Figure 2. Photographs of coupon 2, after 6 months of corrosion testing, are shown in Figure 3. Photographs of coupon 3, after 10 months of corrosion testing, are shown in Figure 4.

A photograph of the baseline screen is shown in Figure 5. A photograph of screen 1, after 3 months of corrosion testing, is shown in Figure 6. A photograph of screen 2, after 6 months of corrosion testing, is shown in Figure 7. A photograph of screen 2, after 10 months of corrosion testing, is shown in Figure 8.

2.2 Cleaning

The coupon and screen were cleaned with solution C.2.1 per ASTM G1.[3] One cleaning cycle was approximately 1 minute. After each cleaning cycle, the samples were rinsed in water, dried, and weighed. The cleaning and weighing cycle was completed five times for the coupon and screen. The weights of the samples as-received, after corrosion testing but before cleaning, and after each cleaning cycle are presented in Table 2.

Optical macrographs of the baseline coupon and screen are shown in Figures 9 and 16, respectively. Representative optical macrographs of the samples after a 3 month corrosion test, before and after cleaning, are shown in Figures 10 – 11 and 17 – 18. Representative optical macrographs of the sample after a 6 month corrosion test, before and after cleaning, are shown in Figures 12 – 13 and 19 – 20. Representative optical macrographs of the sample after a 10 month corrosion test, before and after cleaning, are shown in Figures 14 – 15 and 21 – 22.

The mass loss versus the number of cleaning cycles was plotted, shown in Figures 23 – 25. The equations for best fit lines AB and BC, calculated using IGOR Pro, are listed in Table 3. Point B, indicated by the red circle in each plot, corresponds to the mass loss due to corrosion during the cleaning process for each sample. This mass loss was subtracted from the weight of the sample before cleaning and from the weight of the sample as-received to determine the total

[2] The magnifications of the optical and scanning electron micrographs in this report are approximate and should not be used as a basis for dimensional analyses unless otherwise indicated.
[3] 500 mL hydrochloric acid + 500 ml reagent water.

mass loss from corrosion. The corrosion rate of each sample was determined by the formula specified in Section 8.1 of ASTM G1:

$$Corrosion\ Rate = \frac{K\ x\ W}{A\ x\ T\ x\ D}$$

where K = 8.76 x 10^4, T = time of exposure in hours, A = area in cm^2, W = mass loss in grams, and D = density in g/cm^3. The total mass loss from corrosion and the calculated corrosion rate of each sample is shown in Table 4.

2.3 Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy

The baseline coupon, coupon 1, and coupon 2 were examined with a scanning electron microscope. Representative scanning electron micrographs of the baseline coupon are shown in Figure 26. Representative scanning electron micrographs of coupon 1 before and after cleaning are shown in Figures 27 – 28. Representative scanning electron micrographs of coupon 2 before and after cleaning are shown in Figures 29 – 30. Representative scanning electron micrographs of coupon 3 before and after cleaning are shown in Figures 31 – 32. Energy dispersive x-ray spectra of the baseline coupon and coupons 1 – 3 before and after cleaning are shown in Figures 33 – 36.

2.4 Metallography

Cross sections were taken from the coupon and prepared for a metallographic examination. Optical micrographs of the surfaces for coupons 1 – 3 are shown in Figures 37 – 39. A wide, shallow pit measuring 80 µm in depth was observed in coupon 1. Small, shallow pits, the deepest of which measured 22 µm, were observed in coupon 2. Small, narrow pits, the deepest of which measured 34 µm, were observed in coupon 3.

3.0 DISCUSSION

The coupon and screen showed minimal mass loss and pitting overall after 3, 6, and 10 months of corrosion testing. The coupons had more material loss over time, but maintained a consistent corrosion rate over the duration of the corrosion test. The screens had more material loss over time, but had a decreasing corrosion rate over the duration of the corrosion test.

4.0 CONCLUSIONS[4]

The following conclusions are based upon the submitted samples and the evidence gathered:

[4] The conclusions in this report are based upon the available information and evidence provided by the client and gathered by Anamet, within the scope of work authorized by the client, and they are hereby presented by Anamet to a reasonable degree of engineering and scientific certainty. Anamet reserves the right to amend or supplement its conclusions or opinions presented in this report should additional data or information become available, or further work be approved by the client.

1. The coupon, after 3 months of corrosion testing, had a mass loss of 0.256 grams and a corrosion rate of 0.022 mm / year.

2. The screen, after 3 months of corrosion testing, had a mass loss of 14.48 grams and a corrosion rate of 0.129 mm / year.

3. The coupon, after 6 months of corrosion testing, had a mass loss of 0.550 grams and a corrosion rate of 0.023 mm / year.

4. The screen, after 6 months of corrosion testing, had a mass loss of 15.24 grams and a corrosion rate of 0.067 mm / year.

5. The coupon, after 10 months of corrosion testing, had a mass loss of 0.726 grams and a corrosion rate of 0.018 mm / year.

6. The screen, after 10 months of corrosion testing, had a mass loss of 17.96 grams and a corrosion rate of 0.047 mm / year.

Prepared by:

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Materials Engineer

Reviewed by:

Audrey A. Fasching, Ph.D., P.E.
Senior Materials Engineer

Table 1
Sample Identifications

Description: Alloy	Description: Part	V&A Engineering Identification (As-Received)	Anamet Identification (in report)	Notes
CDA 706 (Cu 90 – Ni 10)	**Flat Plate** 4-inch x 4-inch x 1/8-inch	CDA 706 1	Plate	None
	Coupon 1-inch x 3-inch x 1/8-inch with autogenous weld bead	CDA 706W 1	Coupon 1	3 Month Immersion
		CDA 706W 2	Coupon 2	6 Month Immersion
		CDA 706W 3	Coupon 3	10 Month Immersion
		CDA 706W 4	Coupon 4	12 Month Immersion
		CDA 706W 5	Coupon 5	Baseline Sample (no exposure)
	Wedge Wire Screen 4-inch x 4-inch x 1-inch with 2 mm spacing	None	Screen 1	3 Month Immersion
		None	Screen 2	6 Month Immersion
		None	Screen 3	10 Month Immersion
		None	Screen 4	12 Month Immersion
		None	Screen 5	12 Month Immersion

Table 2
Sample Weights

Sample	Baseline Measurement	Measurements after 3 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 1	25.8560	25.6429	25.6003	25.5972	25.5954	25.5930	25.5915
Screen 1	310.59	301.27	298.54	296.15	295.97	295.80	295.78

Sample	Baseline Measurement	Measurements after 6 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 2	25.9215	25.4409	25.3721	25.3689	25.3689	25.3650	25.3630
Screen 2	310.45	300.16	295.21	295.17	295.13	295.11	-

Sample	Baseline Measurement	Measurements after 10 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 3	25.5983	25.0228	24.8784	24.8715	24.8693	24.8678	24.8672
Screen 3	309.69	296.62	292.59	291.65	291.58	291.57	291.38

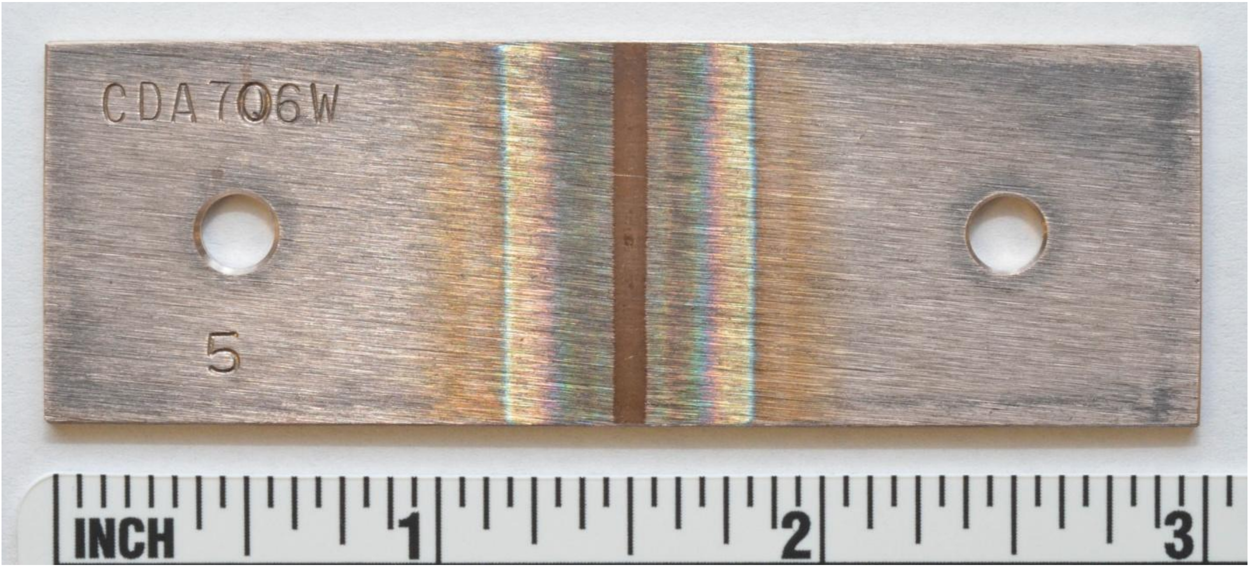
Table 3
Equations of Lines AB and BC for Corrosion Testing Samples

Sample	Line AB	Line BC	Point B (Approximate Mass Loss from Corrosion)
Coupon 1	y = 0.043x	y = 0.002x + 0.041	0.043 grams
Coupon 2	y = 0.061x	y = 0.002x + 0.067	0.069 grams
Coupon 3	y = 0.144x	y = 0.001x + 0.149	0.150 grams
Screen 1	y = 2.59x	y = 0.13x + 4.90	5.16 grams
Screen 2	y = 4.95x	y = 0.03x + 4.92	4.95 grams
Screen 3	y = 4.03x	y = 0.08x + 4.79	4.89 grams

Table 4
Total Mass Loss from Corrosion and Corrosion Rate

Sample	Total Mass Loss from Corrosion*	Corrosion Rate
Coupon 1	0.256 grams	0.022 mm / year
Coupon 2	0.550 grams	0.023 mm / year
Coupon 3	0.726 grams	0.018 mm / year
Screen 1	14.48 grams	0.129 mm / year
Screen 2	15.24 grams	0.067 mm / year
Screen 3	17.95 grams	0.047 mm / year

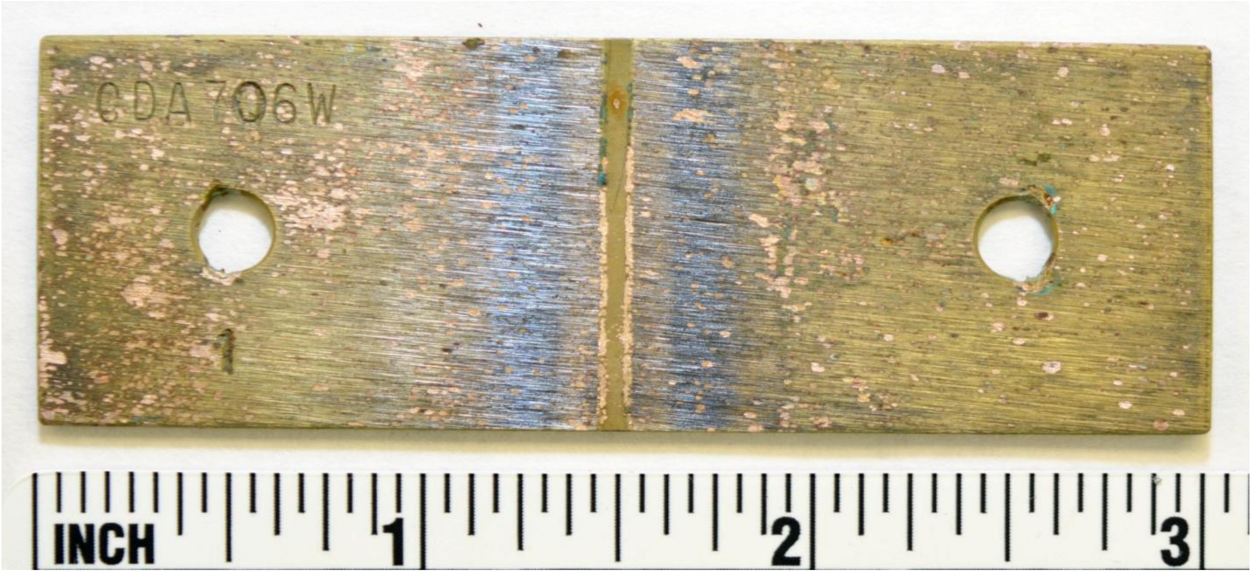
* Weight As-Received – (Weight Before Cleaning – Mass Loss from Corrosion During Cleaning)



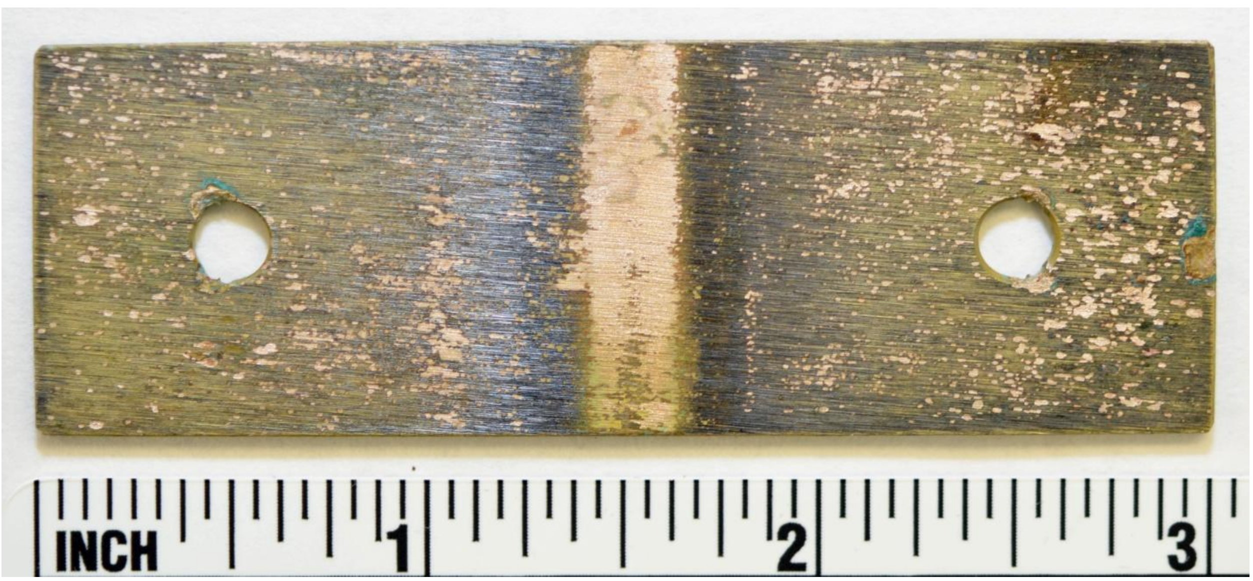
(a) CDA 706 Baseline Coupon, Front Side

(b) CDA 706 Baseline Coupon, Back Side

Figure 1 Photographs of the CDA 706 baseline coupon (a) front and (b) back side.

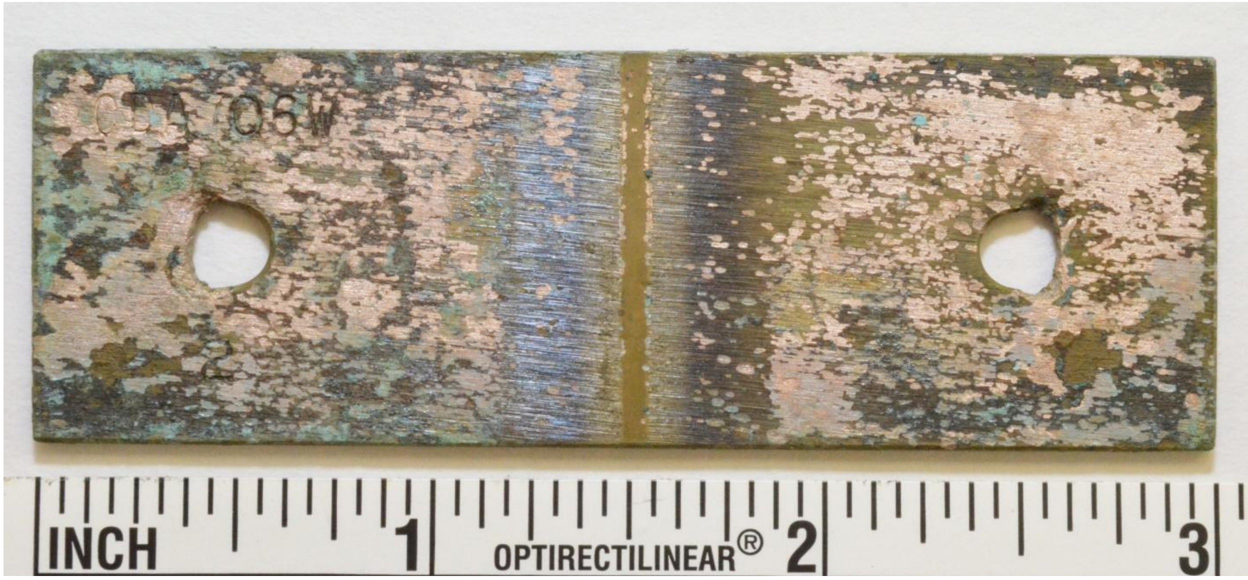


(a) CDA 706 Coupon 1, Front Side

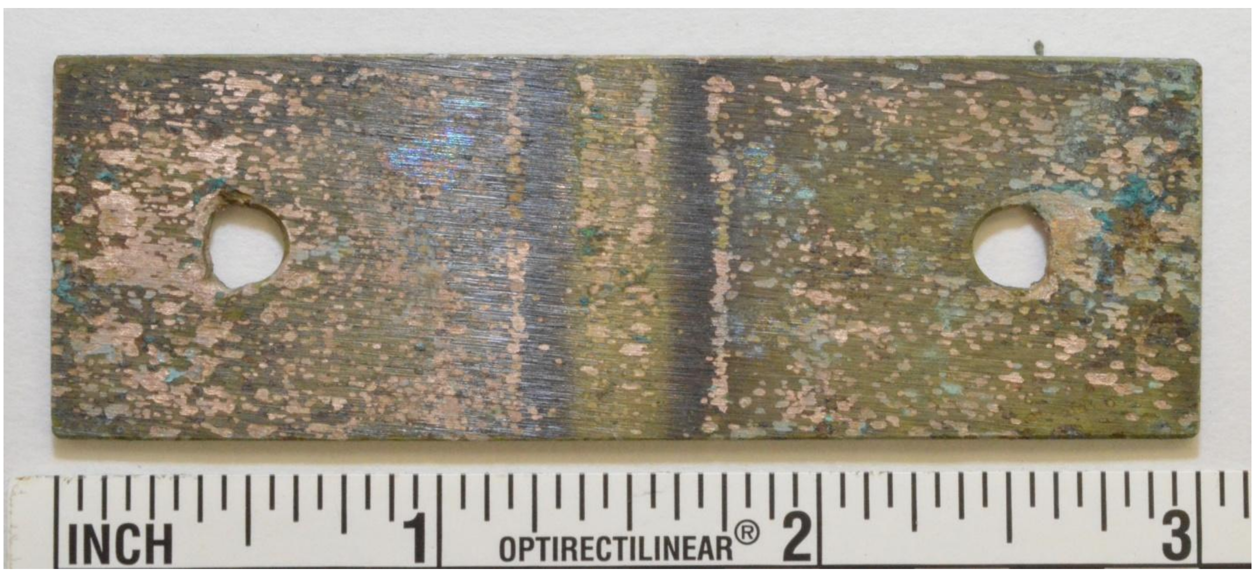


(b) CDA 706 Coupon 1, Back Side

Figure 2 Photographs of CDA 706 coupon 1 (a) front and (b) back side after a 3 month corrosion test.

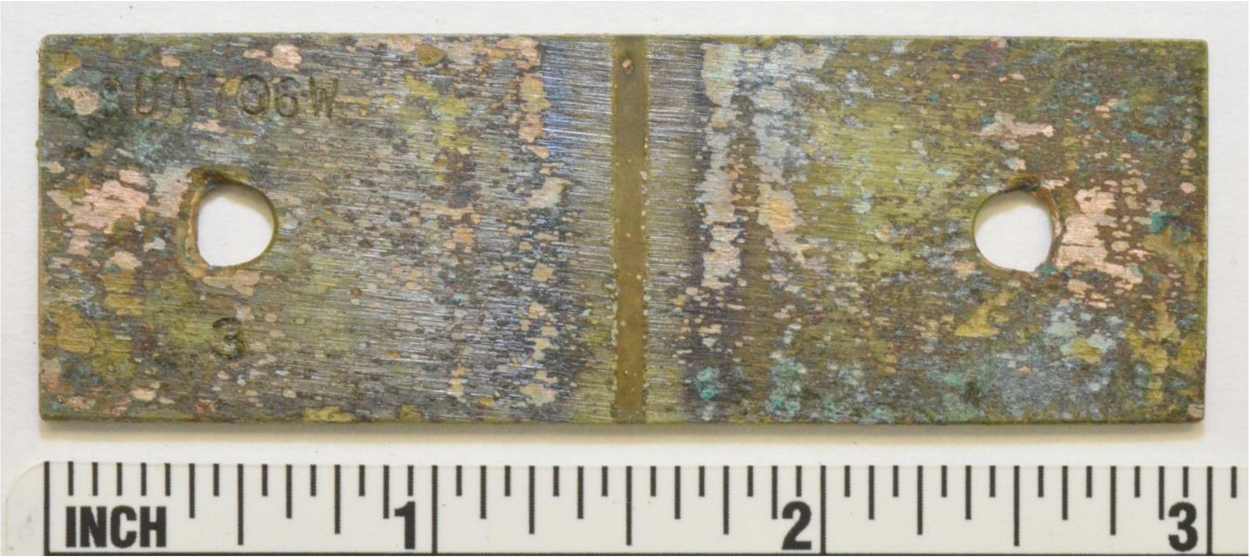


(a) CDA 706 Coupon 2, Front Side

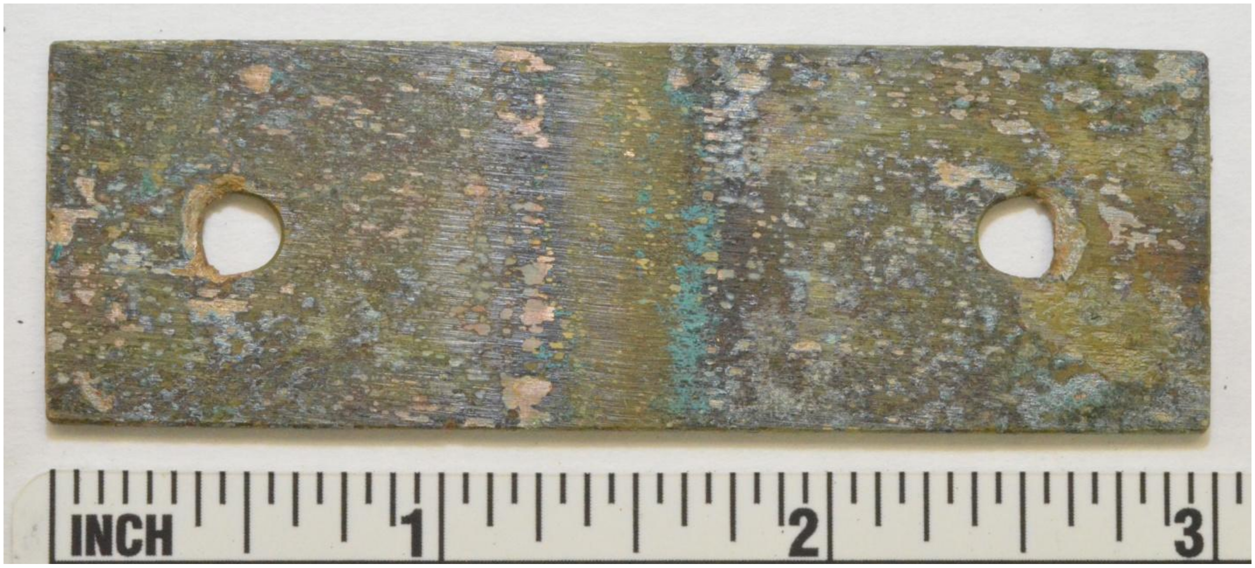


(b) CDA 706 Coupon 2, Back Side

Figure 3 Photographs of CDA 706 coupon 2 (a) front and (b) back side after a 6 month corrosion test.

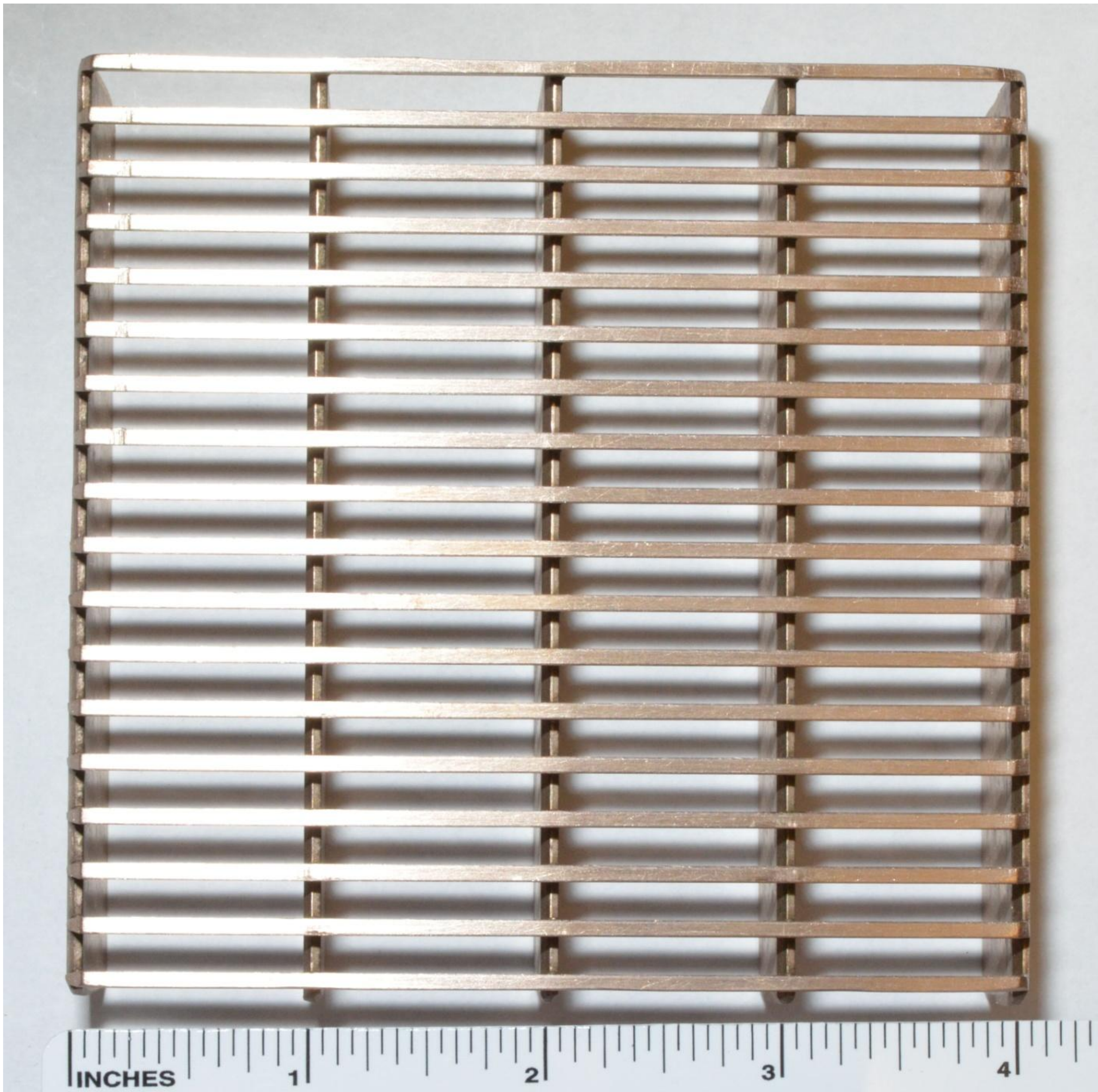


(a) CDA 706 Coupon 3, Front Side



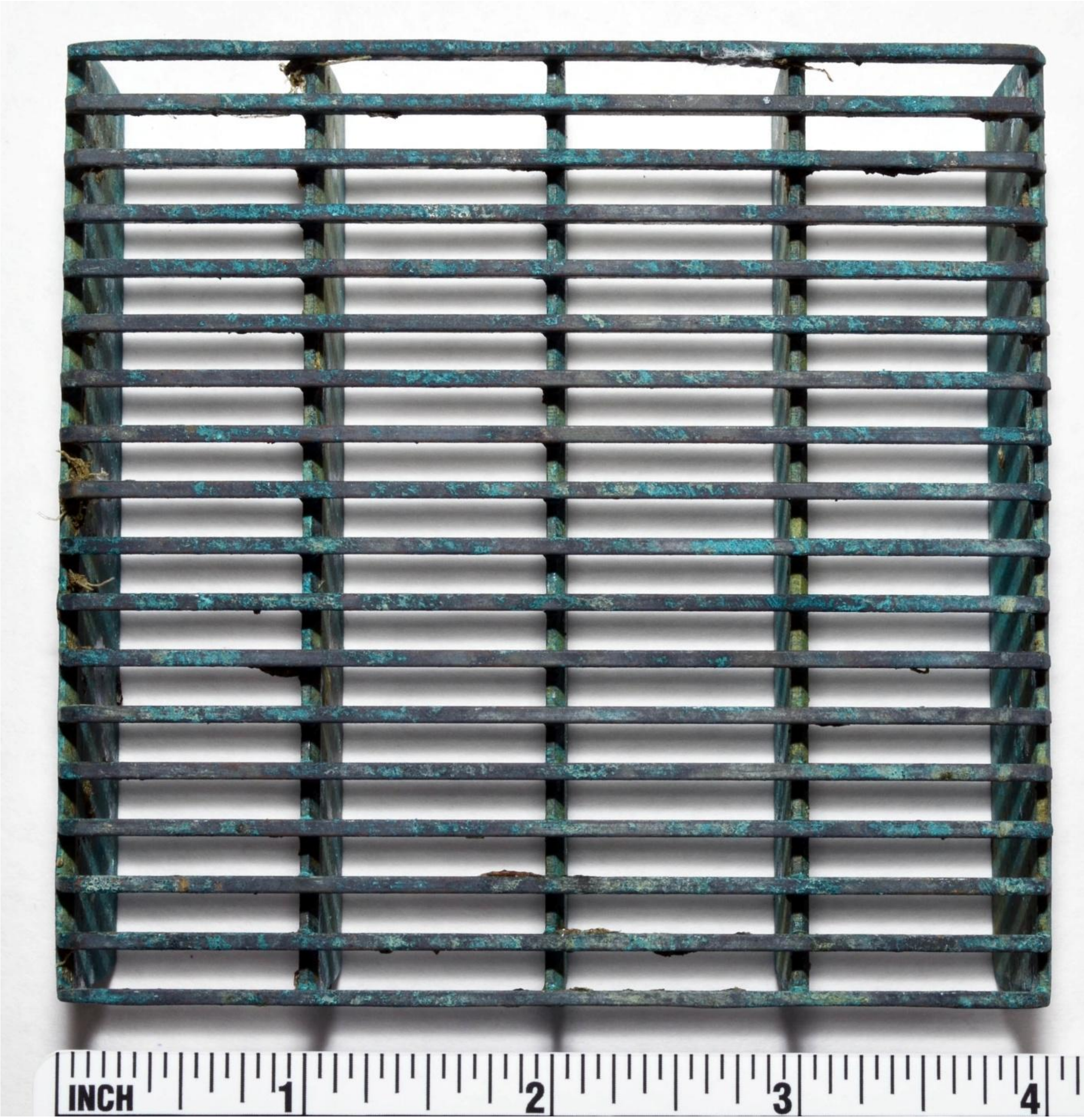
(b) CDA 706 Coupon 3, Back Side

Figure 4 Photographs of CDA 706 coupon 3 (a) front and (b) back side after a 10 month corrosion test.



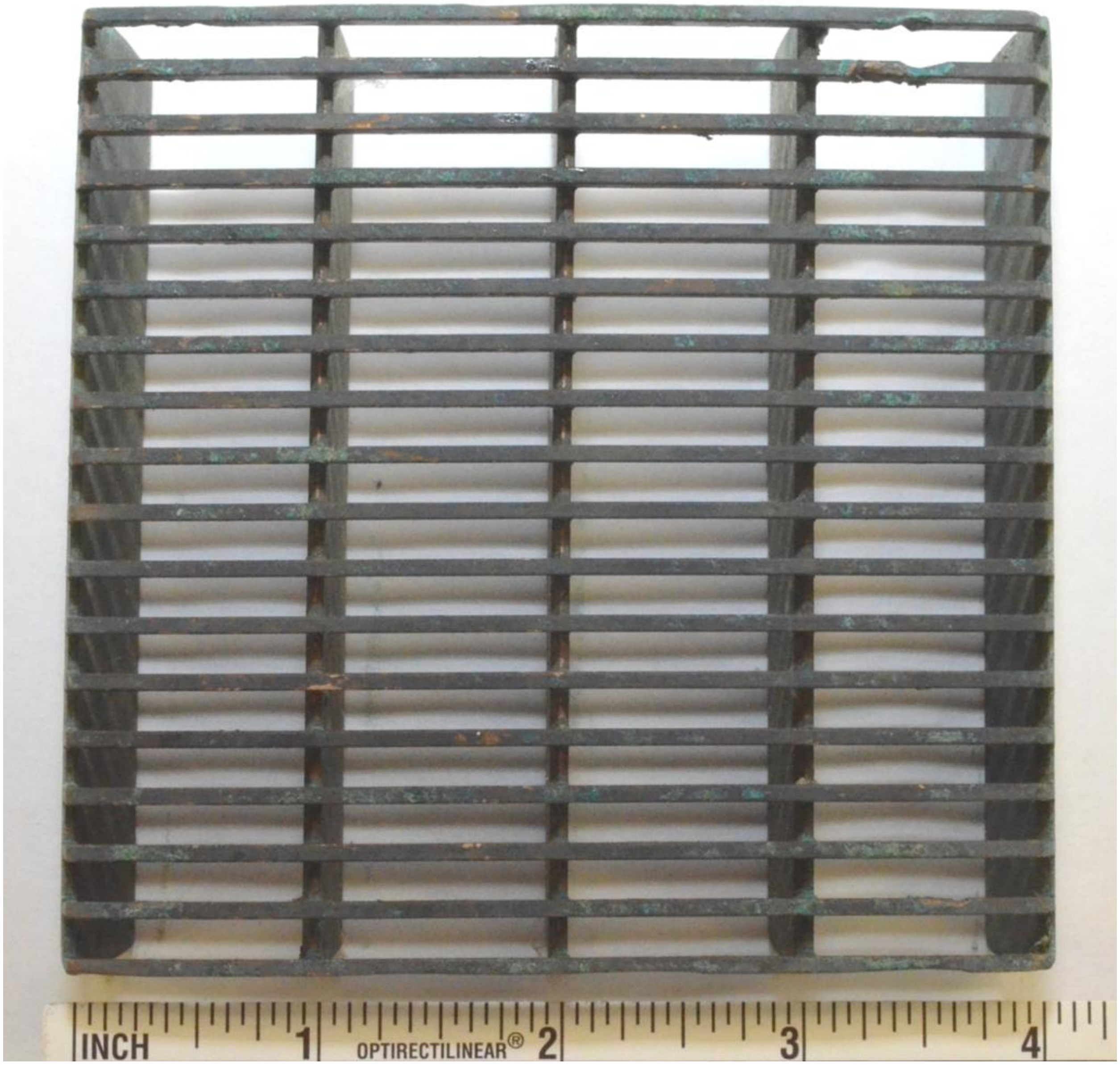
(a) CDA 706 Baseline Screen

Figure 5 Photograph of the CDA 706 baseline screen.



(a) CDA 706 Screen 1

Figure 6 Photograph of CDA 706 screen 1 after a 3 month corrosion test.

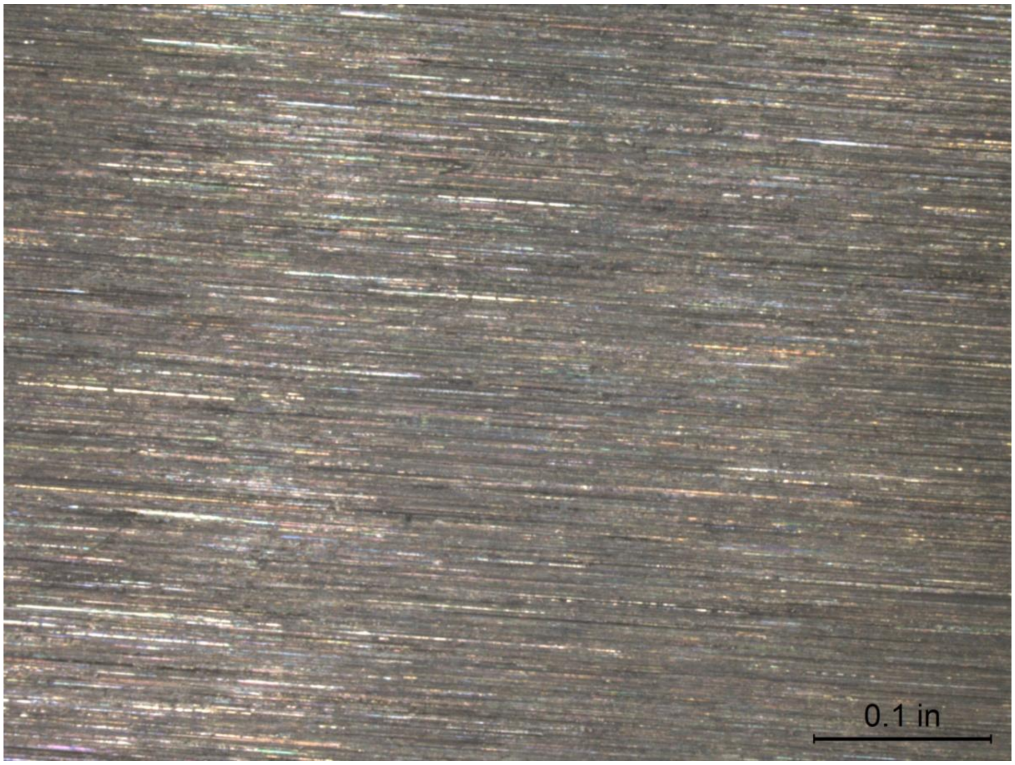


(a) CDA 706 Screen 2

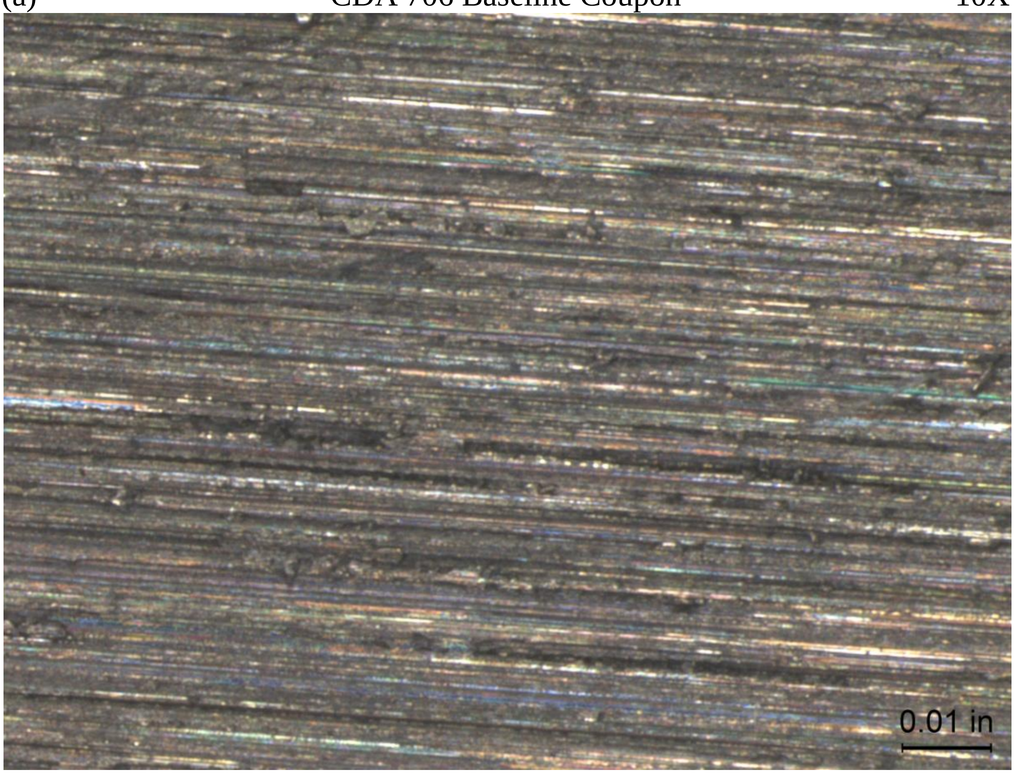
Figure 7 Photograph of CDA 706 screen 2 after a 6 month corrosion test.

(a) CDA 706 Screen 3

Figure 8 Photograph of CDA 706 screen 3 after a 10 month corrosion test.

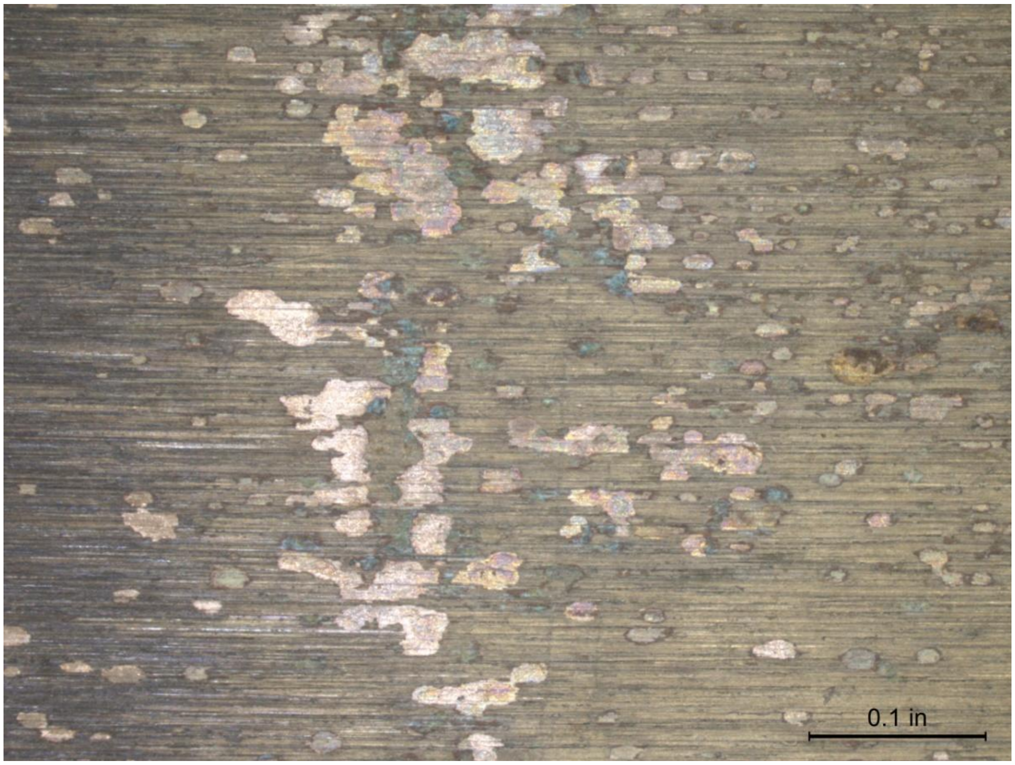


(a) CDA 706 Baseline Coupon 10X

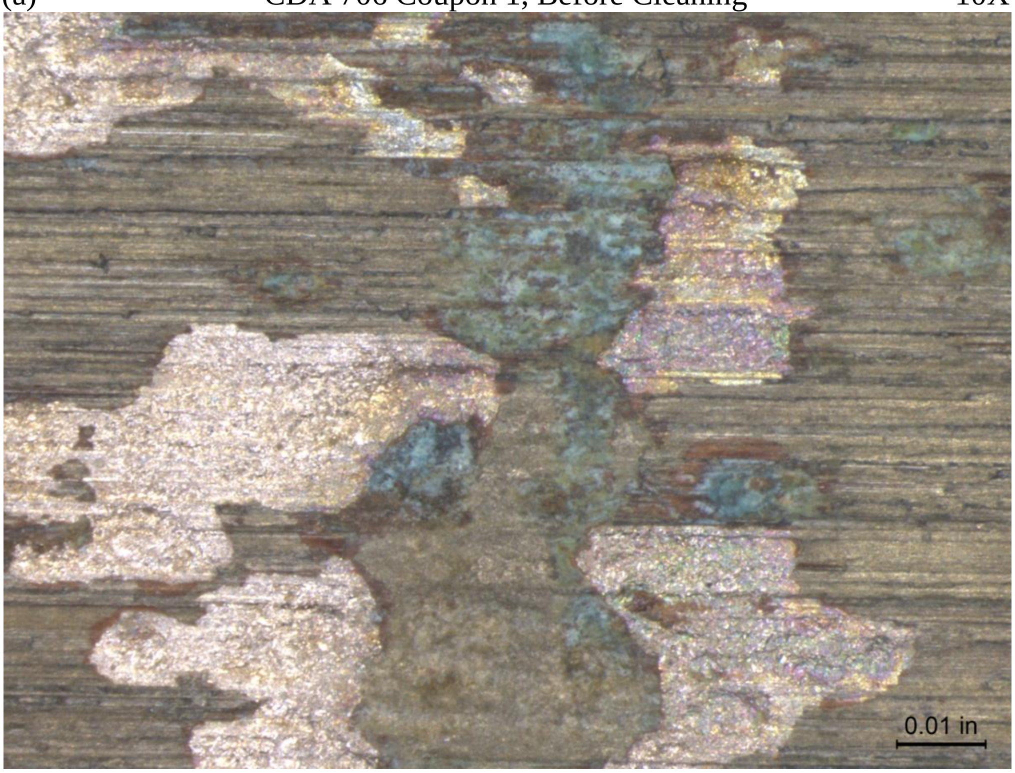


(b) CDA 706 Baseline Coupon 50X

Figure 9 Optical macrographs of the CDA 706 baseline coupon.



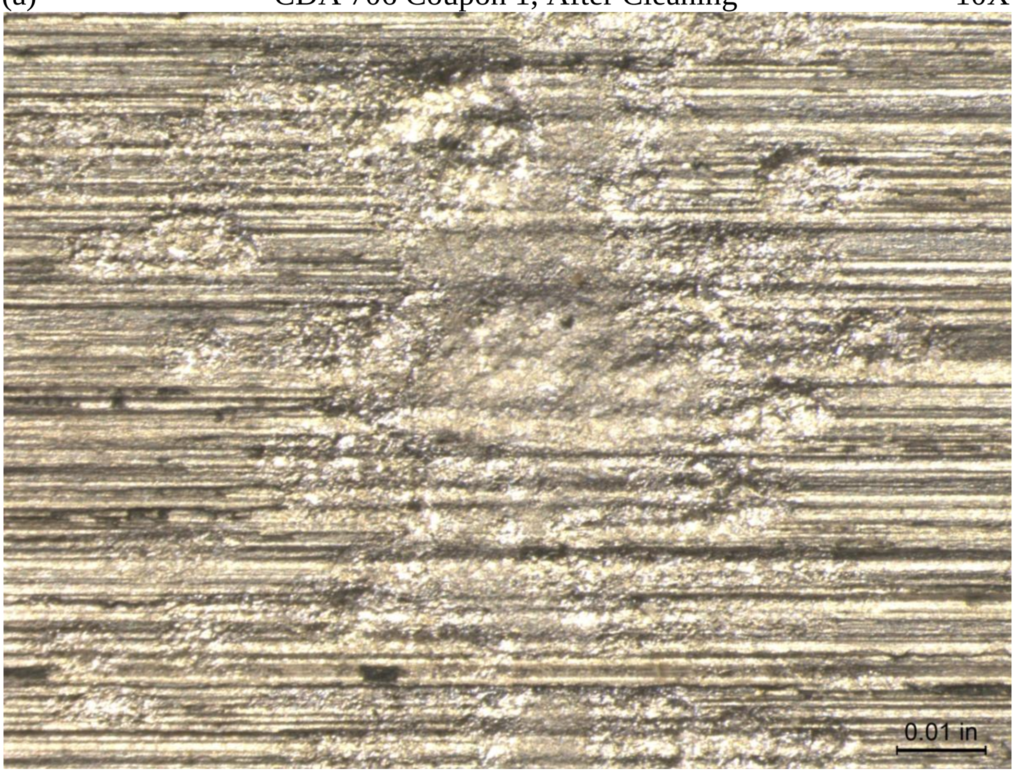
(a) CDA 706 Coupon 1, Before Cleaning 10X



(b) CDA 706 Coupon 1, Before Cleaning 50X

Figure 10 Optical macrographs of CDA 706 coupon 1 after a 3 month corrosion test, before cleaning.

(a) CDA 706 Coupon 1, After Cleaning 10X



(b) CDA 706 Coupon 1, After Cleaning 50X

Figure 11 Optical macrographs of CDA 706 coupon 1 after a 3 month corrosion test, after cleaning.

(a) CDA 706 Coupon 2, Before Cleaning 10X

(b) CDA 706 Coupon 2, Before Cleaning 50X

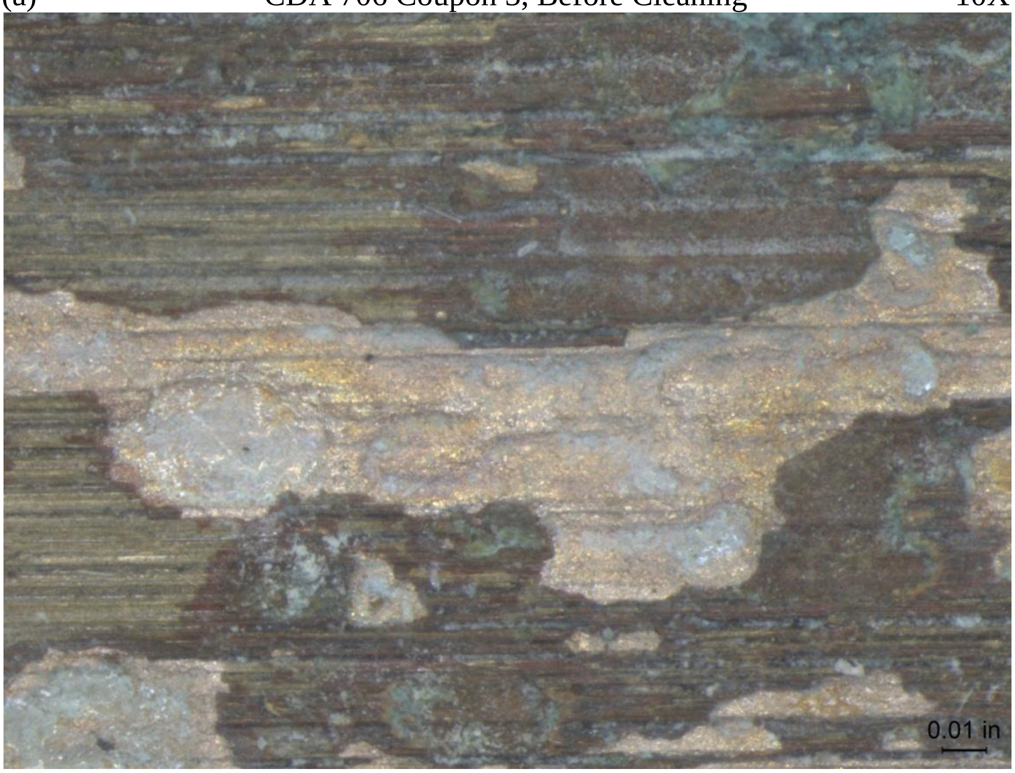
Figure 12 Optical macrographs of CDA 706 coupon 2 after a 6 month corrosion test, before cleaning.

(a) CDA 706 Coupon 2, After Cleaning 10X

(b) CDA 706 Coupon 2, After Cleaning 50X

Figure 13 Optical macrographs of CDA 706 coupon 2 after a 6 month corrosion test, after cleaning.

(a) CDA 706 Coupon 3, Before Cleaning 10X



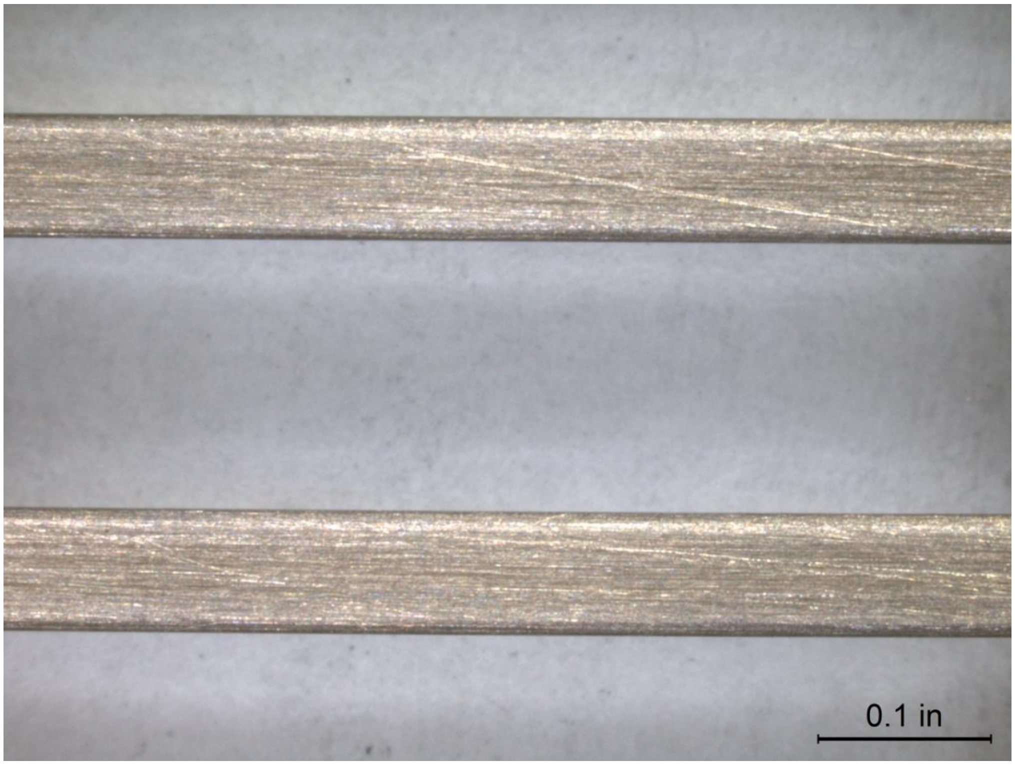
(b) CDA 706 Coupon 3, Before Cleaning 50X

Figure 14 Optical macrographs of CDA 706 coupon 3 after a 10 month corrosion test, before cleaning.

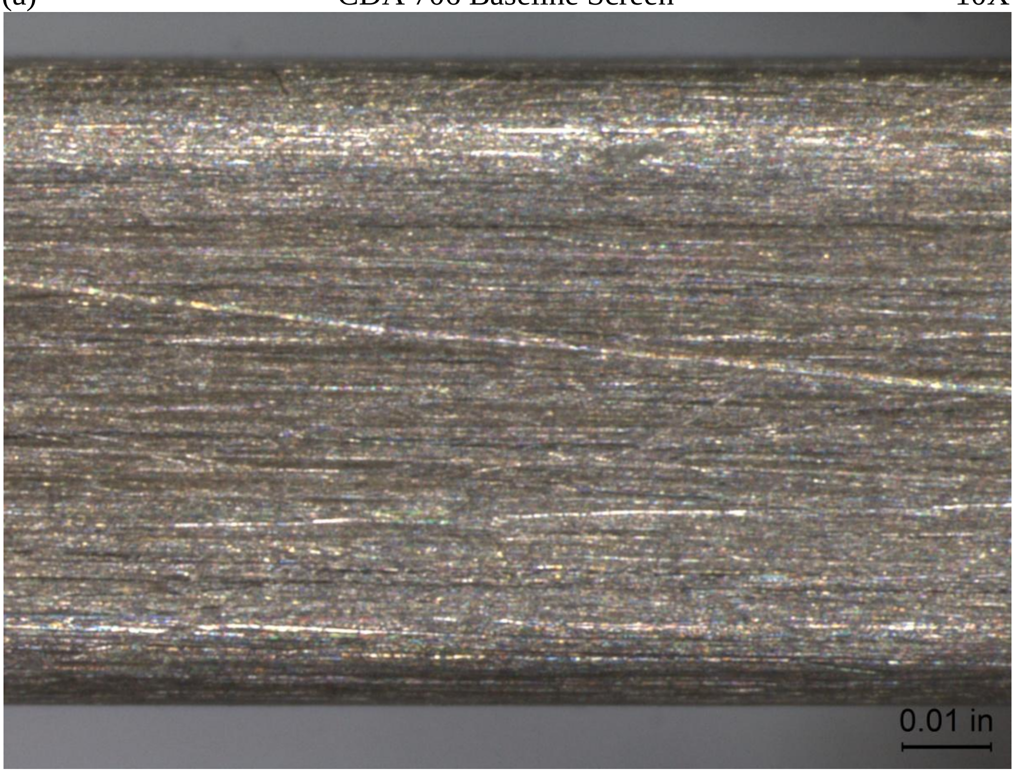
(a) CDA 706 Coupon 3, After Cleaning 10X

(b) CDA 706 Coupon 3, After Cleaning 50X

Figure 15 Optical macrographs of CDA 706 coupon 3 after a 10 month corrosion test, after cleaning.

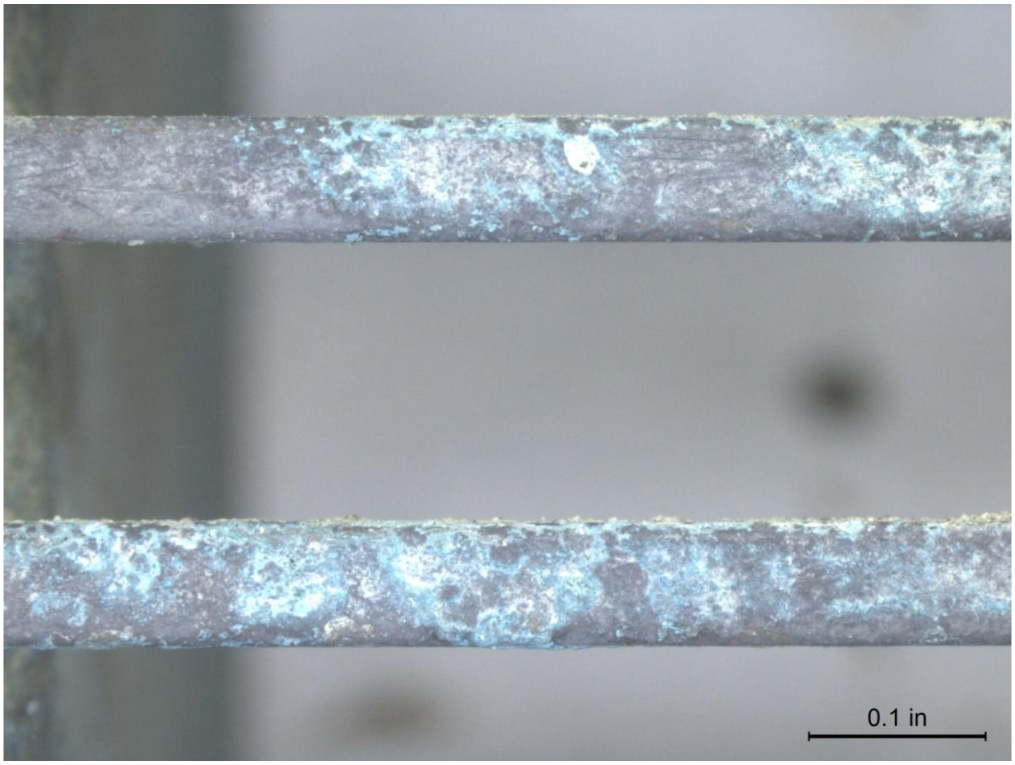


(a) CDA 706 Baseline Screen 10X

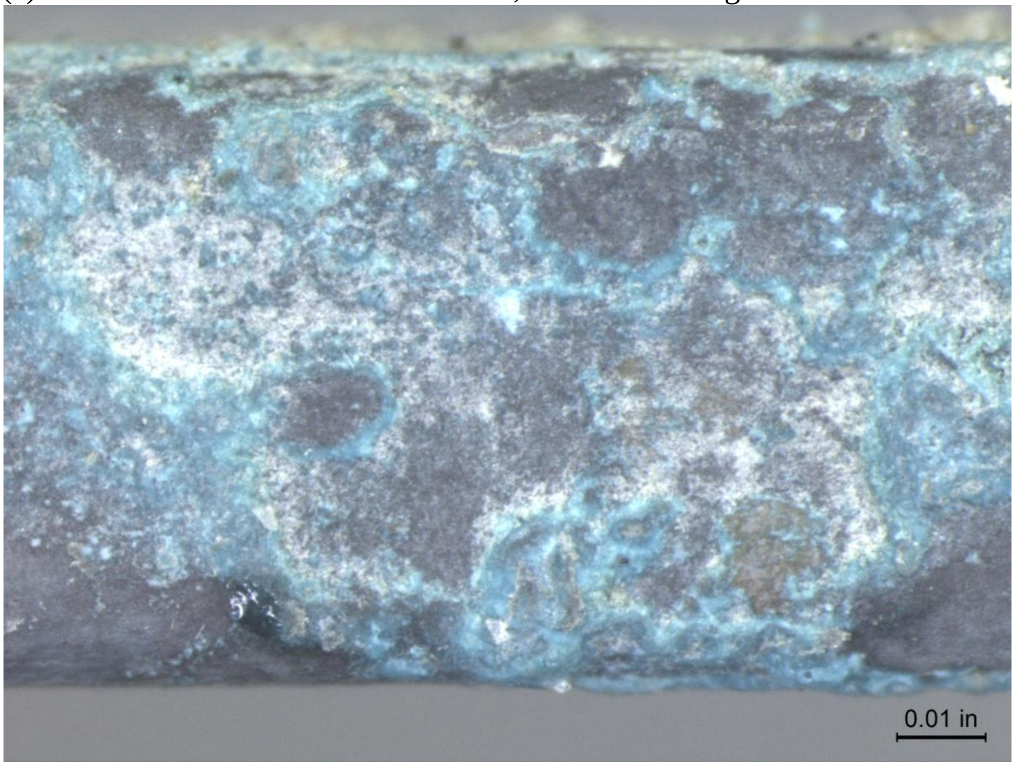


(b) CDA 706 Baseline Screen 50X

Figure 16 Optical macrographs of the CDA 706 baseline screen.

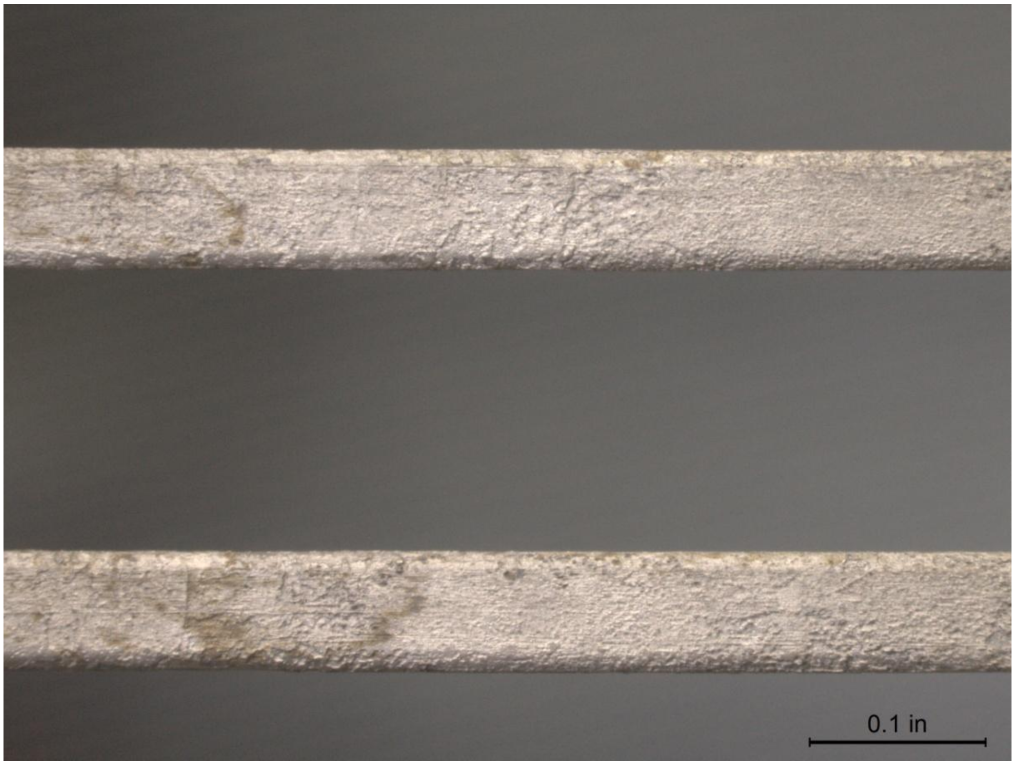


(a) CDA 706 Screen 1, Before Cleaning 10X



(b) CDA 706 Screen 1, Before Cleaning 50X

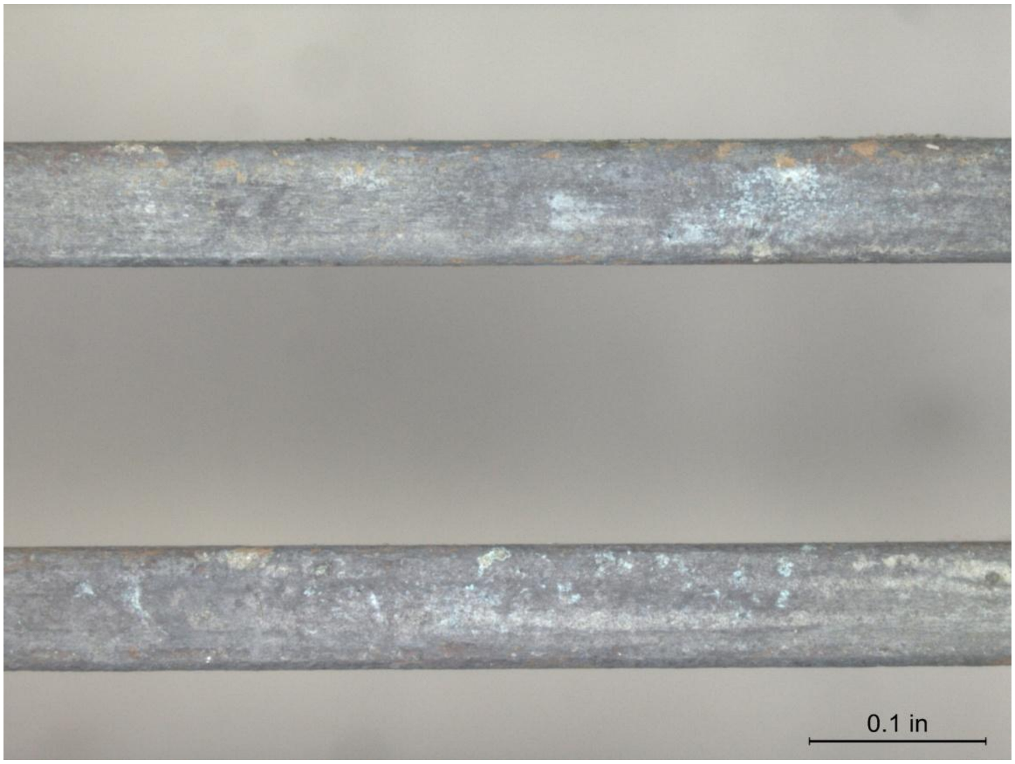
Figure 17 Optical macrographs of CDA 706 screen 1 after a 3 month corrosion test, before cleaning.



(a) CDA 706 Screen 1, After Cleaning 10X

(b) CDA 706 Screen 1, After Cleaning 50X

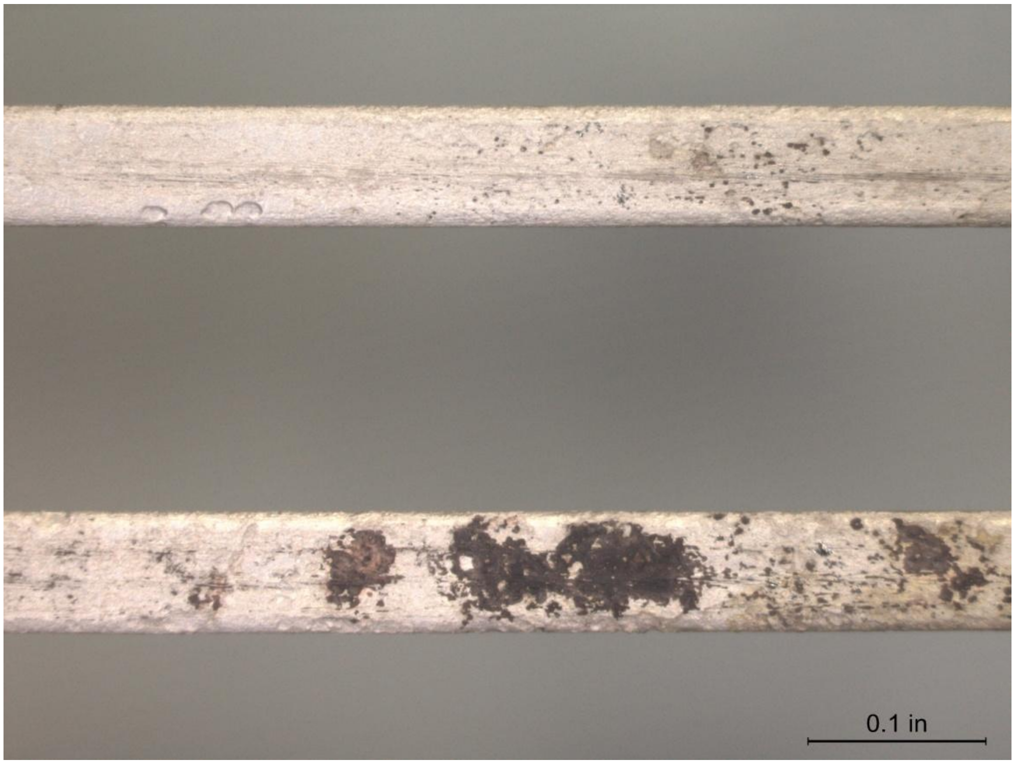
Figure 18 Optical macrographs of CDA 706 screen 1 after a 3 month corrosion test, after cleaning.



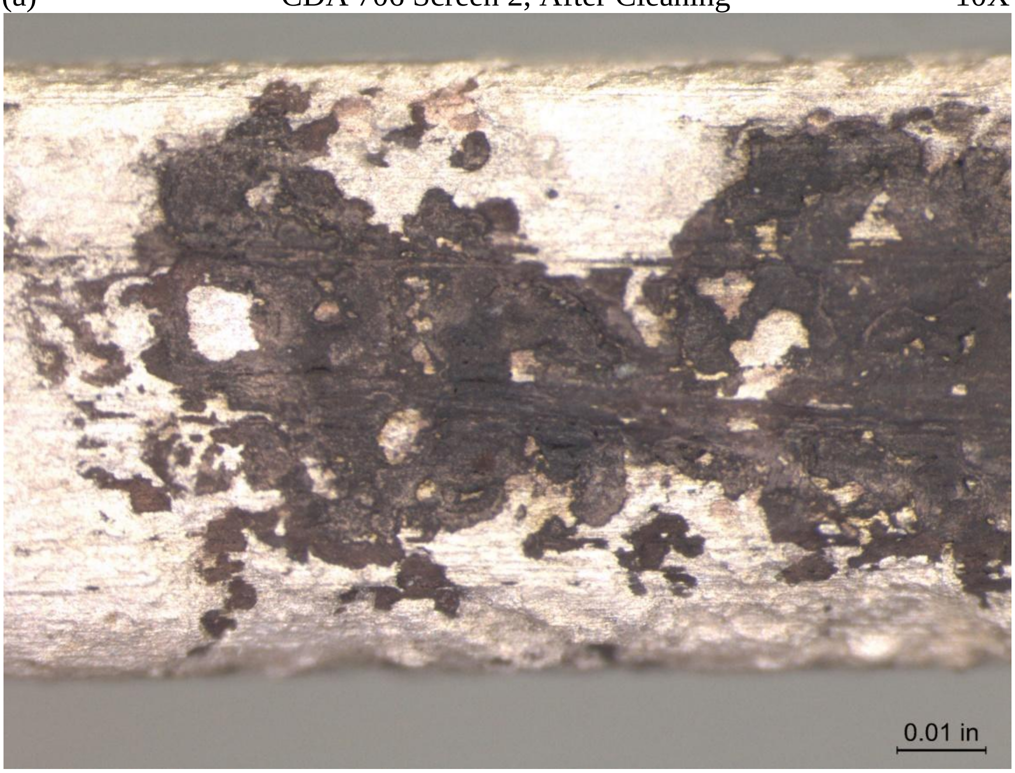
(a) CDA 706 Screen 2, Before Cleaning 10X

(b) CDA 706 Screen 2, Before Cleaning 50X

Figure 19 Optical macrographs of CDA 706 screen 2 after a 6 month corrosion test, before cleaning.

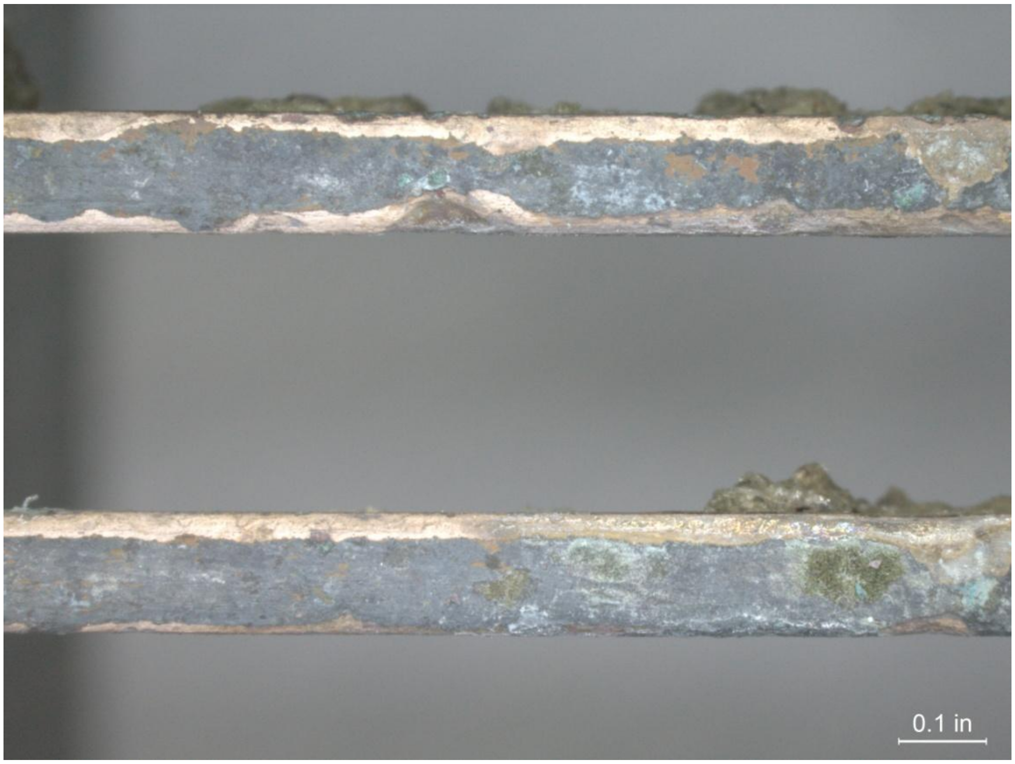


(a) CDA 706 Screen 2, After Cleaning 10X



(b) CDA 706 Screen 2, After Cleaning 50X

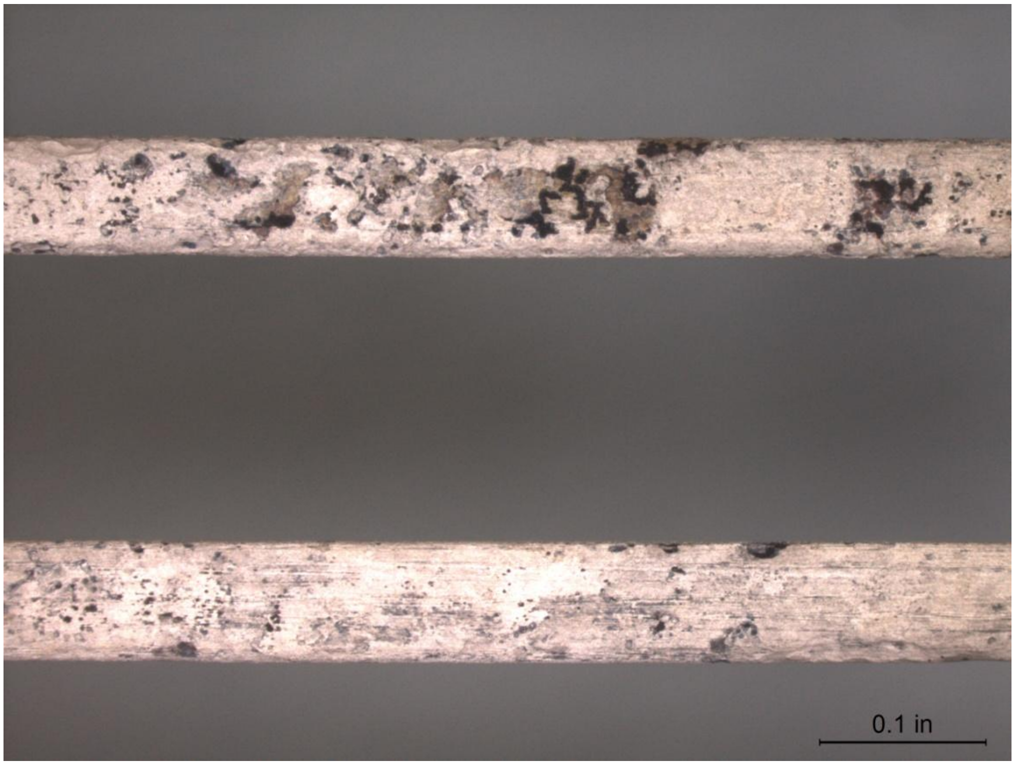
Figure 20 Optical macrographs of CDA 706 screen 2 after a 6 month corrosion test, after cleaning.



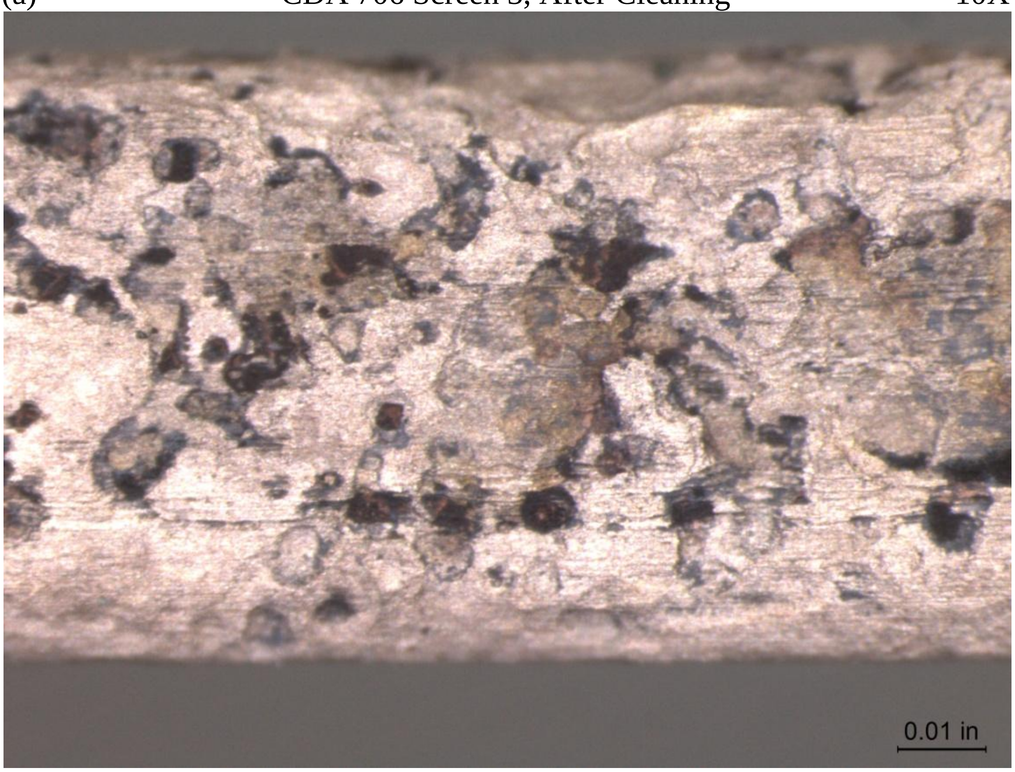
(a) CDA 706 Screen 3, Before Cleaning 10X

(b) CDA 706 Screen 3, Before Cleaning 50X

Figure 21 Optical macrographs of CDA 706 screen 3 after a 10 month corrosion test, before cleaning.

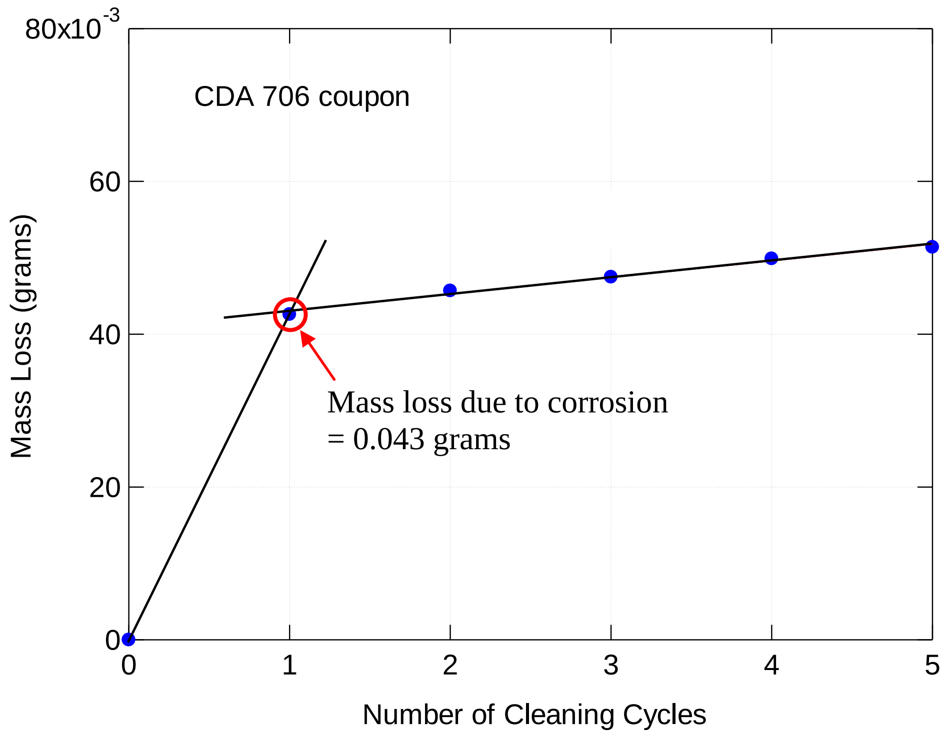


(a) CDA 706 Screen 3, After Cleaning 10X

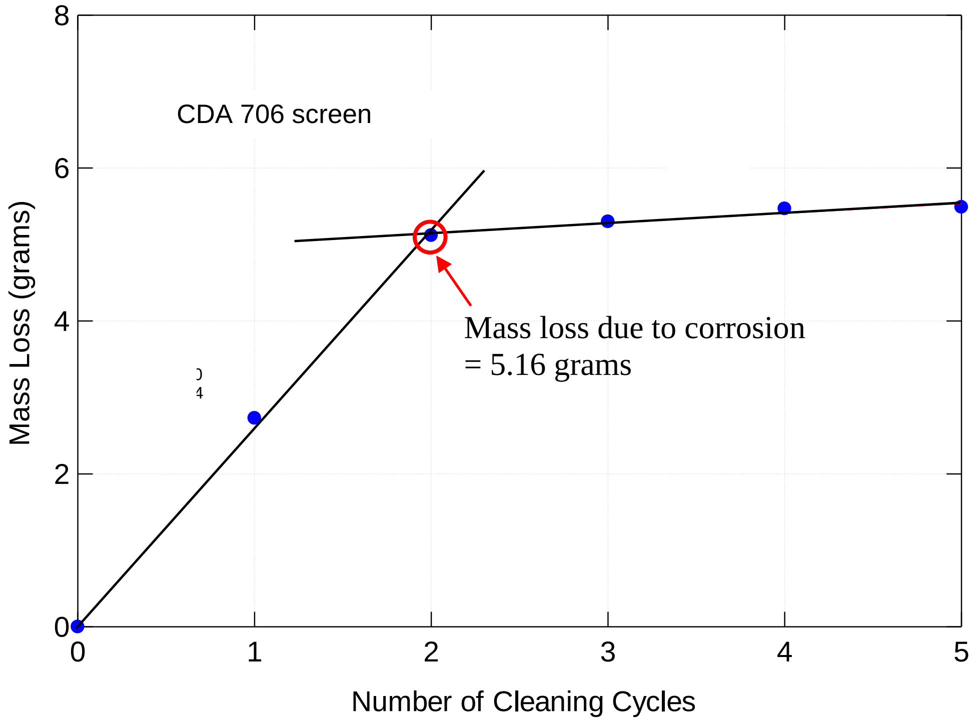


(b) CDA 706 Screen 3, After Cleaning 50X

Figure 22 Optical macrographs of CDA 706 screen 3 after a 10 month corrosion test, after cleaning.

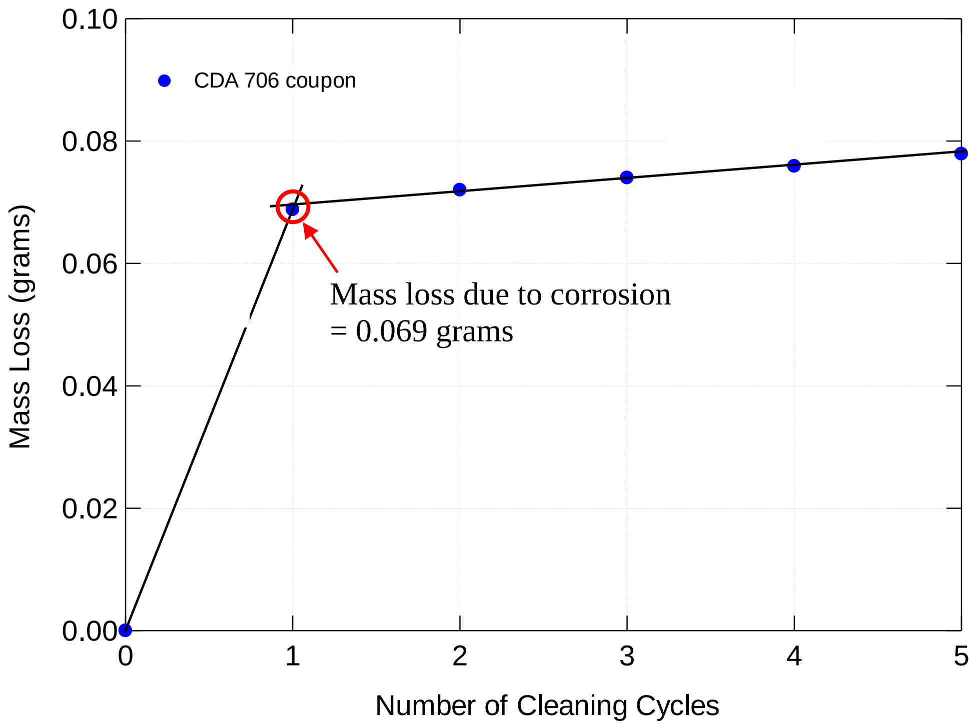


(a)

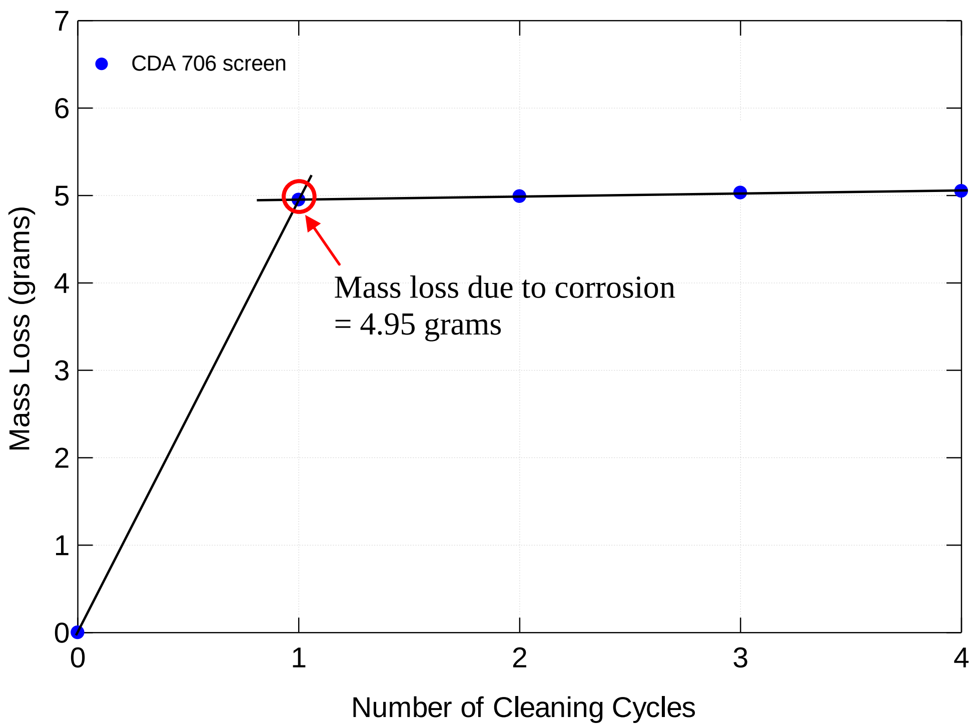


(b)

Figure 23 Mass loss of CDA 706 (a) coupon 1 and (b) screen 1 during cleaning.

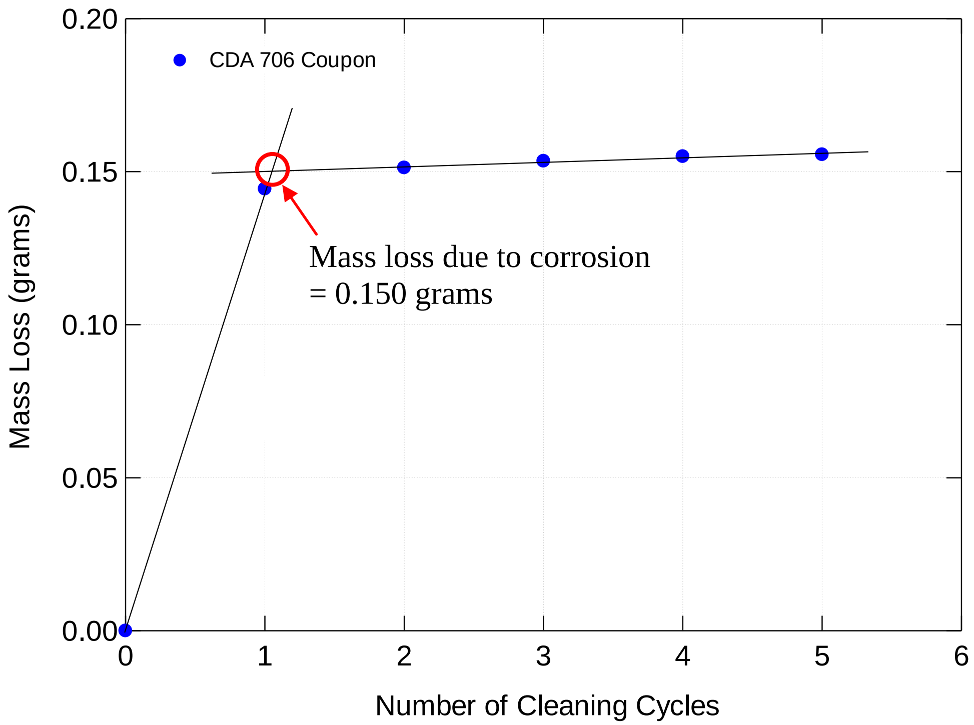


(a)

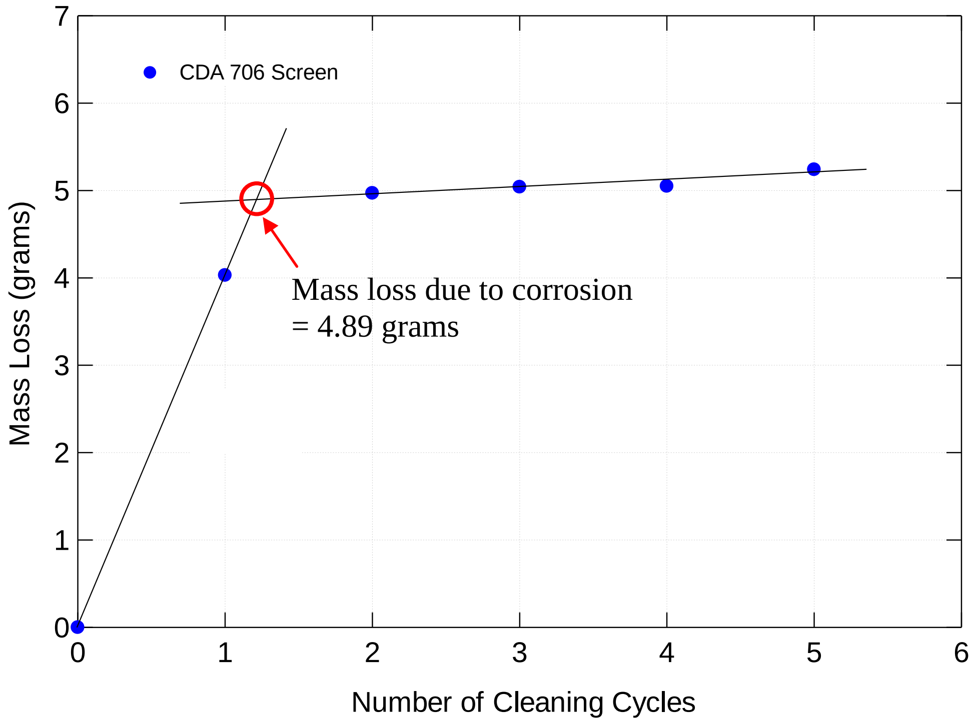


(b)

Figure 24 Mass loss of CDA 706 (a) coupon 2 and (b) screen 2 during cleaning.

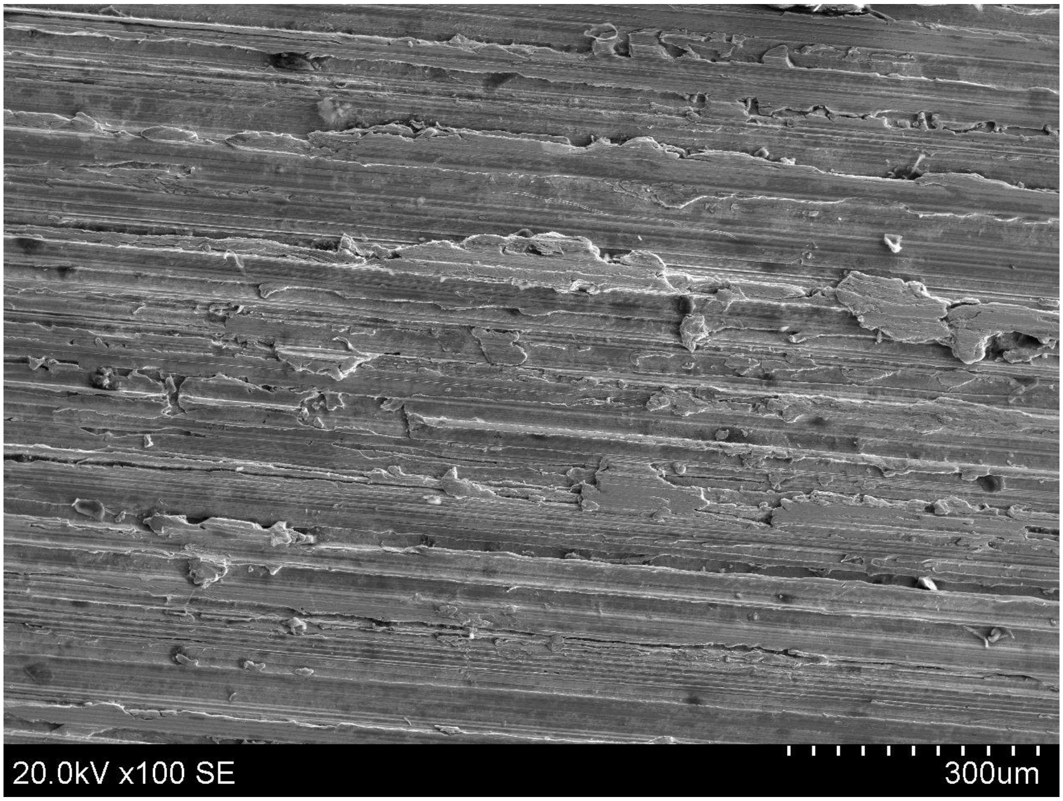


(a)

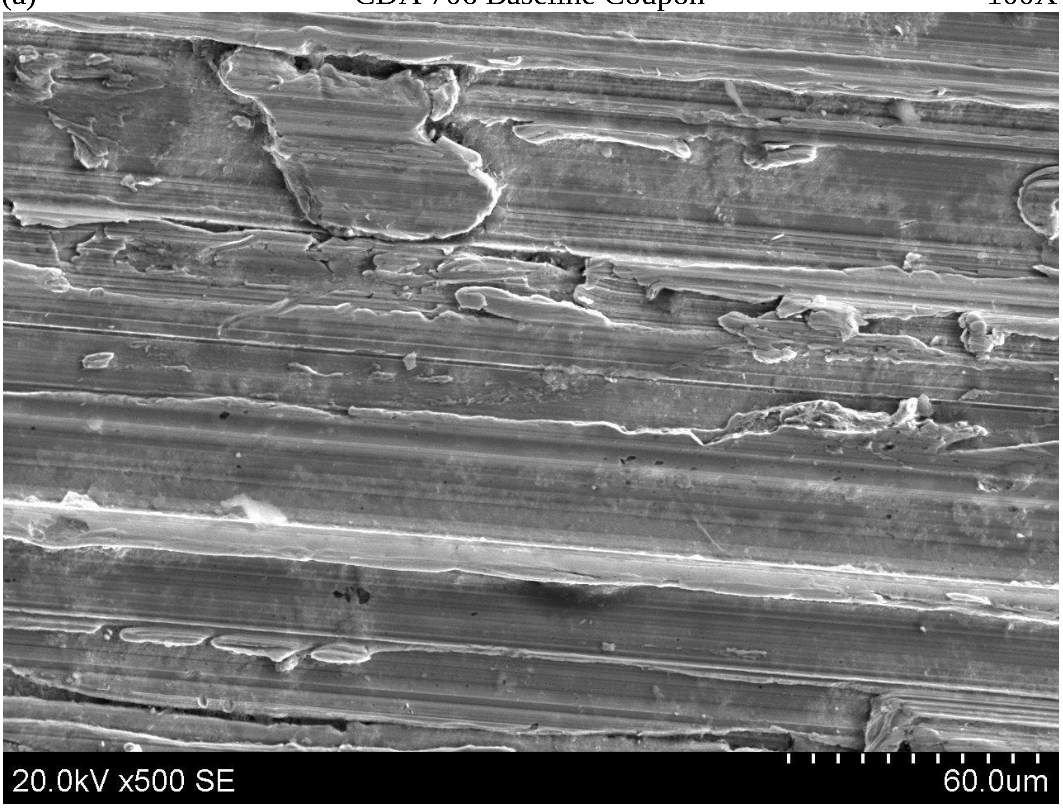


(b)

Figure 25 Mass loss of CDA 706 (a) coupon 3 and (b) screen 3 during cleaning.

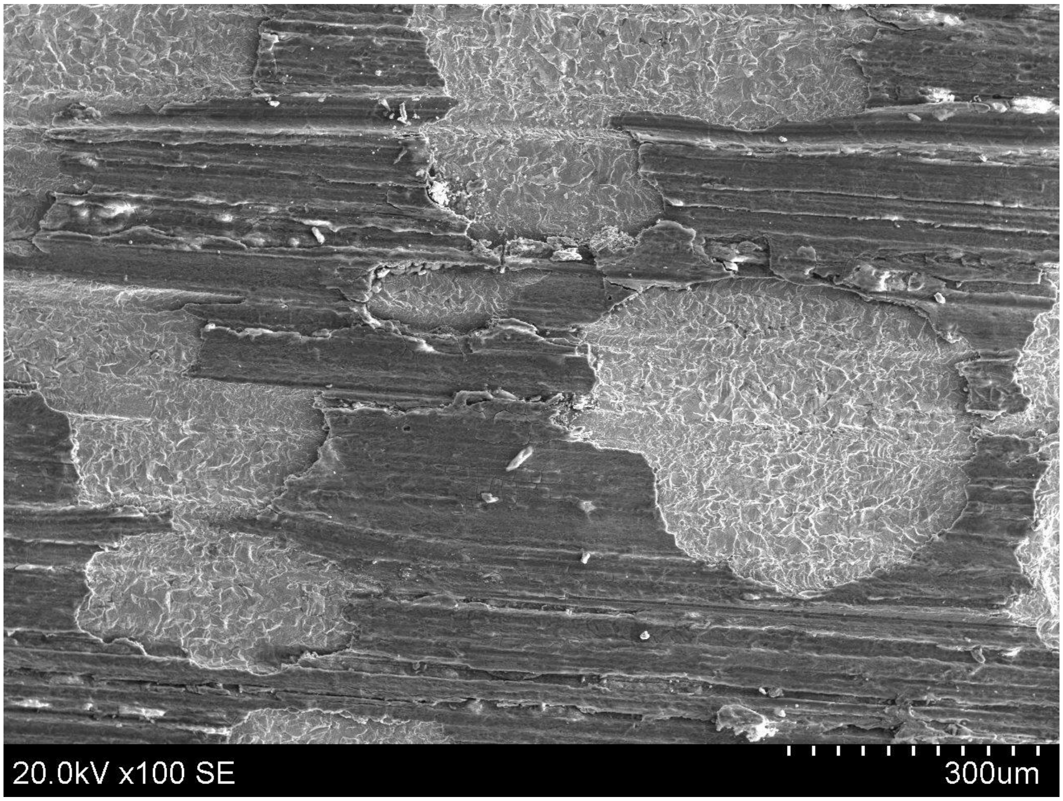


(a) CDA 706 Baseline Coupon 100X

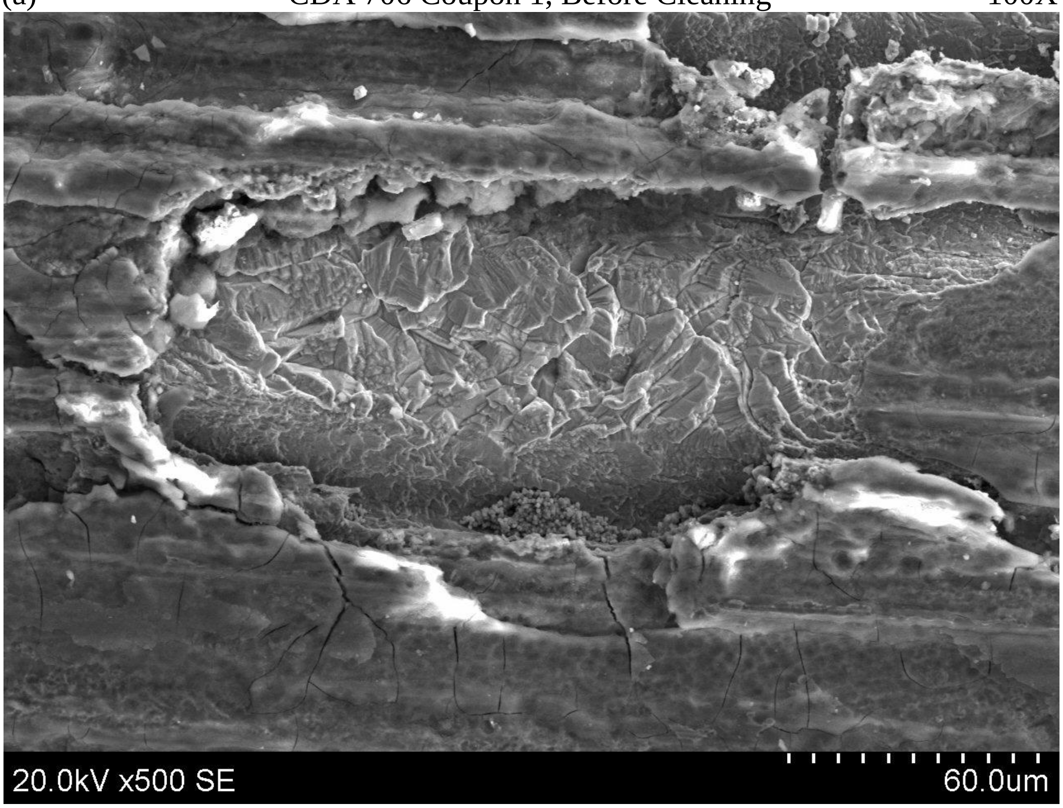


(b) CDA 706 Baseline Coupon 500X

Figure 26 Scanning electron micrographs of the CDA 706 baseline coupon.

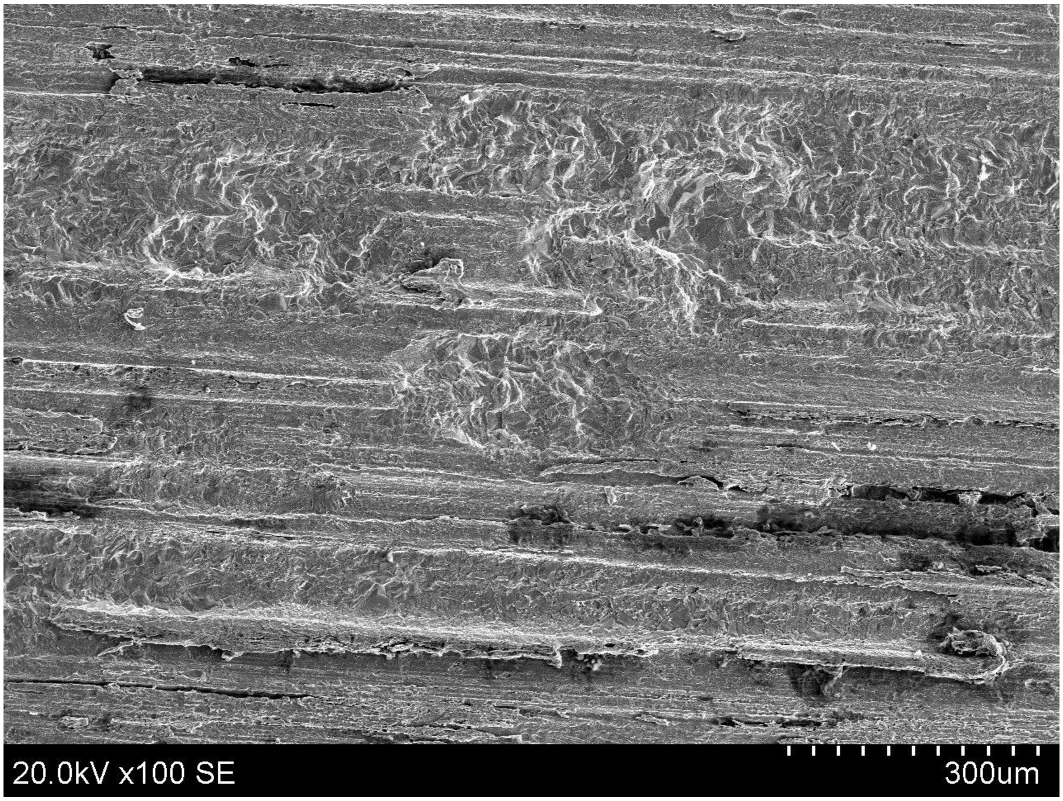


(a) CDA 706 Coupon 1, Before Cleaning 100X

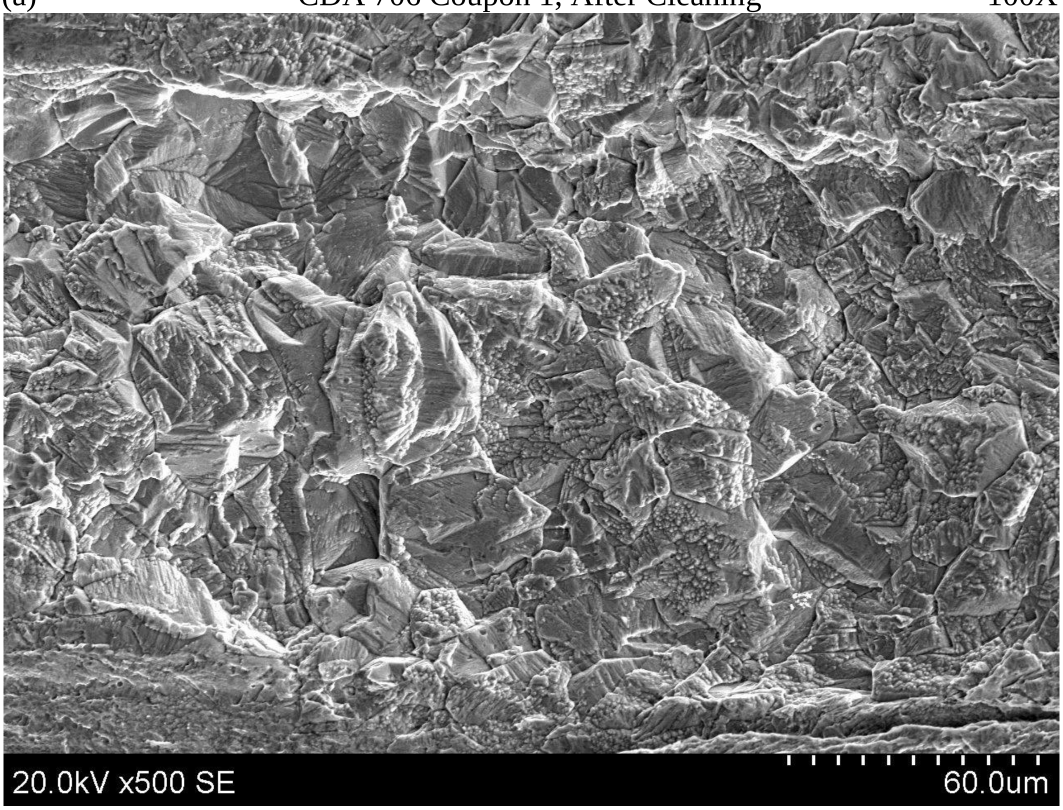


(b) CDA 706 Coupon 1, Before Cleaning 500X

Figure 27 Scanning electron micrographs of CDA 706 coupon 1 after a 3 month corrosion test, before cleaning.

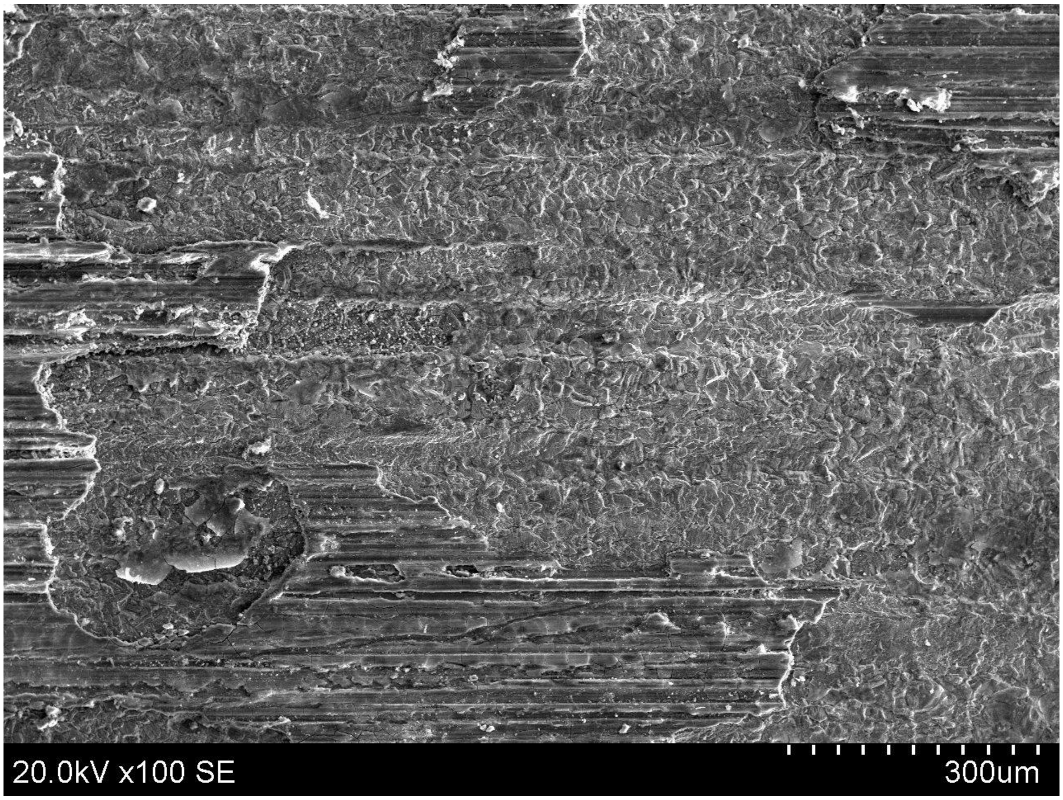


(a) CDA 706 Coupon 1, After Cleaning 100X

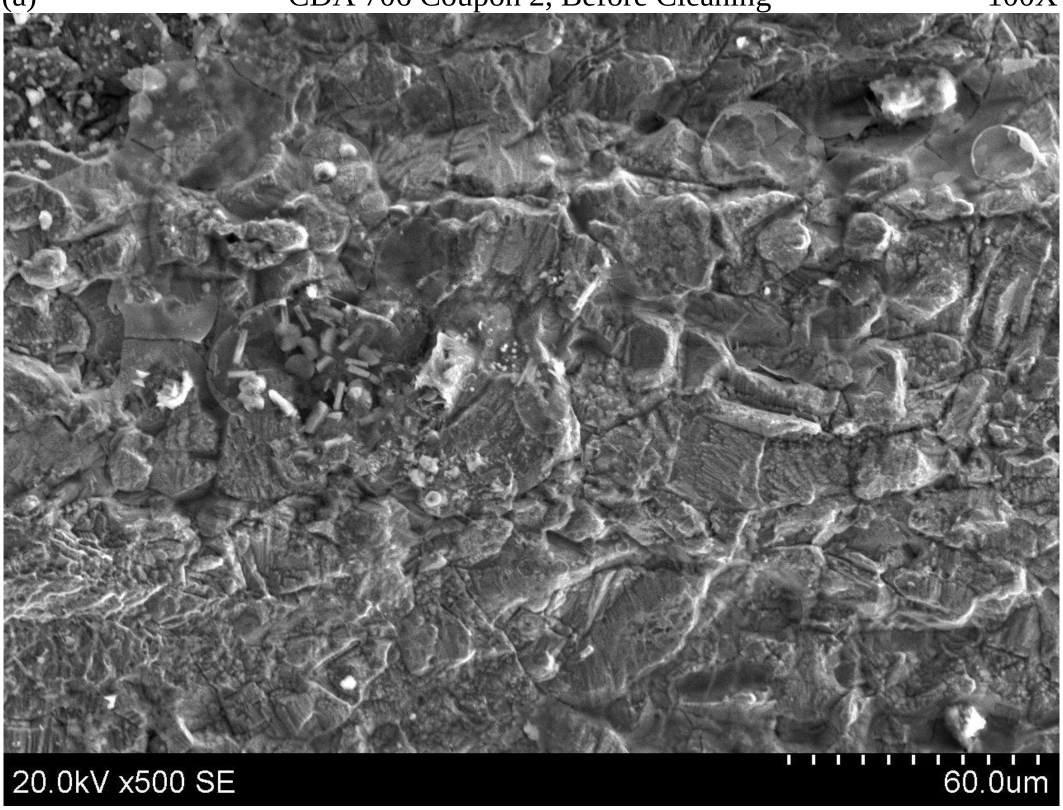


(b) CDA 706 Coupon 1, After Cleaning 500X

Figure 28 Scanning electron micrographs of CDA 706 coupon 1 after a 3 month corrosion test, after cleaning.

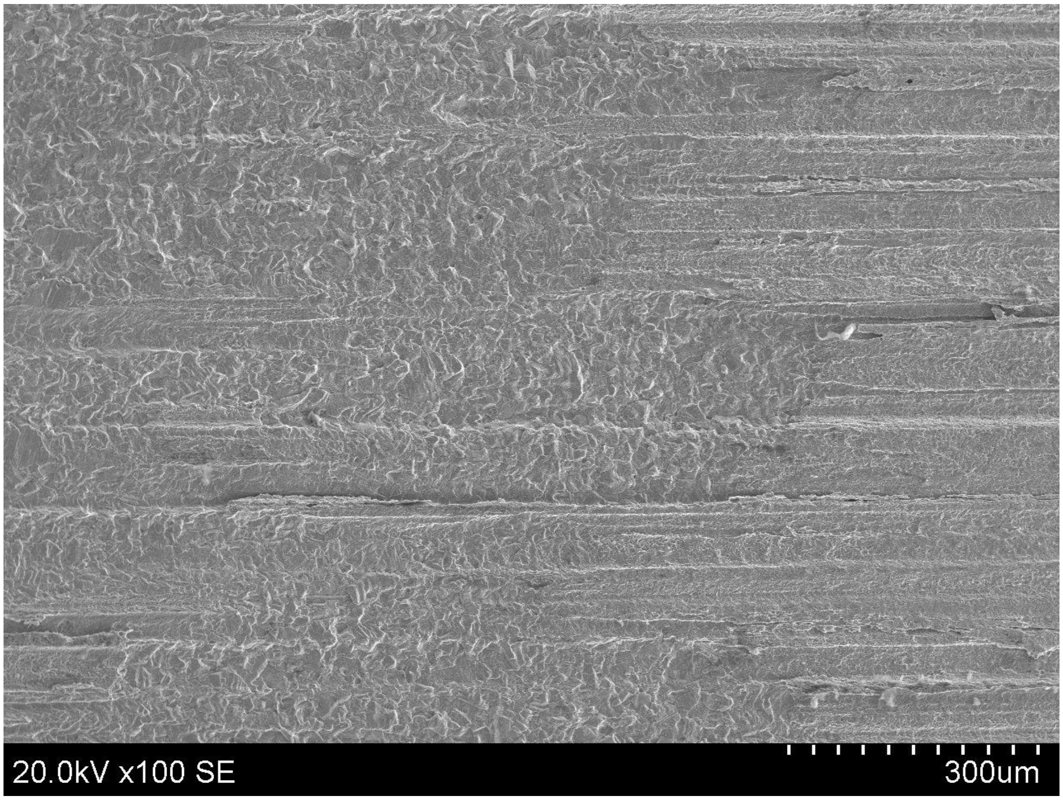


(a) CDA 706 Coupon 2, Before Cleaning 100X

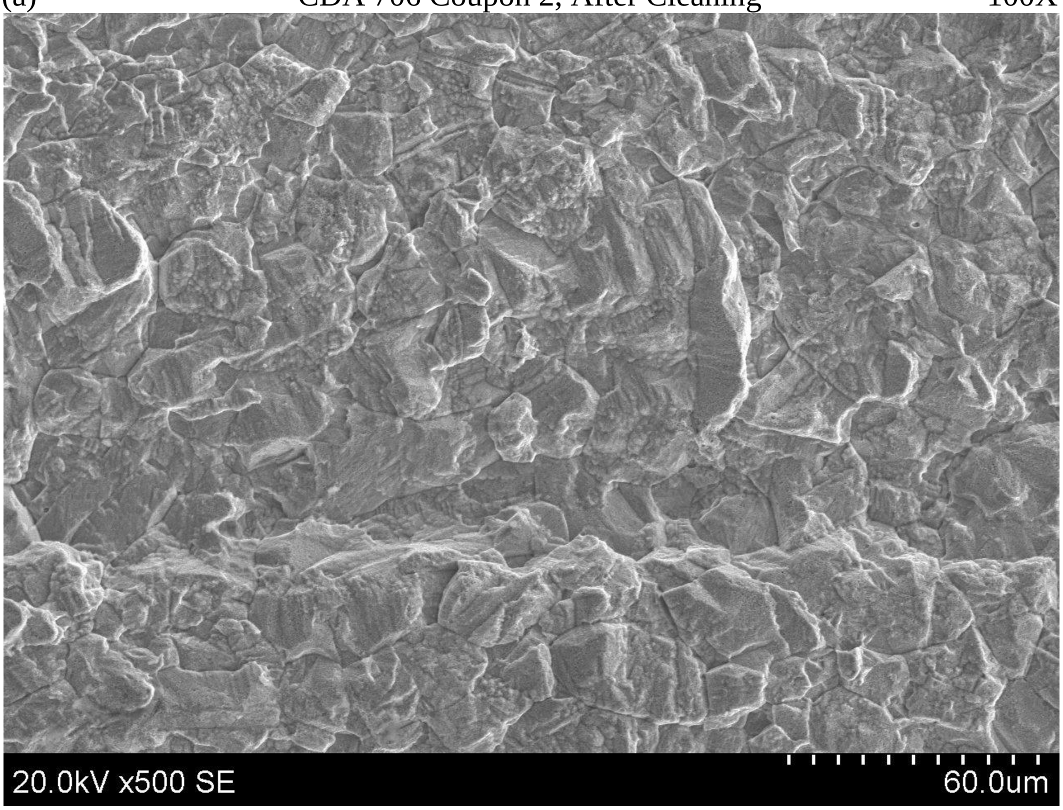


(b) CDA 706 Coupon 2, Before Cleaning 500X

Figure 29 Scanning electron micrographs of CDA 706 coupon 2 after a 6 month corrosion test, before cleaning.

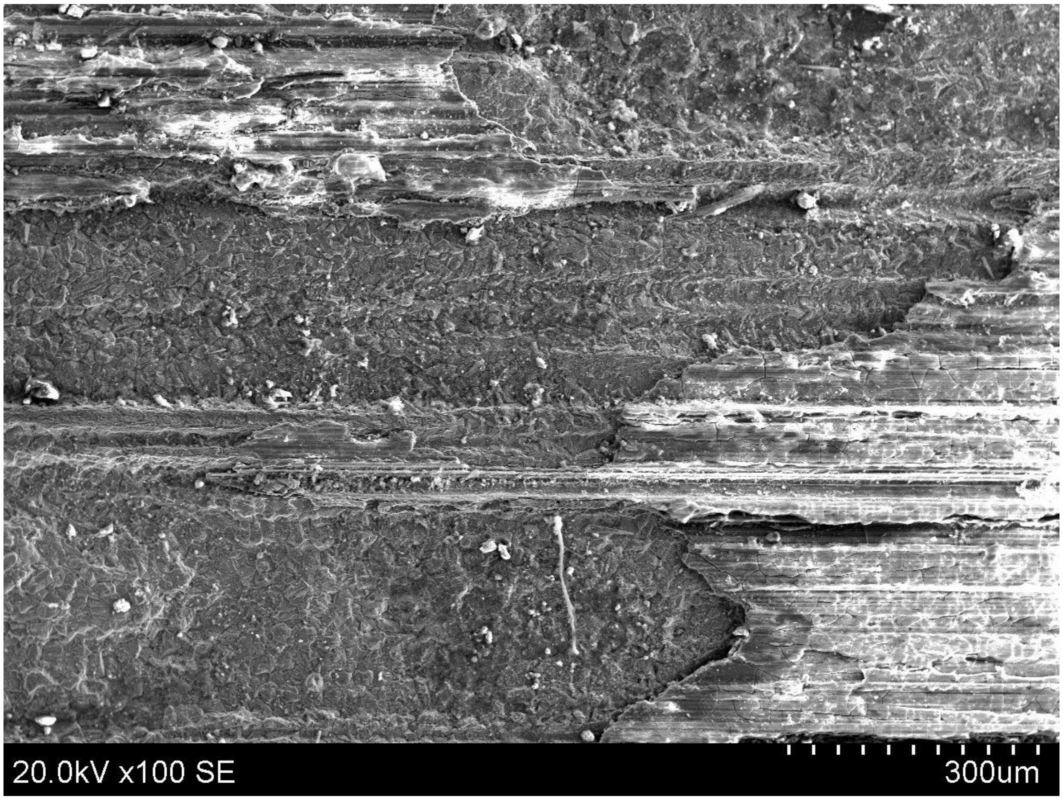


(a) CDA 706 Coupon 2, After Cleaning 100X

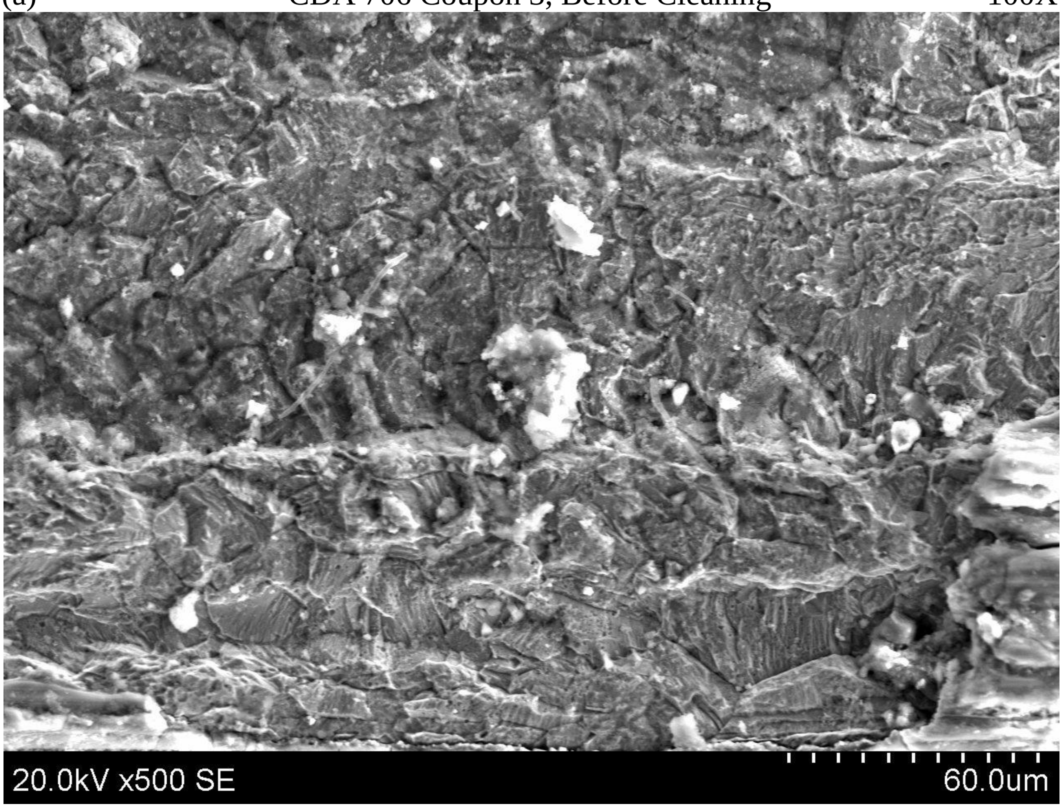


(b) CDA 706 Coupon 2, After Cleaning 500X

Figure 30 Scanning electron micrographs of CDA 706 coupon 2 after a 6 month corrosion test, after cleaning.

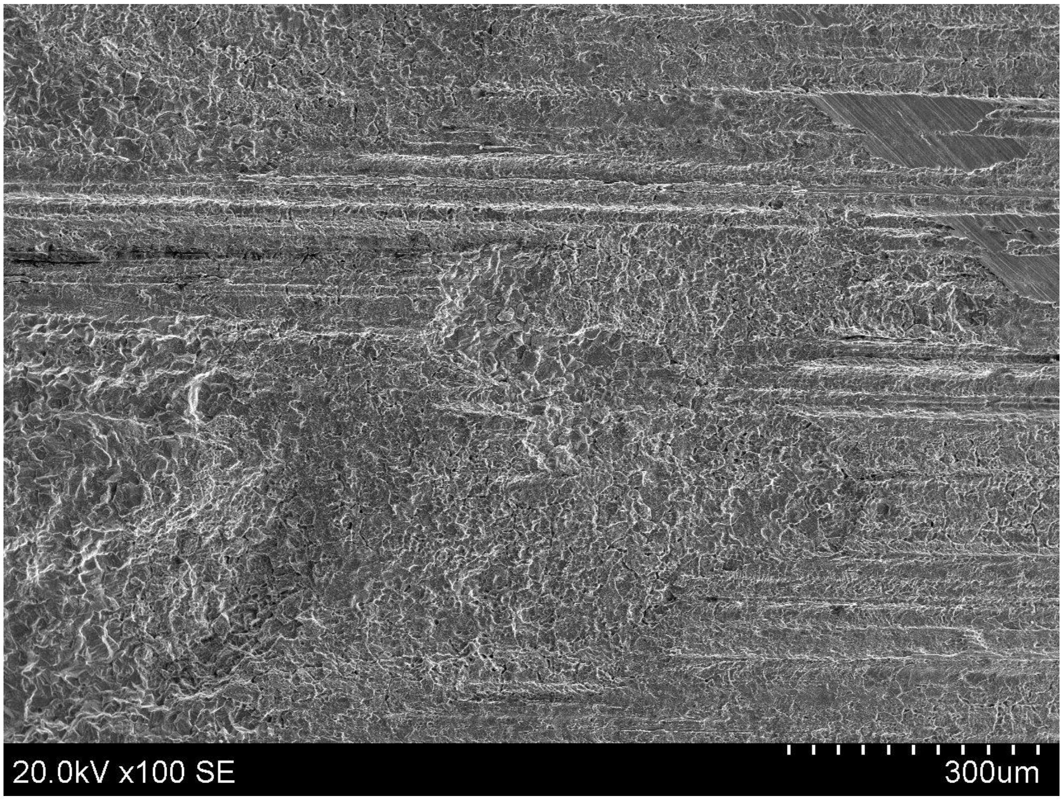


(a) CDA 706 Coupon 3, Before Cleaning 100X

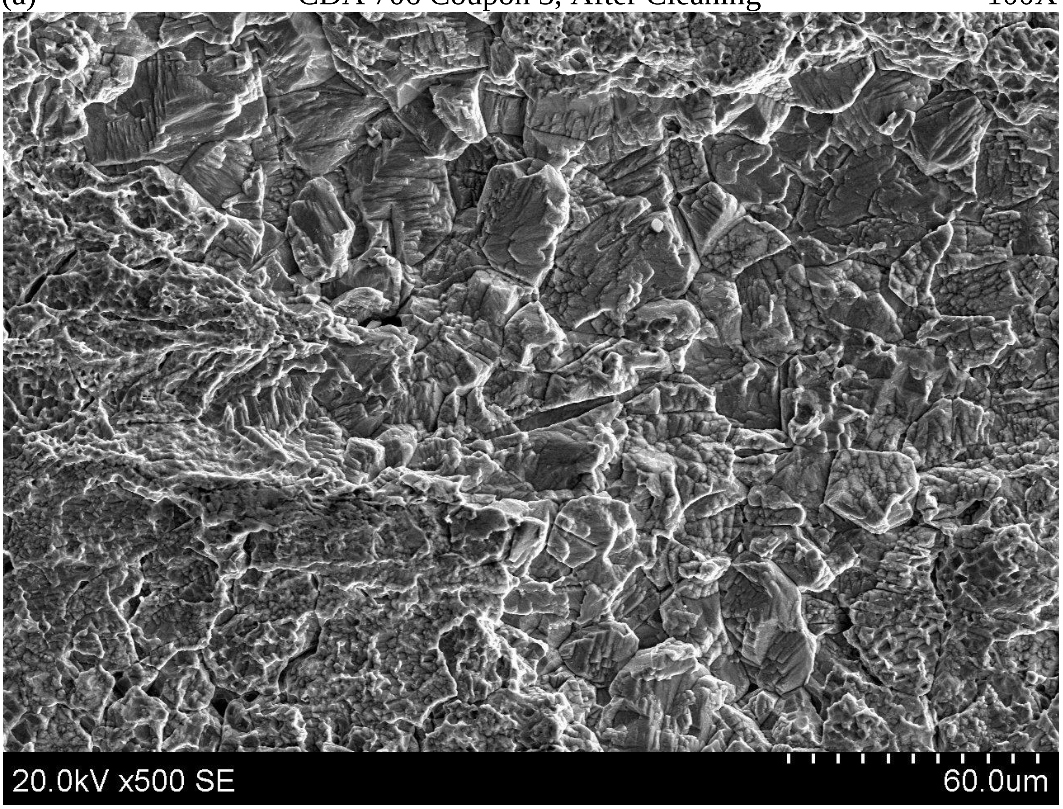


(b) CDA 706 Coupon 3, Before Cleaning 500X

Figure 31 Scanning electron micrographs of CDA 706 coupon 3 after a 10 month corrosion test, before cleaning.

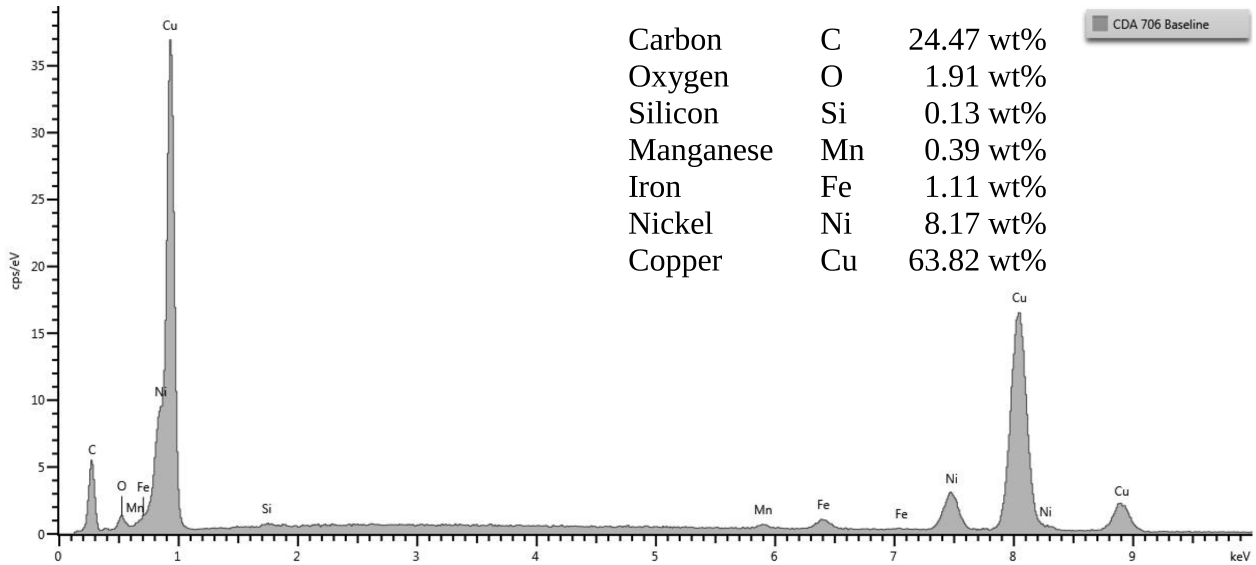


(a) CDA 706 Coupon 3, After Cleaning 100X



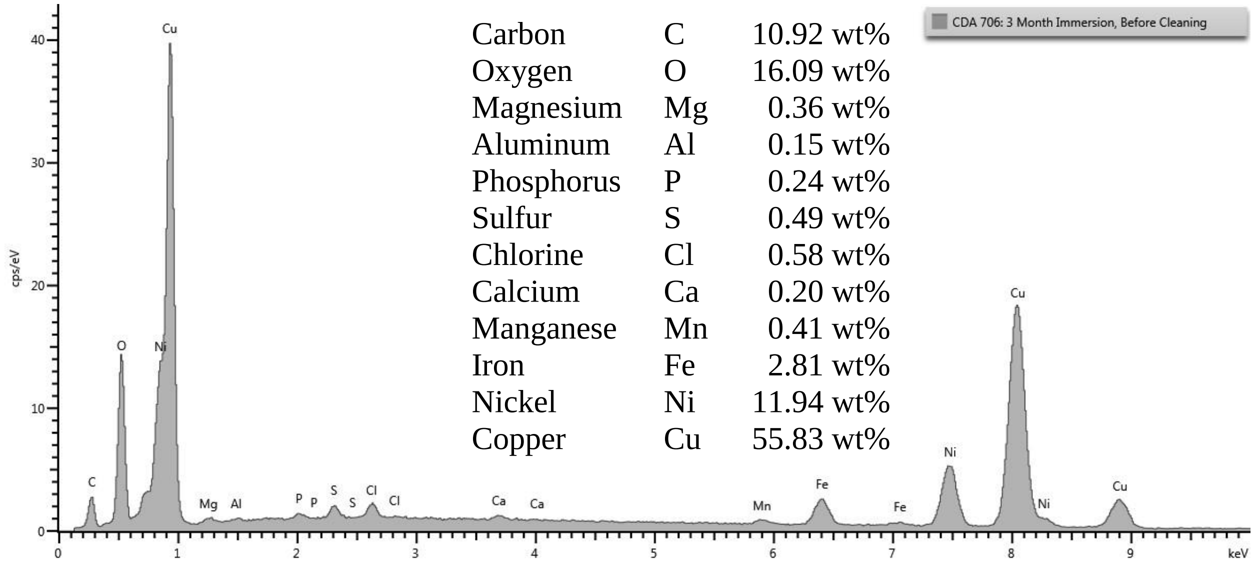
(b) CDA 706 Coupon 3, After Cleaning 500X

Figure 32 Scanning electron micrographs of CDA 706 coupon 3 after a 10 month corrosion test, after cleaning.

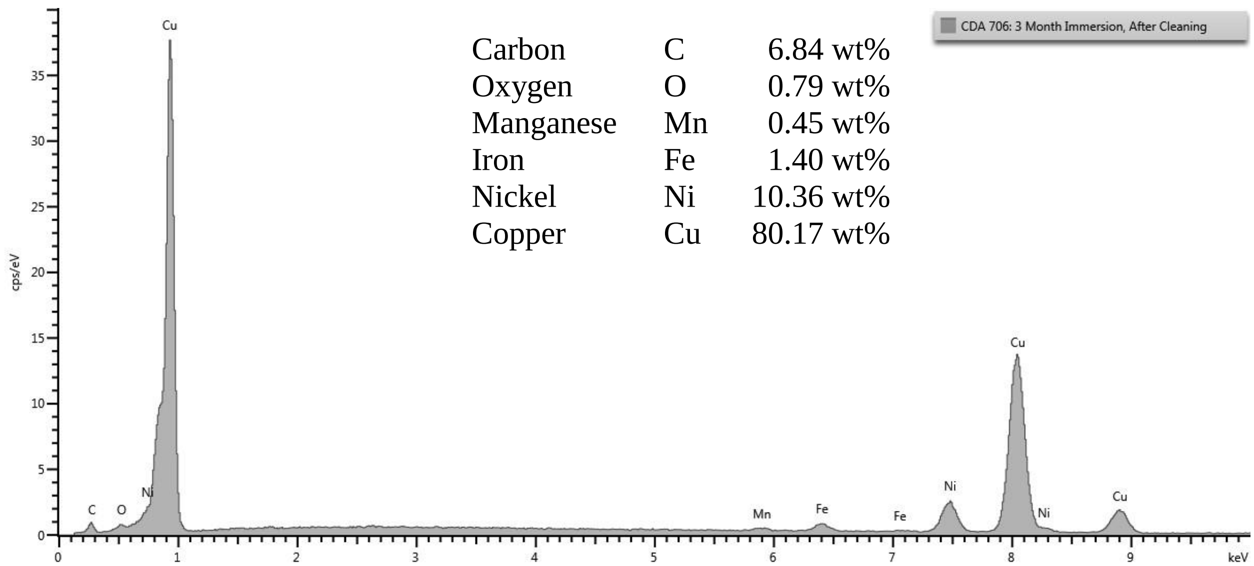


(b) CDA 706 Baseline Coupon

Figure 33 Energy dispersive x-ray spectra of the CDA 706 baseline coupon.

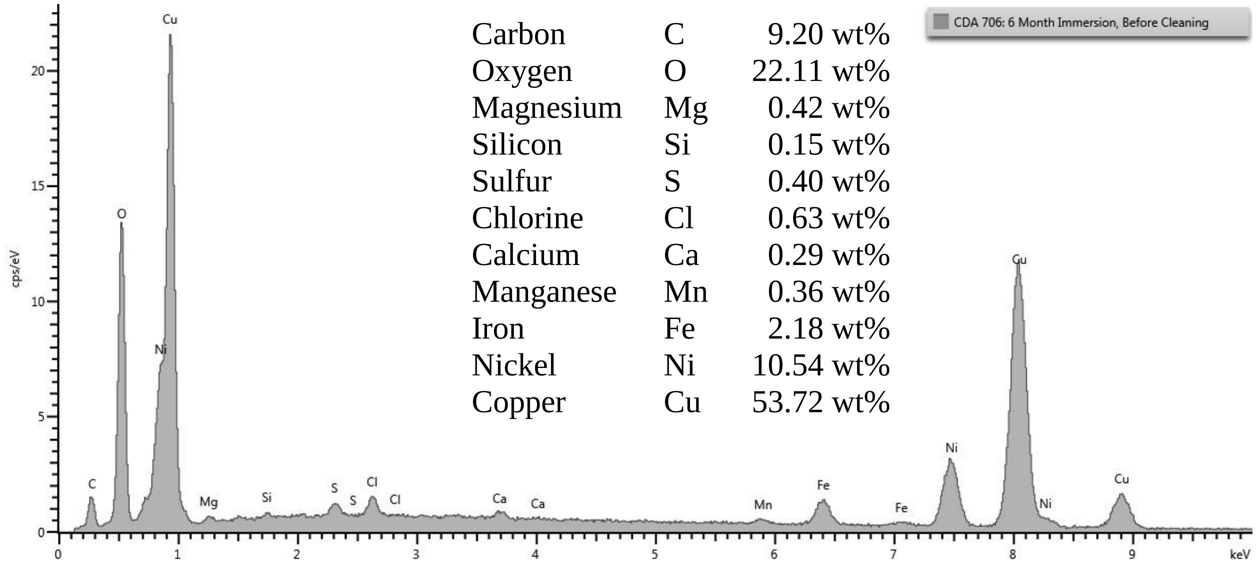


(a) CDA 706 Coupon 1, Before Cleaning

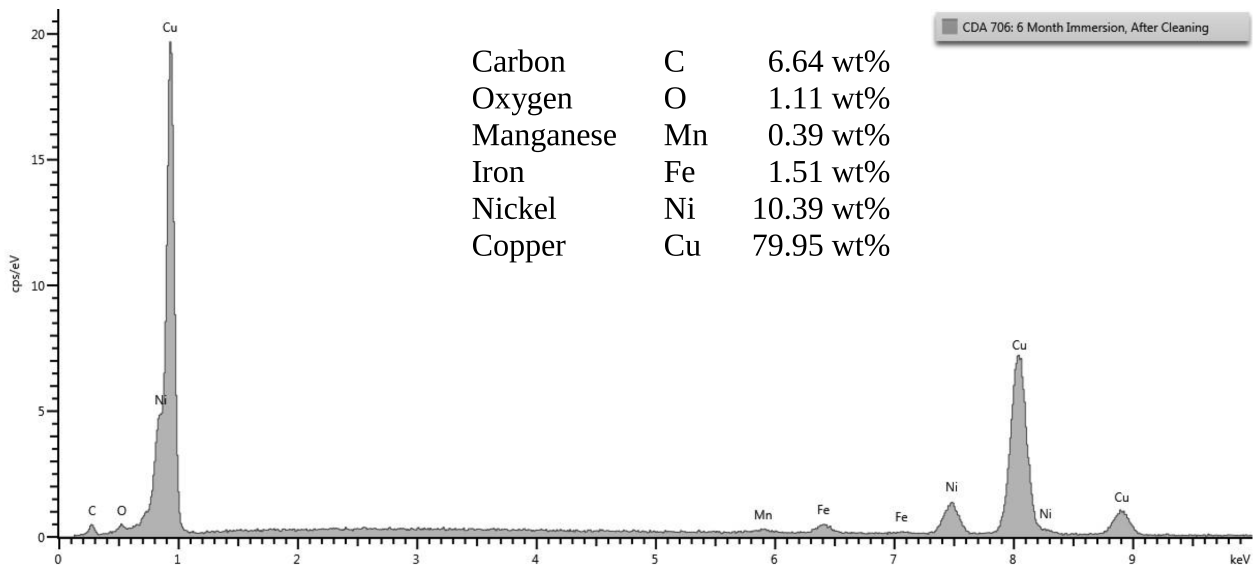


(b) CDA 706 Coupon 1, After Cleaning

Figure 34 Energy dispersive x-ray spectra of CDA 706 coupon 1 after a 3 month corrosion test (a) before cleaning and (b) after cleaning.

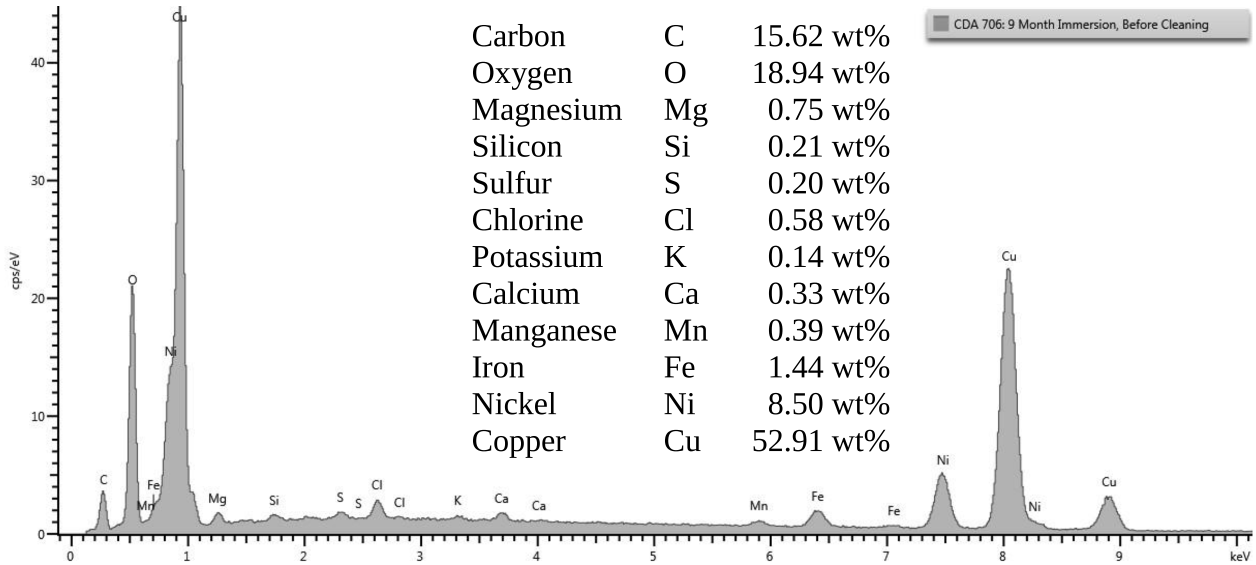


(a) CDA 706 Coupon 2, Before Cleaning

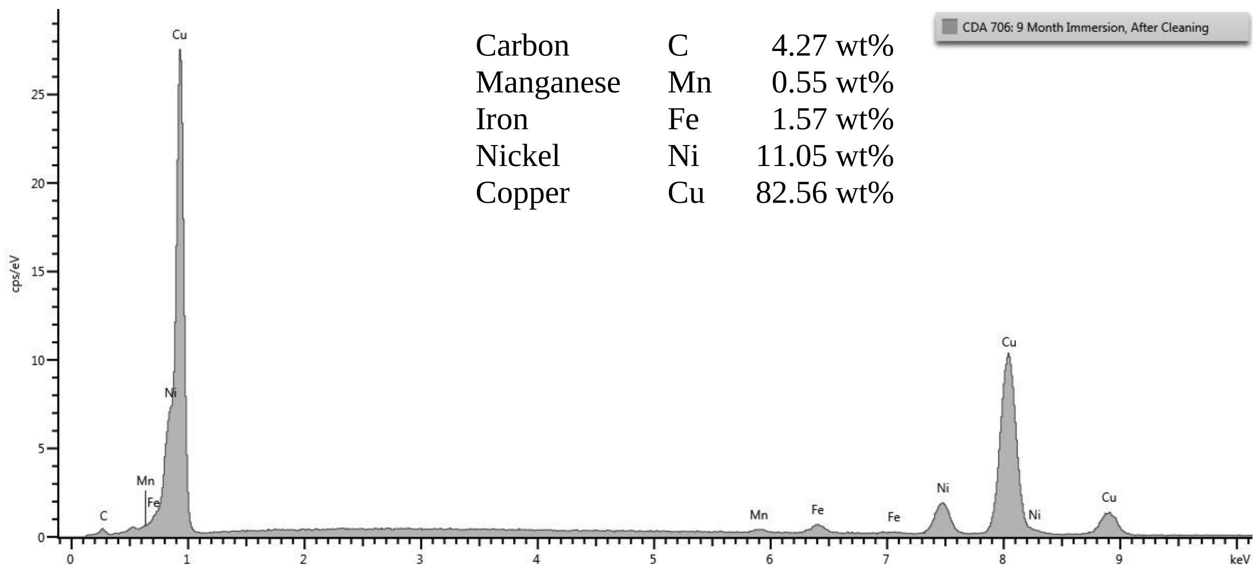


(b) CDA 706 Coupon 2, After Cleaning

Figure 35 Energy dispersive x-ray spectra of CDA 706 coupon 2 after a 6 month corrosion test (a) before cleaning and (b) after cleaning.



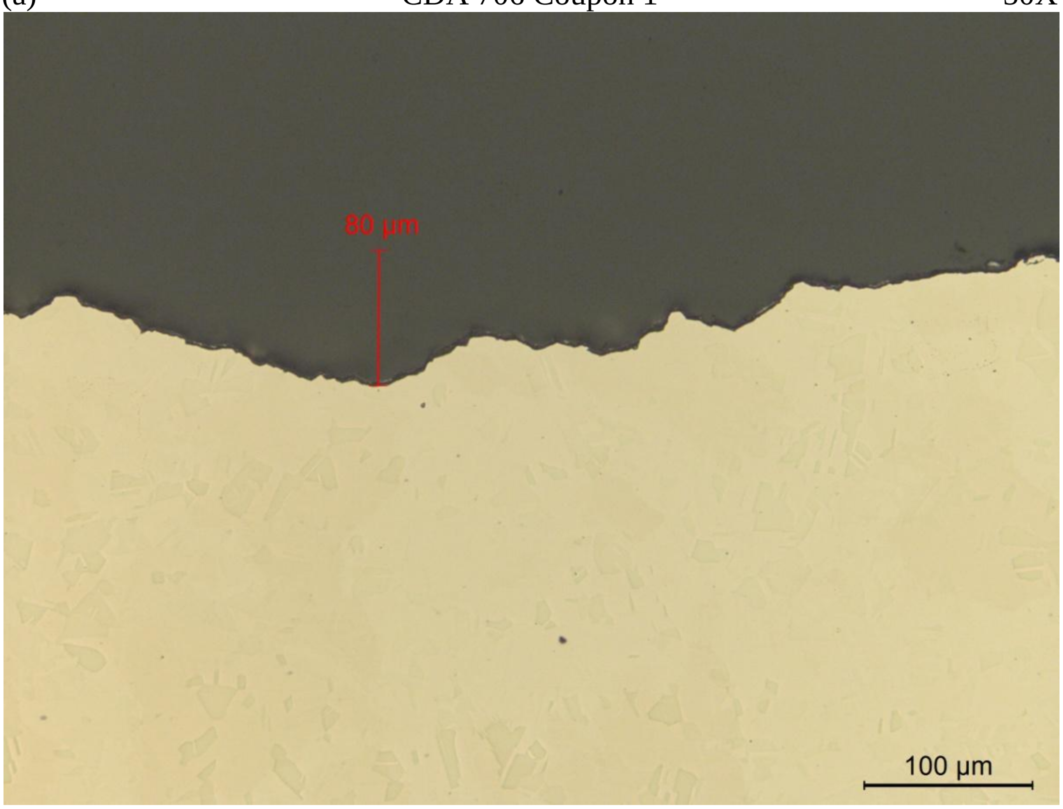
(a) CDA 706 Coupon 3, Before Cleaning



(b) CDA 706 Coupon 3, After Cleaning

Figure 36 Energy dispersive x-ray spectra of CDA 706 coupon 3 after a 10 month corrosion test (a) before cleaning and (b) after cleaning.

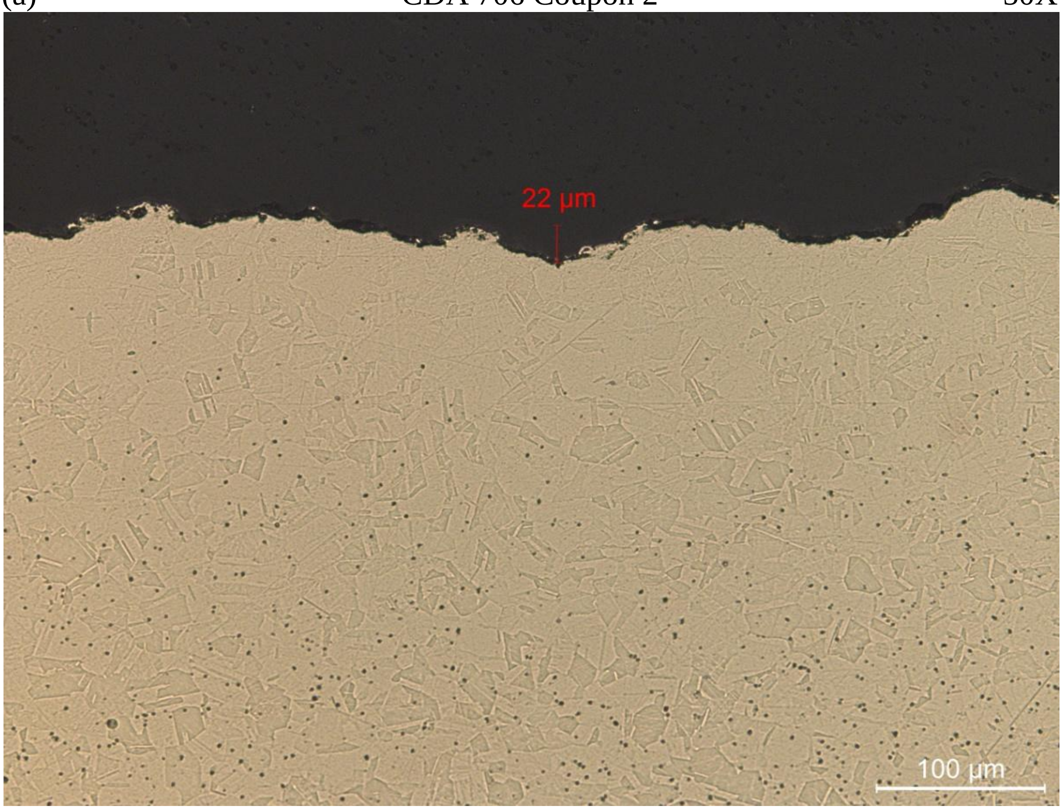
(a) CDA 706 Coupon 1 50X



(b) CDA 706 Coupon 1 200X

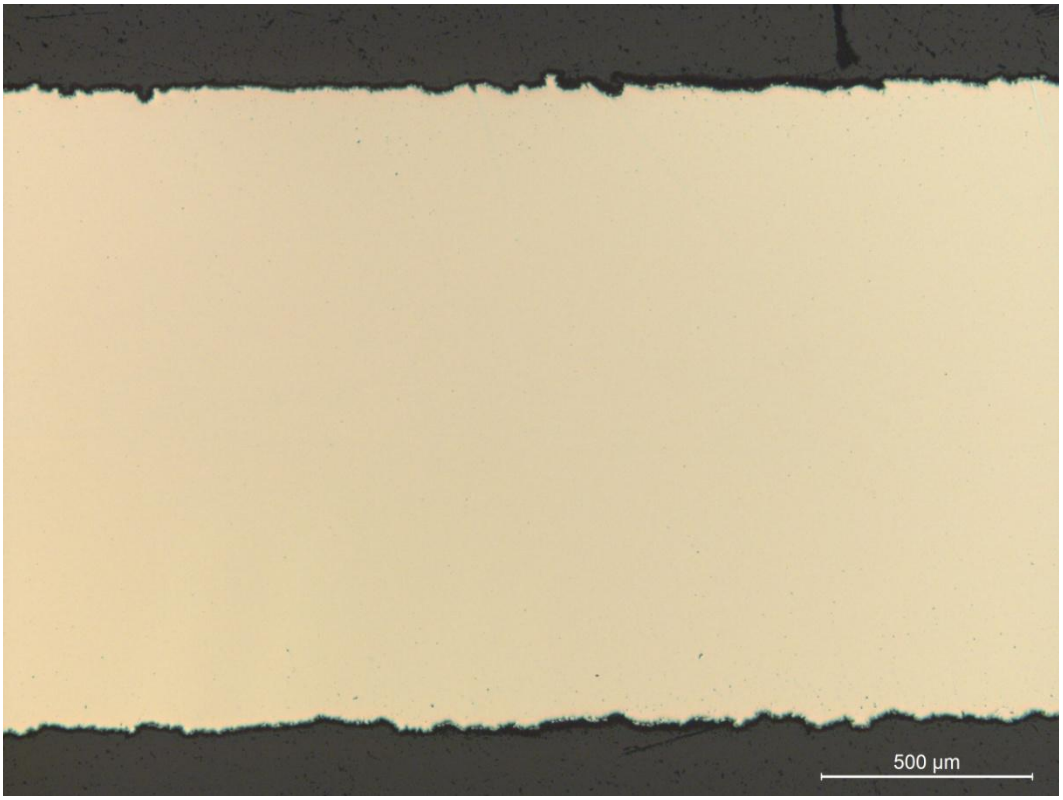
Figure 37 Optical micrographs of CDA 706 coupon 1.

(a) CDA 706 Coupon 2 50X

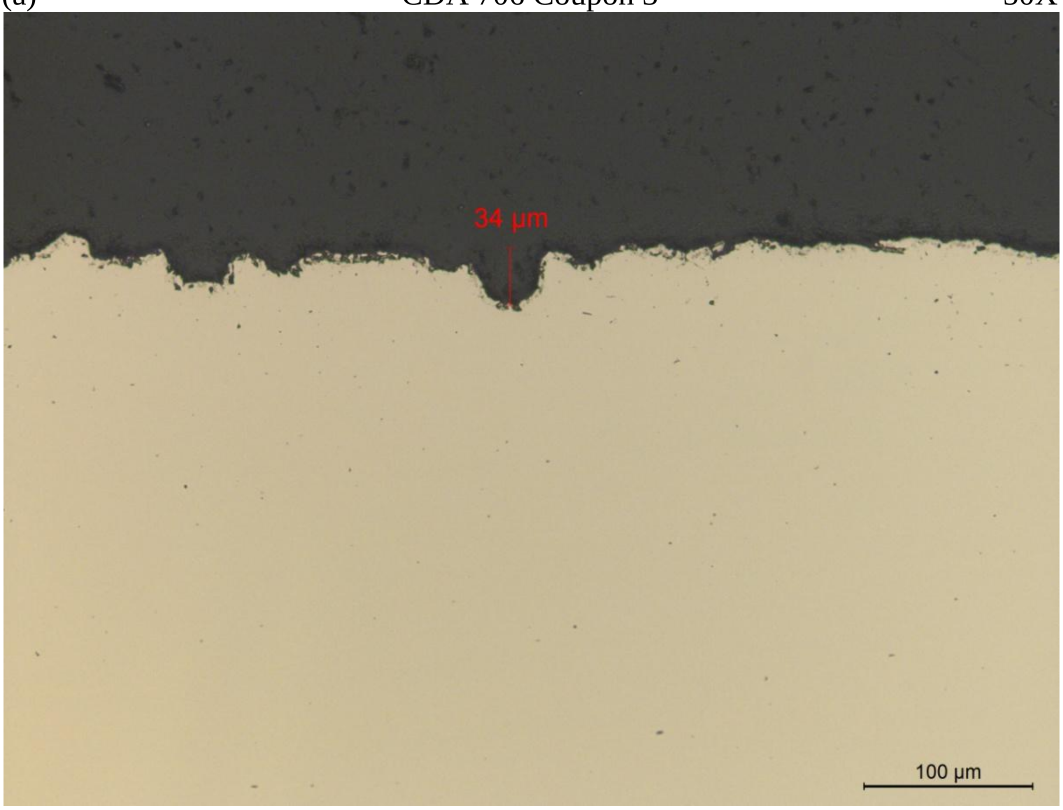


(b) CDA 706 Coupon 2 200X

Figure 38 Optical micrographs of CDA 706 coupon 2.



(a) CDA 706 Coupon 3 50X



(b) CDA 706 Coupon 3 200X

Figure 39 Optical micrographs of CDA 706 coupon 3.

Report No. 5005.0361D **May 19, 2015**

CORROSION EVALUATION OF CDA 715 COUPONS AND SCREENS

Customer Authorization: Verbal

Report To: V & A Engineering
Attn: Manuel Najar
155 Grand Avenue, Suite 700
Oakland, CA 94612

1.0 INTRODUCTION

Five coupons, five wedge wire screens, and one plate made from CDA 715, a 70-Copper, 30-Nickel alloy, were submitted by V&A Engineering for corrosion evaluation. The coupons were 1-inch by 3-inches by ¼-inch thick. The wedge wire screens were 4-inches by 4-inches by 1/4-inch tall with 2 mm spacing. The plate was 4-inches by 4-inches by 1/8-inch thick.

Four coupons and four screens were to be placed in seawater for a period up to one year. After every 3 month interval, one coupon and one screen were to be removed from the test system and examined for corrosion. The purpose of this evaluation was to document the samples in the baseline as-received condition, then again after 3, 6, 10, and 12 months of water exposure, record any loss in mass, examine for any pitting corrosion, and estimate the corrosion rate.

The samples were evaluated by the following laboratory procedures:

1) Visual examination and weighing
2) Cleaning per ASTM G1[1]
3) Scanning electron microscopy
4) Metallography

The results of the evaluation showed minimal mass loss and corrosion for the coupon and screen after 3, 6, and 10 months of corrosion testing. The coupon and screen, after 3 months of corrosion testing, had a corrosion rate of approximately 0.021 millimeters per year and 0.022 millimeters per year, respectively. The coupon and screen, after 6 months of corrosion testing, had a corrosion rate of approximately 0.016 millimeters per year and 0.022 millimeters per year, respectively. The coupon and screen, after 10 months of corrosion testing, had a corrosion rate of approximately 0.010 millimeters per year and 0.016 millimeters per year, respectively.

[1] G1: Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

2.0 EVALUATION[2]

2.1 Visual Examination

The sample identifications for the coupons and wedge wire screens and their corresponding immersion times are shown in Table 1. The coupons had identification numbers stamped on the front face by V&A Engineering. A number of notches, corresponding to the sample number, were sawed at the edge of each screen for identification after the corrosion test. The weights of the samples were recorded. Coupons 1 – 4 and screens 1 – 5 were sent back to V&A for corrosion testing. Coupon 5 was the baseline sample and documented by photography, optical stereoscopy and scanning electron microscopy for comparison to the tested samples. Screen 5 was documented as a baseline by photography and optical stereoscopy, and then sent to V&A for testing.

Photographs of the baseline coupon are shown in Figure 1. Photographs of coupon 1, after 3 months of corrosion testing, are shown in Figure 2. Photographs of coupon 2, after 6 months of corrosion testing, are shown in Figure 3. Photographs of coupon 3, after 10 months of corrosion testing, are shown in Figure 4.

A photograph of the baseline screen is shown in Figure 5. A photograph of screen 1, after 3 months of corrosion testing, is shown in Figure 6. A photograph of screen 2, after 6 months of corrosion testing, is shown in Figure 7. A photograph of screen 3, after 10 months of corrosion testing, is shown in Figure 8.

2.2 Cleaning

The coupon and screen were cleaned with solution C.2.1 per ASTM G1.[3] One cleaning cycle was approximately 1 minute. After each cleaning cycle, the samples were rinsed in water, dried, and weighed. The cleaning and weighing cycle was completed five times for the coupon and four times for the screen. The weights of the samples as-received, after corrosion testing but before cleaning, and after each cleaning cycle are presented in Table 2.

Optical macrographs of the baseline coupon and screen are shown in Figures 9 and 16, respectively. Representative optical macrographs of the samples after a 3 month corrosion test, before and after cleaning, are shown in Figures 10 – 11 and 17 – 18. Representative optical macrographs of the sample after a 6 month corrosion test, before and after cleaning, are shown in Figures 12 – 13 and 19 – 20. Representative optical macrographs of the sample after a 10 month corrosion test, before and after cleaning, are shown in Figures 14 – 15 and 21 – 22.

The mass loss versus the number of cleaning cycles was plotted, shown in Figures 23 – 25. The equations for best fit lines AB and BC, calculated using IGOR Pro, are listed in Table 3. Point B, indicated by the red circle in each plot, corresponds to the mass loss due to corrosion during the cleaning process for each sample. This mass loss was subtracted from the weight of the sample before cleaning and from the weight of the sample as-received to determine the total

[2] The magnifications of the optical and scanning electron micrographs in this report are approximate and should not be used as a basis for dimensional analyses unless otherwise indicated.
[3] 500 mL hydrochloric acid + 500 ml reagent water.

mass loss from corrosion. The corrosion rate of each sample was determined by the formula specified in Section 8.1 of ASTM G1:

$$Corrosion\ Rate = \frac{K\ x\ W}{A\ x\ T\ x\ D}$$

where K = 8.76 x 10^4, T = time of exposure in hours, A = area in cm^2, W = mass loss in grams, and D = density in g/cm^3. The total mass loss from corrosion and the calculated corrosion rate of each sample is shown in Table 4.

2.3 Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy

The baseline coupon, coupon 1, and coupon 2 were examined with a scanning electron microscope. Representative scanning electron micrographs of the baseline coupon are shown in Figure 26. Representative scanning electron micrographs of coupon 1 before and after cleaning are shown in Figures 27 – 28. Representative scanning electron micrographs of coupon 2 before and after cleaning are shown in Figures 29 – 30. Representative scanning electron micrographs of coupon 3 before and after cleaning are shown in Figures 31 – 32. Energy dispersive x-ray spectra of the baseline coupon and coupons 1 – 3 before and after cleaning are shown in Figures 33 – 36.

2.4 Metallography

A cross section was taken from the coupon and prepared for a metallographic examination. Optical micrographs of the surfaces for coupons 1 – 3 are shown in Figures 37 – 39. Elliptical pits were observed in coupons 1 and 2, the deepest of which measured 52 µm. Small pits were observed in coupon 3, the deepest of which measured 37 µm.

3.0 DISCUSSION

The coupon and screen showed minimal mass loss and pitting overall after 3, 6, and 10 months of corrosion testing. The coupons had more material loss over time, but had a decreasing corrosion rate over the duration of the corrosion test. The screens had more material loss over time, but maintained a consistent corrosion rate over the duration of the corrosion test.

4.0 CONCLUSIONS[4]

The following conclusions are based upon the submitted samples and the evidence gathered:

1. The coupon, after 3 months of corrosion testing, had a mass loss of 0.248 grams and a corrosion rate of 0.021 mm / year.

[4] The conclusions in this report are based upon the available information and evidence provided by the client and gathered by Anamet, within the scope of work authorized by the client, and they are hereby presented by Anamet to a reasonable degree of engineering and scientific certainty. Anamet reserves the right to amend or supplement its conclusions or opinions presented in this report should additional data or information become available, or further work be approved by the client.

2. The screen, after 3 months of corrosion testing, had a mass loss of 2.04 grams and a corrosion rate of 0.022 mm / year.

3. The coupon, after 6 months of corrosion testing, had a mass loss of 0.386 grams and a corrosion rate of 0.016 mm / year.

4. The screen, after 6 months of corrosion testing, had a mass loss of 4.05 grams and a corrosion rate of 0.022 mm / year.

5. The coupon, after 10 months of corrosion testing, had a mass loss of 0.387 grams and a corrosion rate of 0.010 mm / year.

6. The screen, after 10 months of corrosion testing, had a mass loss of 4.94 grams and a corrosion rate of 0.016 mm / year.

Prepared by:

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Reviewed by:

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Senior Materials Engineer

Table 1
Sample Identifications

<table>
<tr><th colspan="2">Description</th><th rowspan="2">V&A Engineering Identification (As-Received)</th><th rowspan="2">Anamet Identification (in report)</th><th rowspan="2">Notes</th></tr>
<tr><th>Alloy</th><th>Part</th></tr>
<tr><td rowspan="11">CDA 715 (Cu 70 – Ni 30)</td><td>Flat Plate
4-inch x 4-inch x 1/8-inch</td><td>CDA 715 1</td><td>Plate</td><td>None</td></tr>
<tr><td rowspan="5">Coupon
1-inch x 3-inch x 1/8-inch with autogenous weld bead</td><td>CDA 715W 1</td><td>Coupon 1</td><td>3 Month Immersion</td></tr>
<tr><td>CDA 715W 2</td><td>Coupon 2</td><td>6 Month Immersion</td></tr>
<tr><td>CDA 715W 3</td><td>Coupon 3</td><td>10 Month Immersion</td></tr>
<tr><td>CDA 715W 4</td><td>Coupon 4</td><td>12 Month Immersion</td></tr>
<tr><td>CDA 715W 5</td><td>Coupon 5</td><td>Baseline Sample (no exposure)</td></tr>
<tr><td rowspan="5">Wedge Wire Screen
4-inch x 4-inch x 1-inch with 2 mm spacing</td><td>None</td><td>Screen 1</td><td>3 Month Immersion</td></tr>
<tr><td>None</td><td>Screen 2</td><td>6 Month Immersion</td></tr>
<tr><td>None</td><td>Screen 3</td><td>10 Month Immersion</td></tr>
<tr><td>None</td><td>Screen 4</td><td>12 Month Immersion</td></tr>
<tr><td>None</td><td>Screen 5</td><td>12 Month Immersion</td></tr>
</table>

Table 2
Sample Weights

Sample	Baseline Measurement	Measurements after 3 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 1	23.3284	23.1538	23.0863	32.0802	23.0795	23.0782	23.0770
Screen 1	210.45	209.34	208.52	208.42	208.41	208.41	-

Sample	Baseline Measurement	Measurements after 6 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 2	24.8463	24.5762	24.4601	24.4578	24.4571	24.4530	24.4519
Screen 2	211.63	208.66	207.58	207.57	207.57	207.53	-

Sample	Baseline Measurement	Measurements after 10 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 3	24.1830	23.9022	23.7974	23.7958	23.7920	23.7909	23.7907
Screen 3	212.46	209.33	207.55	207.48	207.40	207.38	207.32

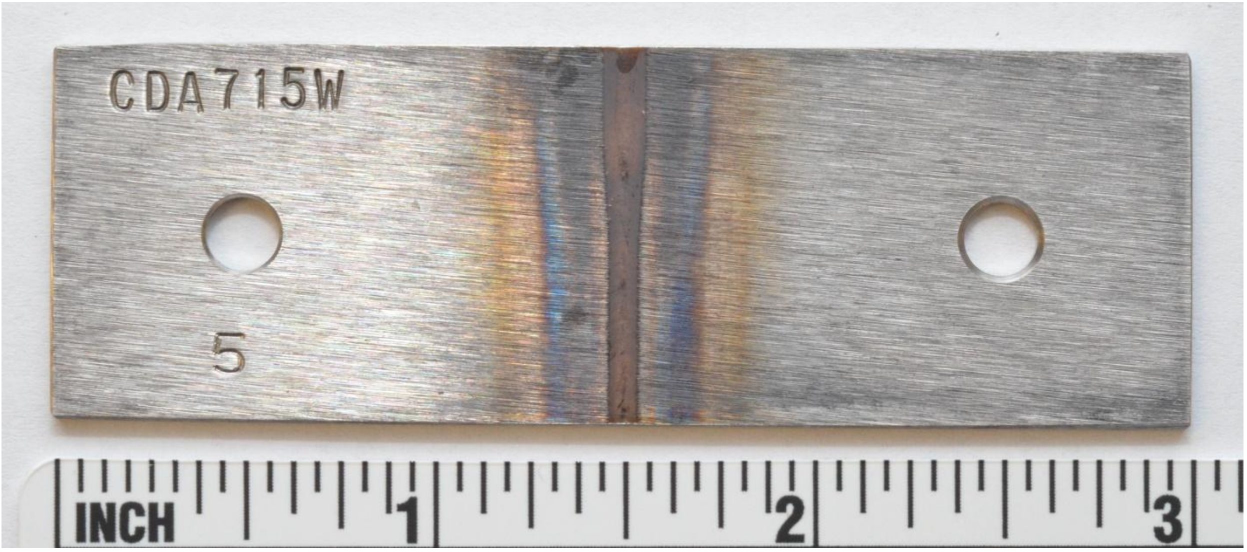
Table 3
Equations of Lines AB and BC for Corrosion Testing Samples

Sample	Line AB	Line BC	Point B (Approximate Mass Loss from Corrosion During Cleaning)
Coupon 1	y = 0.068x	y = 0.001x + 0.072	0.073 grams
Coupon 2	y = 0.116x	y = 0.002x + 0.114	0.116 grams
Coupon 3	y = 0.105x	y = 0.002x + 0.104	0.106 grams
Screen 1	y = 0.83x	y = 0.01x + 0.92	0.93 grams
Screen 2	y = 1.08x	y = 0.02x + 1.06	1.08 grams
Screen 3	y = 1.78x	y = 0.05x + 1.76	1.81 grams

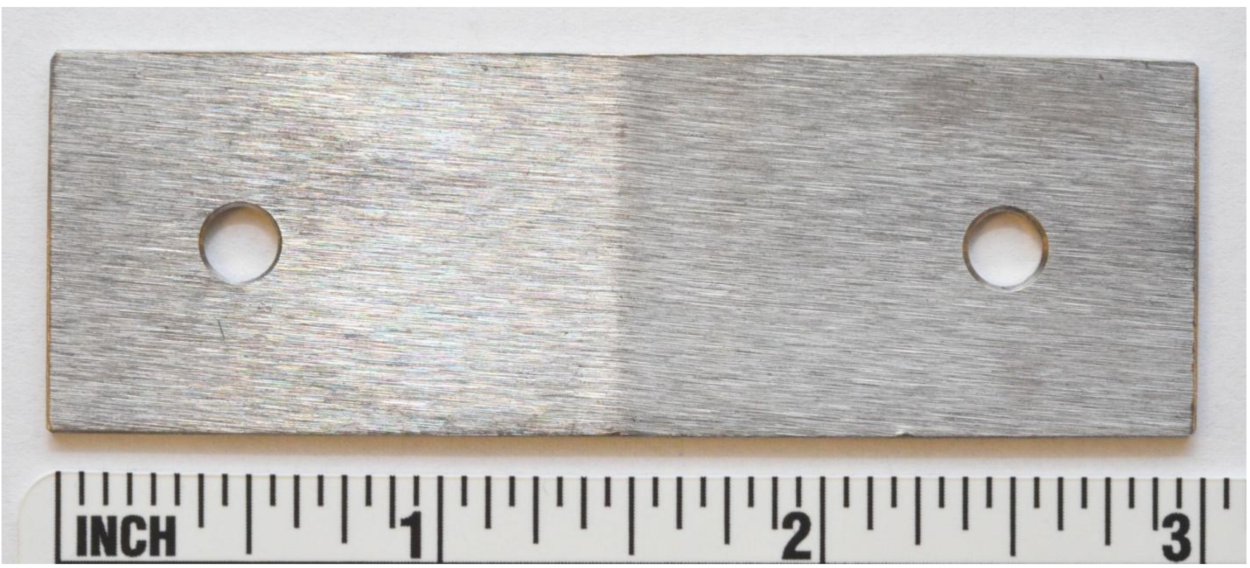
Table 4
Total Mass Loss from Corrosion and Corrosion Rates

Sample	Total Mass Loss from Corrosion*	Corrosion Rate
Coupon 1	0.248 grams	0.021 mm / year
Coupon 2	0.386 grams	0.016 mm / year
Coupon 3	0.387 grams	0.010 mm / year
Screen 1	2.04 grams	0.022 mm / year
Screen 2	4.05 grams	0.022 mm / year
Screen 3	4.94 grams	0.016 mm / year

* Weight As-Received – (Weight Before Cleaning – Mass Loss from Corrosion During Cleaning)

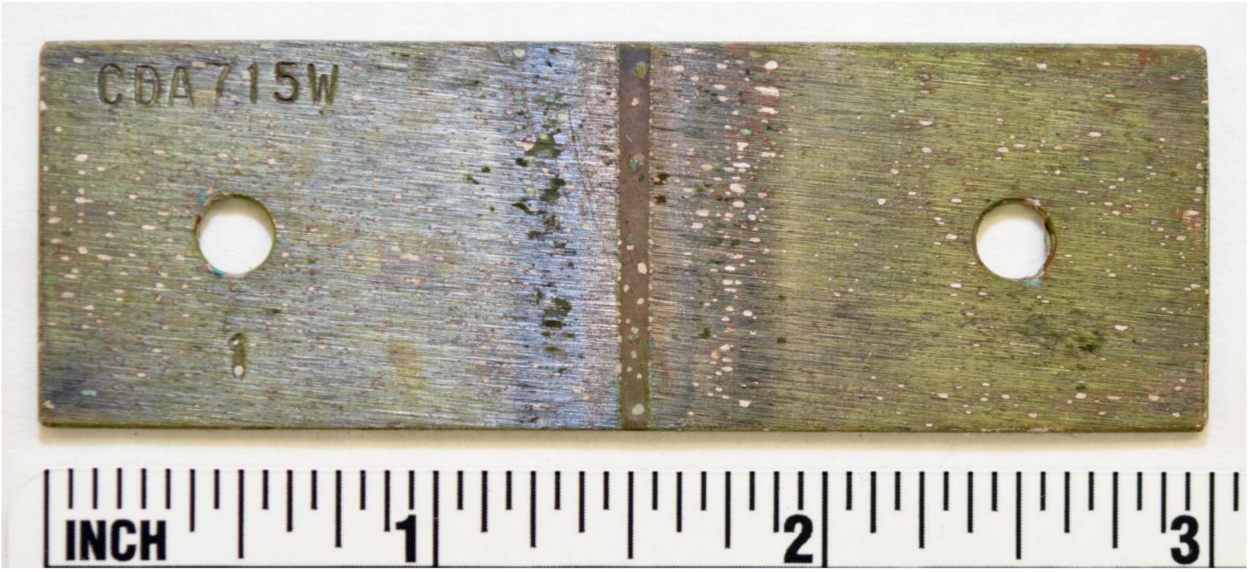


(a) CDA 715 Baseline Coupon, Front Side

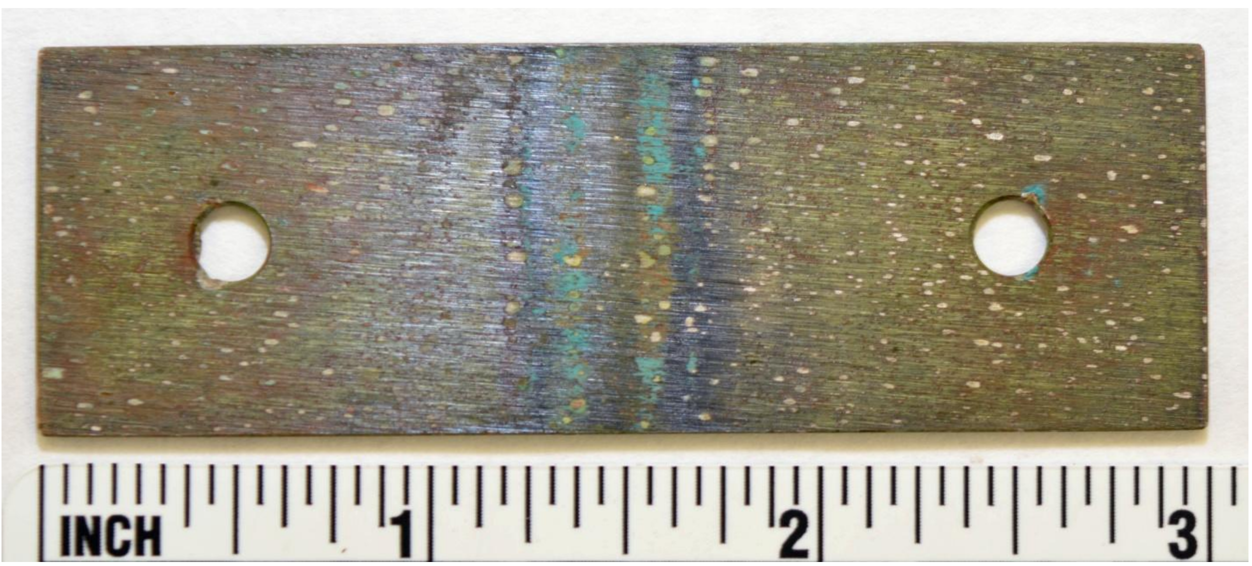


(b) CDA 715 Baseline Coupon, Back Side

Figure 1 Photographs of the CDA 715 baseline coupon (a) front and (b) back side.

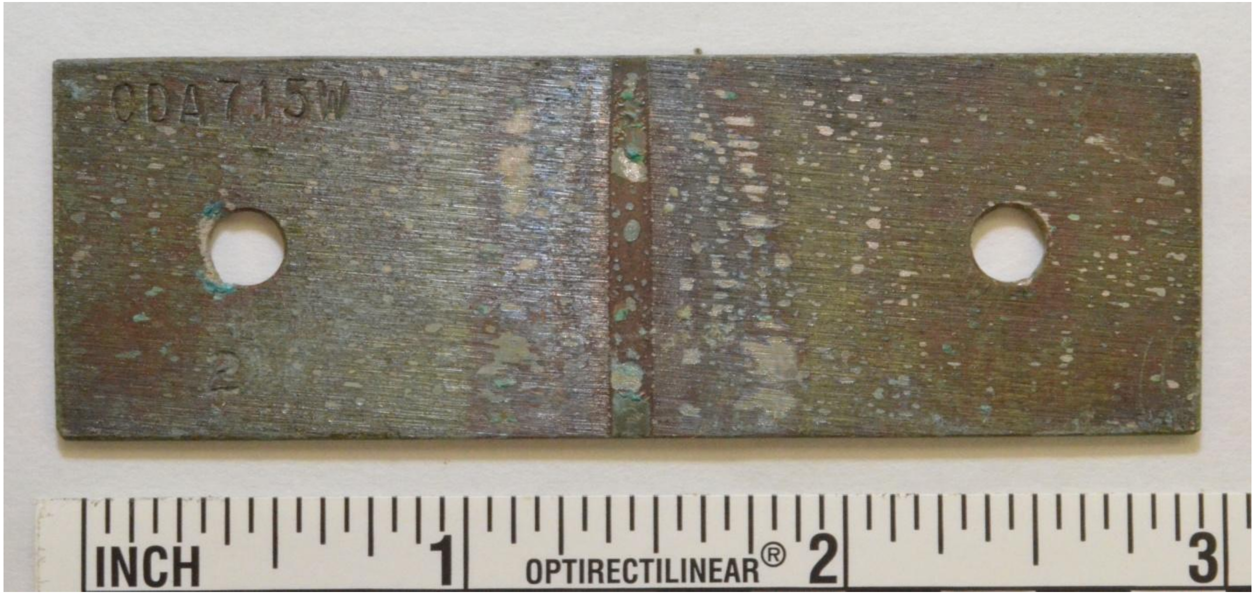


(a) CDA 715 Coupon 1, Front Side

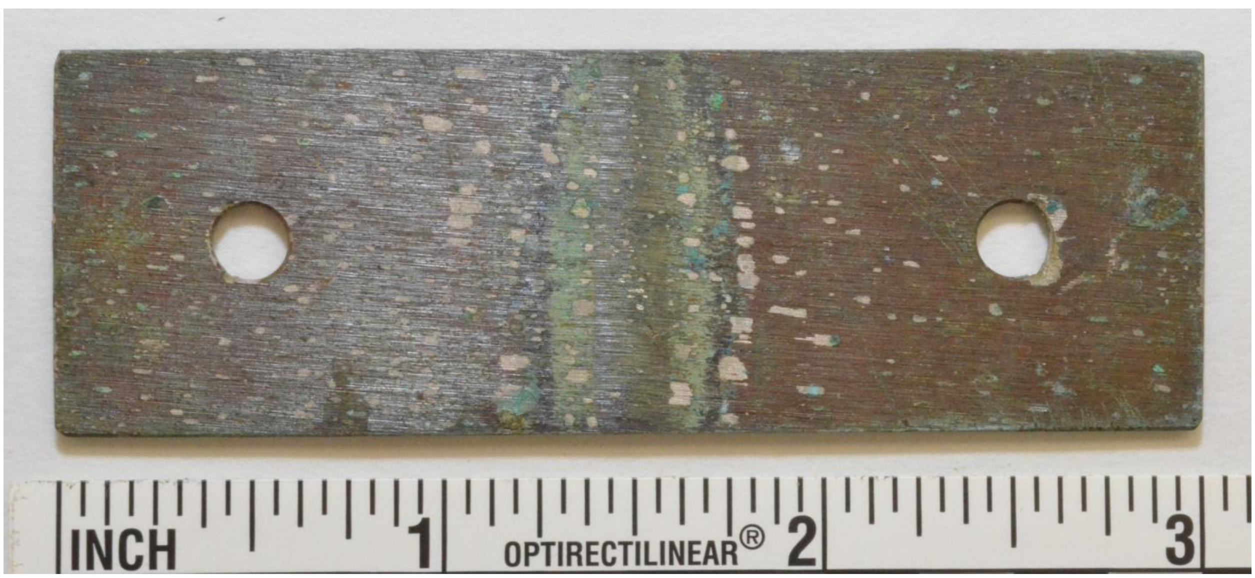


(b) CDA 715 Coupon 1, Back Side

Figure 2 Photographs of CDA 715 coupon 1 (a) front and (b) back side after a 3 month corrosion test.

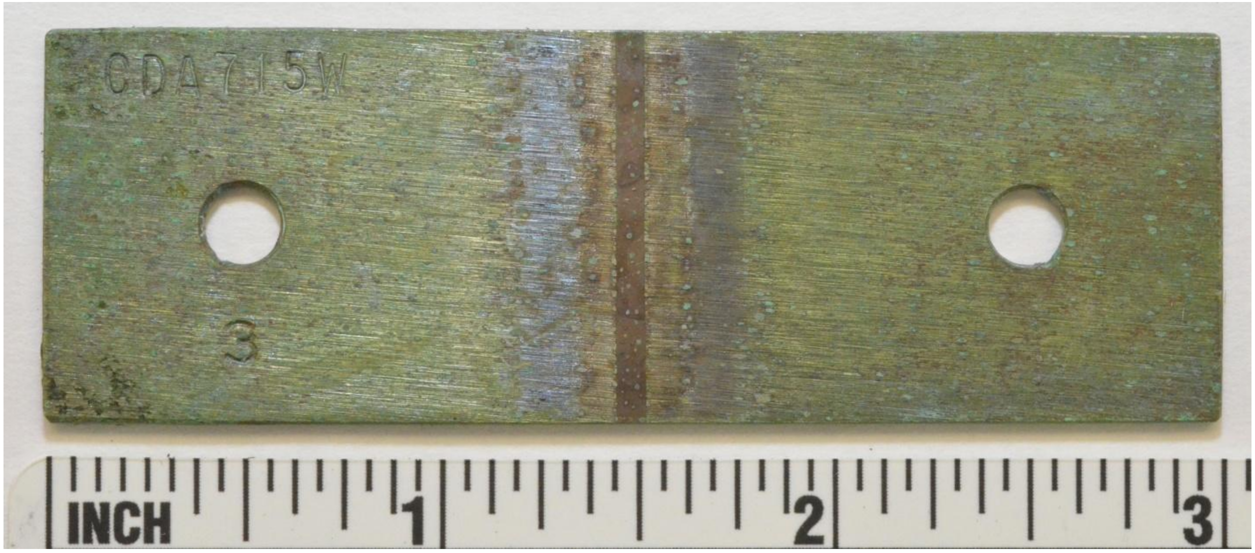


(a) CDA 715 Coupon 2, Front Side

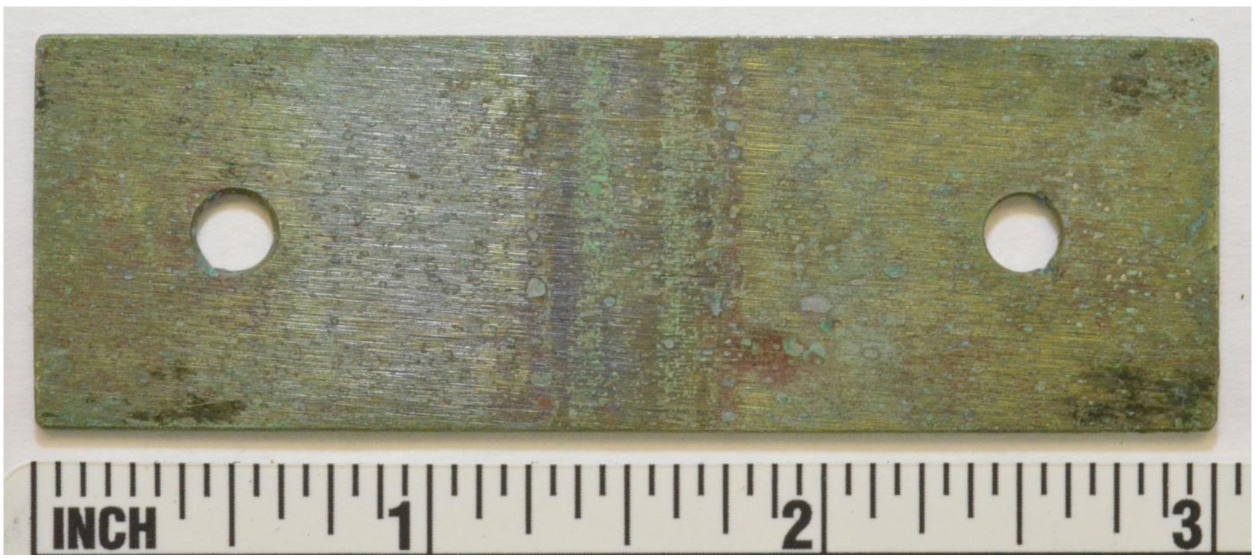


(b) CDA 715 Coupon 2, Back Side

Figure 3 Photographs of CDA 715 coupon 2 (a) front and (b) back side after a 6 month corrosion test.

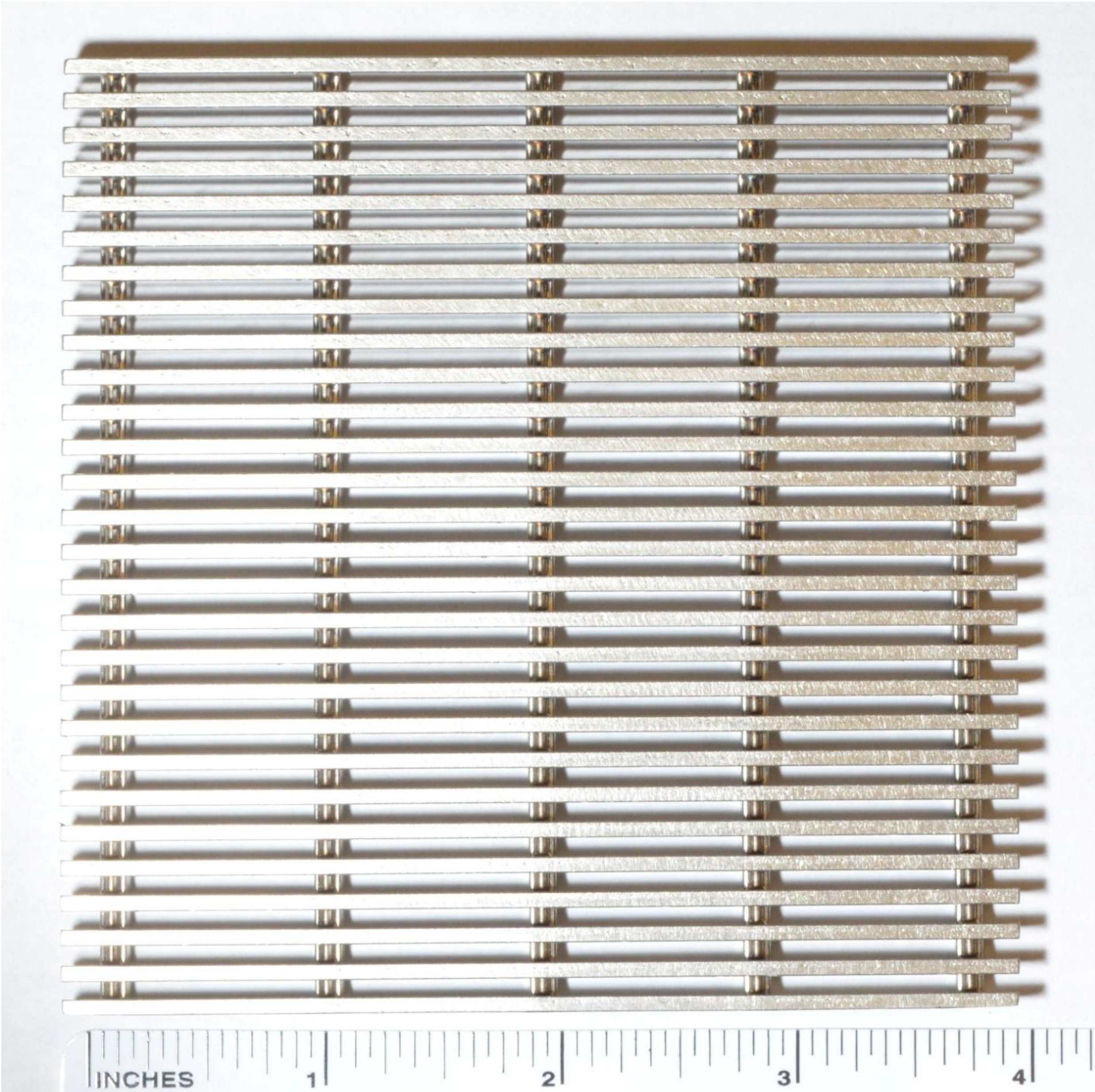


(a) CDA 715 Coupon 3, Front Side



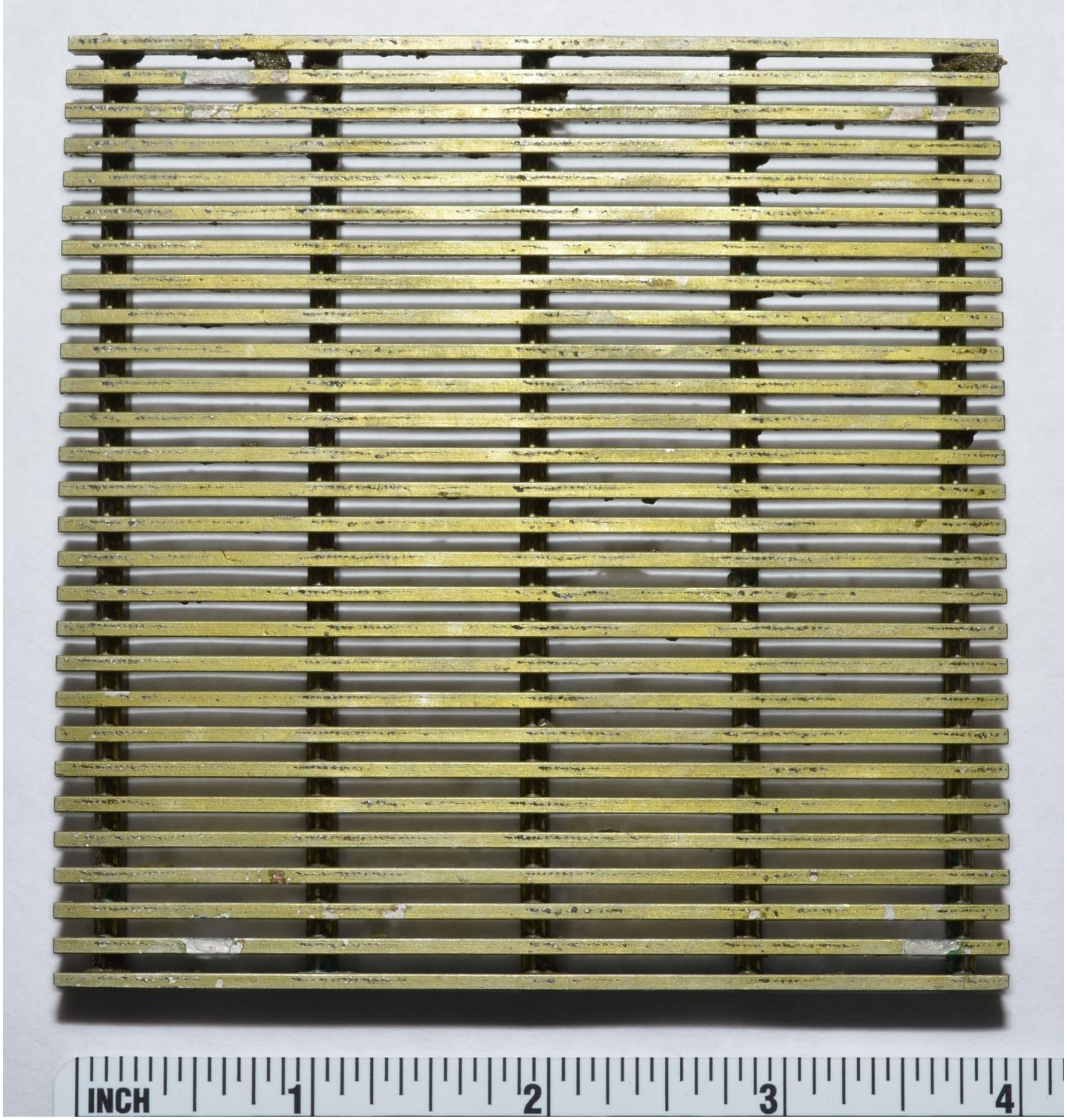
(b) CDA 715 Coupon 3, Back Side

Figure 4 Photographs of CDA 715 coupon 3 (a) front and (b) back side after a 10 month corrosion test.



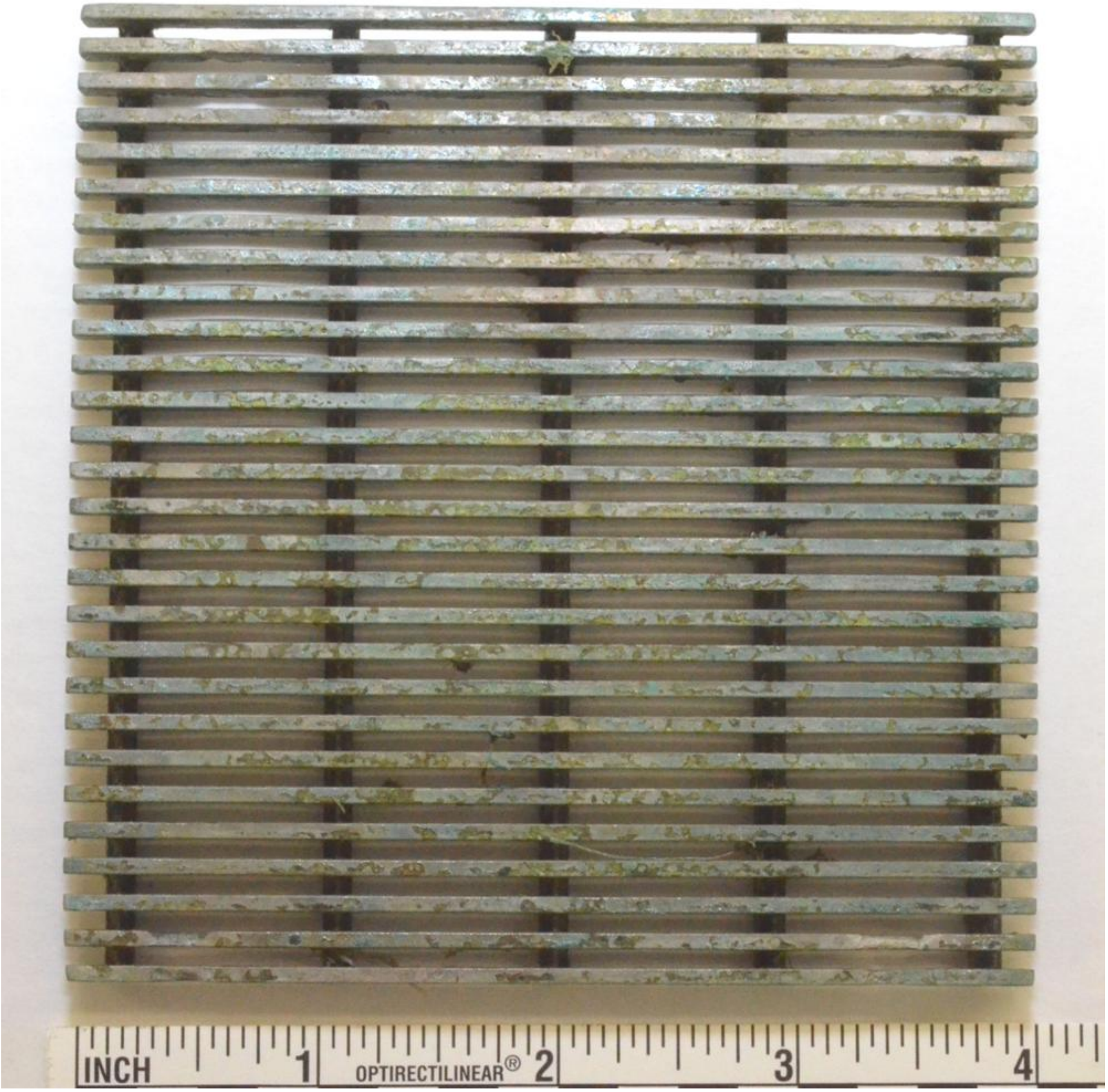
(a) CDA 715 Baseline Screen

Figure 5 Photograph of the CDA 715 baseline screen.



(a) CDA 715 Screen 1

Figure 6 Photograph of CDA 715 screen 1 after a 3 month corrosion test.

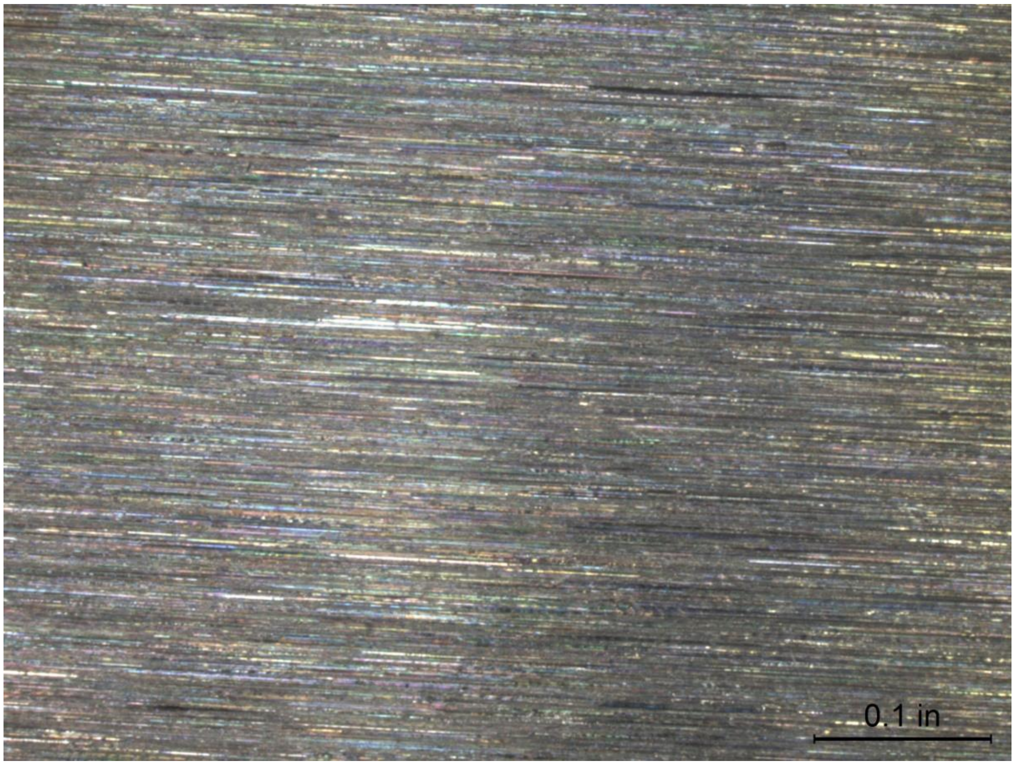


(a) CDA 715 Screen 2

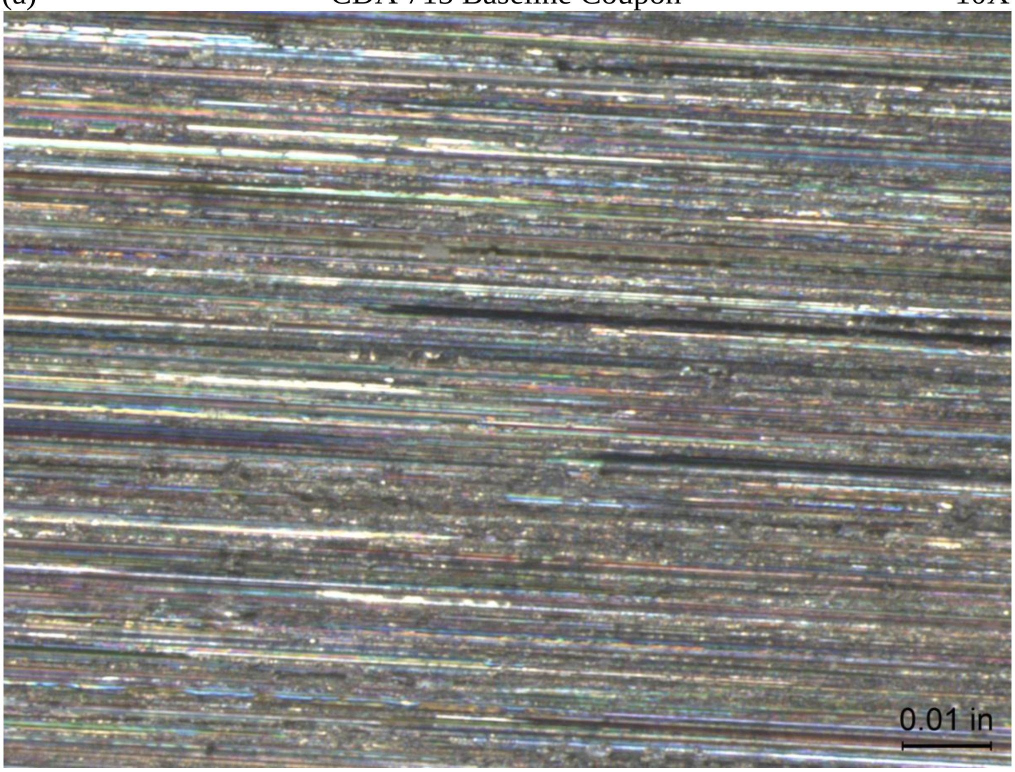
Figure 7 Photograph of CDA 715 screen 2 after a 6 month corrosion test.

(a) CDA 715 Screen 3

Figure 8 Photograph of CDA 715 screen 3 after a 10 month corrosion test.



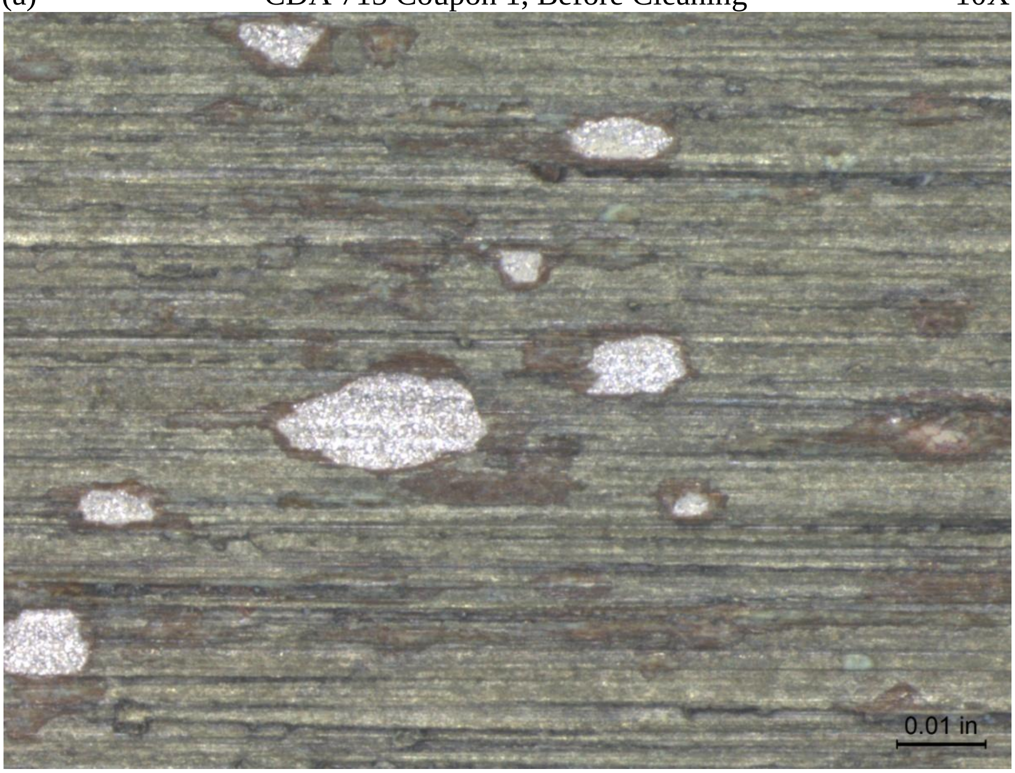
(a) CDA 715 Baseline Coupon 10X



(b) CDA 715 Baseline Coupon 50X

Figure 9 Optical macrographs of the CDA 715 baseline coupon.

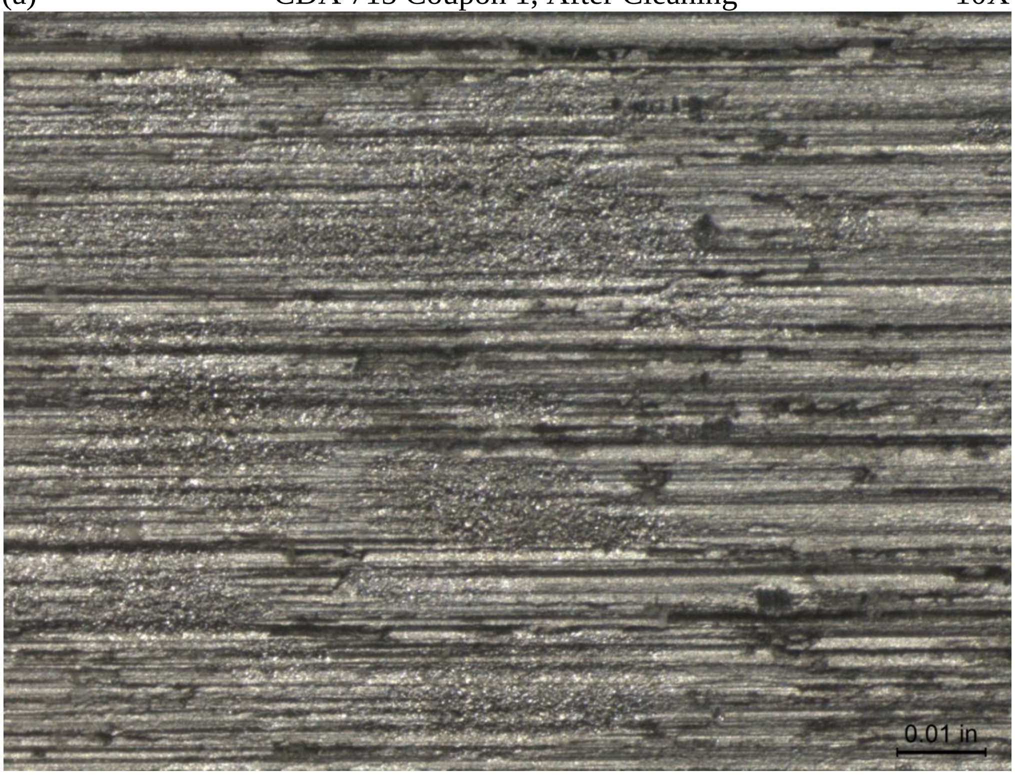
(a) CDA 715 Coupon 1, Before Cleaning 10X



(b) CDA 715 Coupon 1, Before Cleaning 50X

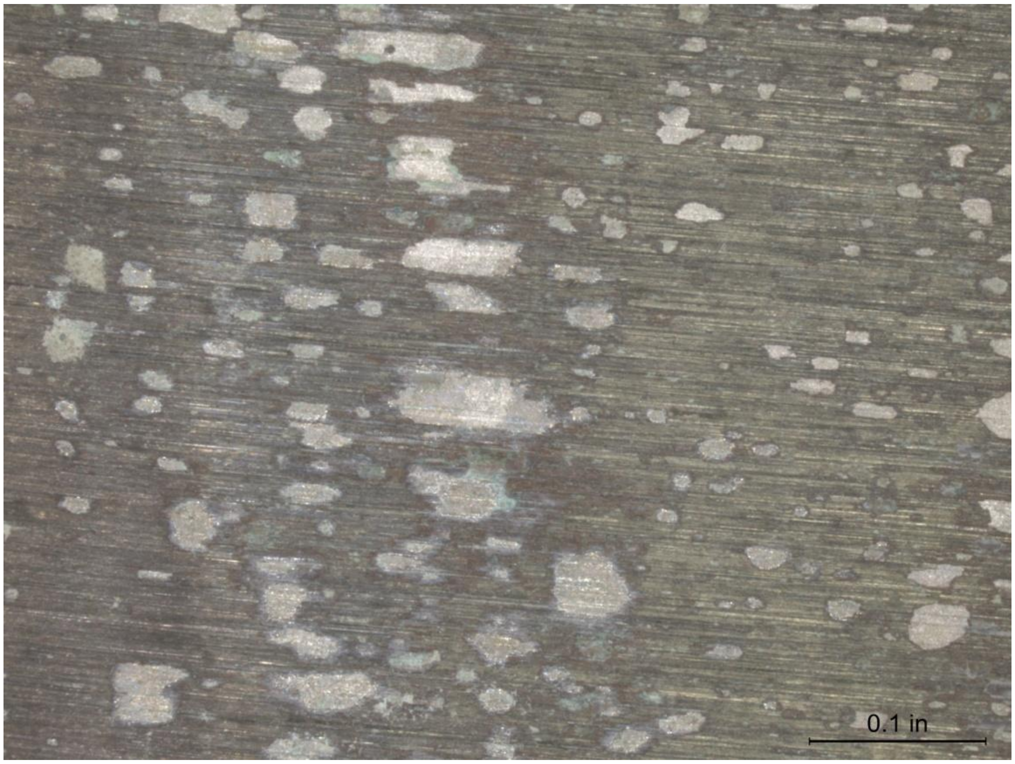
Figure 10 Optical macrographs of CDA 715 coupon 1 after a 3 month corrosion test, before cleaning.

(a) CDA 715 Coupon 1, After Cleaning 10X

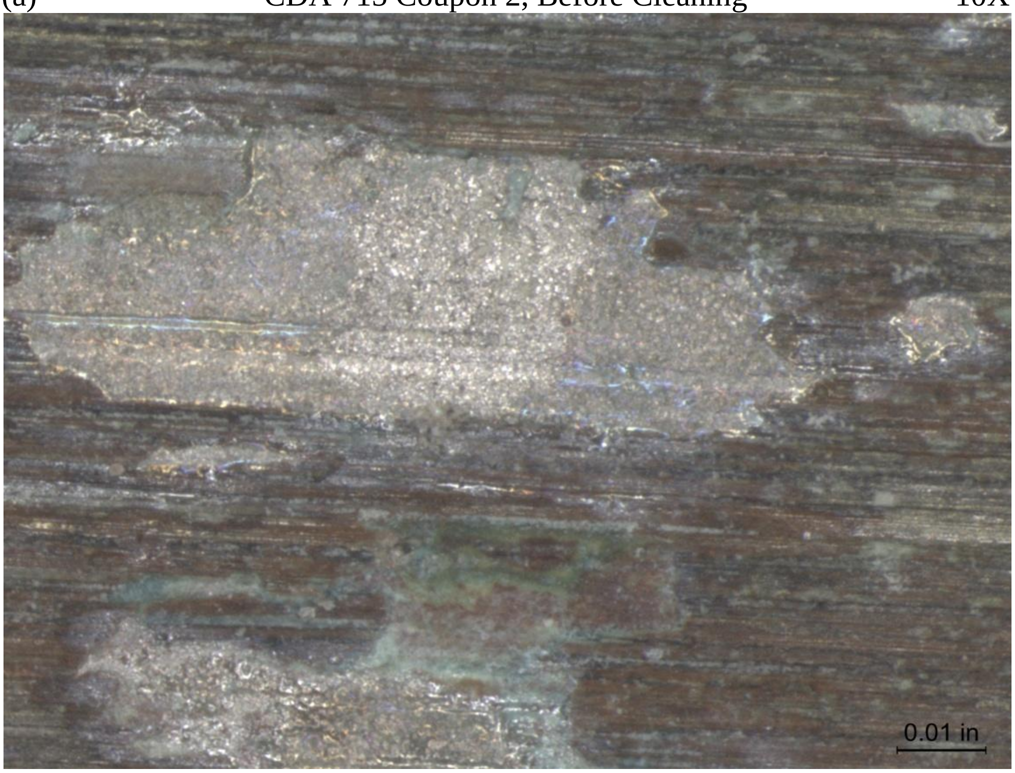


(b) CDA 715 Coupon 1, After Cleaning 50X

Figure 11 Optical macrographs of CDA 715 coupon 1 after a 3 month corrosion test, after cleaning.



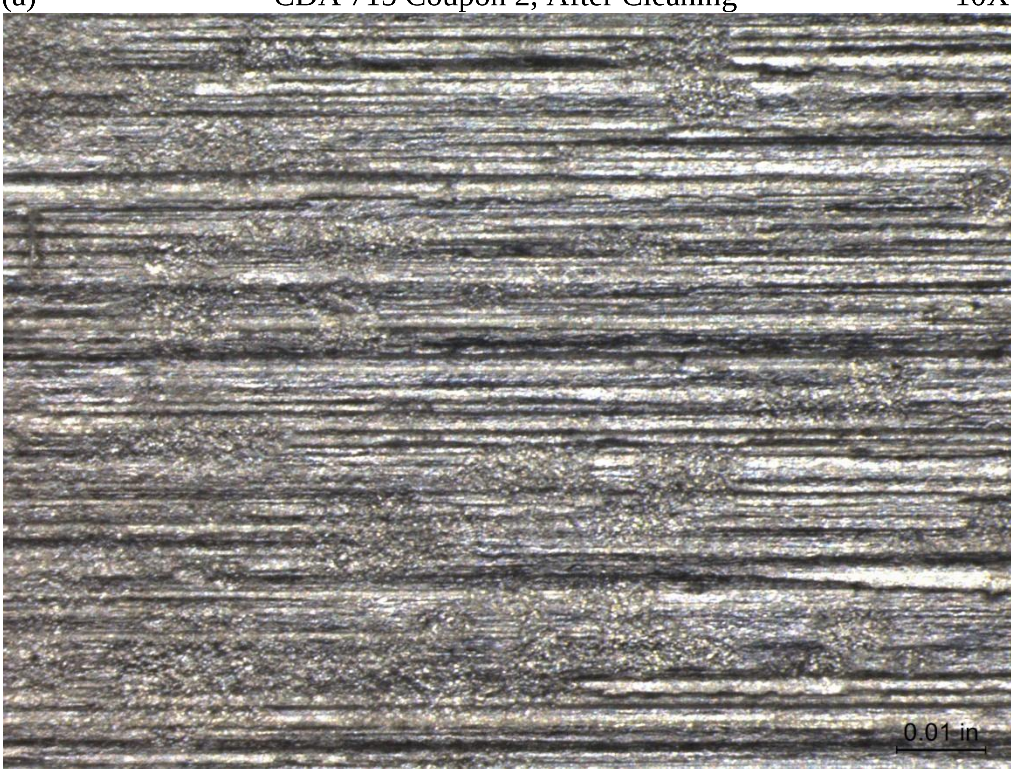
(a) CDA 715 Coupon 2, Before Cleaning 10X



(b) CDA 715 Coupon 2, Before Cleaning 50X

Figure 12 Optical macrographs of CDA 715 coupon 2 after a 6 month corrosion test, before cleaning.

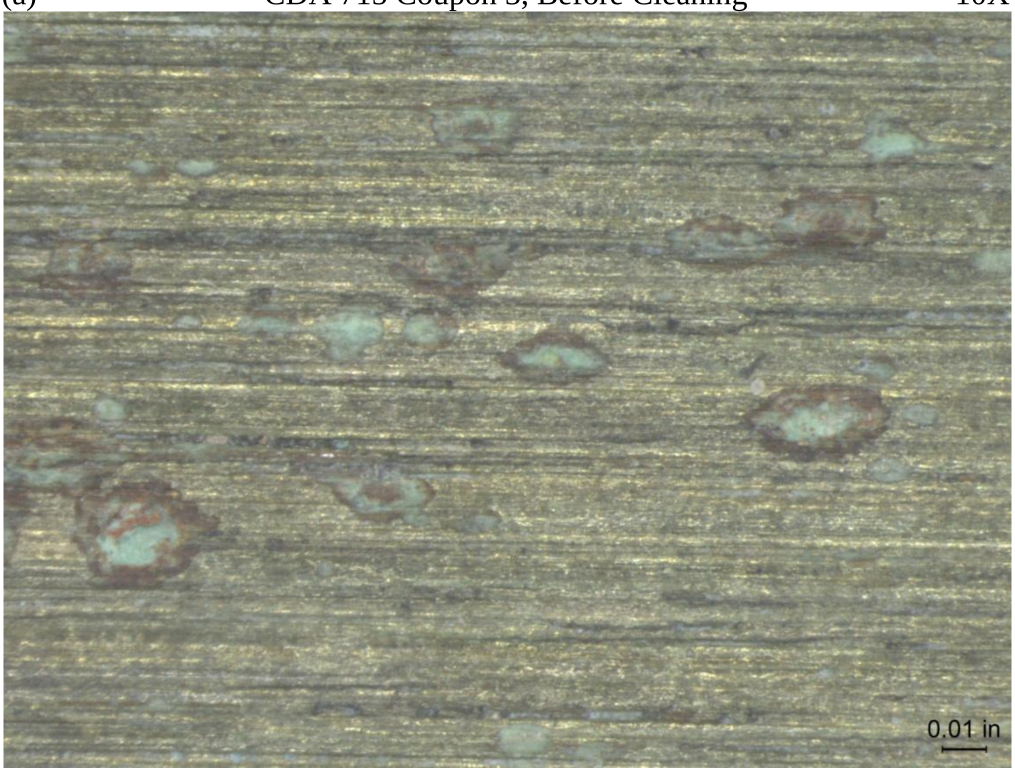
(a) CDA 715 Coupon 2, After Cleaning 10X



(b) CDA 715 Coupon 2, After Cleaning 50X

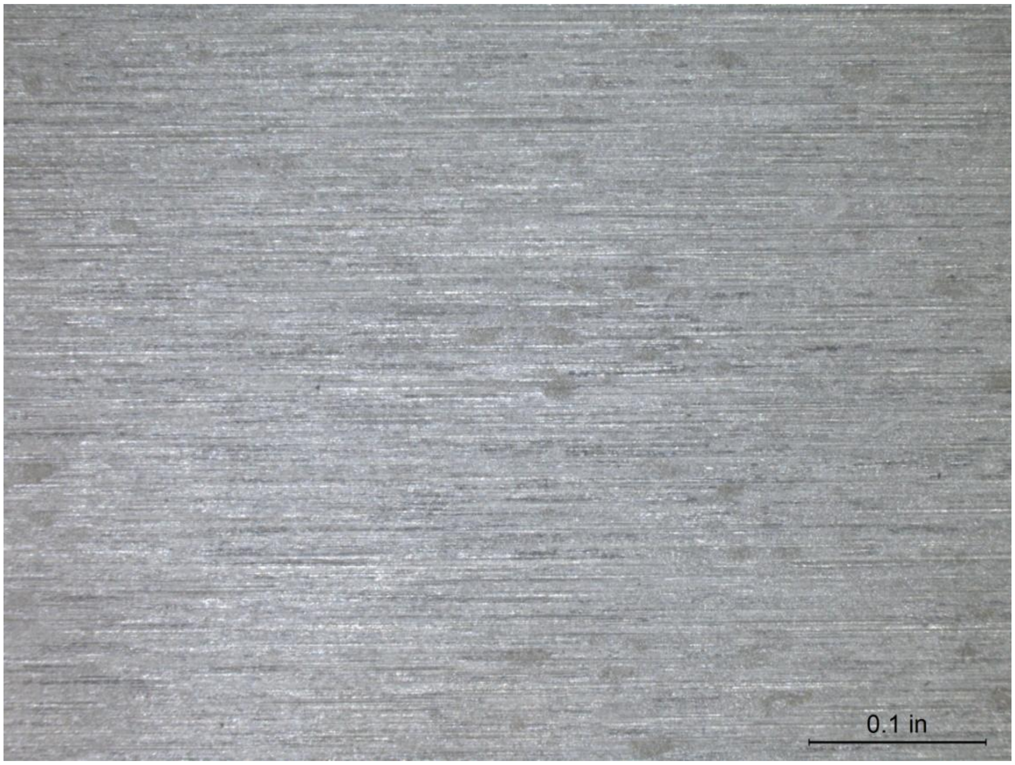
Figure 13 Optical macrographs of CDA 715 coupon 2 after a 6 month corrosion test, after cleaning.

(a) CDA 715 Coupon 3, Before Cleaning 10X

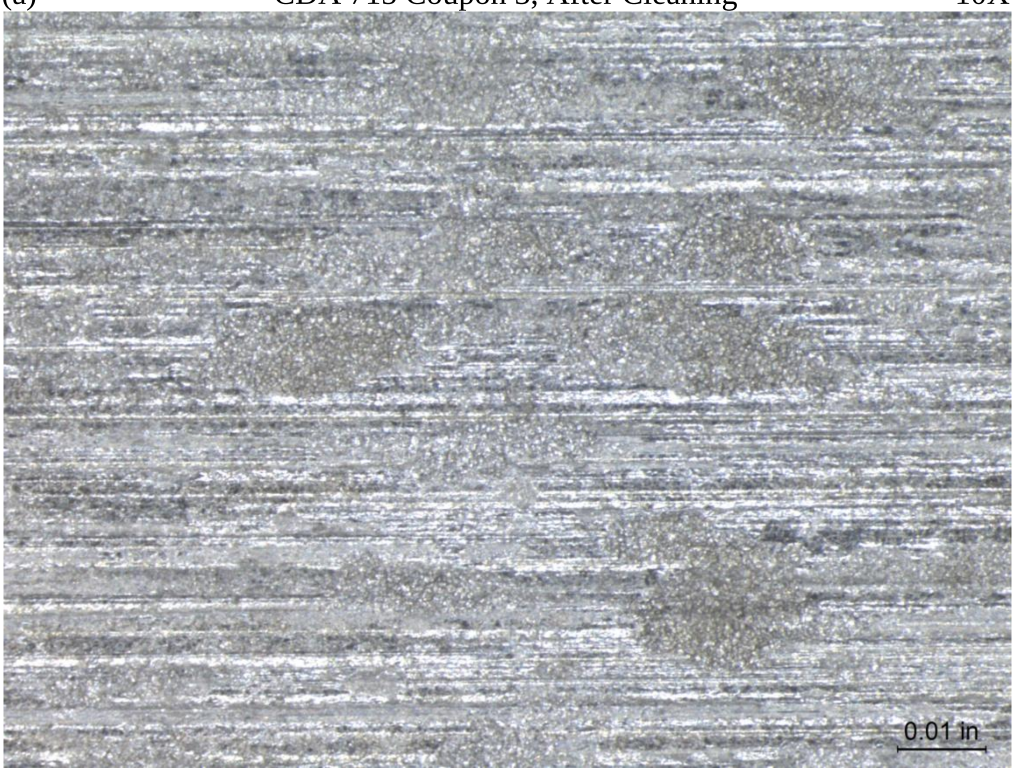


(b) CDA 715 Coupon 3, Before Cleaning 50X

Figure 14 Optical macrographs of CDA 715 coupon 3 after a 10 month corrosion test, before cleaning.

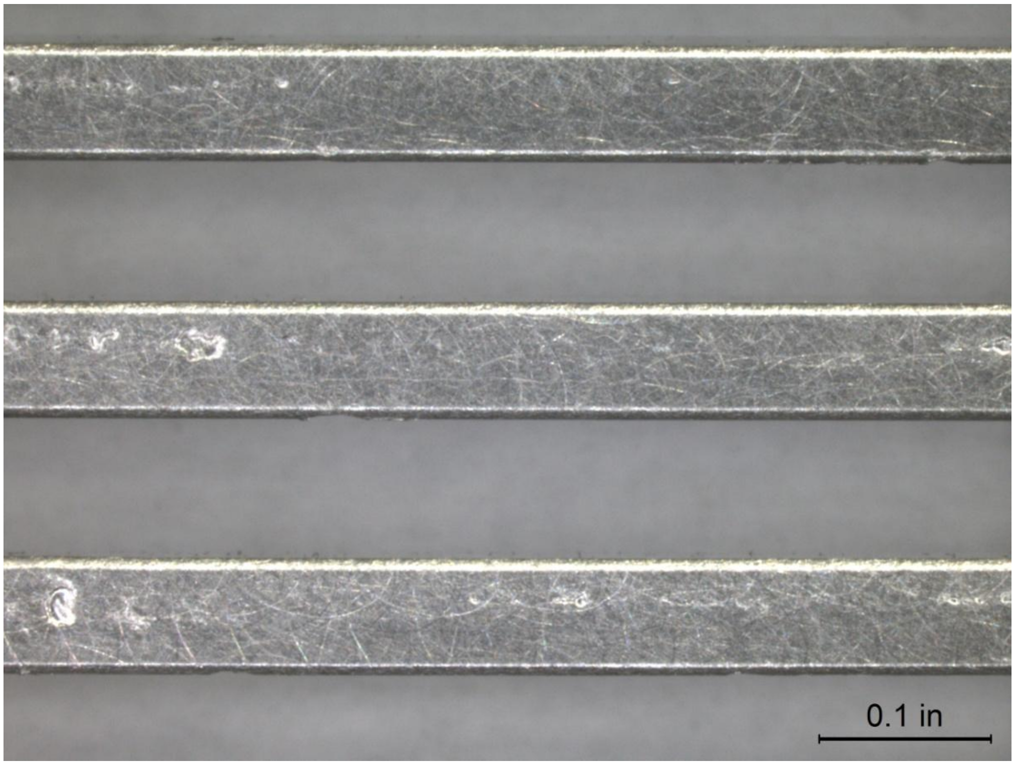


(a) CDA 715 Coupon 3, After Cleaning 10X

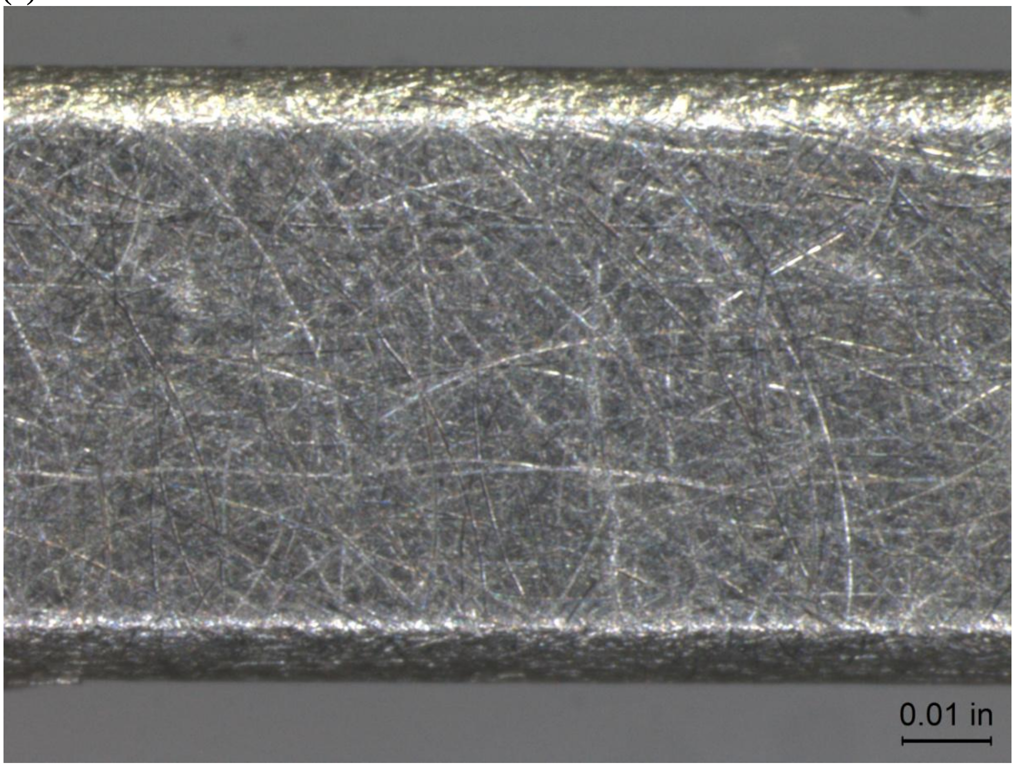


(b) CDA 715 Coupon 3, After Cleaning 50X

Figure 15 Optical macrographs of CDA 715 coupon 3 after a 10 month corrosion test, after cleaning.

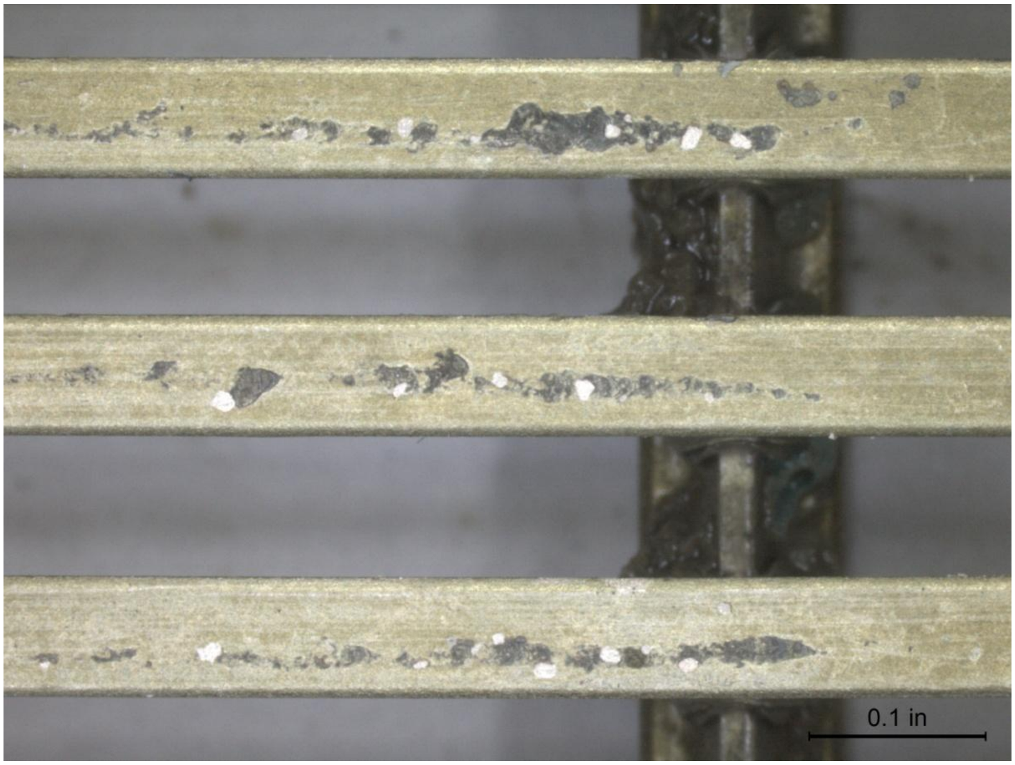


(a) CDA 715 Baseline Screen 10X

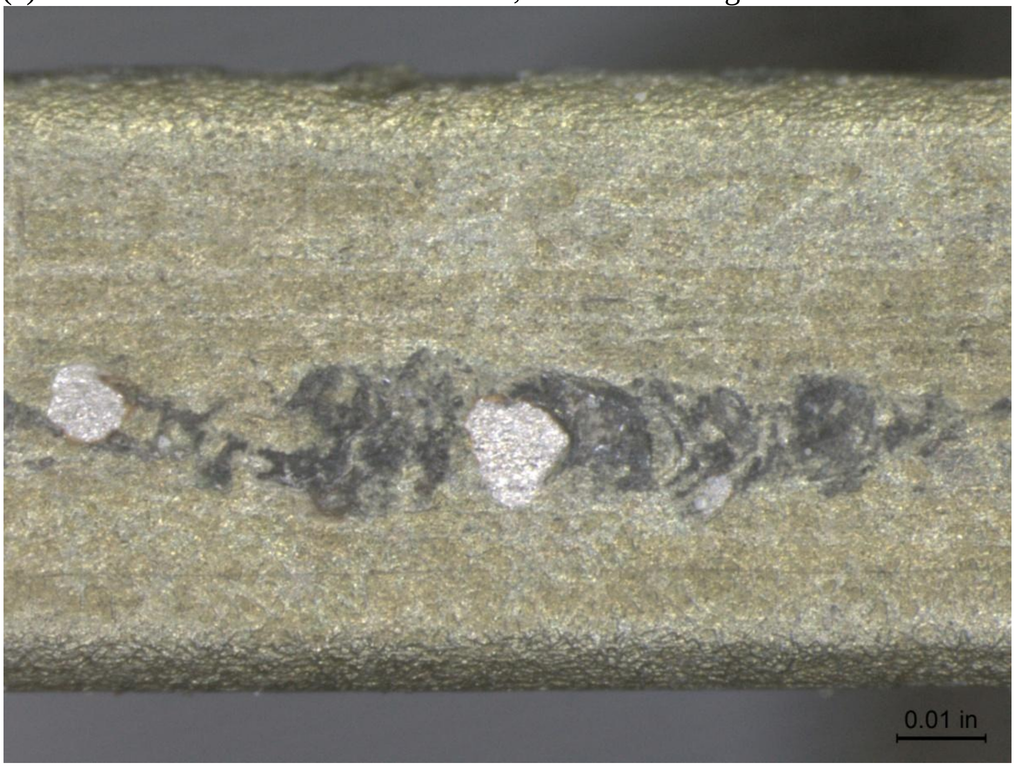


(b) CDA 715 Baseline Screen 50X

Figure 16 Optical macrographs of the CDA 715 baseline screen.

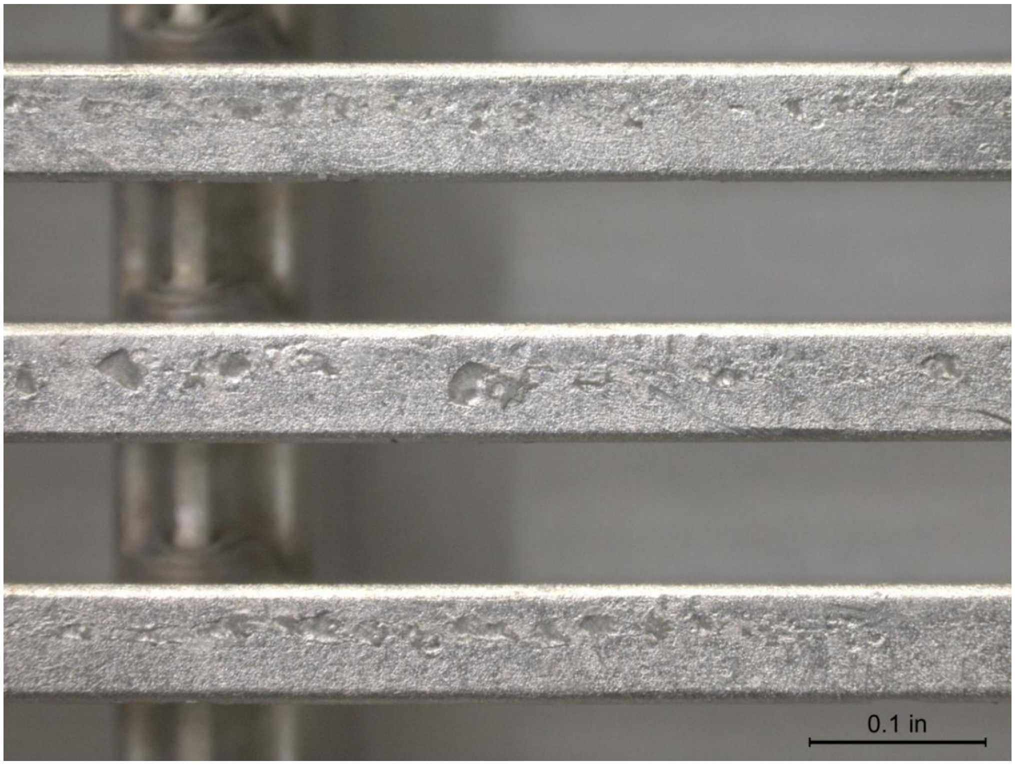


(a) CDA 715 Screen 1, Before Cleaning 10X



(b) CDA 715 Screen 1, Before Cleaning 50X

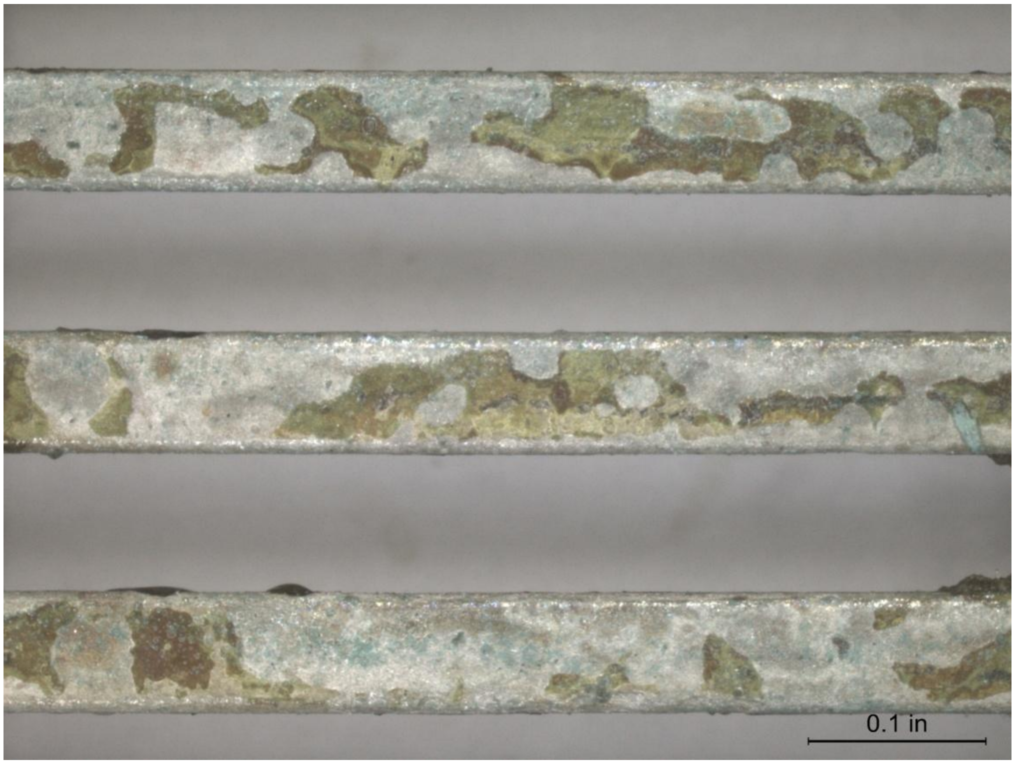
Figure 17 Optical macrographs of CDA 715 screen 1 after a 3 month corrosion test, before cleaning.



(a) CDA 715 Screen 1, After Cleaning 10X

(b) CDA 715 Screen 1, After Cleaning 50X

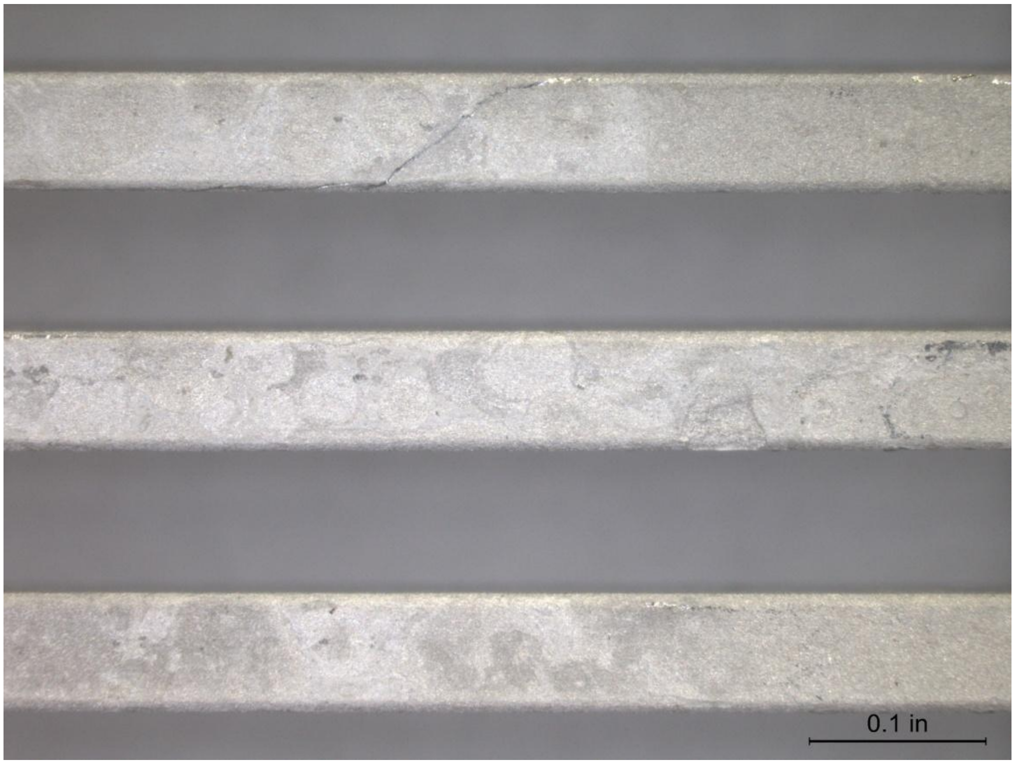
Figure 18 Optical macrographs of CDA 715 screen 1 after a 3 month corrosion test, after cleaning.



(a) CDA 715 Screen 2, Before Cleaning 10X

(b) CDA 715 Screen 2, Before Cleaning 50X

Figure 19 Optical macrographs of CDA 715 screen 2 after a 6 month corrosion test, before cleaning.



(a) CDA 715 Screen 2, After Cleaning 10X

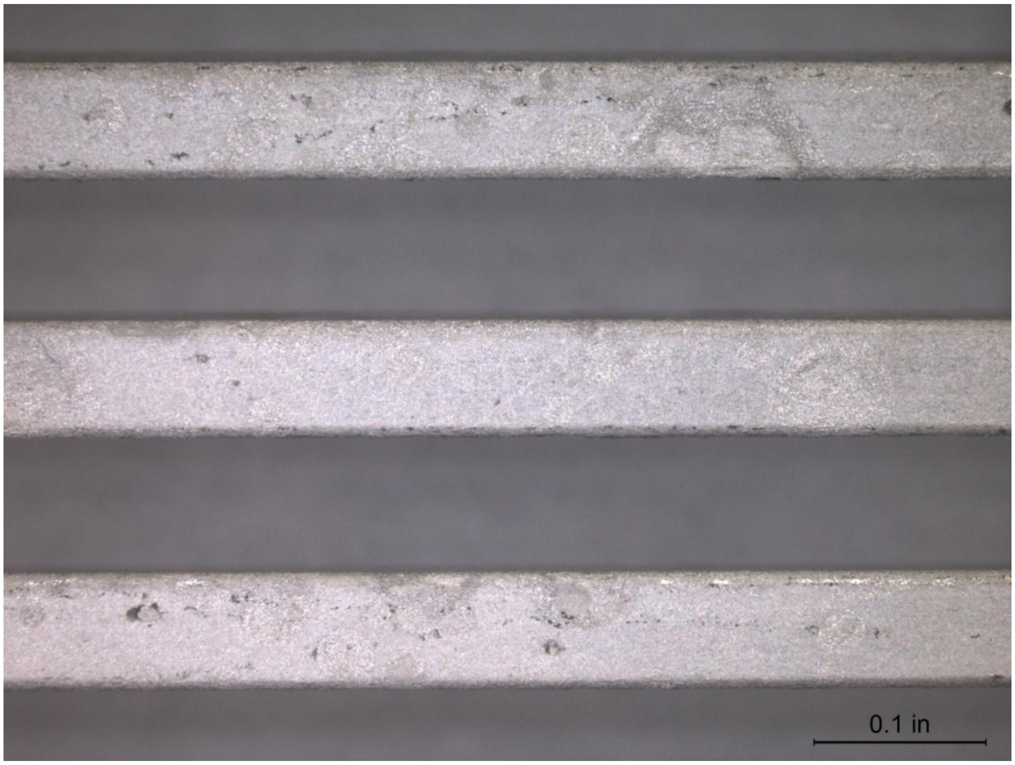
(b) CDA 715 Screen 2, After Cleaning 50X

Figure 20 Optical macrographs of CDA 715 screen 2 after a 6 month corrosion test, after cleaning.

(a) CDA 715 Screen 3, Before Cleaning 10X

(b) CDA 715 Screen 3, Before Cleaning 50X

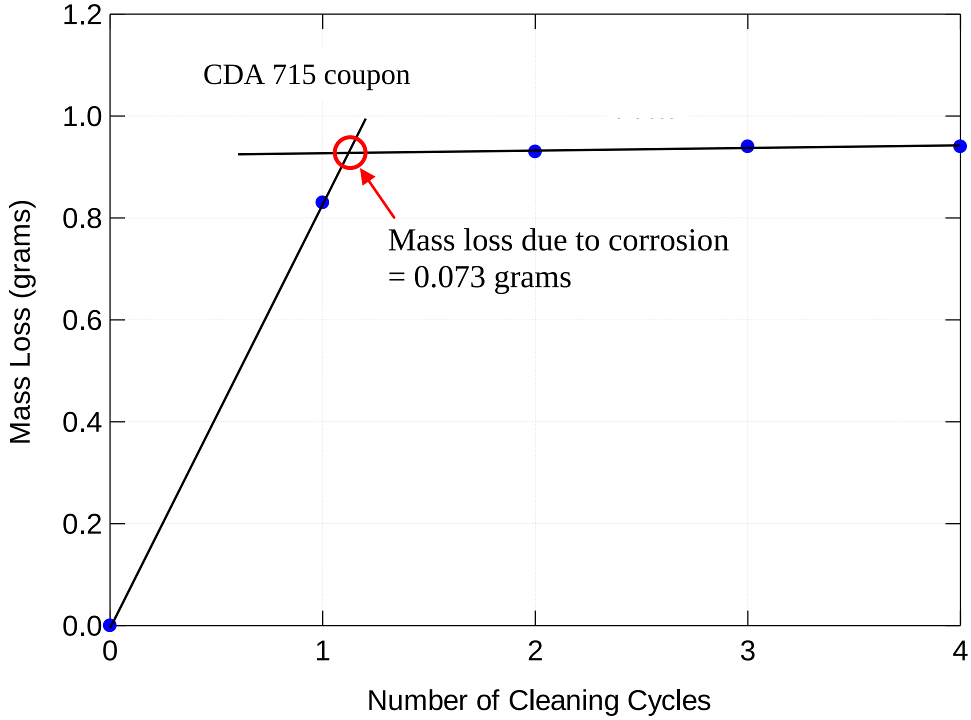
Figure 21 Optical macrographs of CDA 715 screen 3 after a 10 month corrosion test, before cleaning.



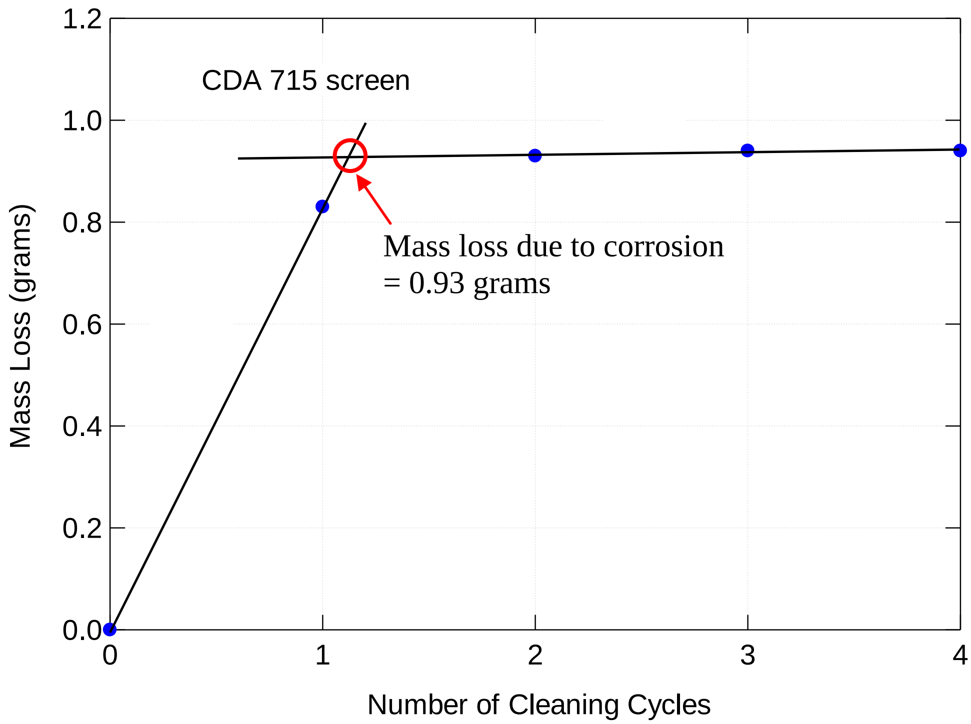
(a) CDA 715 Screen 3, After Cleaning 10X

(b) CDA 715 Screen 3, After Cleaning 50X

Figure 22 Optical macrographs of CDA 715 screen 3 after a 10 month corrosion test, after cleaning.

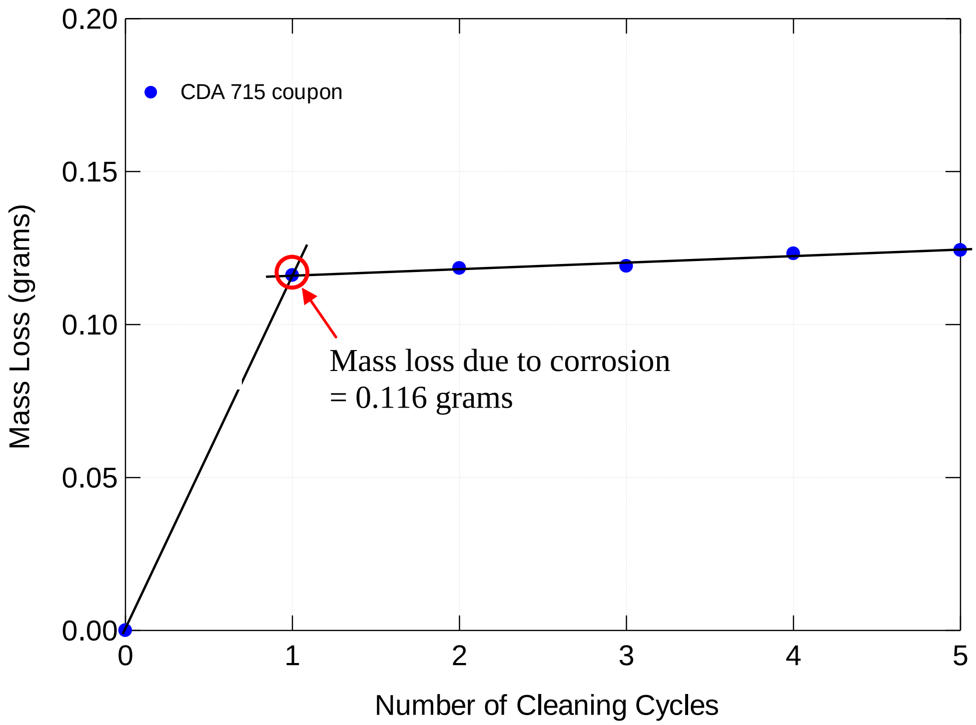


(a)

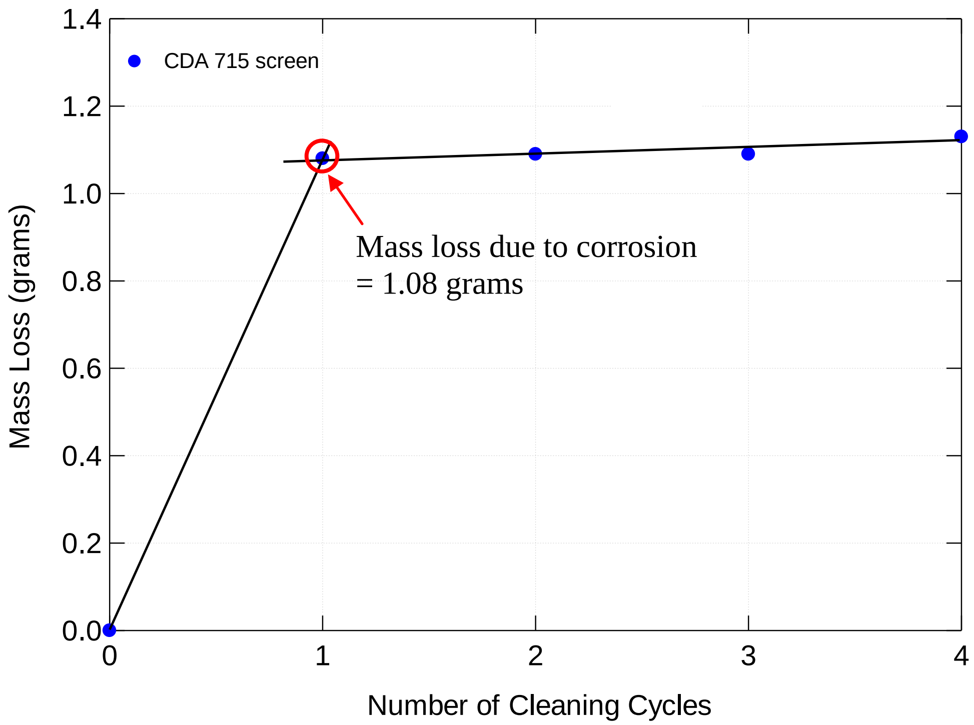


(b)

Figure 23 Mass loss of CDA 715 (a) coupon 1 and (b) screen 1 during cleaning.

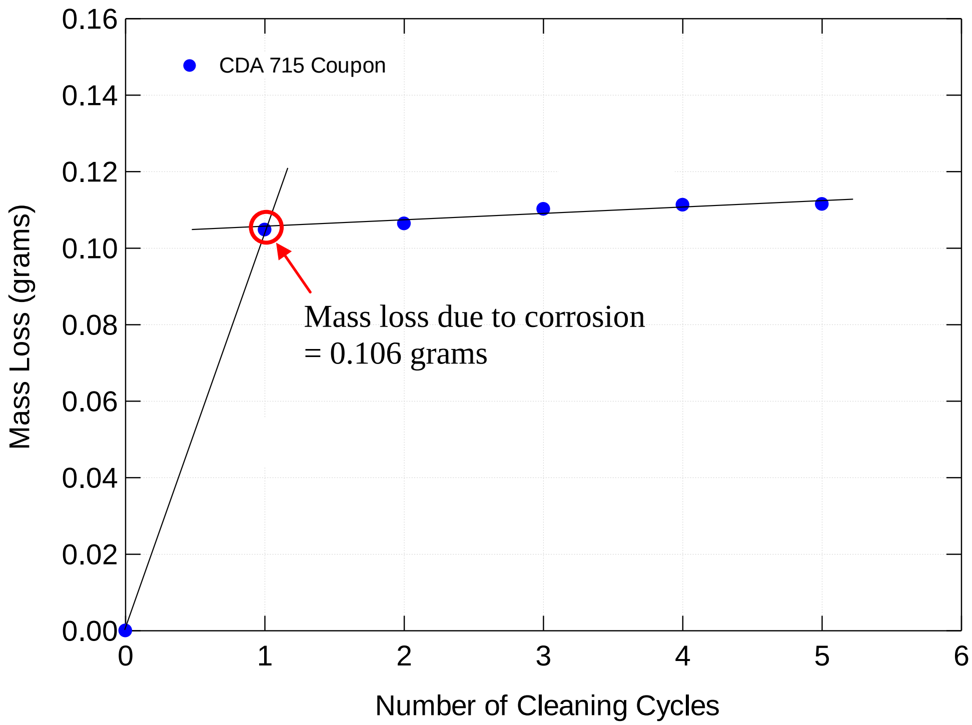


(a)

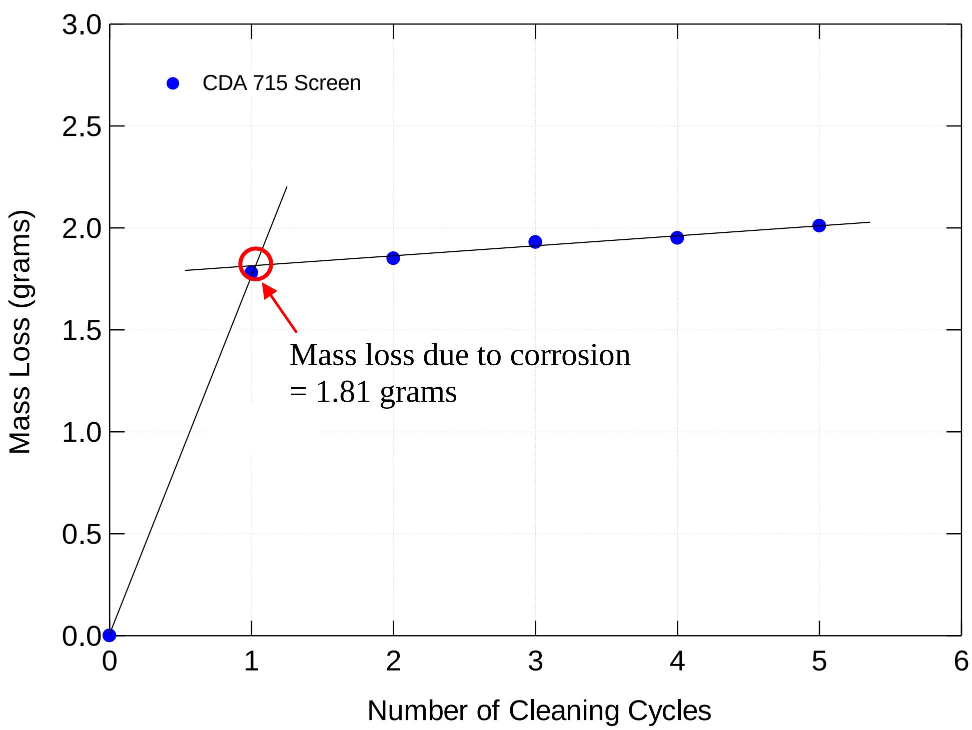


(b)

Figure 24 Mass loss of CDA 715 (a) coupon 2 and (b) screen 2 during cleaning.

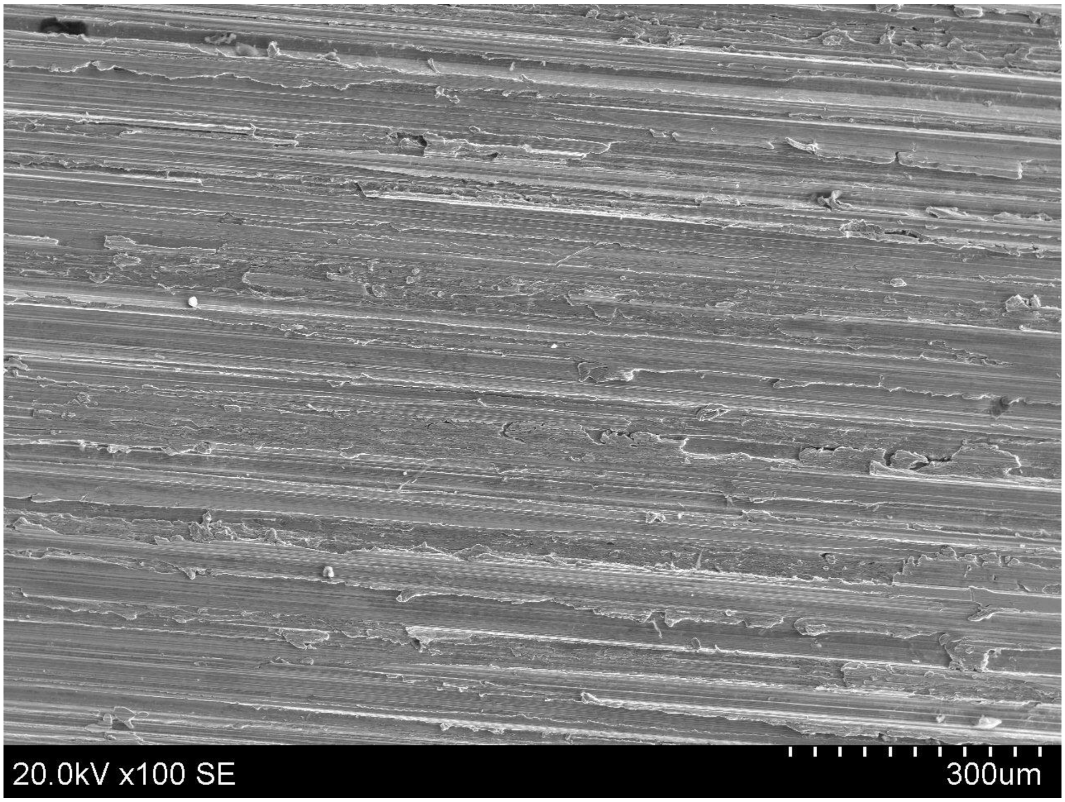


(a)

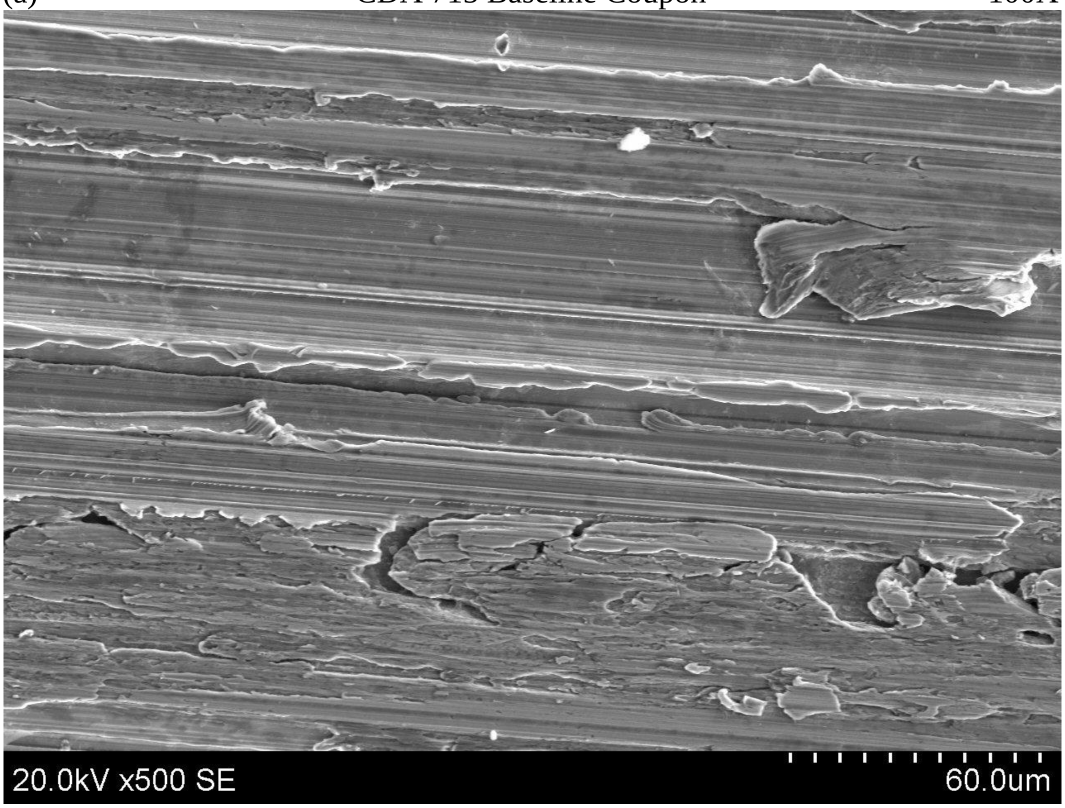


(b)

Figure 25 Mass loss of CDA 715 (a) coupon 3 and (b) screen 3 during cleaning.

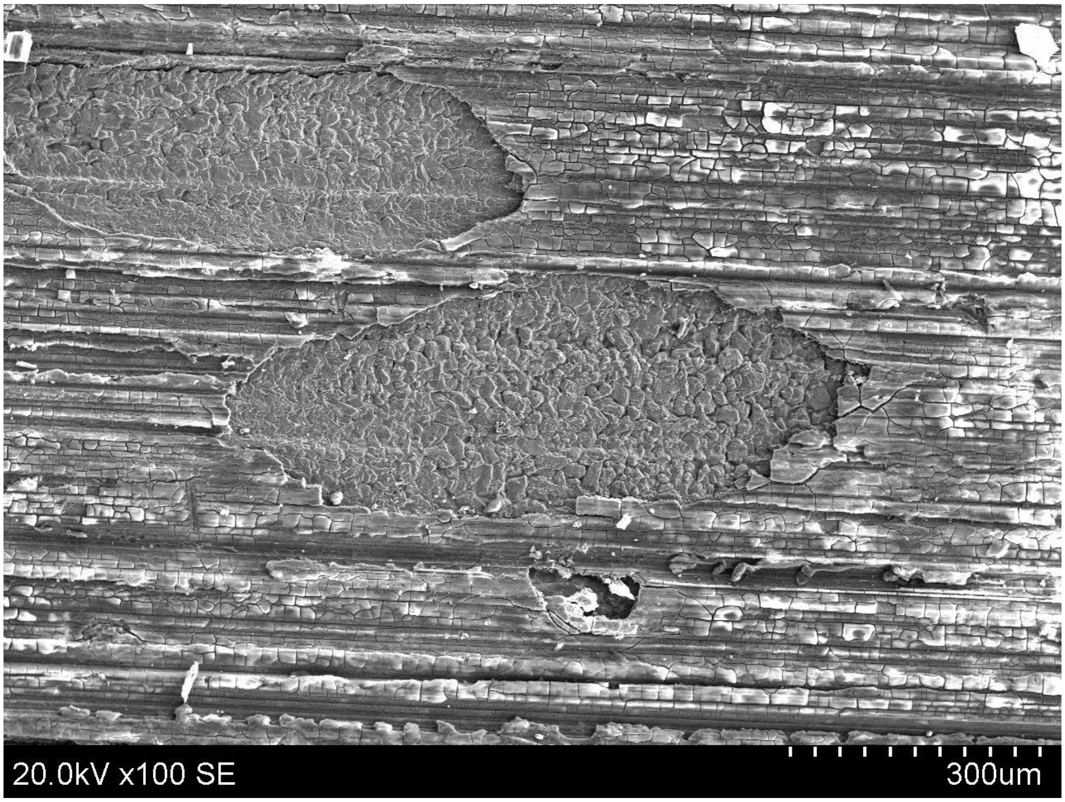


(a) CDA 715 Baseline Coupon 100X

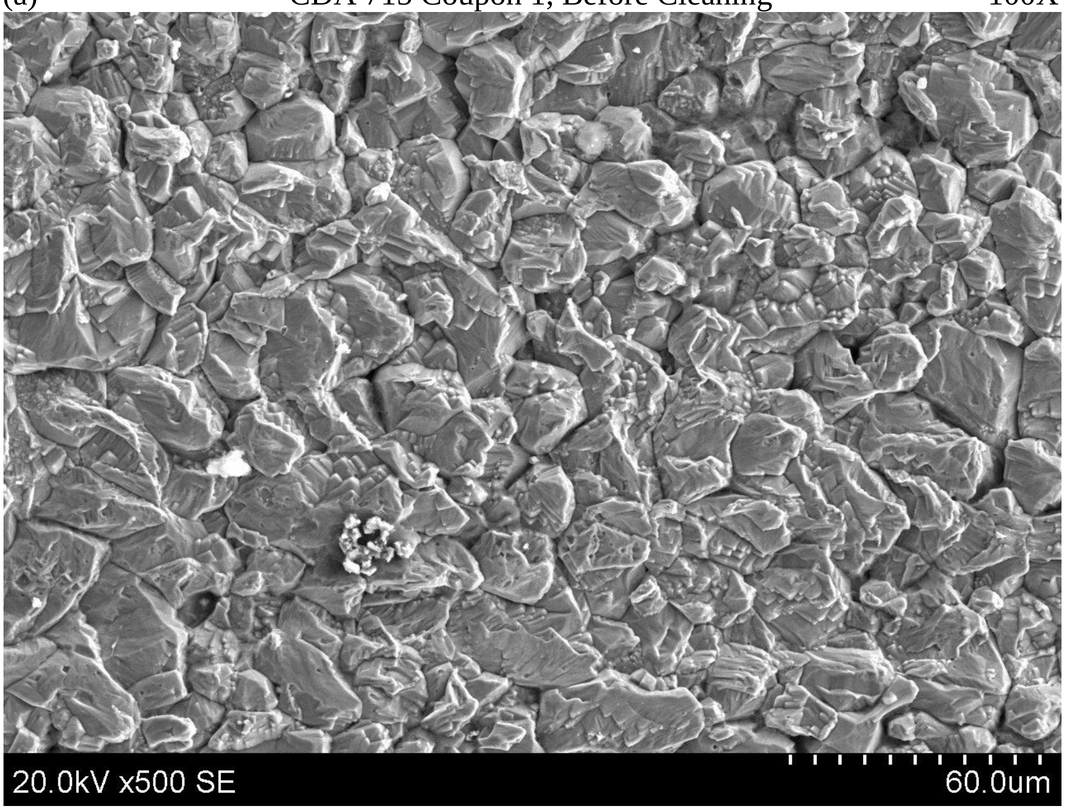


(b) CDA 715 Baseline Coupon 500X

Figure 26 Scanning electron micrographs of the CDA 715 baseline coupon.

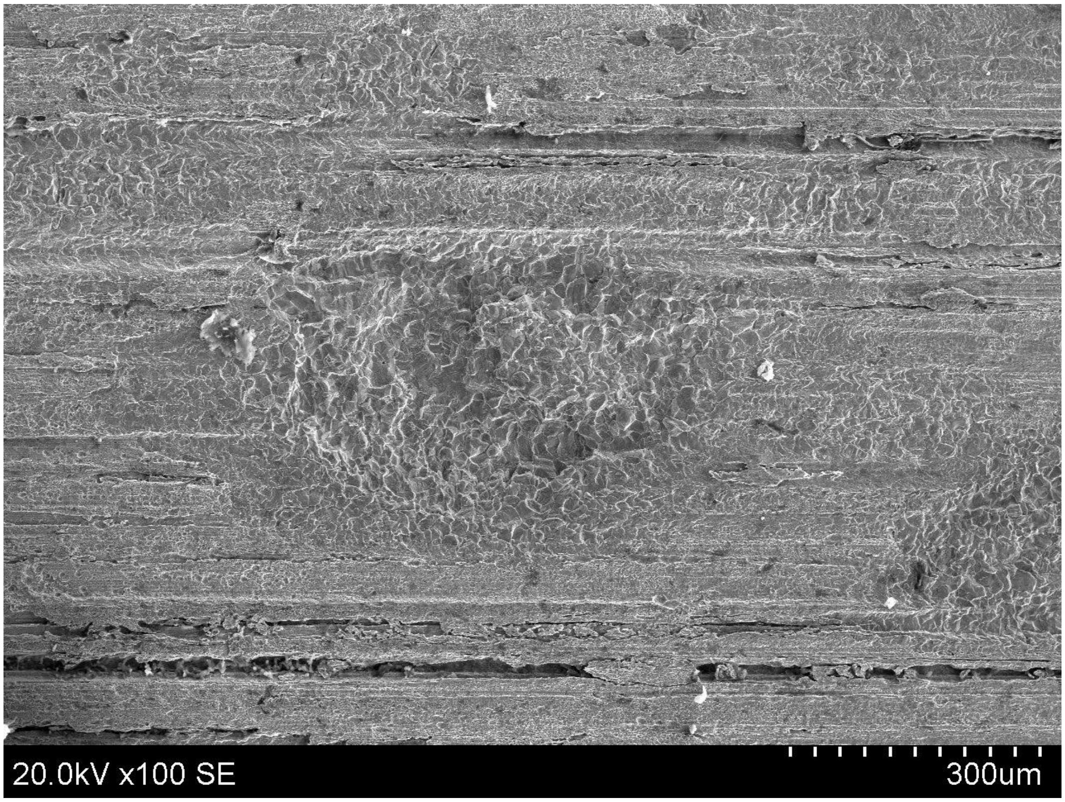


(a) CDA 715 Coupon 1, Before Cleaning 100X

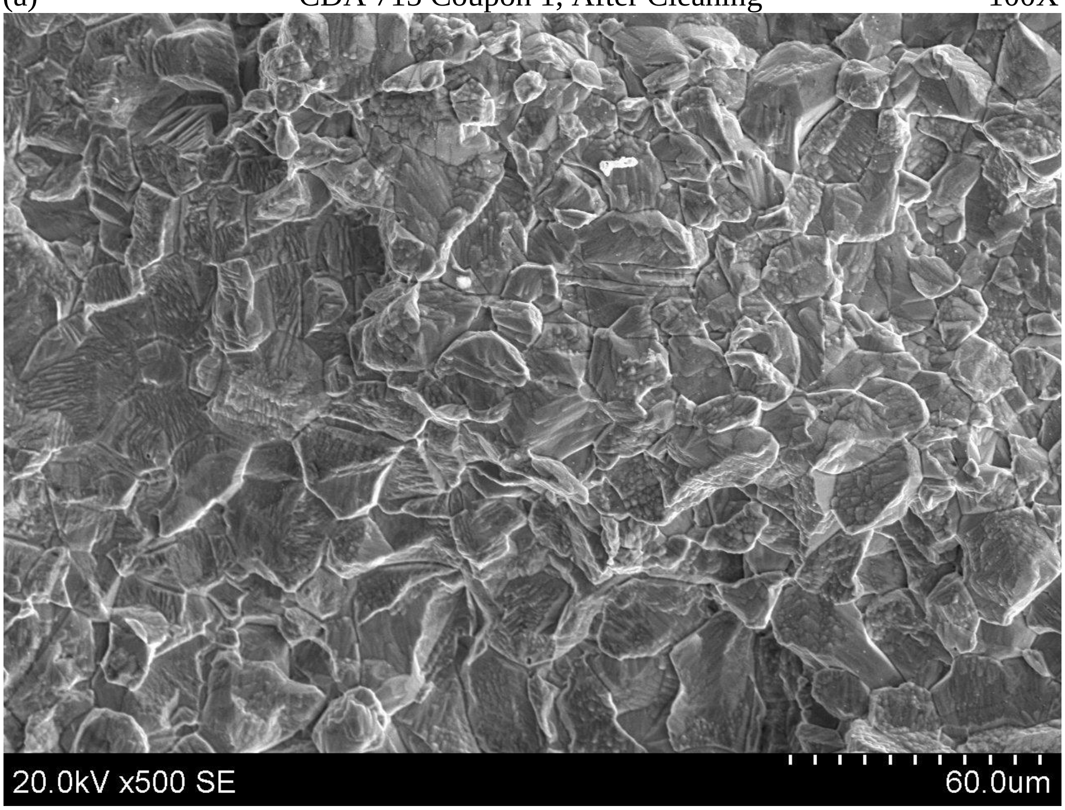


(b) CDA 715 Coupon 1, Before Cleaning 500X

Figure 27 Scanning electron micrographs of CDA 715 coupon 1 after a 3 month immersion test, before cleaning.



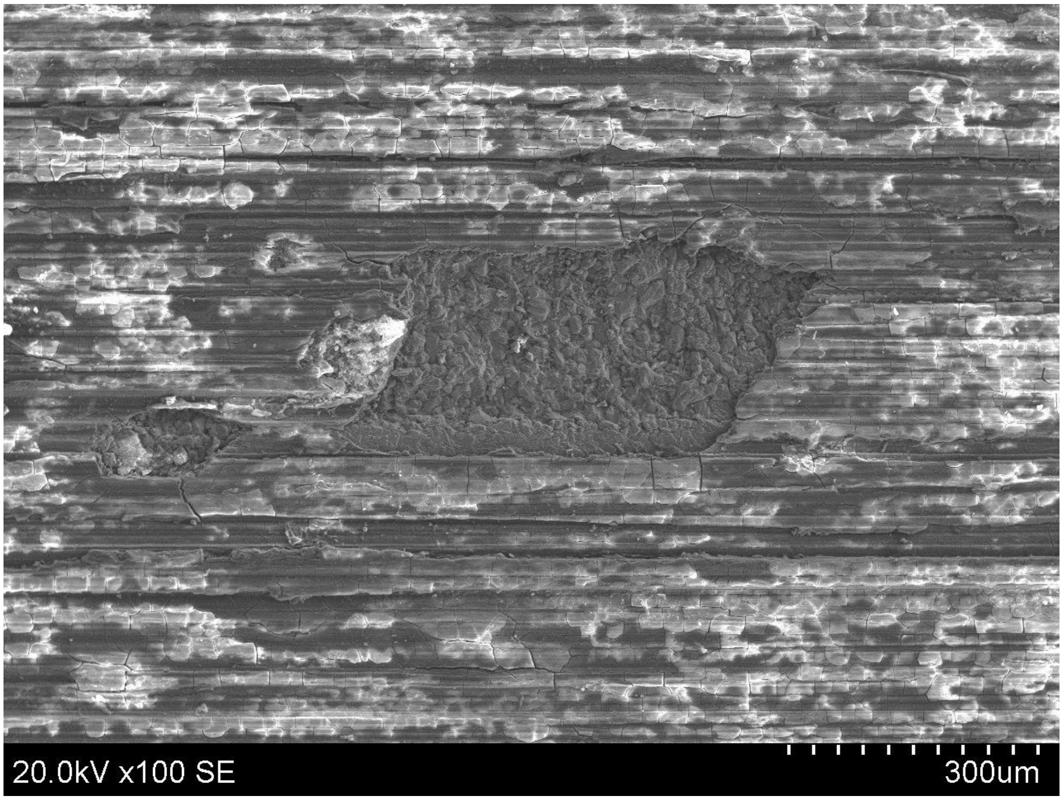
(a) CDA 715 Coupon 1, After Cleaning 100X



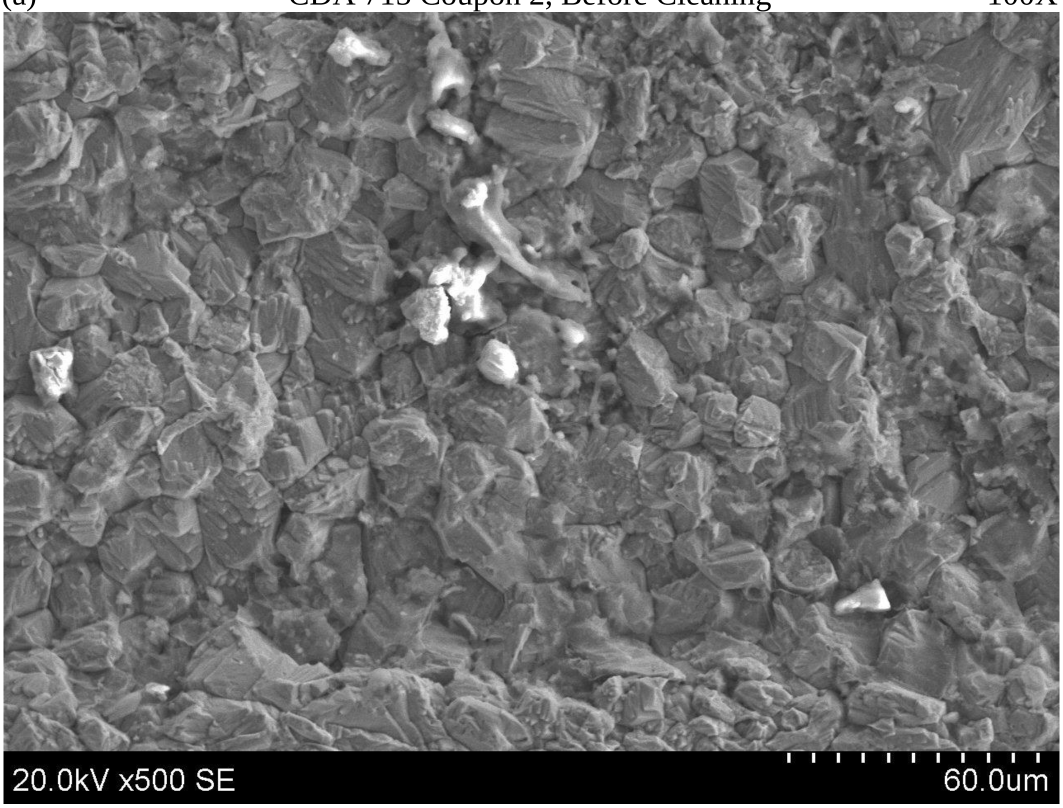
(b) CDA 715 Coupon 1, After Cleaning 500X

Figure 28 Scanning electron micrographs of CDA 715 coupon 1 after a 3 month immersion test, after cleaning

.

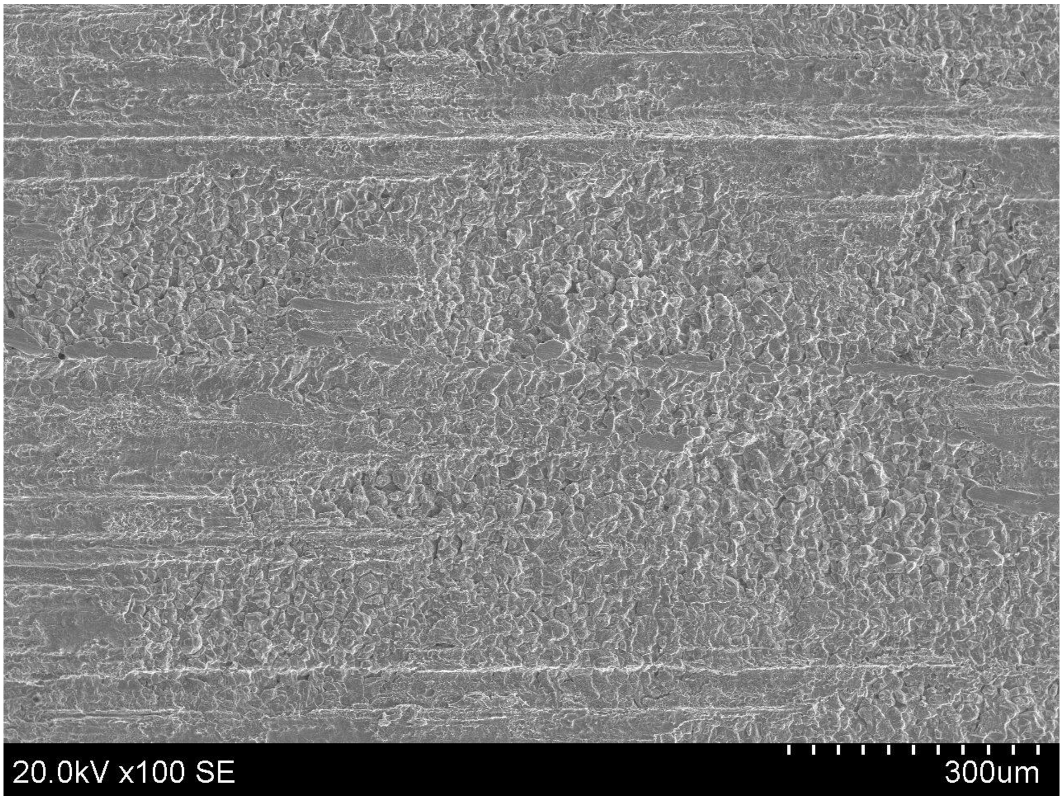


(a) CDA 715 Coupon 2, Before Cleaning 100X

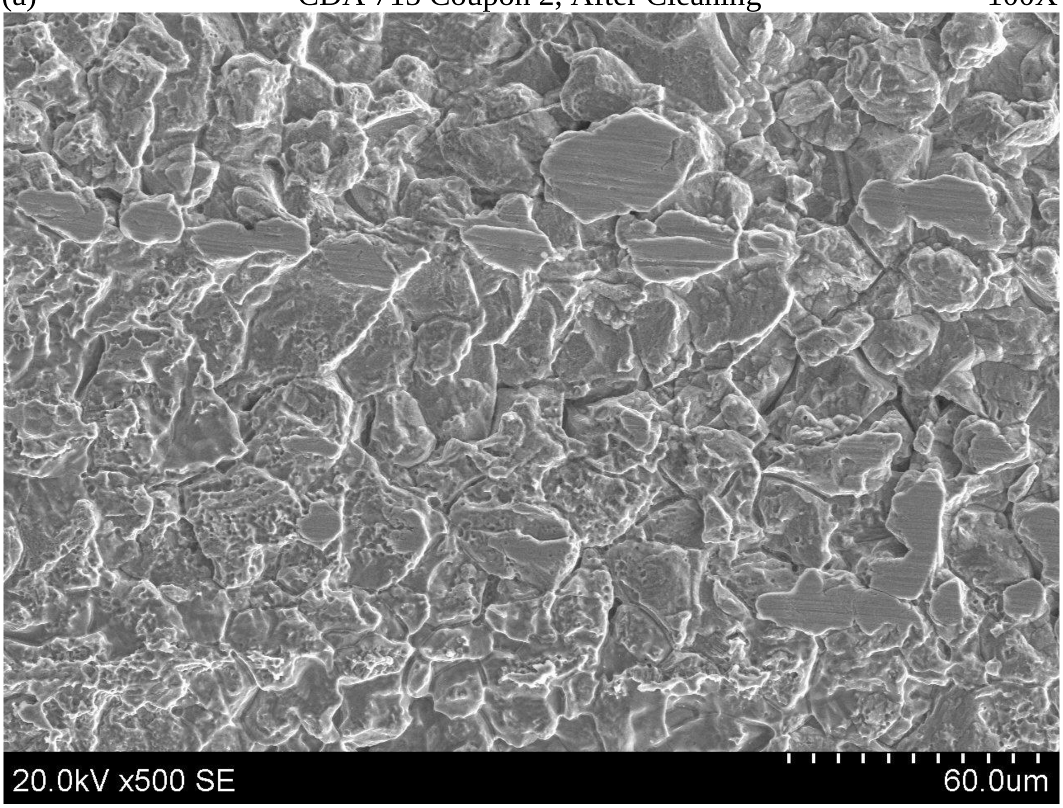


(b) CDA 715 Coupon 2, Before Cleaning 500X

Figure 29 Scanning electron micrographs of CDA 715 coupon 2 after a 6 month immersion test, before cleaning.

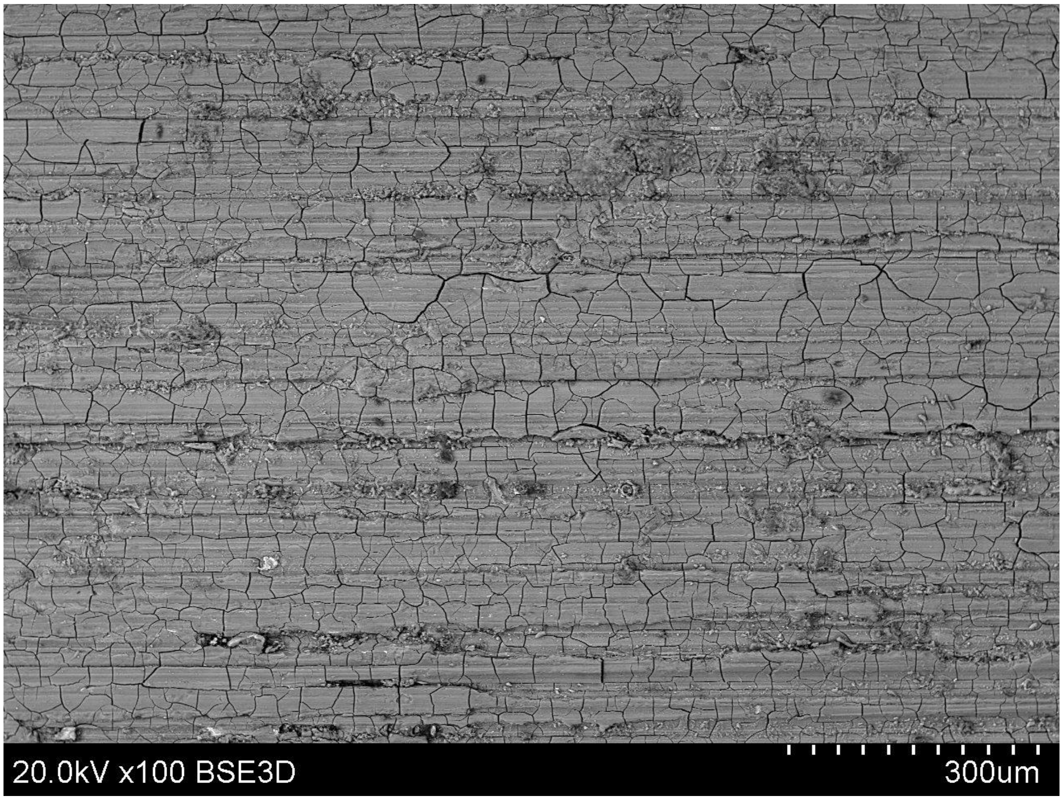


(a) CDA 715 Coupon 2, After Cleaning 100X

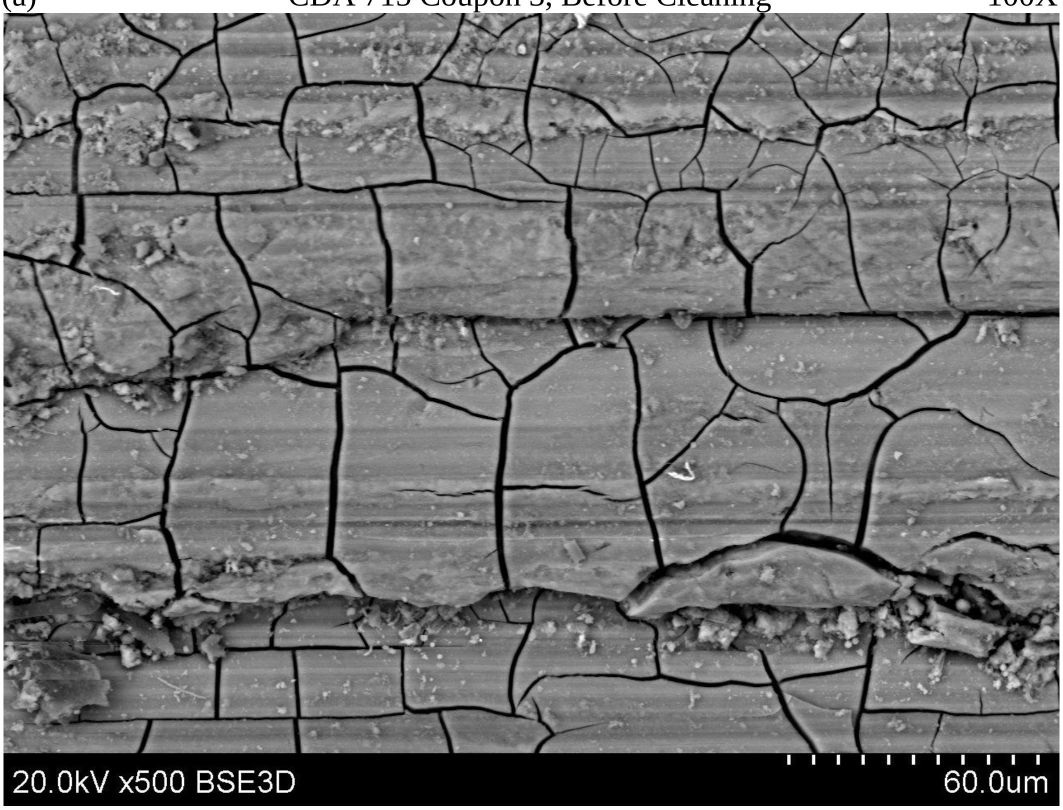


(b) CDA 715 Coupon 2, After Cleaning 500X

Figure 30 Scanning electron micrographs of CDA 715 coupon 2 after a 6 month immersion test, after cleaning.

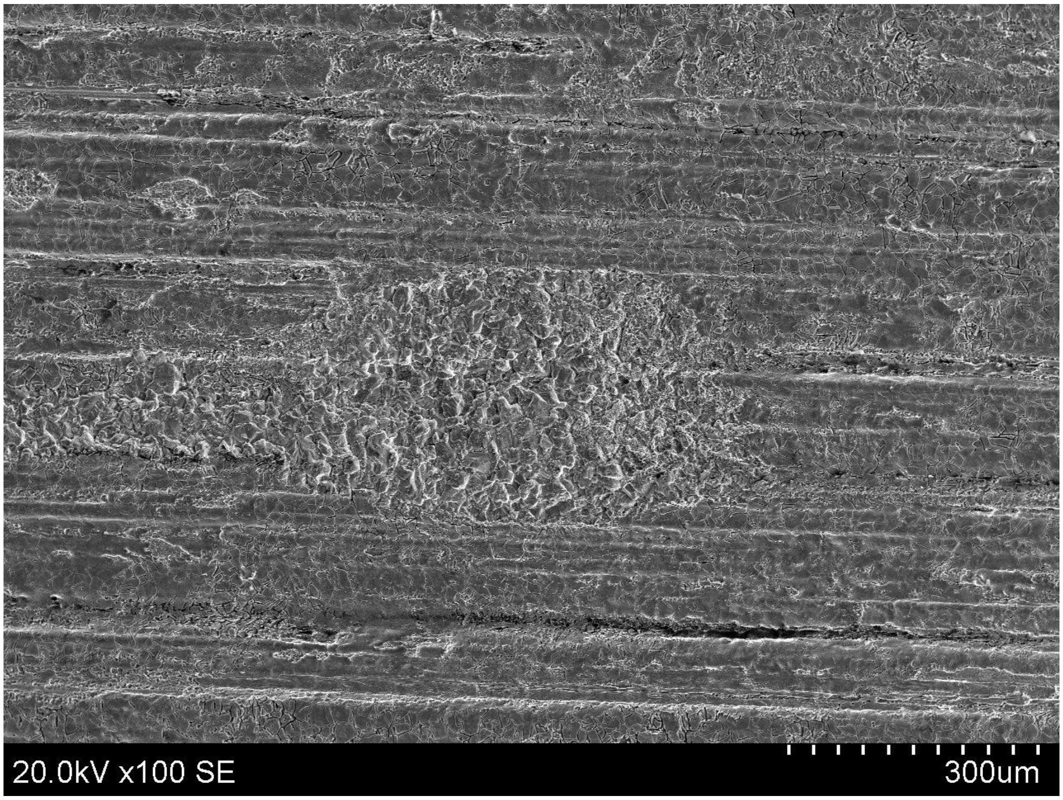


(a) CDA 715 Coupon 3, Before Cleaning 100X

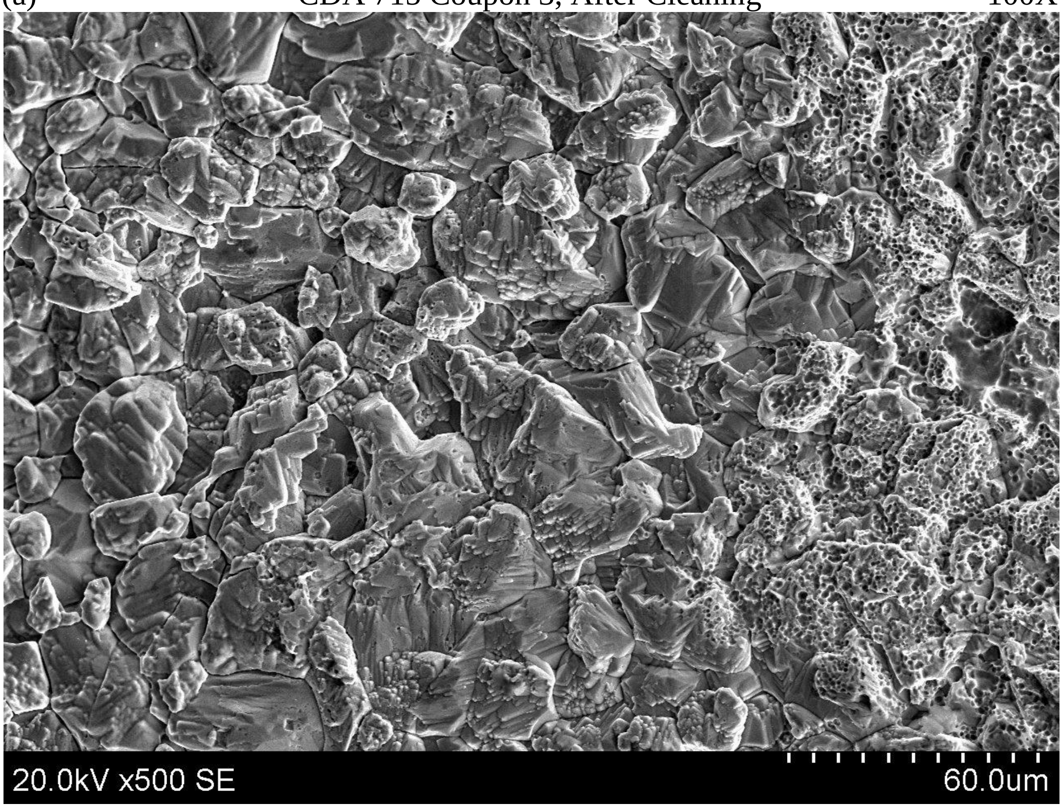


(b) CDA 715 Coupon 3, Before Cleaning 500X

Figure 31 Scanning electron micrographs of CDA 715 coupon 3 after a 10 month immersion test, before cleaning.

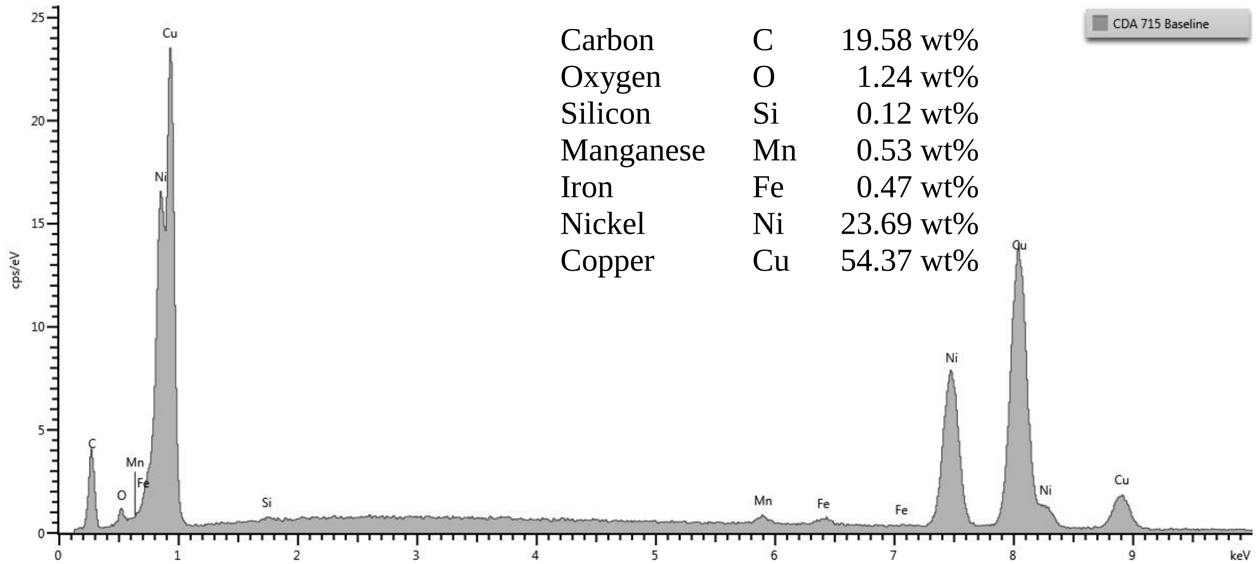


(a) CDA 715 Coupon 3, After Cleaning 100X



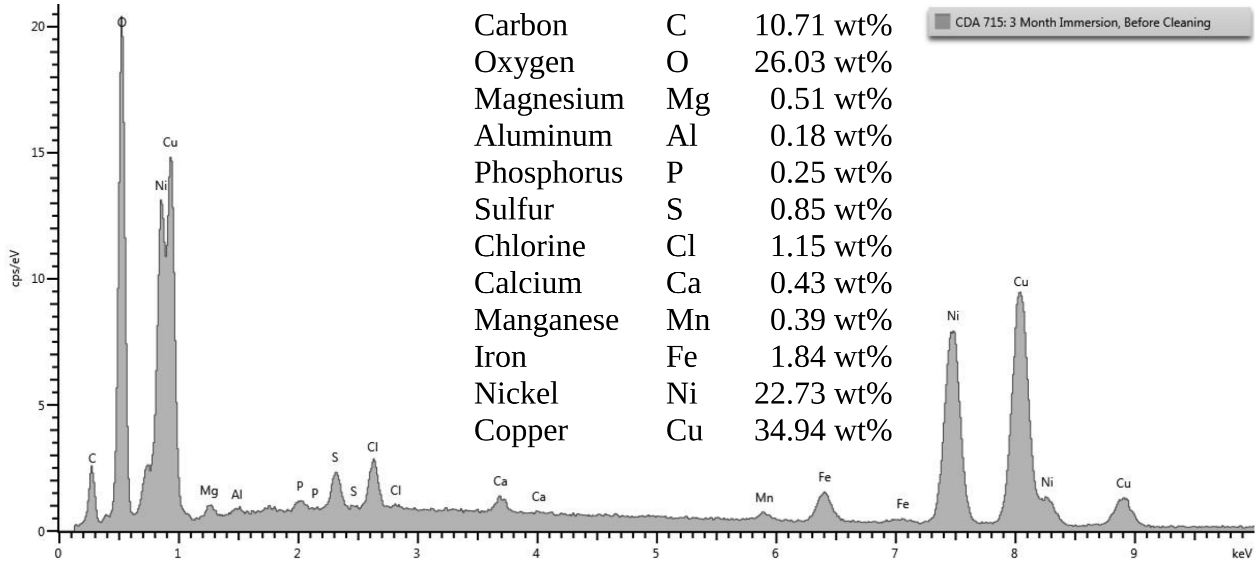
(b) CDA 715 Coupon 3, After Cleaning 500X

Figure 32 Scanning electron micrographs of CDA 715 coupon 3 after a 10 month immersion test, after cleaning.

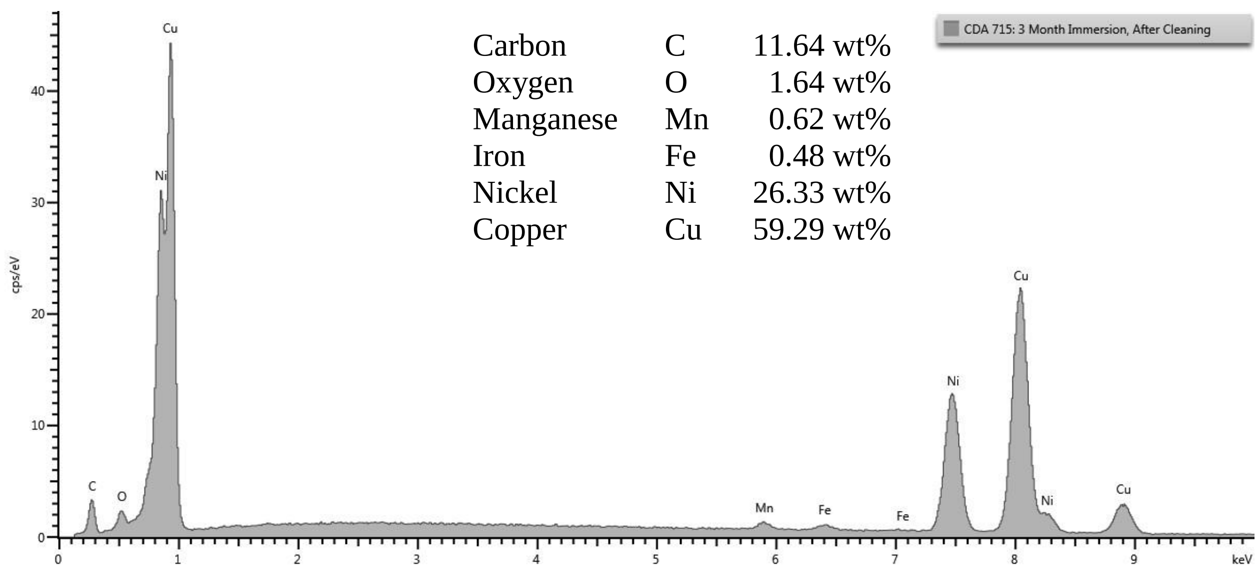


(a) CDA 715 Baseline Coupon

Figure 33 Energy dispersive x-ray spectra of the CDA 715 baseline coupon.

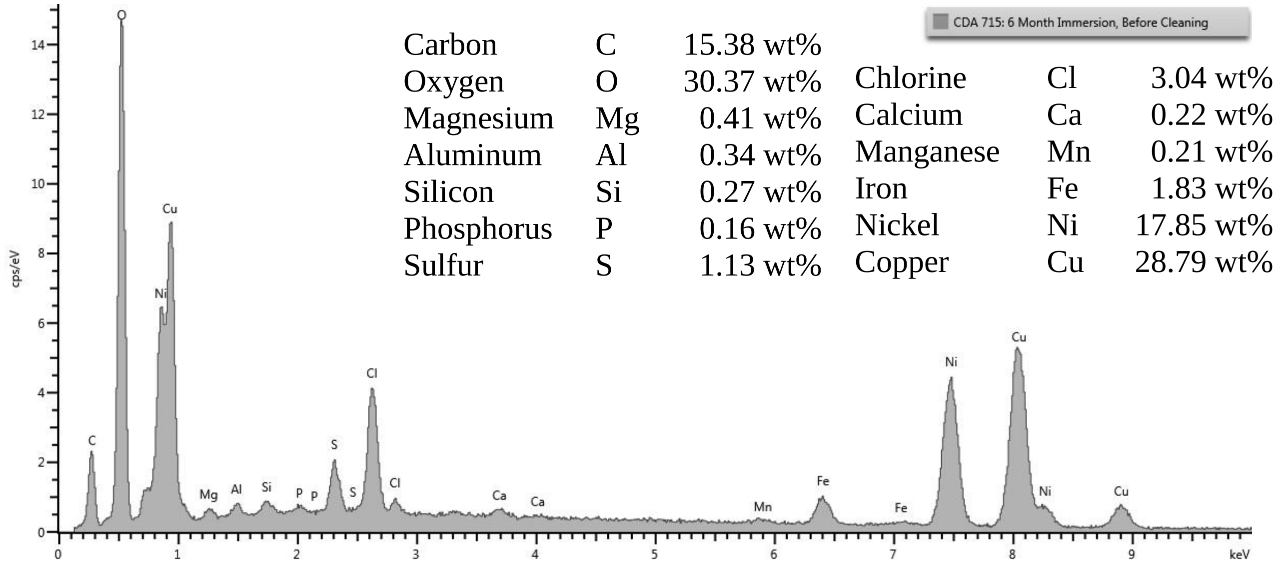


(a) CDA 715 Coupon 1, Before Cleaning

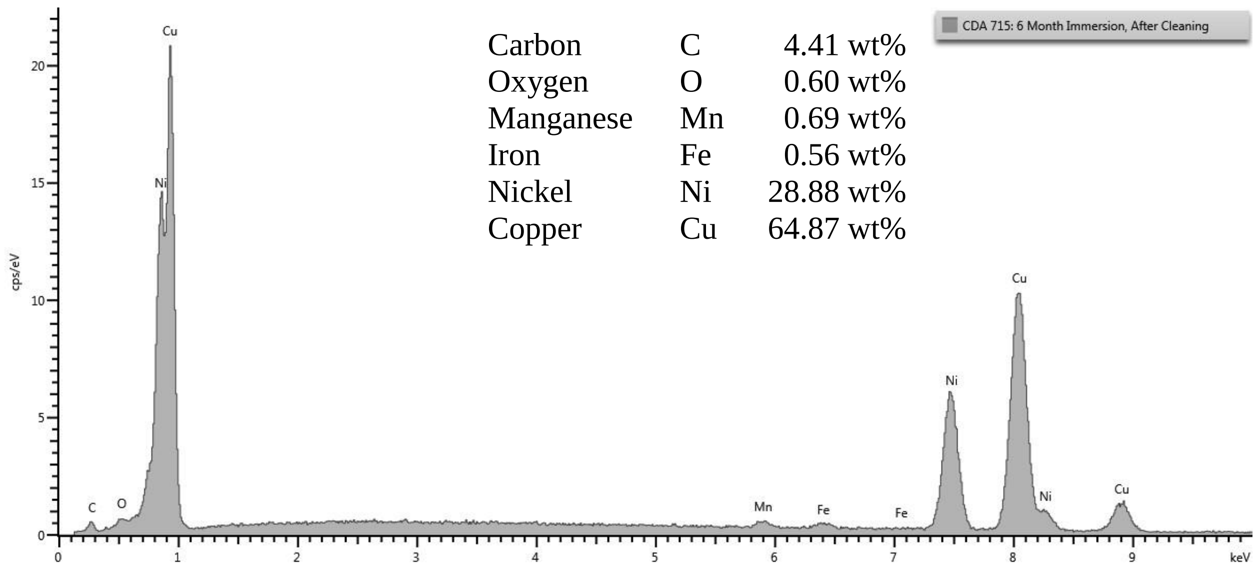


(b) CDA 715 Coupon 1, After Cleaning

Figure 34 Energy dispersive x-ray spectra of CDA 715 coupon 1 after a 3 month corrosion test (a) before cleaning and (b) after cleaning.

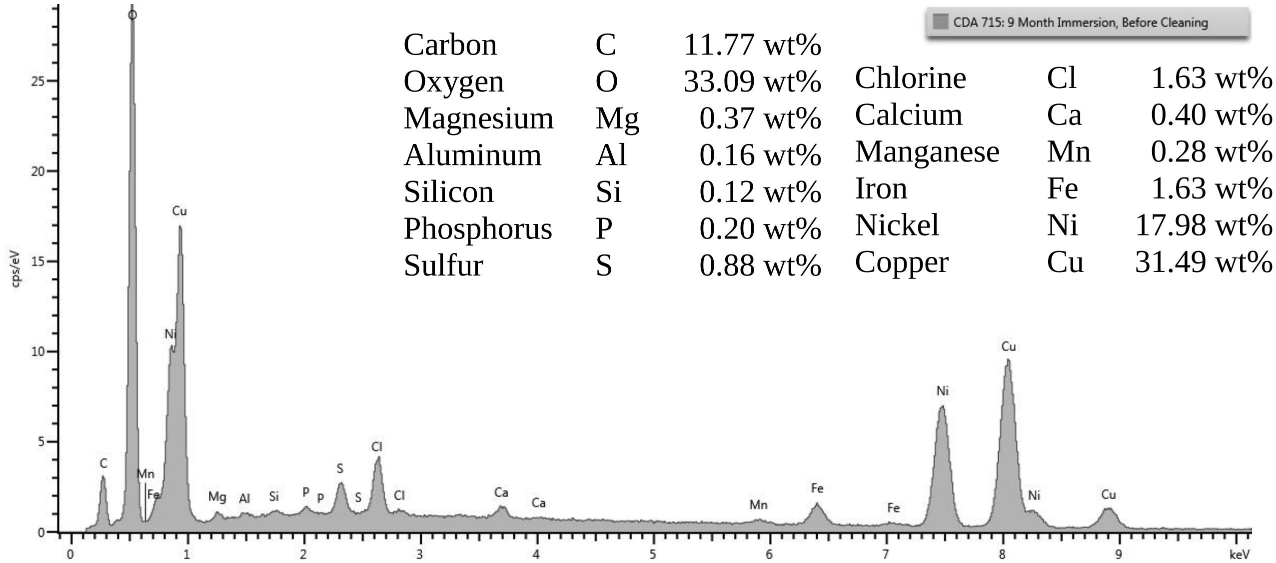


(a) CDA 715 Coupon 2, Before Cleaning

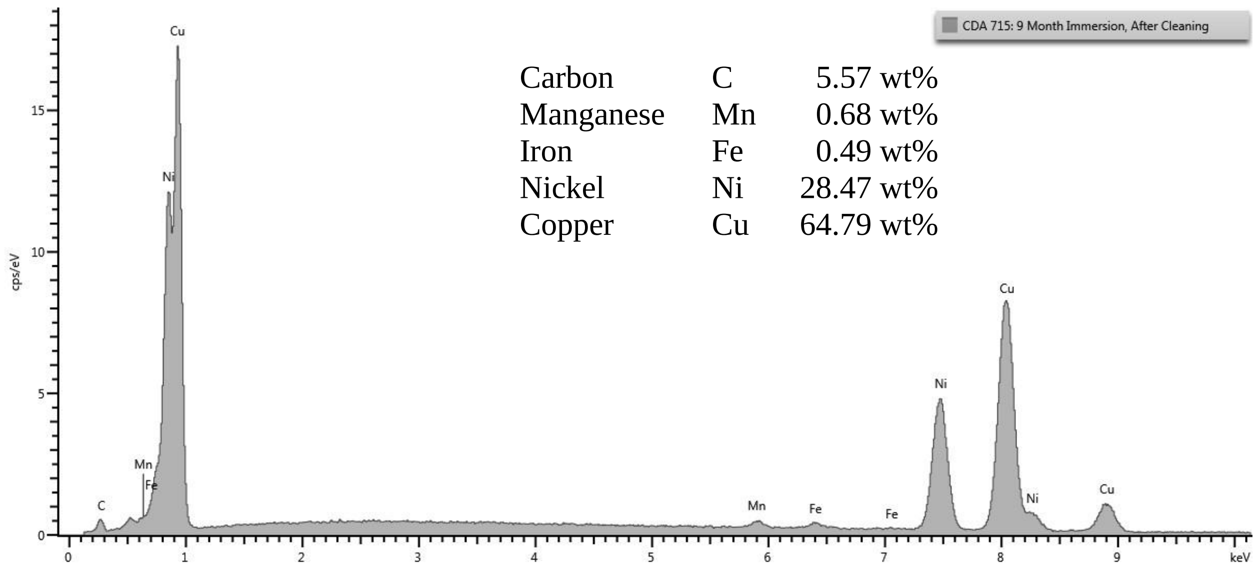


(b) CDA 715 Coupon 2, After Cleaning

Figure 35 Energy dispersive x-ray spectra of CDA 715 coupon 2 after a 6 month corrosion test (a) before cleaning and (b) after cleaning.

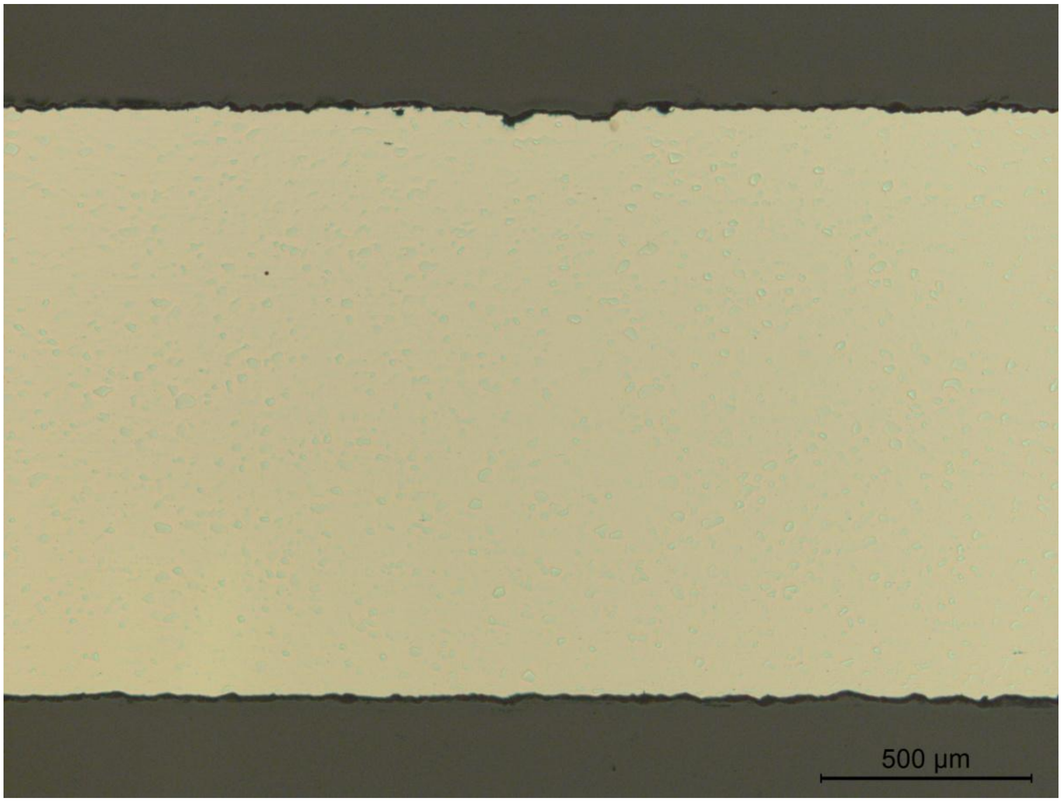


(a) CDA 715 Coupon 3, Before Cleaning

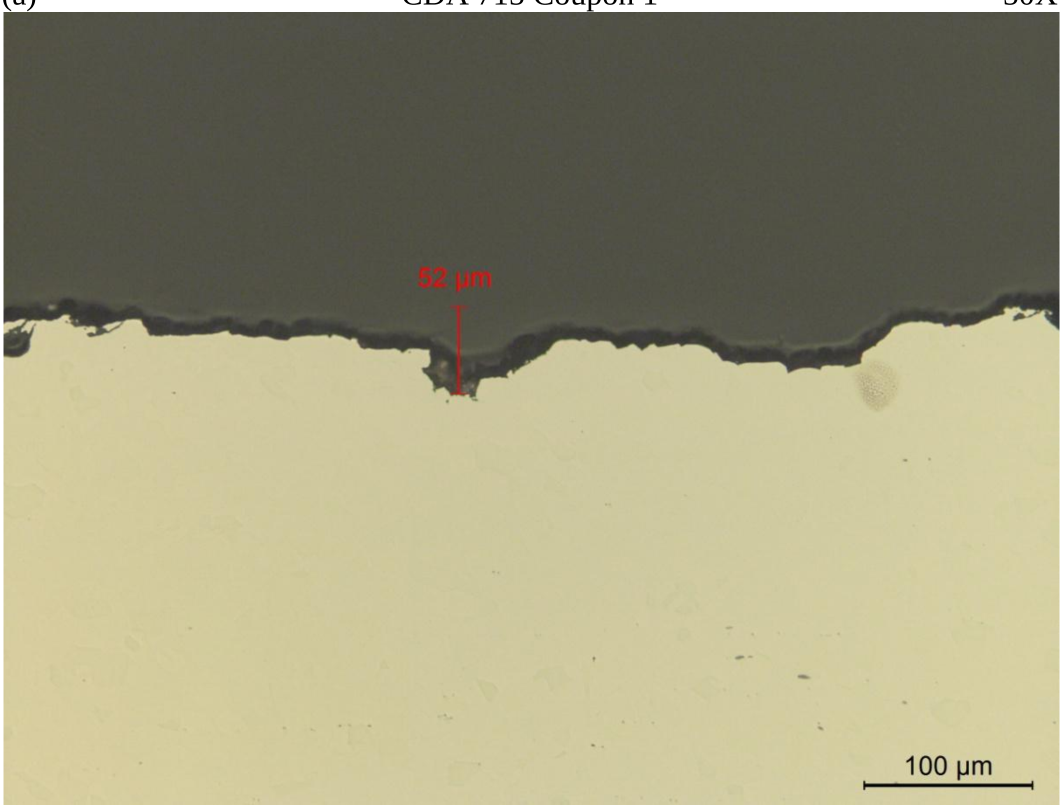


(b) CDA 715 Coupon 3, After Cleaning

Figure 36 Energy dispersive x-ray spectra of CDA 715 coupon 3 after a 10 month corrosion test (a) before cleaning and (b) after cleaning.



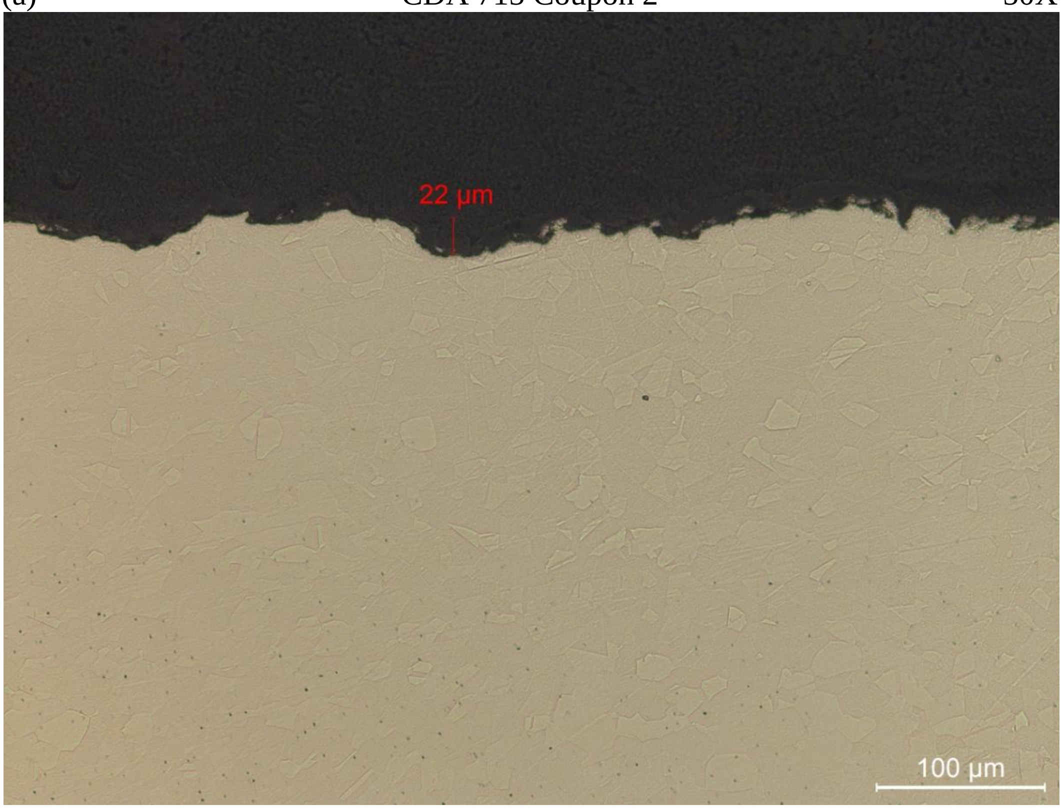
(a) CDA 715 Coupon 1 50X



(b) CDA 715 Coupon 1 200X

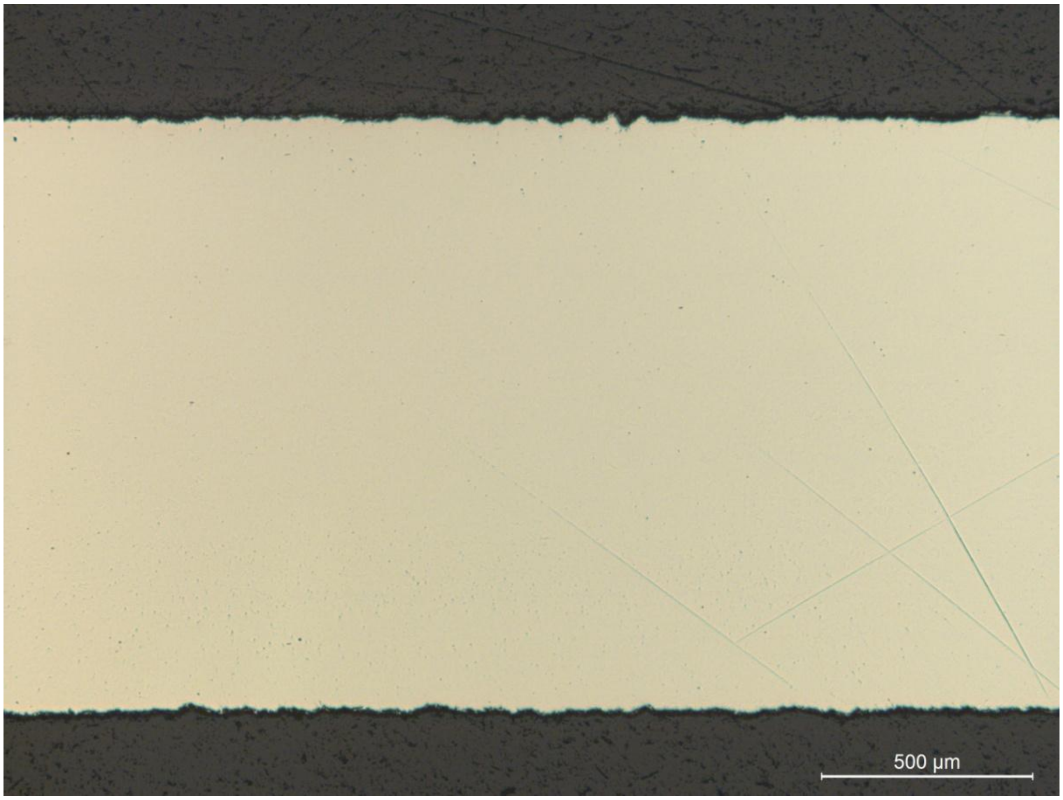
Figure 37 Optical micrographs of CDA 715 coupon 1.

(a) CDA 715 Coupon 2 50X

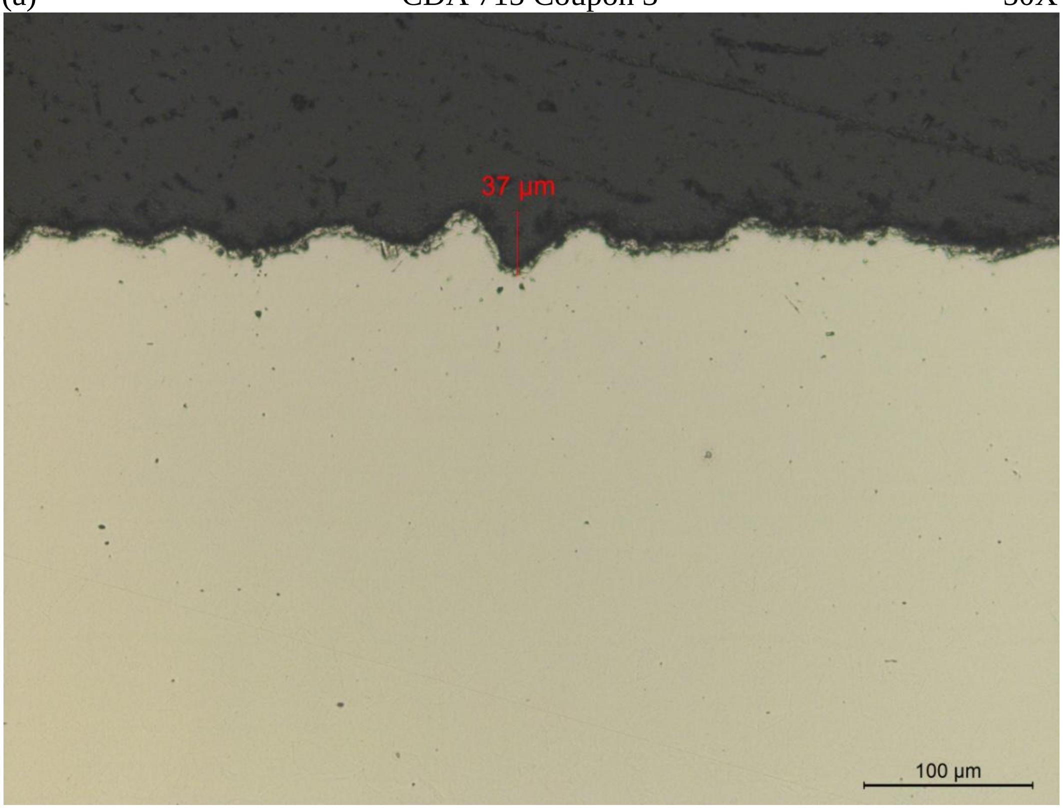


(b) CDA 715 Coupon 2 200X

Figure 38 Optical micrographs of CDA 715 coupon 2.



(a) CDA 715 Coupon 3 50X



(b) CDA 715 Coupon 3 200X

Figure 39 Optical micrographs of CDA 715 coupon 3.

Report No. 5005.0361E **May 19, 2015**

CORROSION EVALUATION OF Z-ALLOY COUPONS AND SCREENS

Customer Authorization: Verbal

Report To: V & A Engineering
Attn: Manuel Najar
155 Grand Avenue, Suite 700
Oakland, CA 94612

1.0 INTRODUCTION

Five coupons, five wedge wire screens, and one plate made from Z-Alloy, a proprietary material from Johnson Screens, were submitted by V&A Engineering for corrosion evaluation. The coupons were 1-inch by 3-inches by ¼-inch thick. The wedge wire screens were 4-inches by 4-inches by 1-inch tall with 2 mm spacing. The plate was 4-inches by 4-inches by 1/8-inch thick.

Four coupons and four screens were to be placed in seawater for a period up to one year. After every 3 month interval, one coupon and one screen were to be removed from the test system and examined for corrosion. The purpose of this evaluation was to document the samples in the baseline as-received condition, then again after 3, 6, 10, and 12 months of water exposure, record any loss in mass, examine for any pitting corrosion, and estimate the corrosion rate.

The samples were evaluated by the following laboratory procedures:

1) Visual examination and weighing
2) Cleaning per ASTM G1[1]
3) Scanning electron microscopy
4) Metallography

The results of the evaluation showed minimal mass loss and corrosion for the coupon and screen after 3, 6, and 10 months of corrosion testing. The coupon and screen, after 3 months of corrosion testing, had a corrosion rate of approximately 0.015 millimeters per year and 0.113 millimeters per year, respectively. The coupon and screen, after 6 months of corrosion testing, had a corrosion rate of approximately 0.010 millimeters per year and 0.062 millimeters per year, respectively. The coupon and screen, after 10 months of corrosion testing, had a corrosion rate of approximately 0.006 millimeters per year and 0.044 millimeters per year, respectively.

[1] G1: Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

2.0 EVALUATION[2]

2.1 Visual Examination

The sample identifications for the coupons and wedge wire screens and their corresponding immersion times are shown in Table 1. The coupons had identification numbers stamped on the front face by V&A Engineering. A number of notches, corresponding to the sample number, were sawed at the edge of each screen for identification after the corrosion test. The weights of the samples were recorded. Coupons 1 – 4 and screens 1 – 5 were sent back to V&A for corrosion testing. Coupons 5 and 6 were the baseline samples and documented by photography, optical stereoscopy and scanning electron microscopy for comparison to the tested samples. Screen 5 was documented as a baseline by photography and optical stereoscopy, and then sent to V&A for testing.

Photographs of the baseline coupon are shown in Figure 1. Photographs of coupon 1, after 3 months of corrosion testing, are shown in Figure 2. Photographs of coupon 2, after 6 months of corrosion testing, are shown in Figure 3. Photographs of coupon 3, after 10 months of corrosion testing, are shown in Figure 4.

A photograph of the baseline screen is shown in Figure 5. A photograph of screen 1, after 3 months of corrosion testing, is shown in Figure 6. A photograph of screen 2, after 6 months of corrosion testing, is shown in Figure 7. A photograph of screen 3, after 10 months of corrosion testing, is shown in Figure 8.

2.2 Cleaning

The coupon and screen were cleaned with solution C.2.1 per ASTM G1.[3] One cleaning cycle was approximately 1 minute. After each cleaning cycle, the samples were rinsed in water, dried, and weighed. The cleaning and weighing cycle was completed five times for the coupon and screen. The weights of the samples as-received, after corrosion testing but before cleaning, and after each cleaning cycle are presented in Table 2.

Optical macrographs of the baseline coupon and screen are shown in Figures 9 and 16, respectively. Representative optical macrographs of the samples after a 3 month corrosion test, before and after cleaning, are shown in Figures 10 – 11 and 17 – 18. Representative optical macrographs of the samples after a 6 month corrosion test, before and after cleaning, are shown in Figures 12 – 13 and 19 – 20. Representative optical macrographs of the samples after a 10 month corrosion test, before and after cleaning, are shown in Figures 14 – 15 and 21 – 22.

The mass loss versus the number of cleaning cycles was plotted, shown in Figures 23 – 25. The equations for best fit lines AB and BC, calculated using IGOR Pro, are listed in Table 3. Point B, indicated by the red circle in each plot, corresponds to the mass loss due to corrosion during the cleaning process for each sample. This mass loss was subtracted from the weight of the sample before cleaning and from the weight of the sample as-received to determine the total

[2] The magnifications of the optical and scanning electron micrographs in this report are approximate and should not be used as a basis for dimensional analyses unless otherwise indicated.
[3] 500 mL hydrochloric acid + 500 ml reagent water.

mass loss from corrosion. The corrosion rate of each sample was determined by the formula specified in Section 8.1 of ASTM G1:

$$Corrosion\ Rate = \frac{K\ x\ W}{A\ x\ T\ x\ D}$$

where K = 8.76×10^4, T = time of exposure in hours, A = area in cm^2, W = mass loss in grams, and D = density in g/cm^3. The density of the Z-Alloy was determined by cutting a section out of the baseline coupon, measuring the length, width, and thickness, and weighing the section with a balance. The total mass loss from corrosion and the calculated corrosion rate of each sample is shown in Table 4.

2.3 Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy

The baseline coupon, coupon 1, and coupon 2 were examined with a scanning electron microscope. Representative scanning electron micrographs of the baseline coupon are shown in Figure 26. Representative scanning electron micrographs of coupon 1 before and after cleaning are shown in Figures 27 – 28. Representative scanning electron micrographs of coupon 2 before and after cleaning are shown in Figures 29 – 30. Representative scanning electron micrographs of coupon 3 before and after cleaning are shown in Figures 31 – 32. Energy dispersive x-ray spectra of the baseline coupon and coupons 1 – 3 before and after cleaning are shown in Figures 33 – 36.

2.4 Metallography

Cross sections were taken from the coupon and prepared for a metallographic examination. Optical micrographs of the surfaces of coupons 1 – 3 are shown in Figures 37 – 39. A wide, shallow pit, measuring 0.2 mm, was observed in coupon 1. Small pits were observed in coupons 2 and 3, the deepest of which measured 15 um.

3.0 DISCUSSION

The coupon and screen showed minimal mass loss and pitting overall after 3, 6, and 10 months of corrosion testing. The coupons had more material loss over time, but had a decreasing corrosion rate over the duration of the corrosion test. The screens had more material loss over time, but had a decreasing corrosion rate over the duration of the corrosion test.

4.0 CONCLUSIONS[4]

The following conclusions are based upon the submitted samples and the evidence gathered:

[4] The conclusions in this report are based upon the available information and evidence provided by the client and gathered by Anamet, within the scope of work authorized by the client, and they are hereby presented by Anamet to a reasonable degree of engineering and scientific certainty. Anamet reserves the right to amend or supplement its conclusions or opinions presented in this report should additional data or information become available, or further work be approved by the client.

1. The coupon, after 3 months of corrosion testing, had a mass loss of 0.172 grams and a corrosion rate of 0.015 mm / year.

2. The screen, after 3 months of corrosion testing, had a mass loss of 14.96 grams and a corrosion rate of 0.113 mm / year.

3. The coupon, after 6 months of corrosion testing, had a mass loss of 0.236 grams and a corrosion rate of 0.010 mm / year.

4. The screen, after 6 months of corrosion testing, had a mass loss of 16.71 grams and a corrosion rate of 0.062 mm / year.

5. The coupon, after 10 months of corrosion testing, had a mass loss of 0.236 grams and a corrosion rate of 0.006 mm / year.

6. The screen, after 10 months of corrosion testing, had a mass loss of 20.00 grams and a corrosion rate of 0.044 mm / year.

Prepared by:

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Materials Engineer

Reviewed by:

Audrey A. Fasching, Ph.D., P.E.
Senior Materials Engineer

Table 1
Sample Identifications

Description		V&A Engineering Identification (As-Received)	Anamet Identification (in report)	Notes
Alloy	Part			
Z Alloy	**Flat Plate** 4-inch x 4-inch x 1/8-inch	Z	Plate	None
	Coupon 1-inch x 3-inch x 1/8-inch with autogenous weld bead	1	Coupon 1	3 Month Immersion
		2	Coupon 2	6 Month Immersion
		3	Coupon 3	10 Month Immersion
		4	Coupon 4	12 Month Immersion
		5	Coupon 5	Baseline Sample (no exposure)
		6	Coupon 6	Baseline Sample (no exposure)
	Wedge Wire Screen 4-inch x 4-inch x 1-inch with 2 mm spacing	None	Screen 1	3 Month Immersion
		None	Screen 2	6 Month Immersion
		None	Screen 3	10 Month Immersion
		None	Screen 4	12 Month Immersion
		None	Screen 5	12 Month Immersion

Table 2
Sample Weights

Sample	Baseline Measurement	Measurements after 3 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 1	26.8665	26.7135	26.6958	26.6926	26.6911	26.6887	26.6872
Screen 1	361.74	352.24	348.56	346.76	346.62	346.50	346.48

Sample	Baseline Measurement	Measurements after 6 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 2	27.0660	26.8593	26.8299	26.8273	26.8255	26.8230	26.8211
Screen 2	359.36	347.99	342.66	342.58	342.48	342.44	-

Sample	Baseline Measurement	Measurements after 10 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 3	27.4856	27.2842	27.2500	27.2471	27.2452	27.2435	27.2423
Screen 3	361.61	347.00	342.58	341.57	341.36	341.30	341.23

Table 3
Equations of Line AB and BC for Corrosion Testing Samples

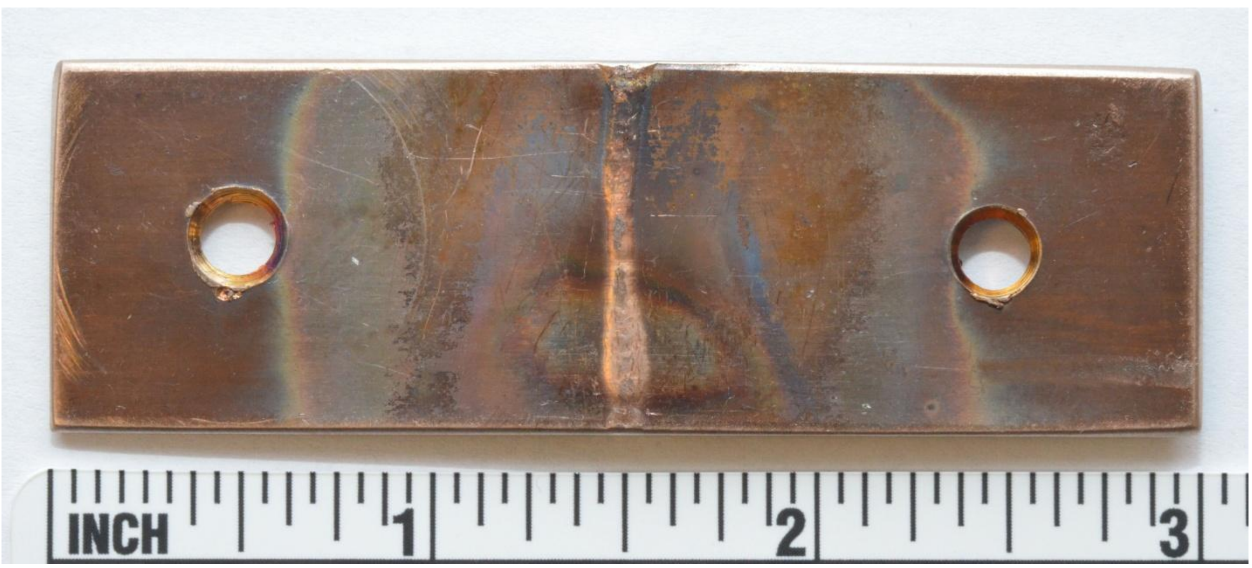
Sample	Line AB	Line BC	Point B (Approximate Mass Loss from Corrosion During Cleaning)
Coupon 1	y = 0.018x	y = 0.002x + 0.017	0.019 grams
Coupon 2	y = 0.029x	y = 0.002x + 0.027	0.029 grams
Coupon 3	y = 0.034x	y = 0.002x + 0.033	0.035 grams
Screen 1	y = 3.68x	y = 0.10x + 5.31	5.46 grams
Screen 2	y = 5.33x	y = 0.08x + 5.26	5.34 grams
Screen 3	y = 4.42x	y = 0.11x + 5.26	5.39 grams

Table 4
Total Mass Loss from Corrosion and Corrosion Rate

Sample	Total Mass Loss from Corrosion*	Corrosion Rate
Coupon 1	0.172 grams	0.015 mm / year
Coupon 2	0.236 grams	0.010 mm / year
Coupon 3	0.236 grams	0.006 mm / year
Screen 1	14.96 grams	0.113 mm / year
Screen 2	16.71 grams	0.062 mm / year
Screen 3	20.00 grams	0.044 mm / year

* Weight As-Received – (Weight Before Cleaning – Mass Loss from Corrosion During Cleaning)

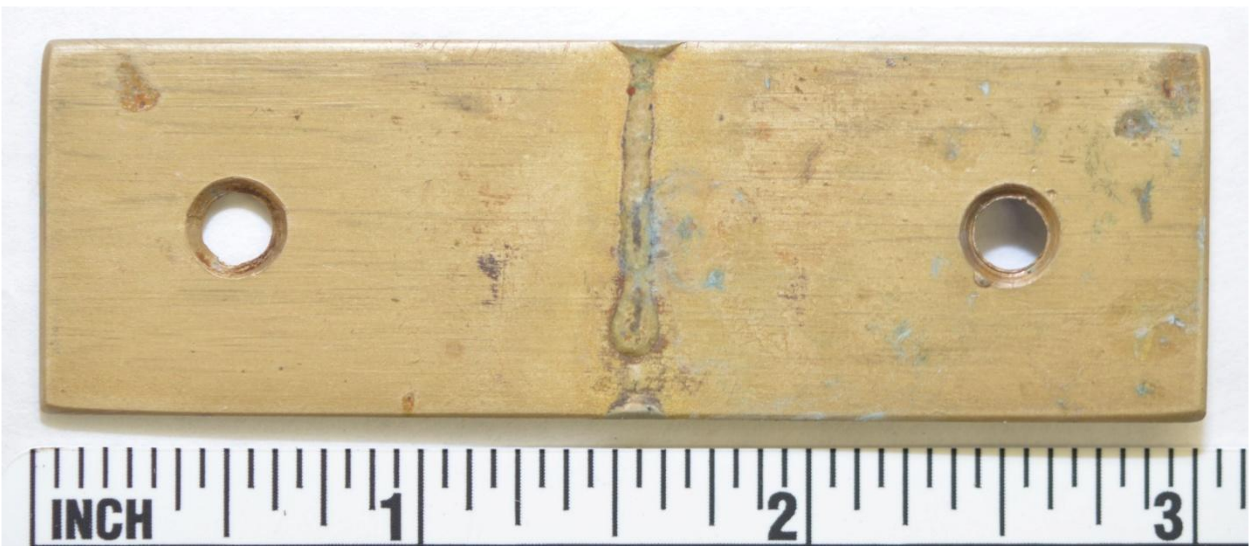
(a) Z-Alloy Baseline Coupon, Front Side



(b) Z-Alloy Baseline Coupon, Back Side

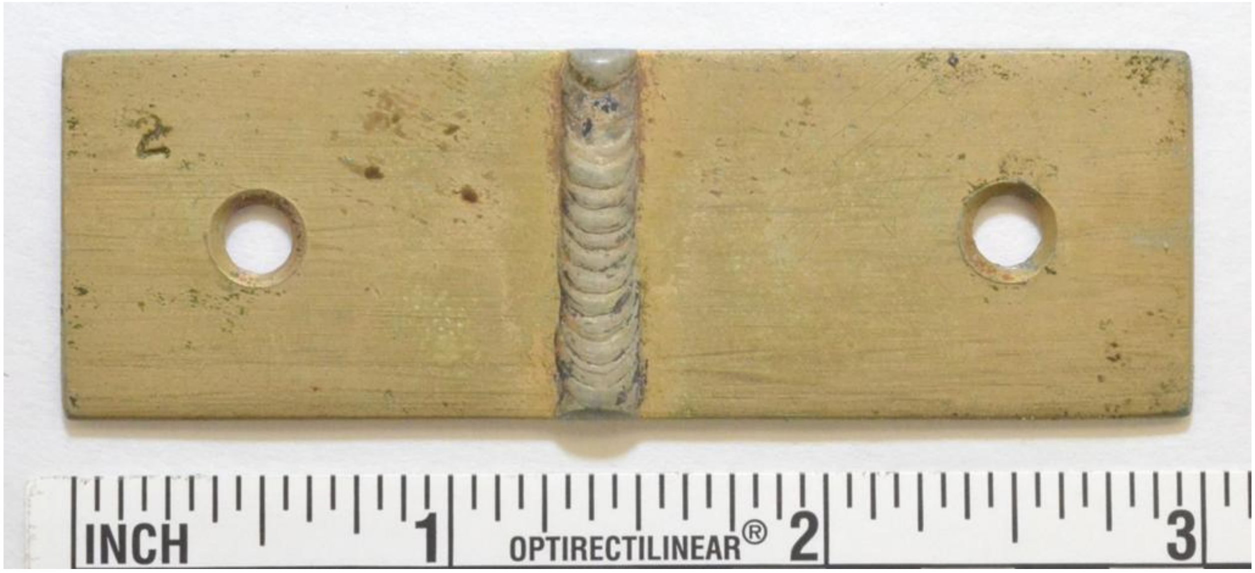
Figure 1 Photographs of the Z-Alloy baseline coupon (a) front and (b) back side.

(a) Z-Alloy Coupon 1 Front Side



(b) Z-Alloy Coupon 1 Back Side

Figure 2 Photographs of Z-Alloy coupon 1 (a) front and (b) back side after a 3 month corrosion test.

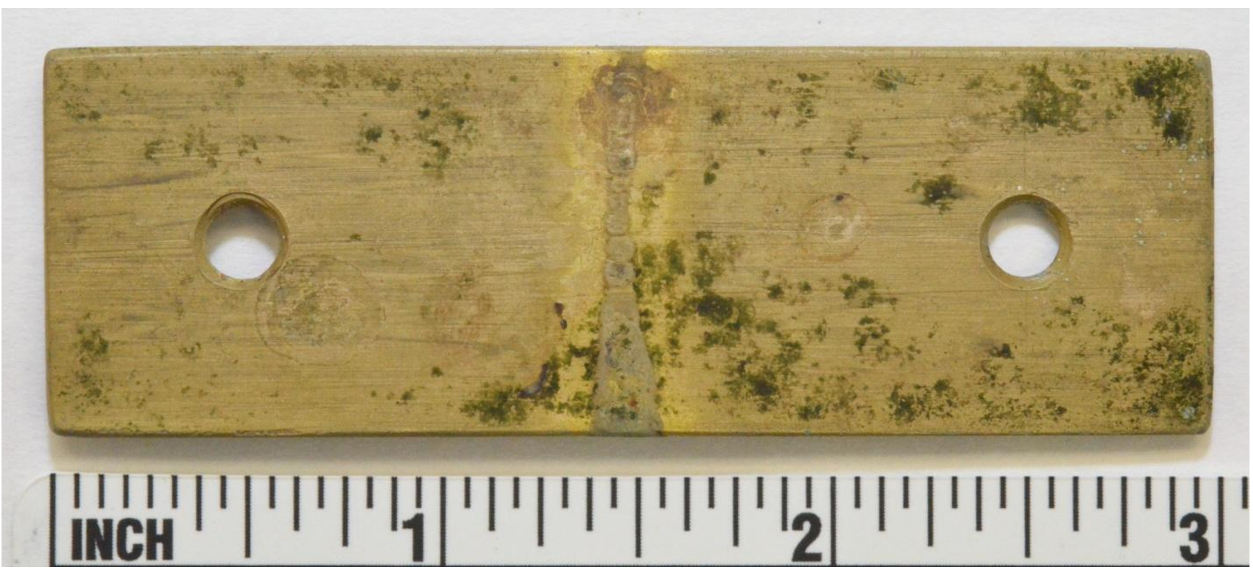


(a) Z-Alloy Coupon 2 Front Side

(b) Z-Alloy Coupon 2 Back Side

Figure 3 Photographs of Z-Alloy coupon 2 (a) front and (b) back side after a 6 month corrosion test.

(a) Z-Alloy Coupon 3 Front Side

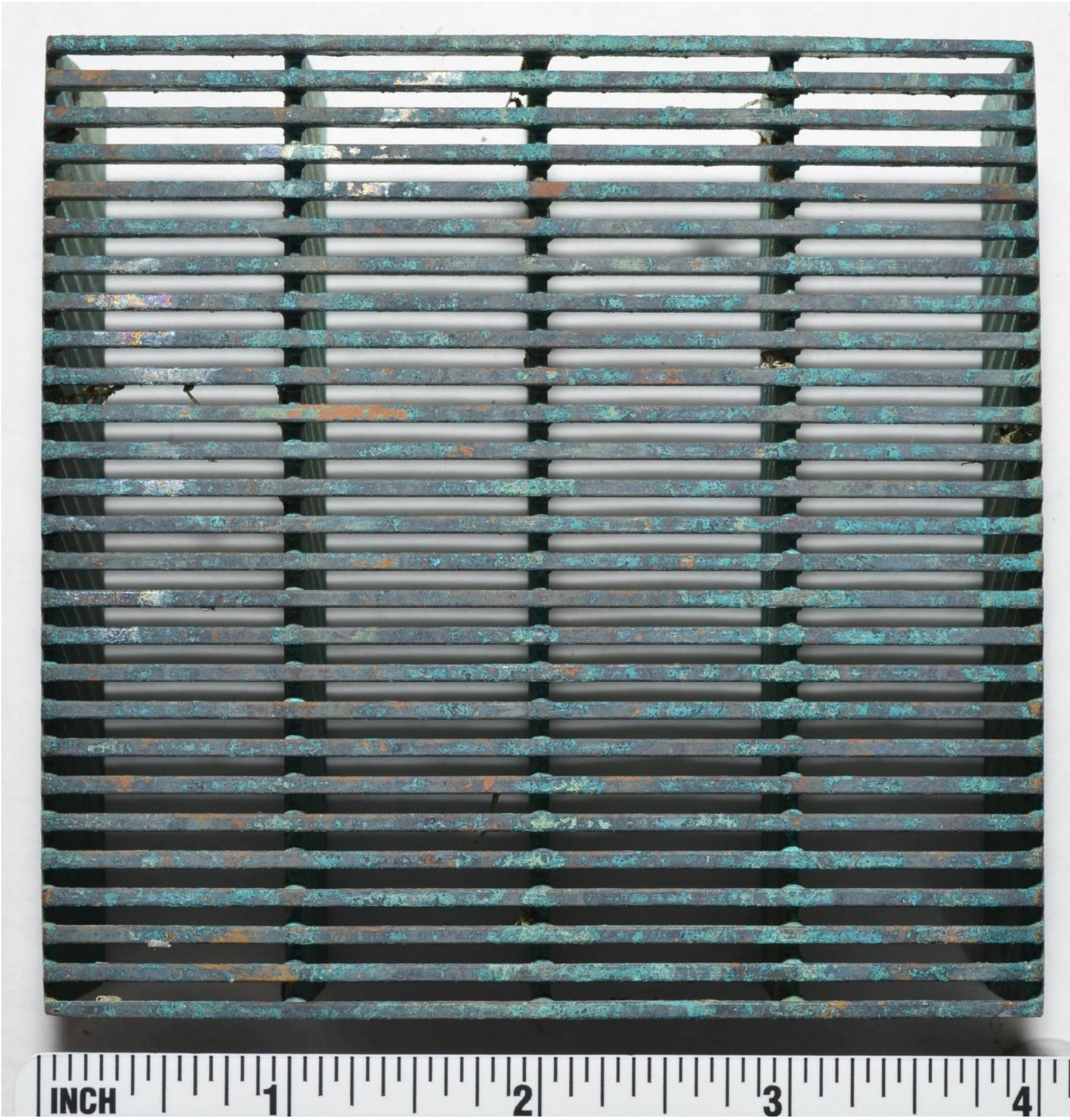


(b) Z-Alloy Coupon 3 Back Side

Figure 4 Photographs of Z-Alloy coupon 3 (a) front and (b) back side after a 10 month corrosion test.

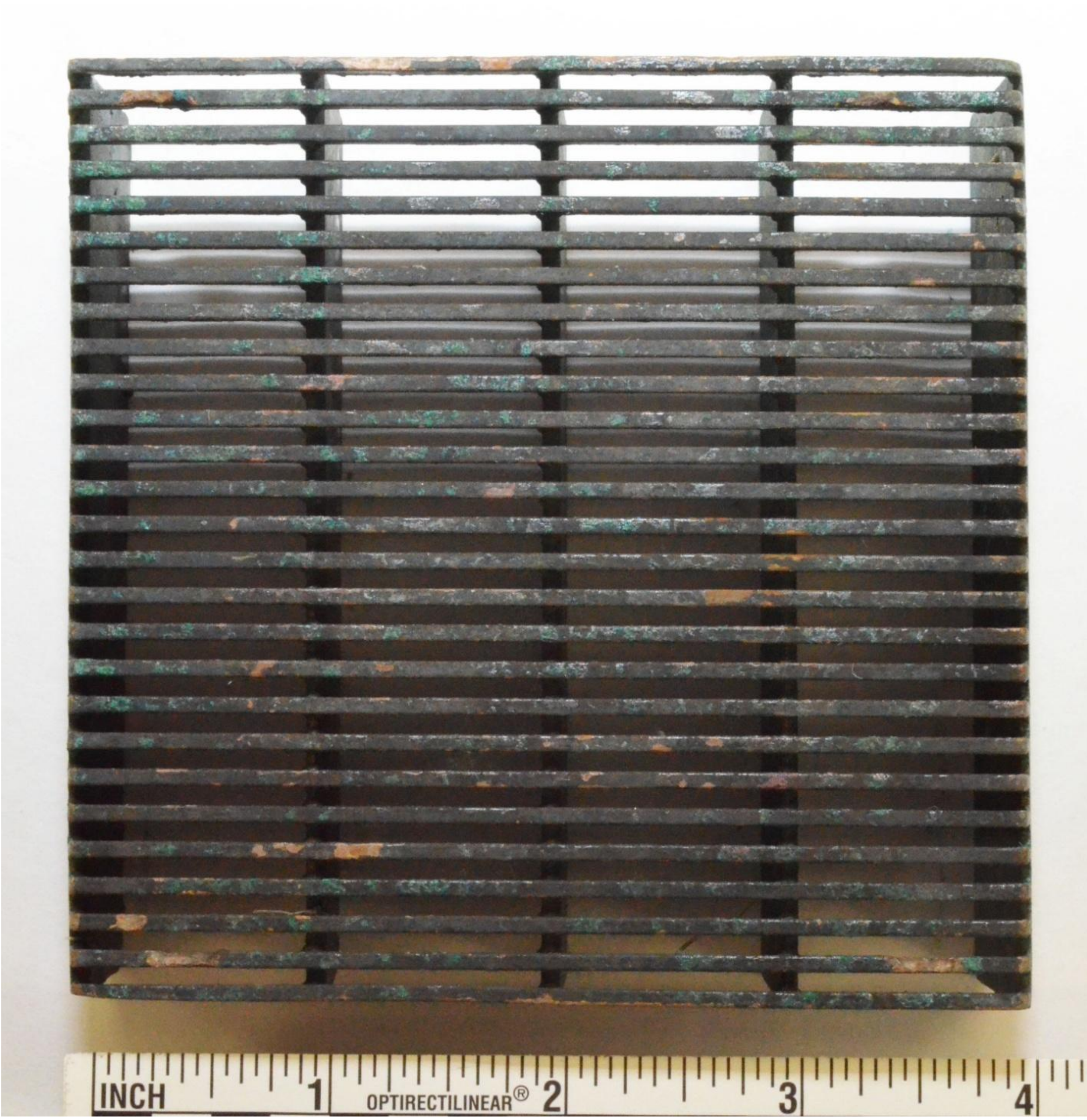
(a) Z-Alloy Baseline Screen

Figure 5 Photograph of the Z-Alloy baseline screen.



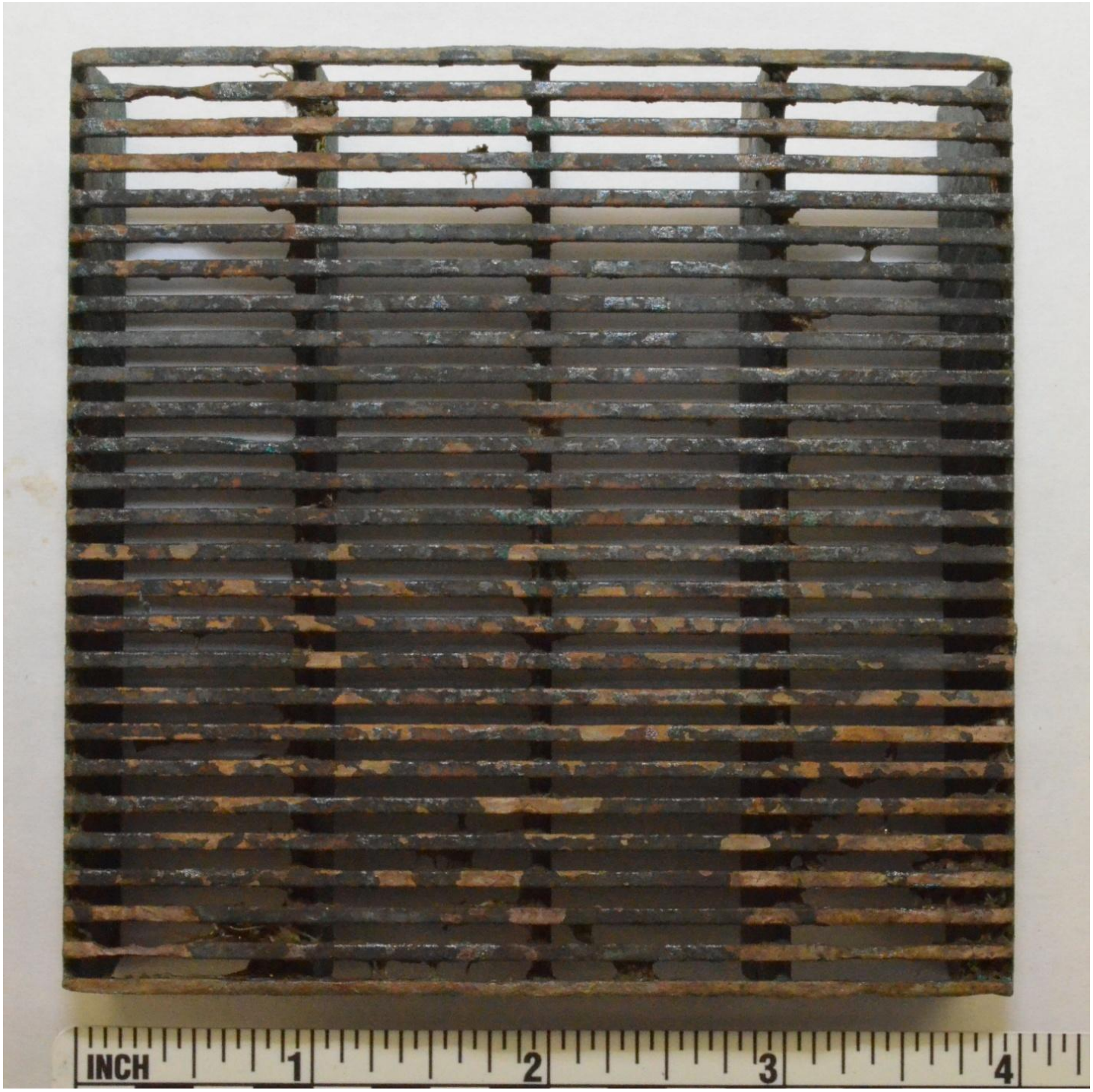
(a) Z-Alloy Screen 1

Figure 6 Photograph of Z-Alloy screen 1 after a 3 month corrosion test.



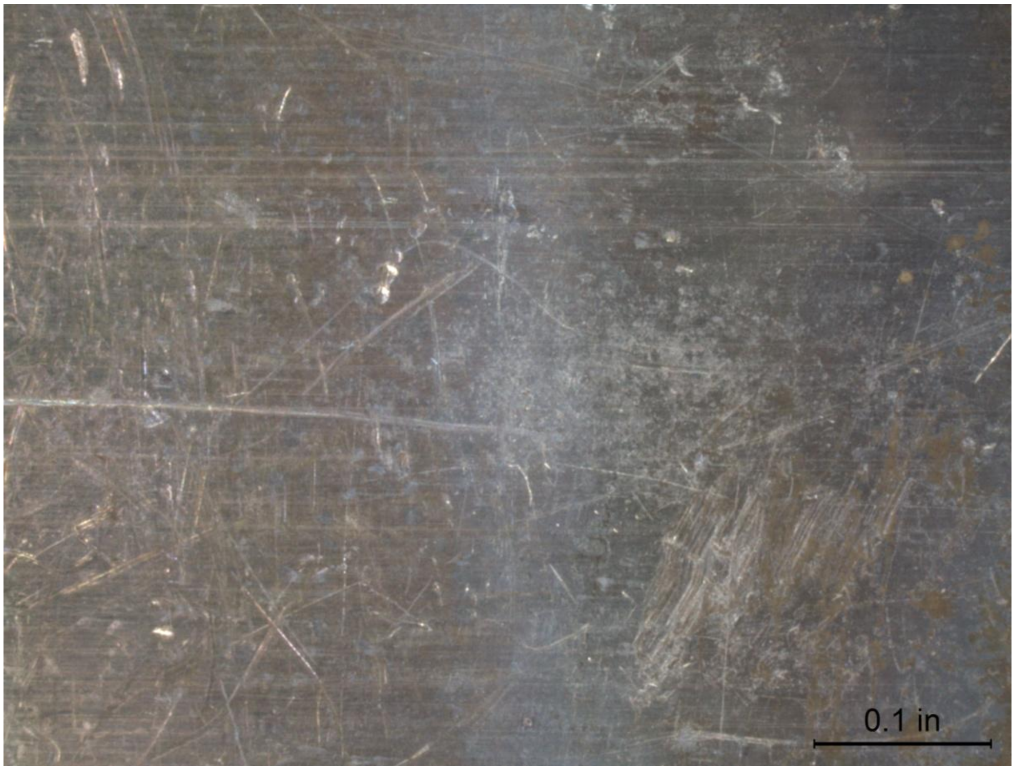
(a) Z-Alloy Screen 2

Figure 7 Photograph of Z-Alloy screen 2 after a 6 month corrosion test.



(a) Z-Alloy Screen 3

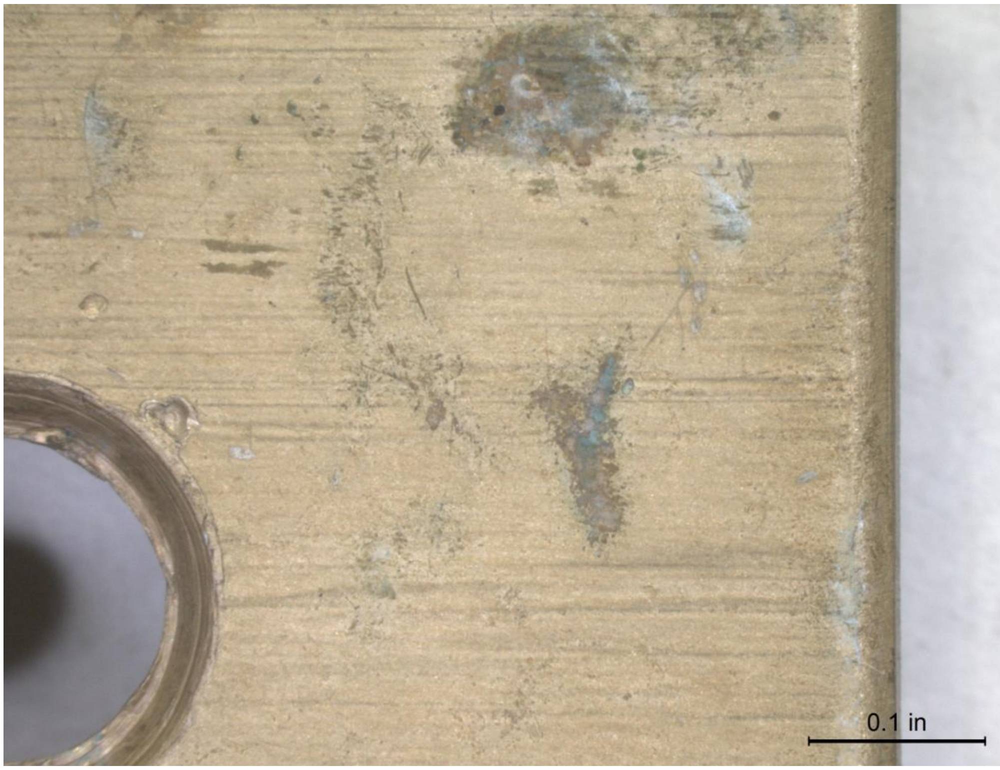
Figure 8 Photograph of Z-Alloy screen 3 after a 10 month corrosion test.



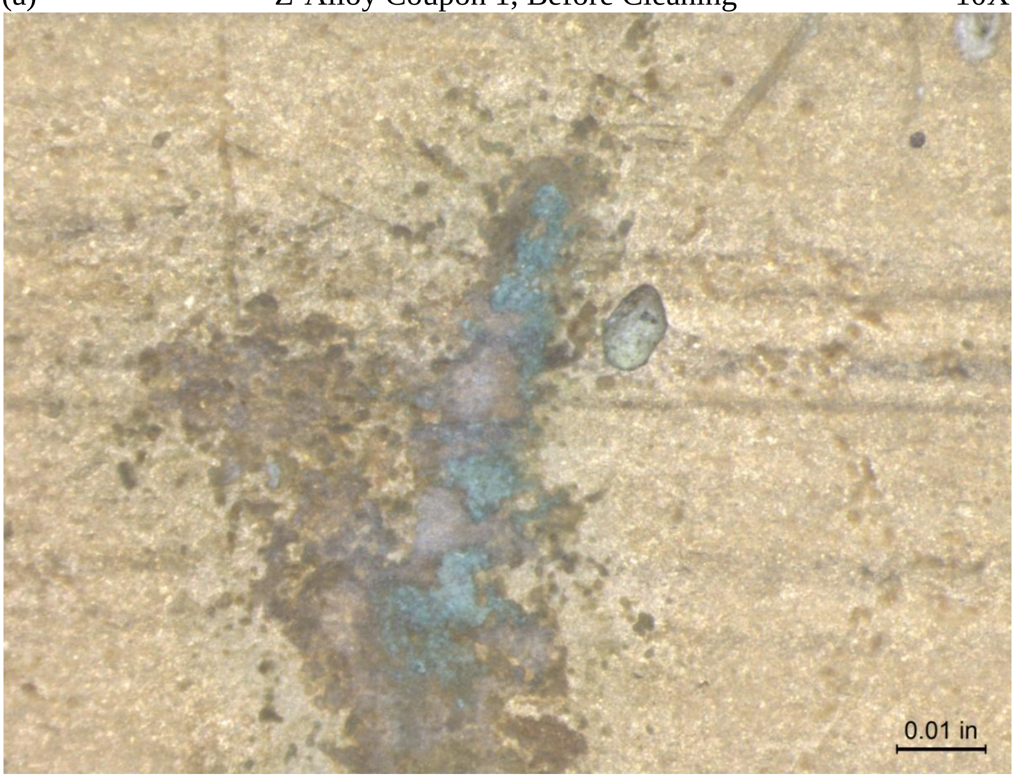
(a) Z-Alloy Baseline Coupon 10X

(b) Z-Alloy Baseline Coupon 50X

Figure 9 Optical macrographs of the Z-Alloy baseline coupon.

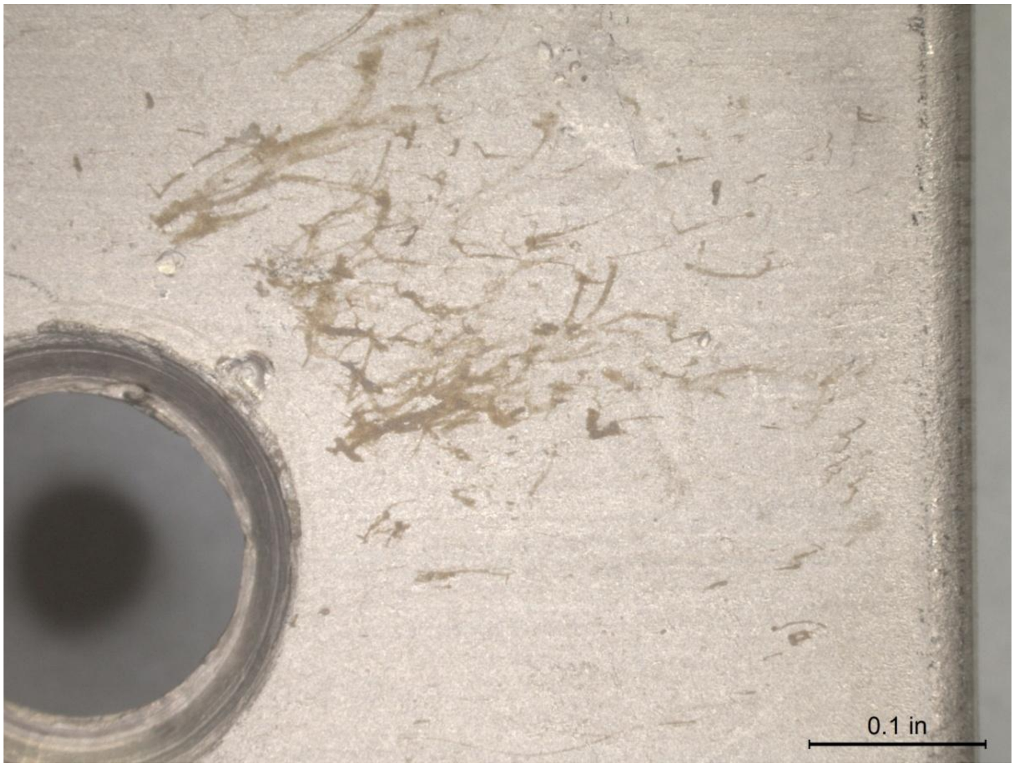


(a) Z-Alloy Coupon 1, Before Cleaning 10X



(b) Z-Alloy Coupon 1, Before Cleaning 50X

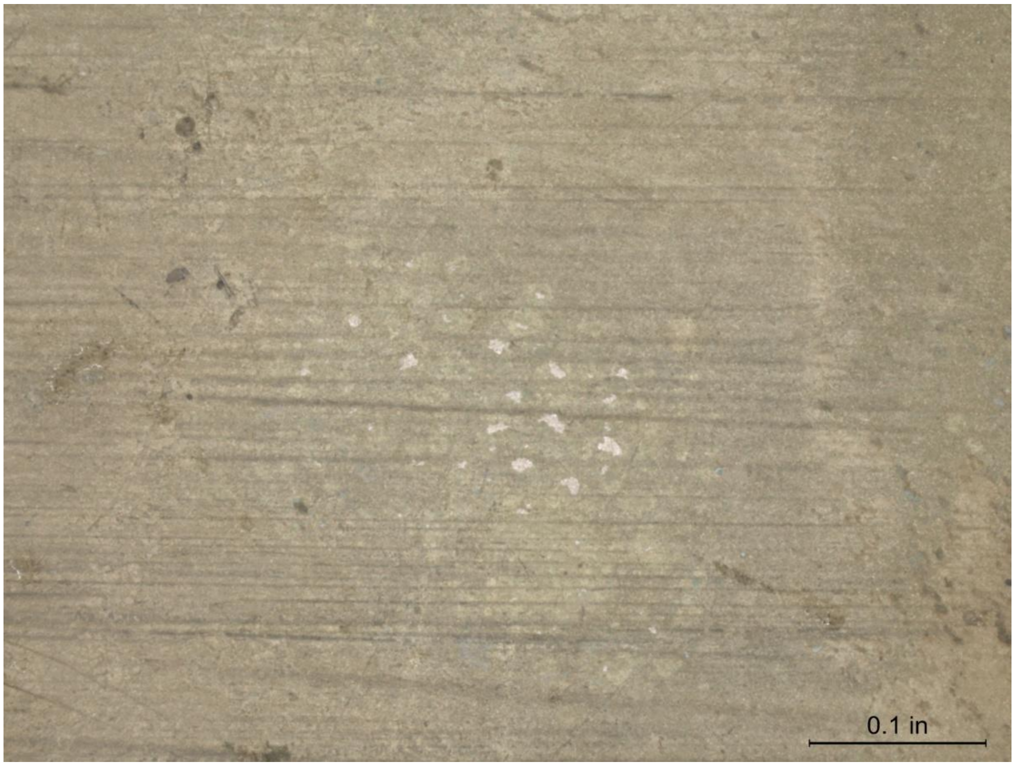
Figure 10 Optical macrographs of Z-Alloy coupon 1 after a 3 month corrosion test, before cleaning.



(a) Z-Alloy Coupon 1, After Cleaning 10X

(b) Z-Alloy Coupon 1, After Cleaning 50X

Figure 11 Optical macrographs of Z-Alloy coupon 1 after a 3 month corrosion test, after cleaning.



(a) Z-Alloy Coupon 2, Before Cleaning 10X

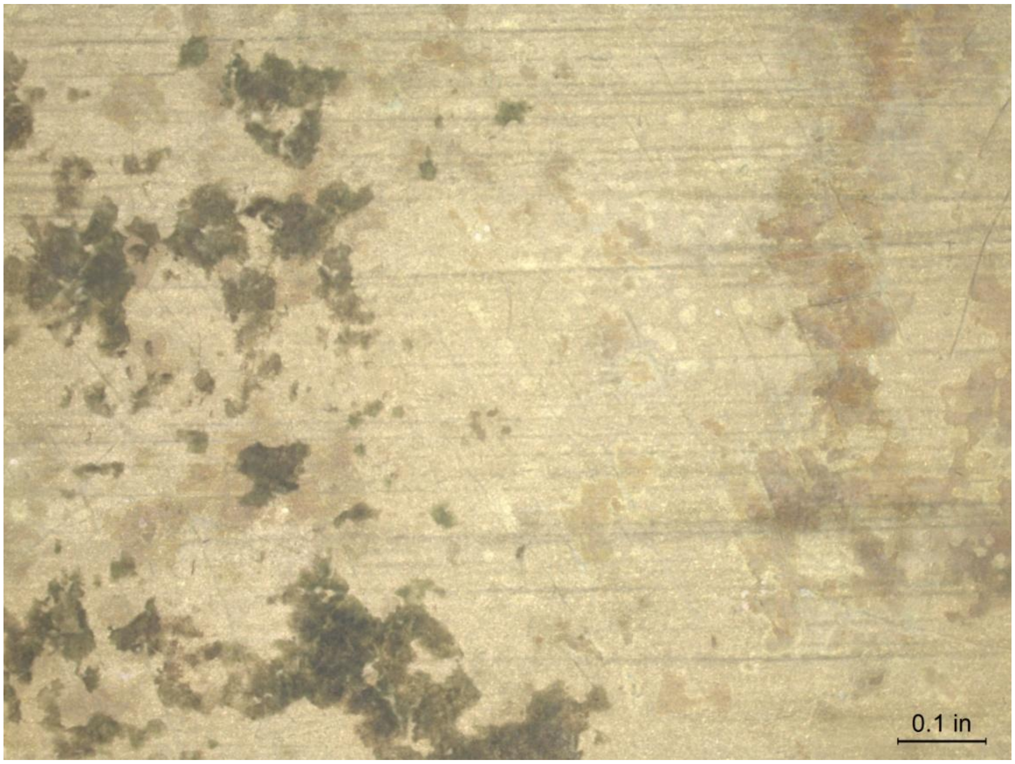
(b) Z-Alloy Coupon 2, Before Cleaning 50X

Figure 12 Optical macrographs of Z-Alloy coupon 2 after a 6 month corrosion test, before cleaning.

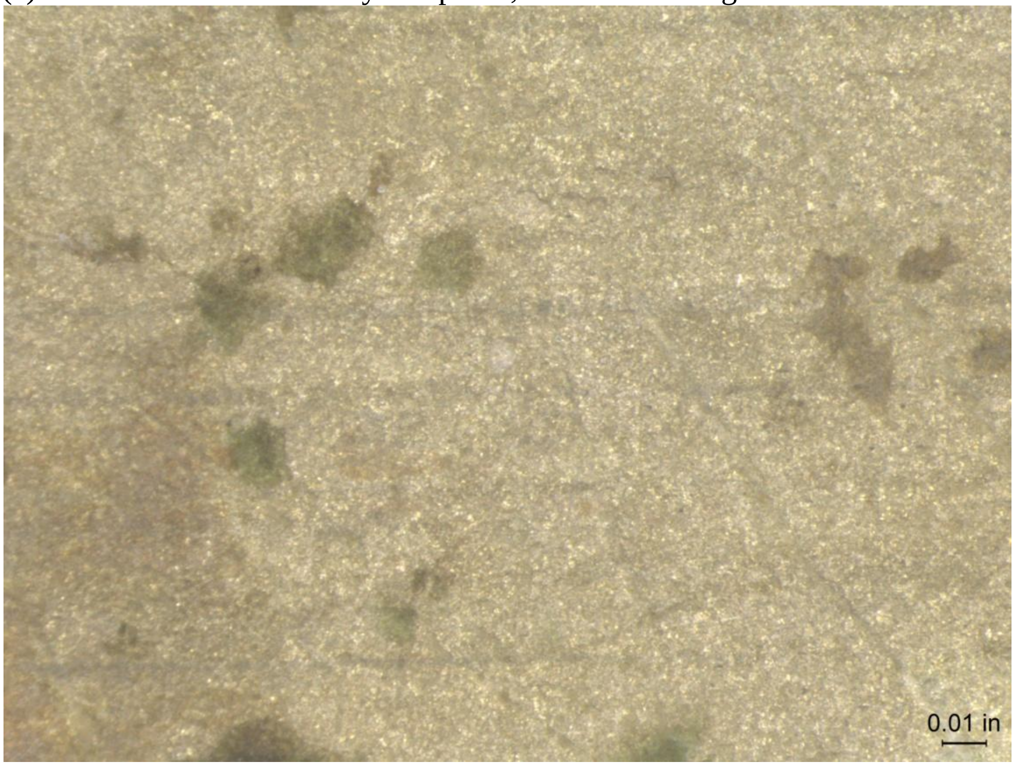
(a) Z-Alloy Coupon 2, After Cleaning 10X

(b) Z-Alloy Coupon 2, After Cleaning 50X

Figure 13 Optical macrographs of Z-Alloy coupon 2 after a 6 month corrosion test, after cleaning.

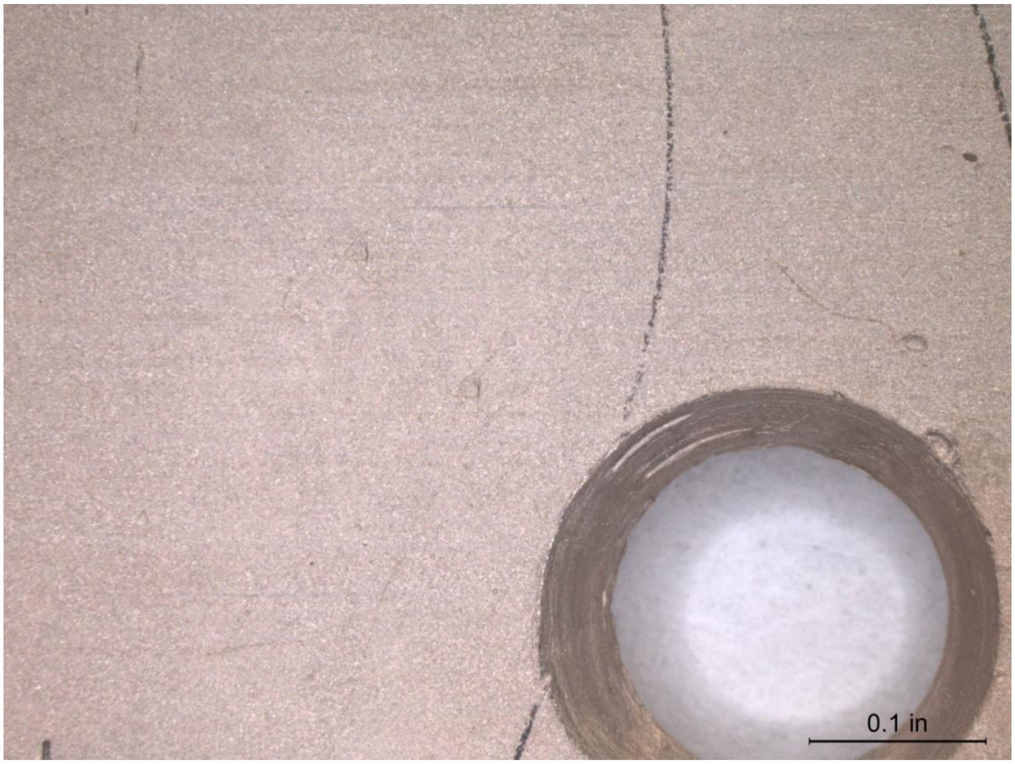


(a) Z-Alloy Coupon 3, Before Cleaning 10X



(b) Z-Alloy Coupon 3, Before Cleaning 50X

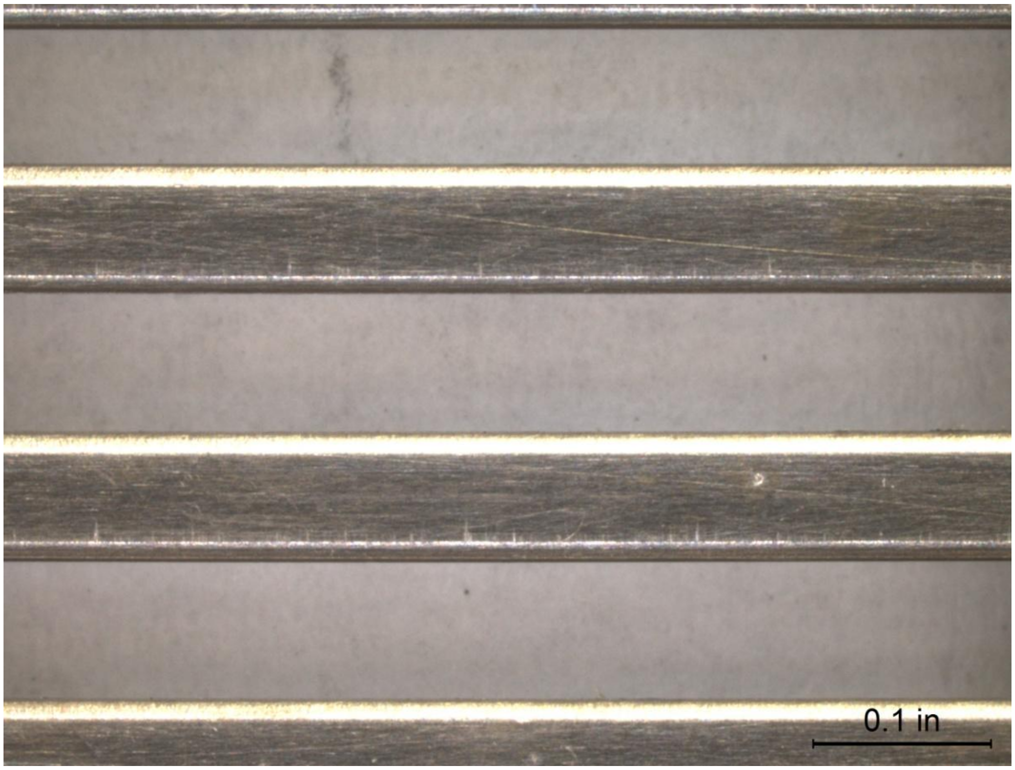
Figure 14 Optical macrographs of Z-Alloy coupon 3 after a 10 month corrosion test, before cleaning.



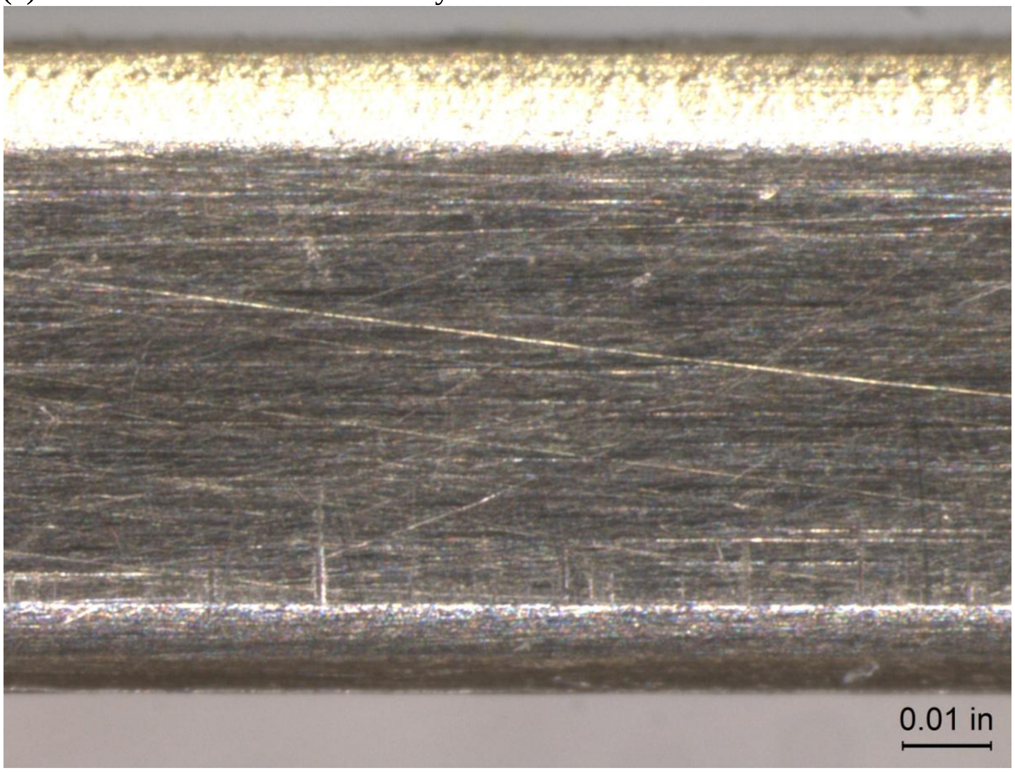
(a) Z-Alloy Coupon 3, After Cleaning 10X

(b) Z-Alloy Coupon 3, After Cleaning 50X

Figure 15 Optical macrographs of Z-Alloy coupon 3 after a 10 month corrosion test, after cleaning.

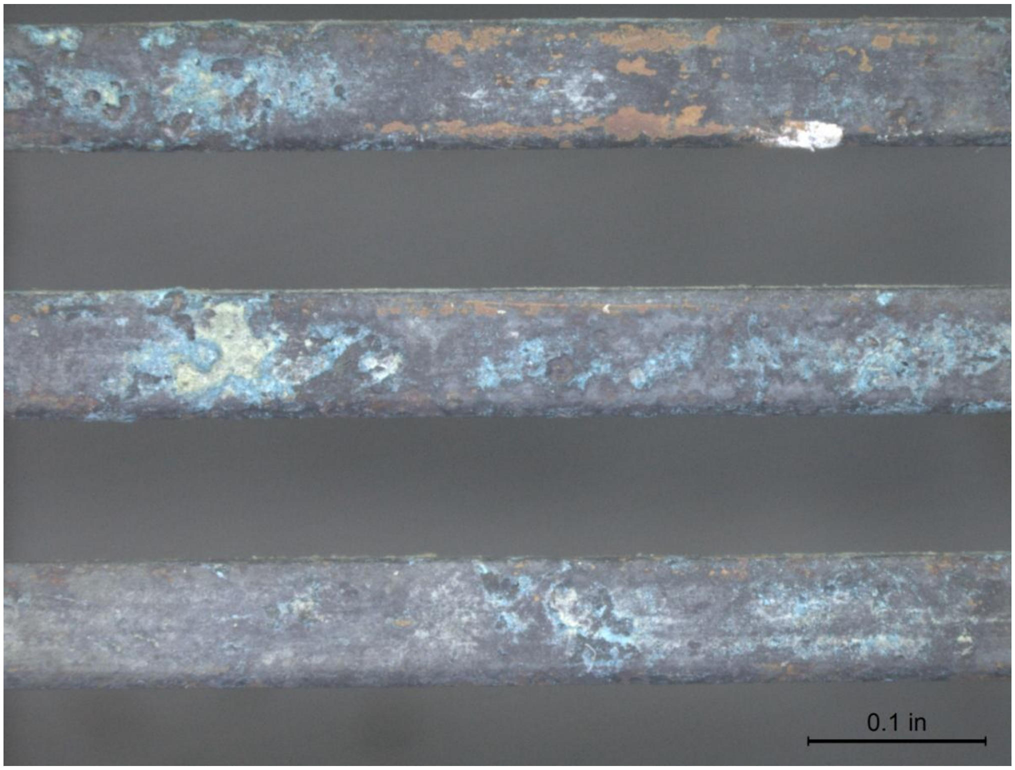


(a) Z-Alloy Baseline Screen 10X

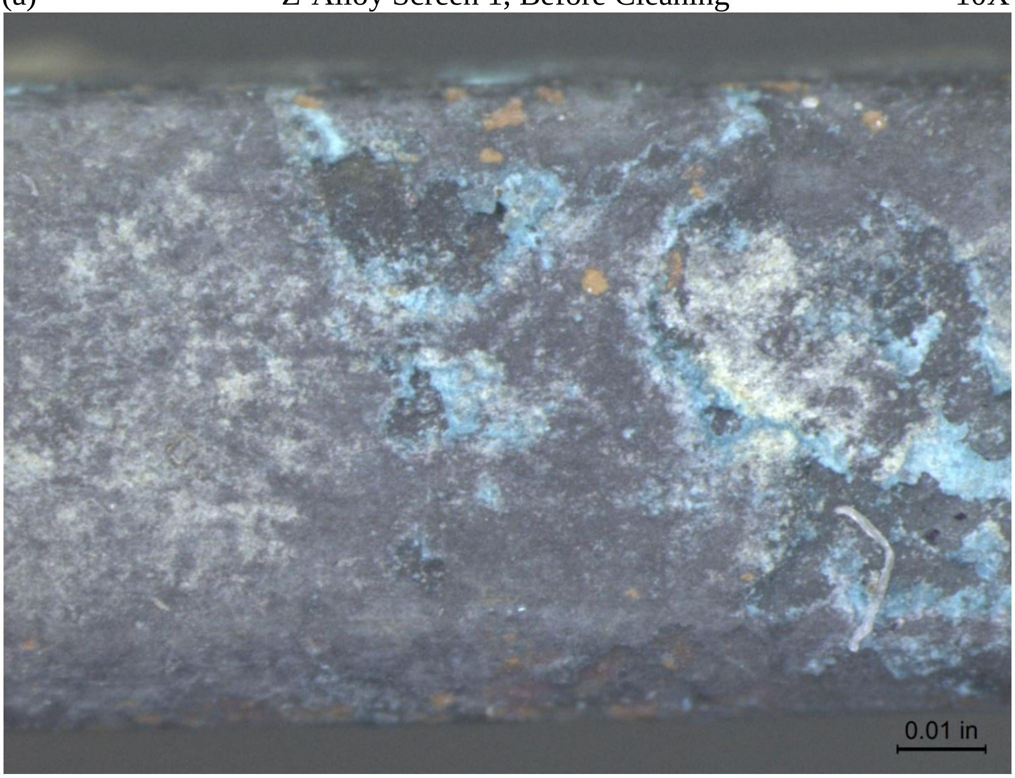


(b) Z-Alloy Baseline Screen 50X

Figure 16 Optical macrographs of the Z-Alloy baseline screen.

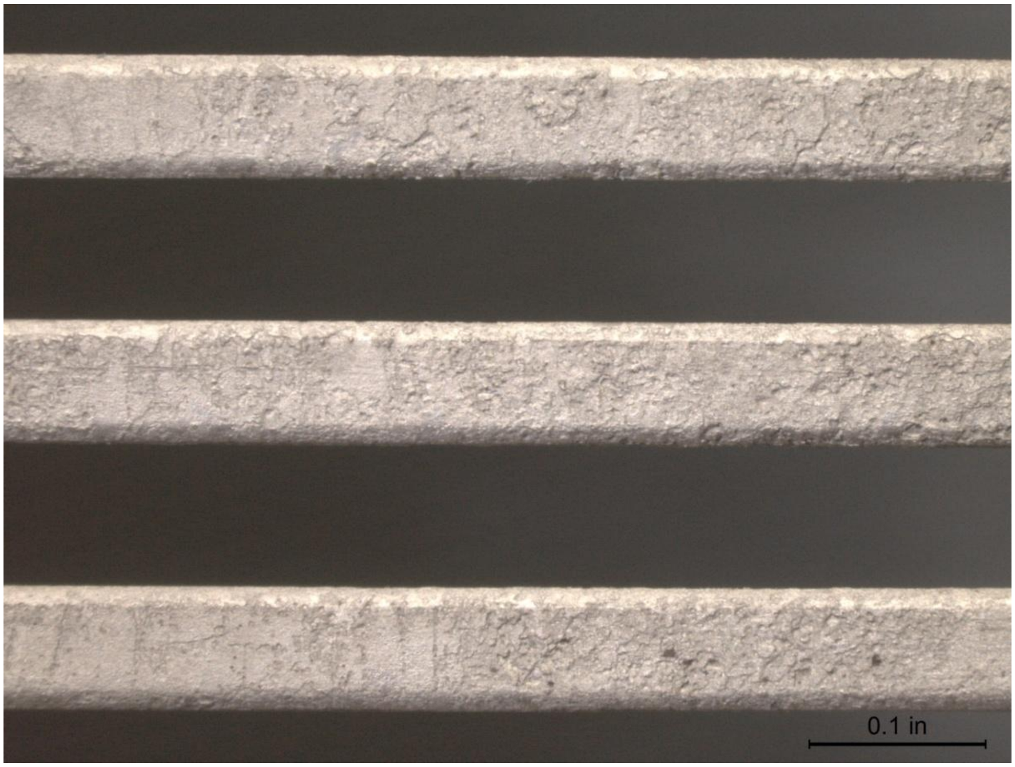


(a) Z-Alloy Screen 1, Before Cleaning 10X

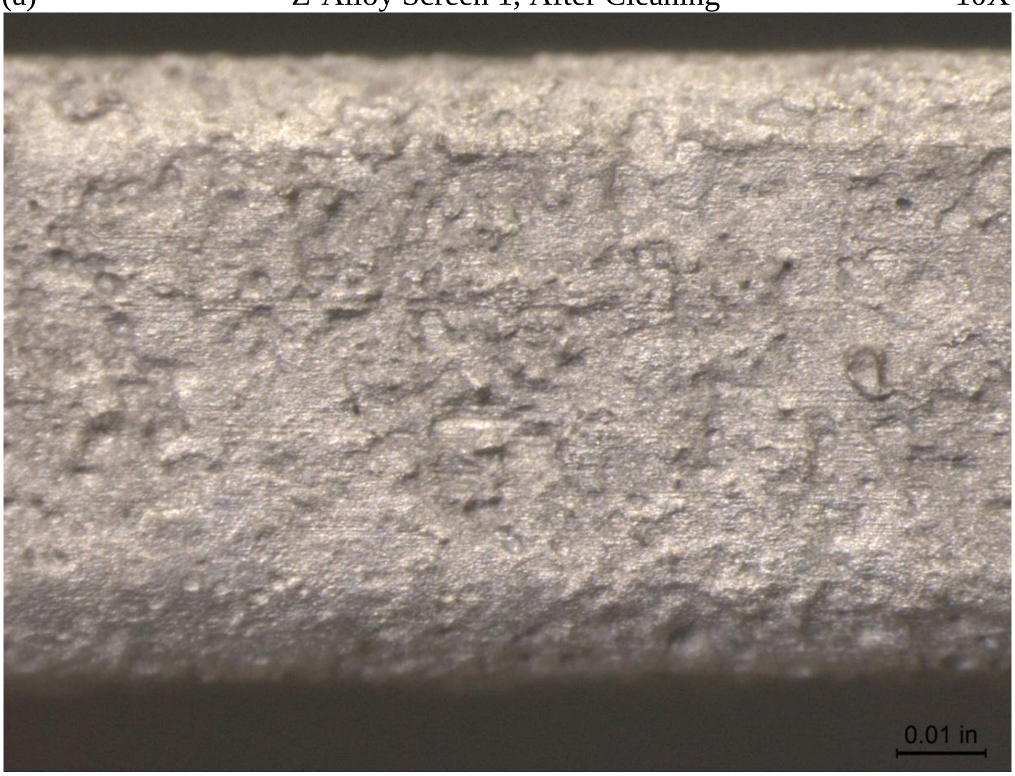


(b) Z-Alloy Screen 1, Before Cleaning 50X

Figure 17 Optical macrographs of Z-Alloy screen 1 after a 3 month corrosion test, before cleaning.

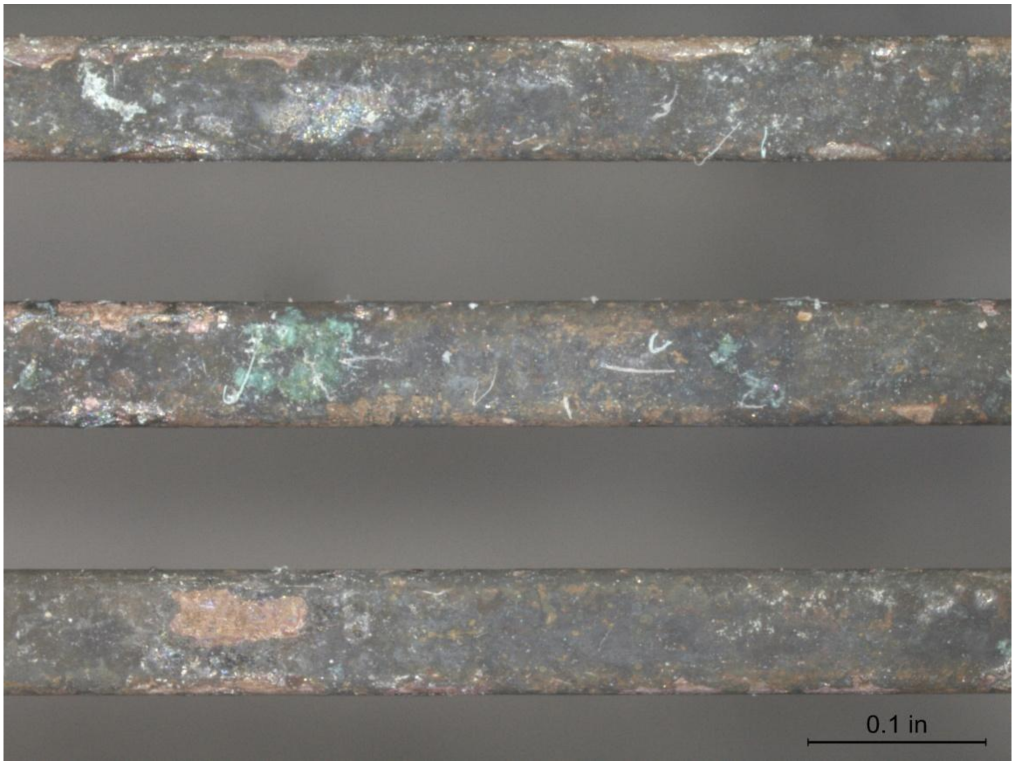


(a) Z-Alloy Screen 1, After Cleaning 10X



(b) Z-Alloy Screen 1, After Cleaning 50X

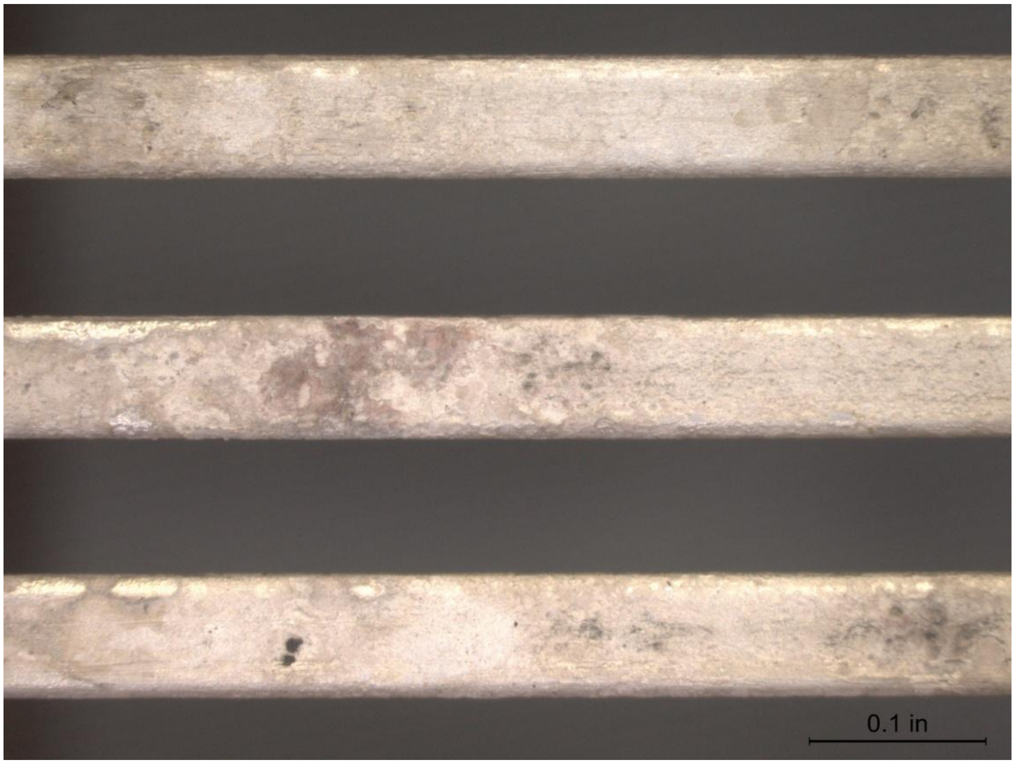
Figure 18 Optical macrographs of Z-Alloy screen 1 after a 3 month corrosion test, after cleaning.



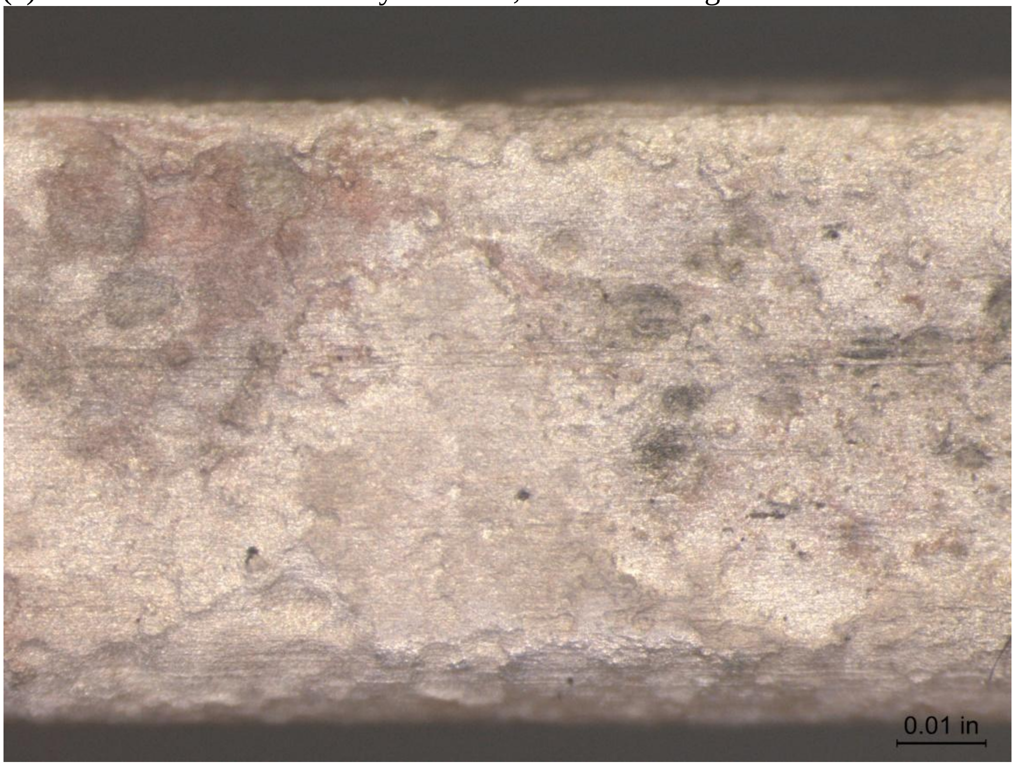
(a) Z-Alloy Screen 2, Before Cleaning 10X

(b) Z-Alloy Screen 2, Before Cleaning 50X

Figure 19 Optical macrographs of Z-Alloy screen 2 after a 6 month corrosion test, before cleaning.

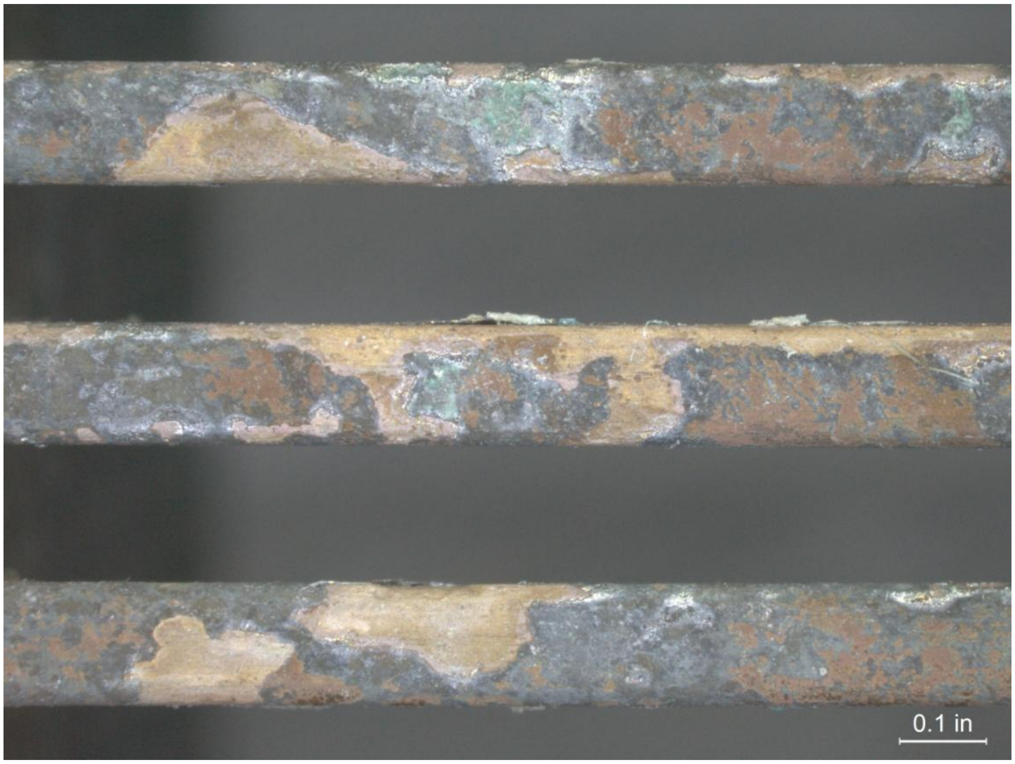


(a) Z-Alloy Screen 2, After Cleaning 10X

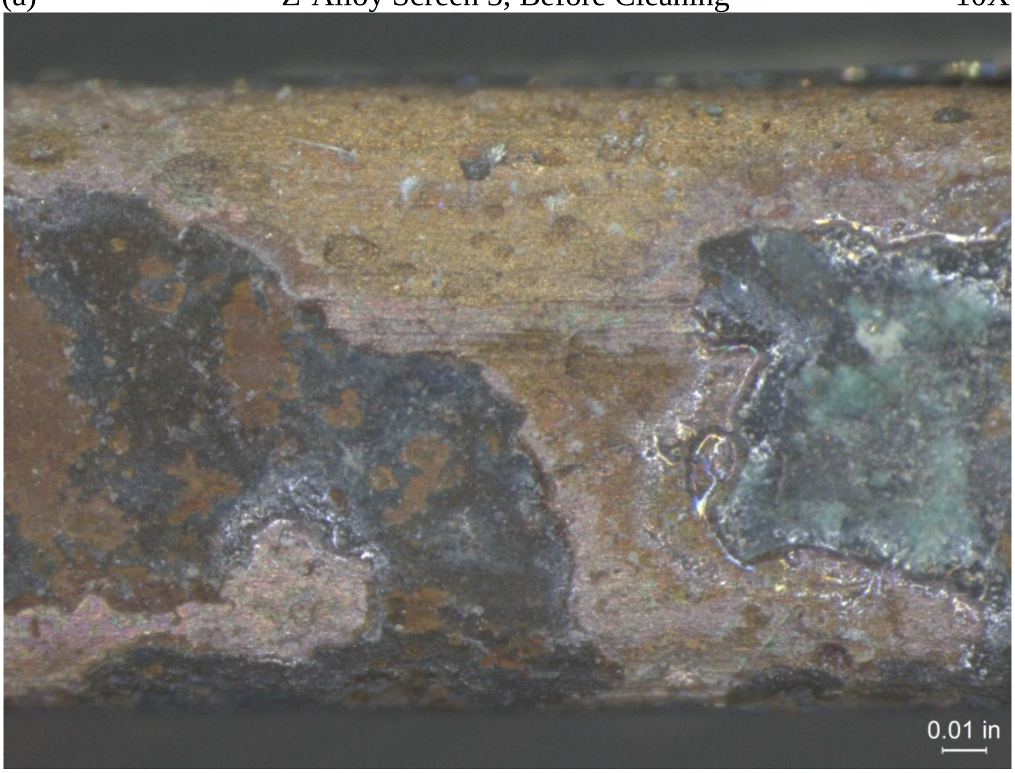


(b) Z-Alloy Screen 2, After Cleaning 50X

Figure 20 Optical macrographs of Z-Alloy screen 2 after a 6 month corrosion test, after cleaning.

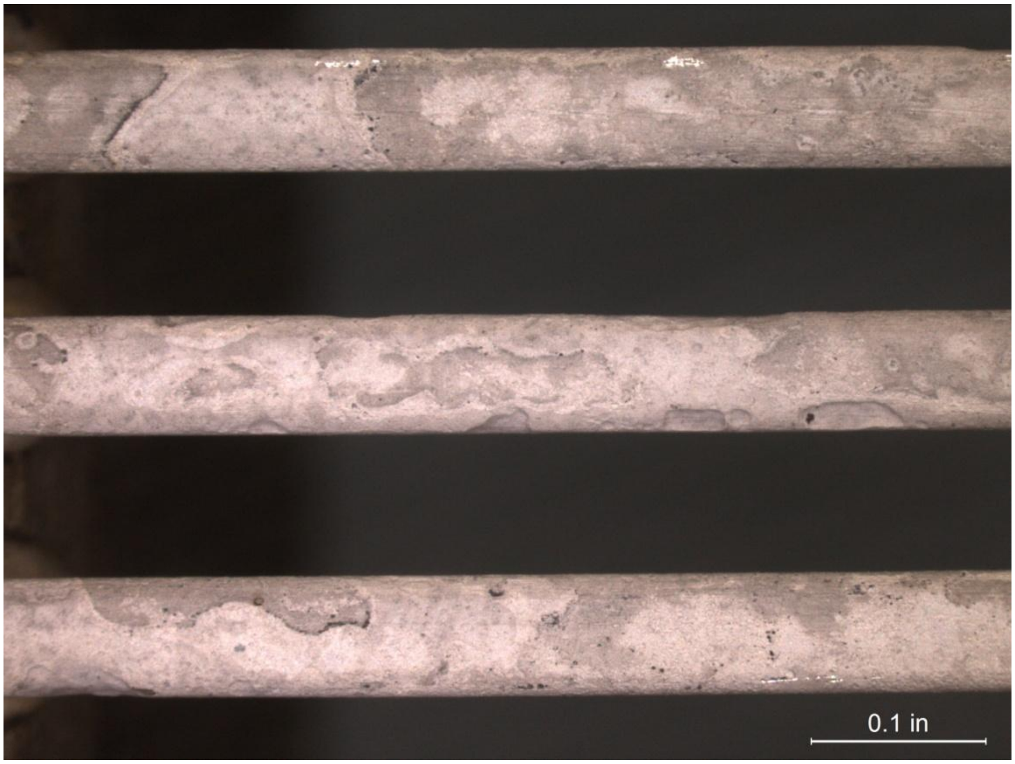


(a) Z-Alloy Screen 3, Before Cleaning 10X

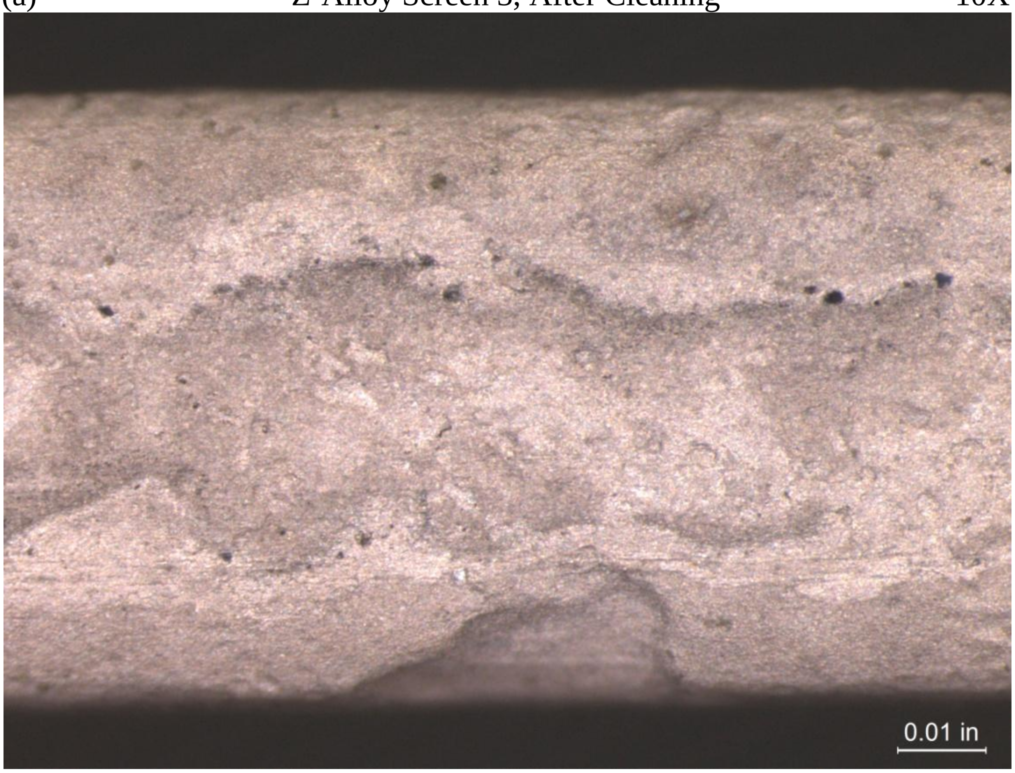


(b) Z-Alloy Screen 3, Before Cleaning 50X

Figure 21 Optical macrographs of Z-Alloy screen 3 after a 10 month corrosion test, before cleaning.

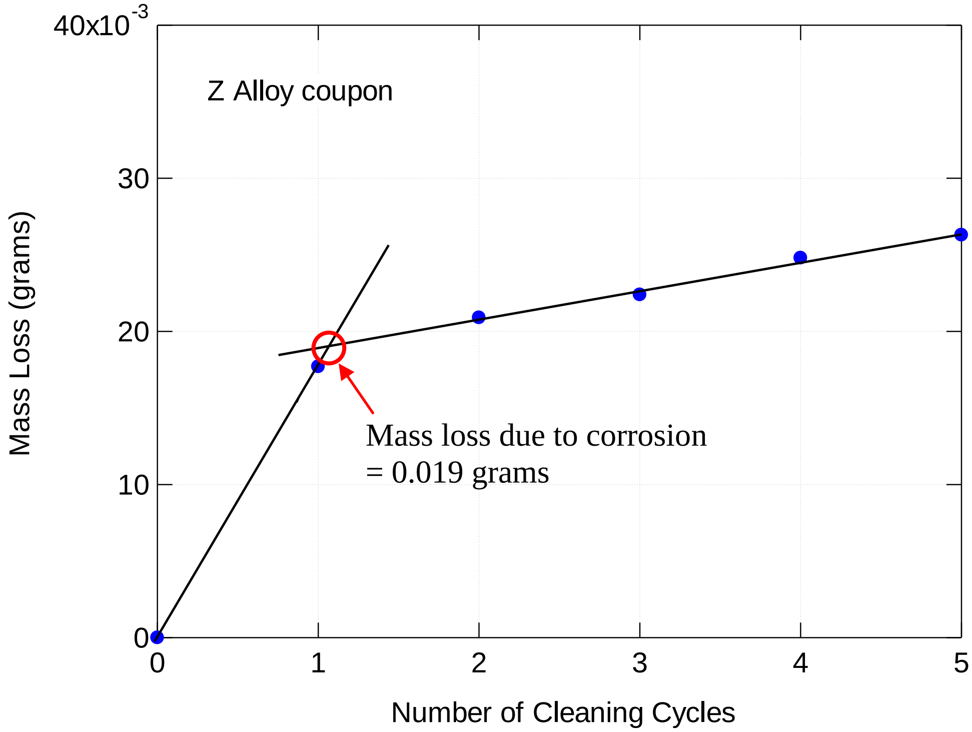


(a) Z-Alloy Screen 3, After Cleaning 10X

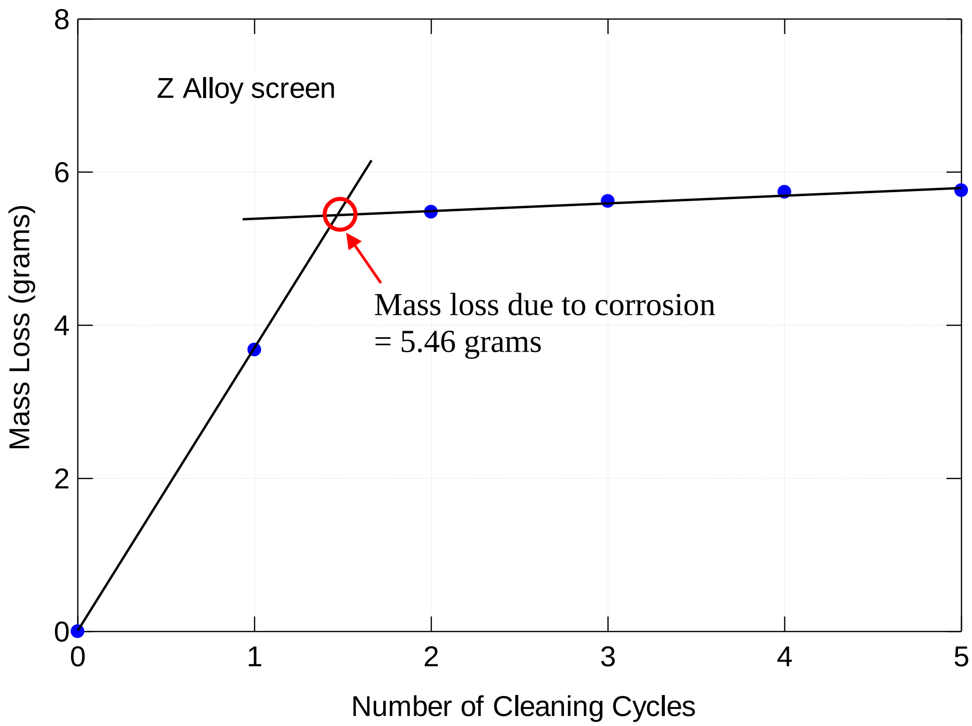


(b) Z-Alloy Screen 3, After Cleaning 50X

Figure 22 Optical macrographs of Z-Alloy screen 3 after a 10 month corrosion test, after cleaning.

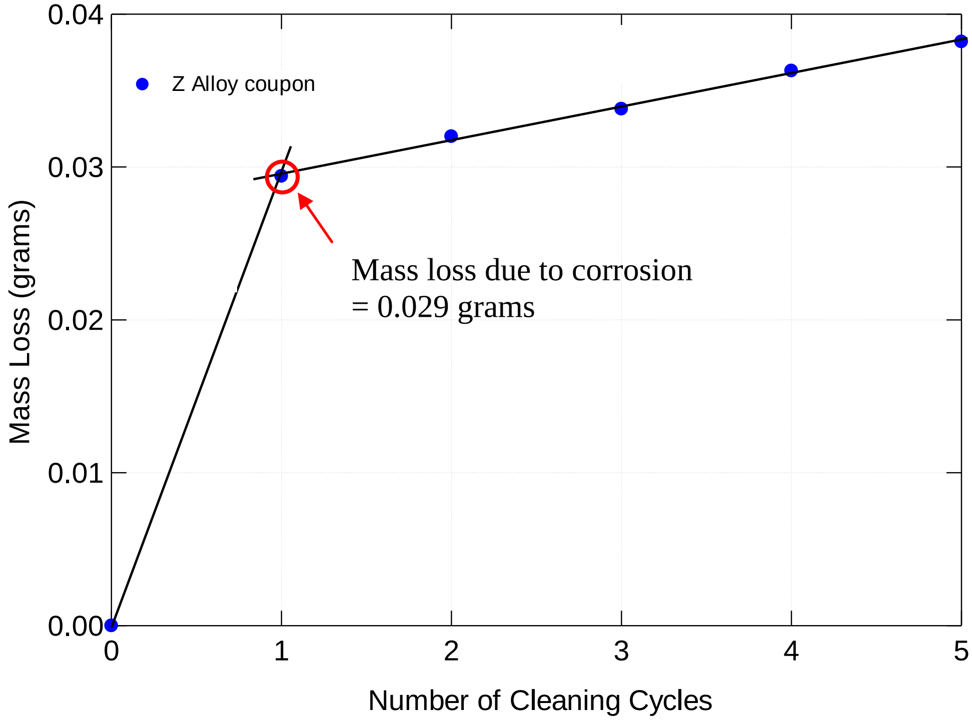


(a)

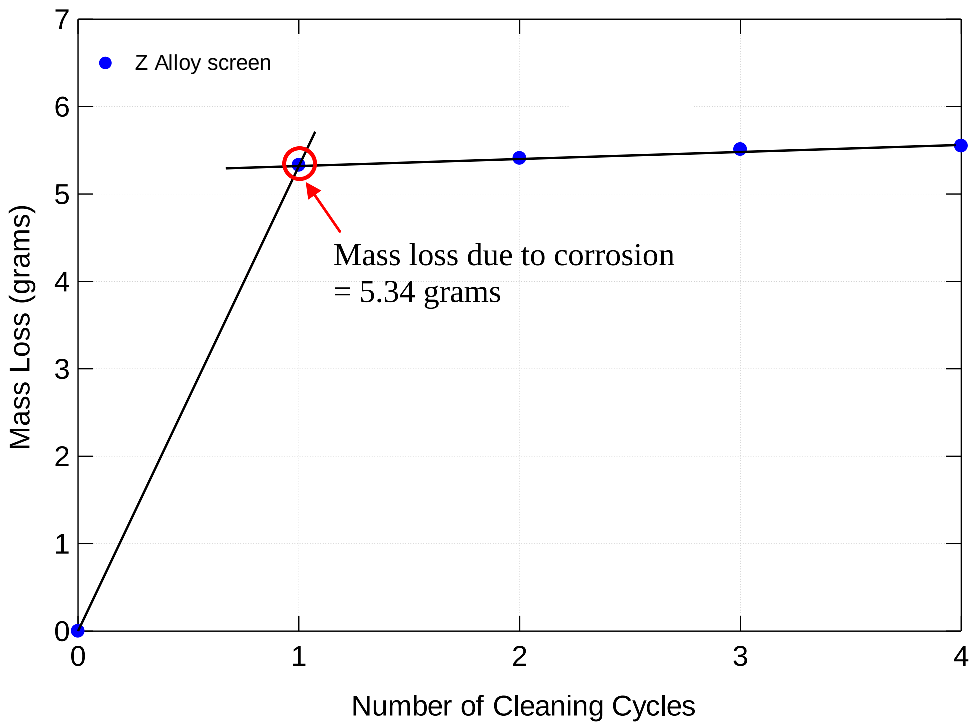


(b)

Figure 23   Mass loss of the Z-Alloy (a) coupon 1 and (b) screen 1 during cleaning.

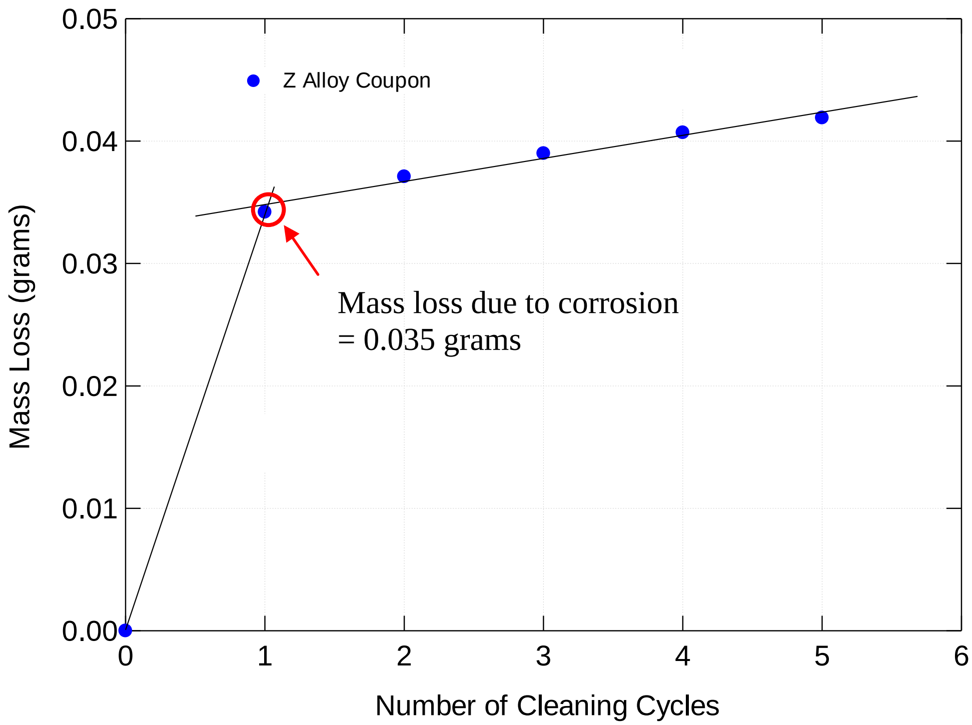


(a)

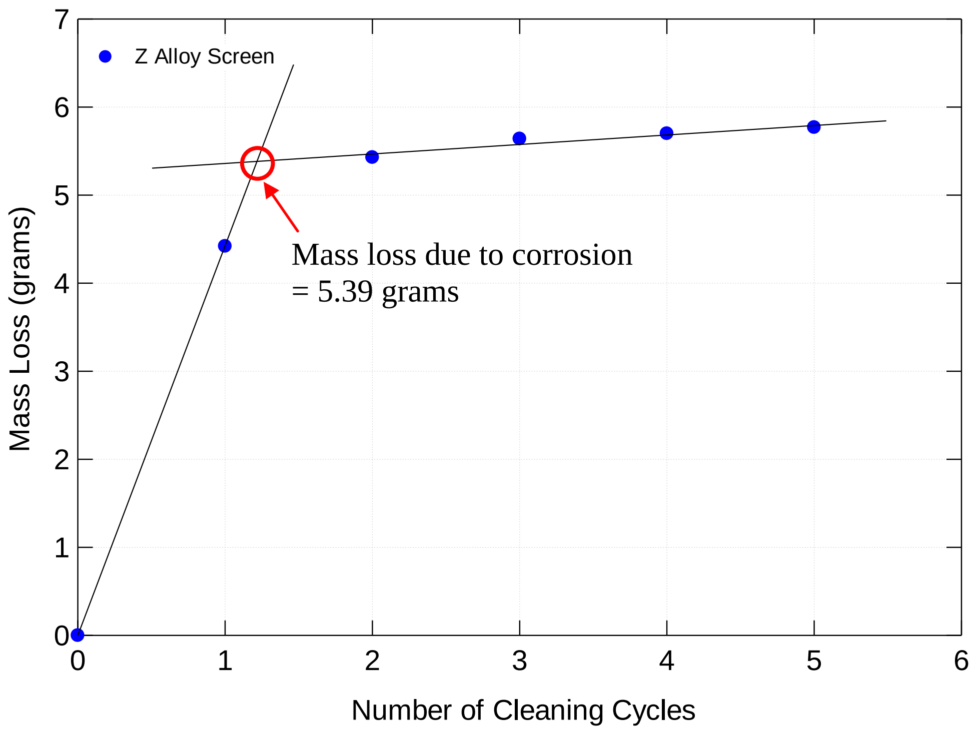


(b)

Figure 24 Mass loss of the Z-Alloy (a) coupon 2 and (b) screen 2 during cleaning.

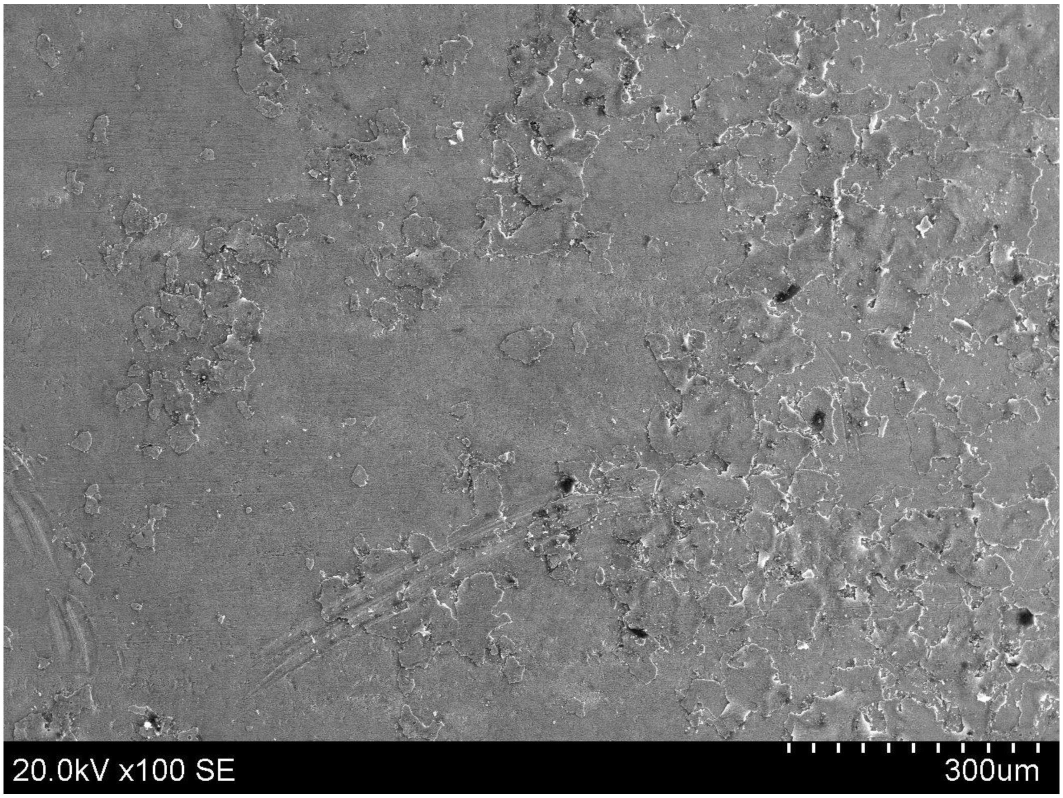


(a)

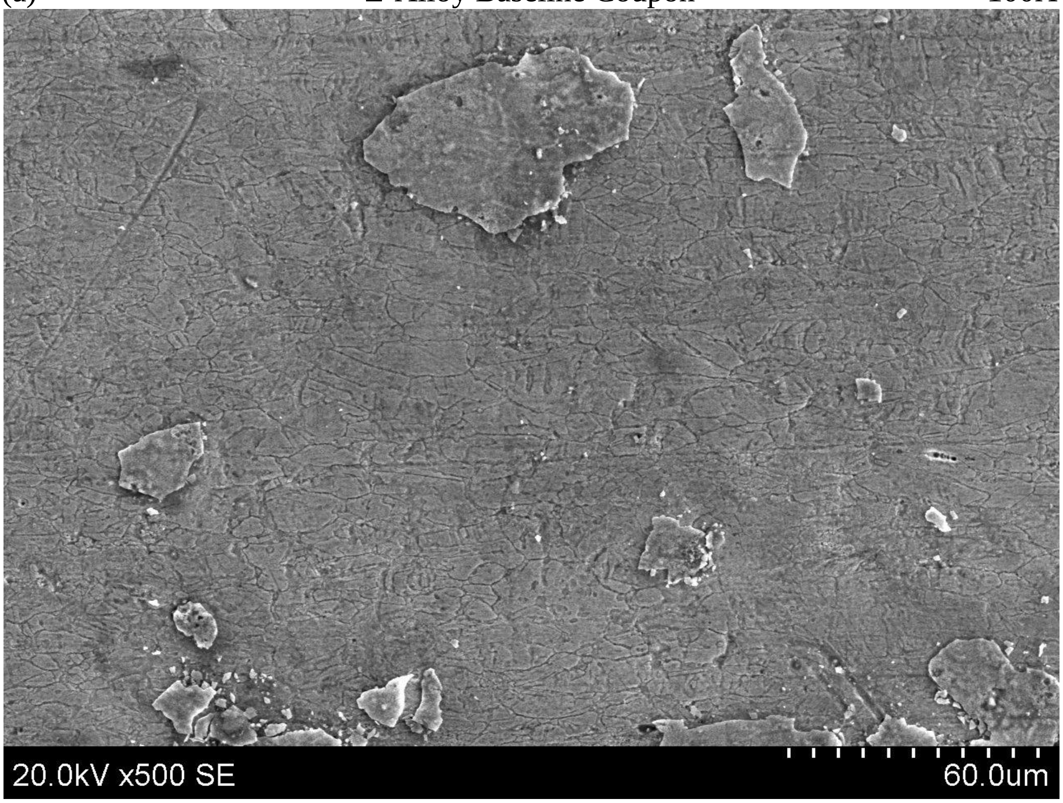


(b)

Figure 25 Mass loss of the Z-Alloy (a) coupon 3 and (b) screen 3 during cleaning.

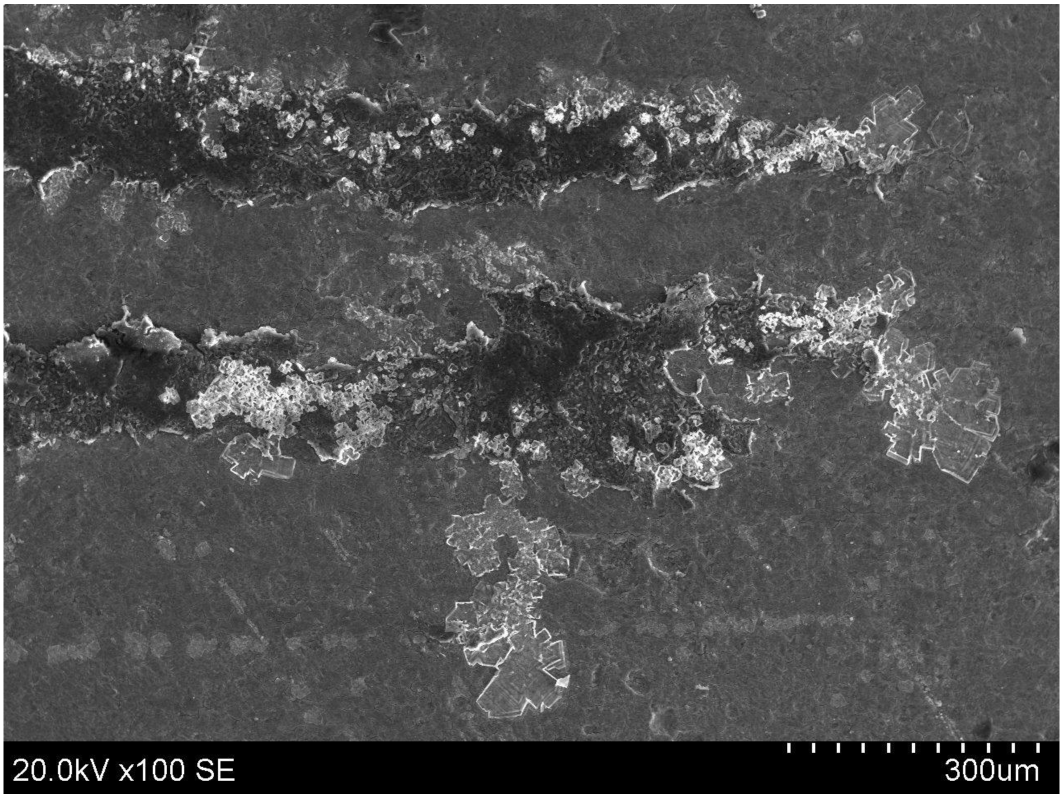


(a) Z-Alloy Baseline Coupon 100X

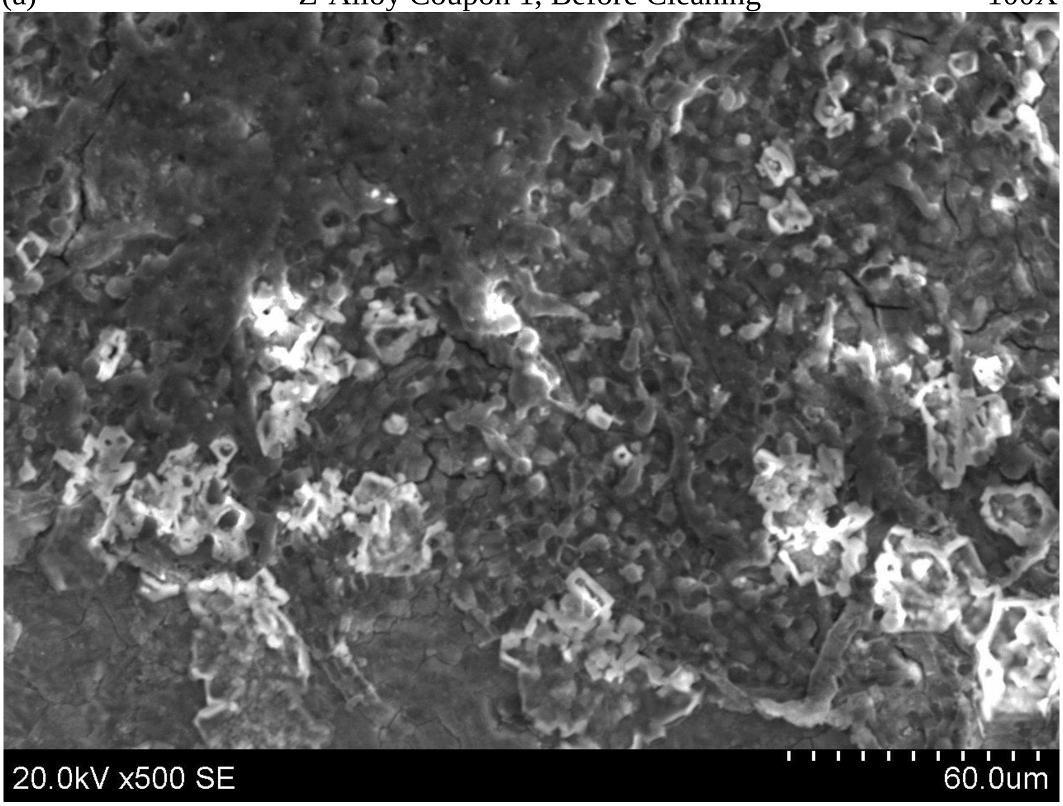


(b) Z-Alloy Baseline Coupon 500X

Figure 26 Scanning electron micrographs of Z-Alloy baseline coupon.



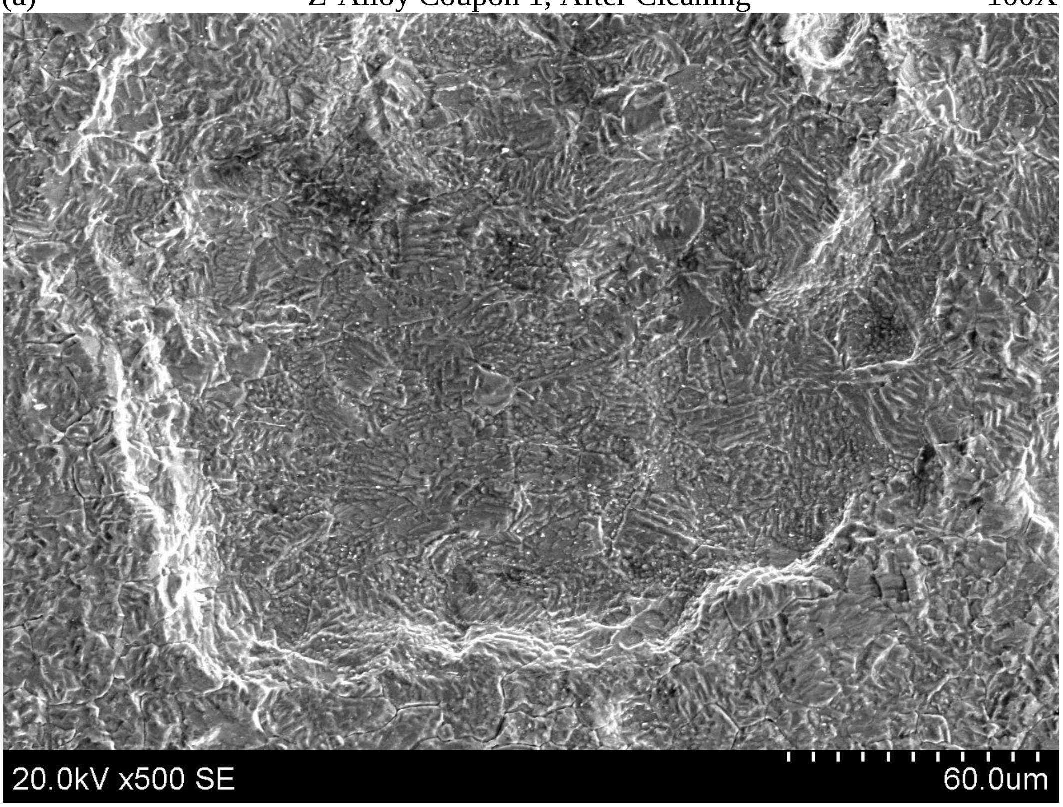
(a) Z-Alloy Coupon 1, Before Cleaning 100X



(b) Z-Alloy Coupon 1, Before Cleaning 500X

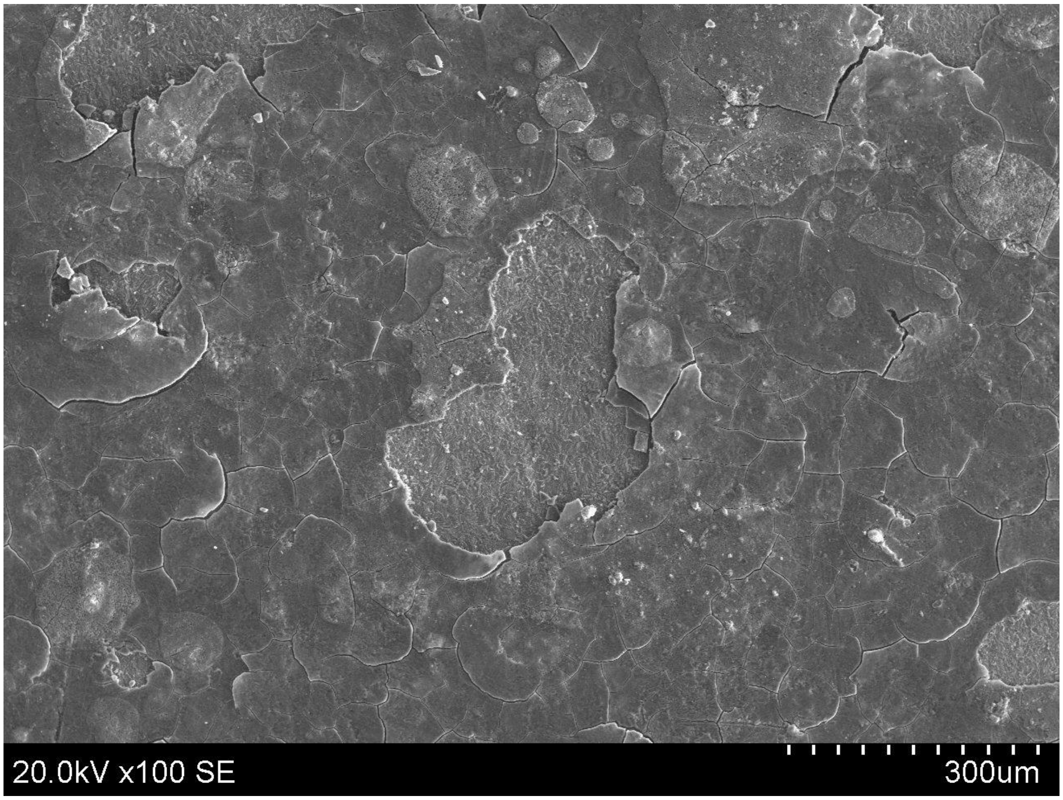
Figure 27 Scanning electron micrographs of Z-Alloy coupon 1 after a 3 month corrosion test, before cleaning.

(a) Z-Alloy Coupon 1, After Cleaning 100X

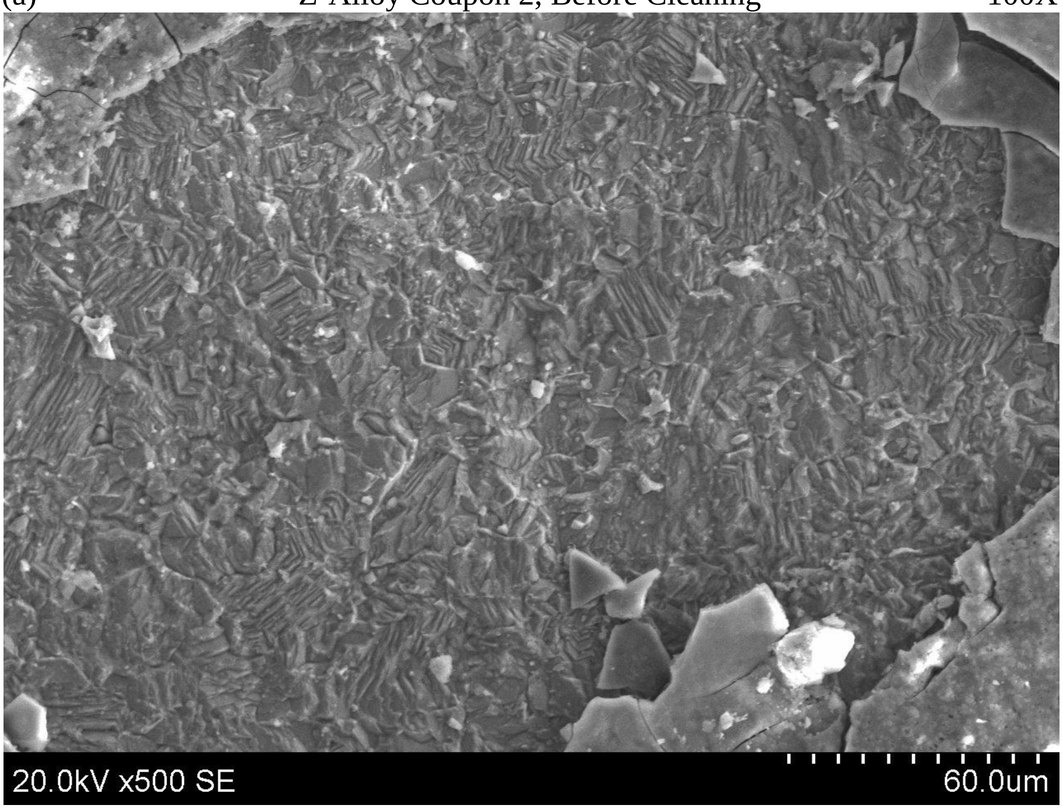


(b) Z-Alloy Coupon 1, After Cleaning 500X

Figure 28 Scanning electron micrographs of Z-Alloy coupon 1 after a 3 month corrosion test, after cleaning.

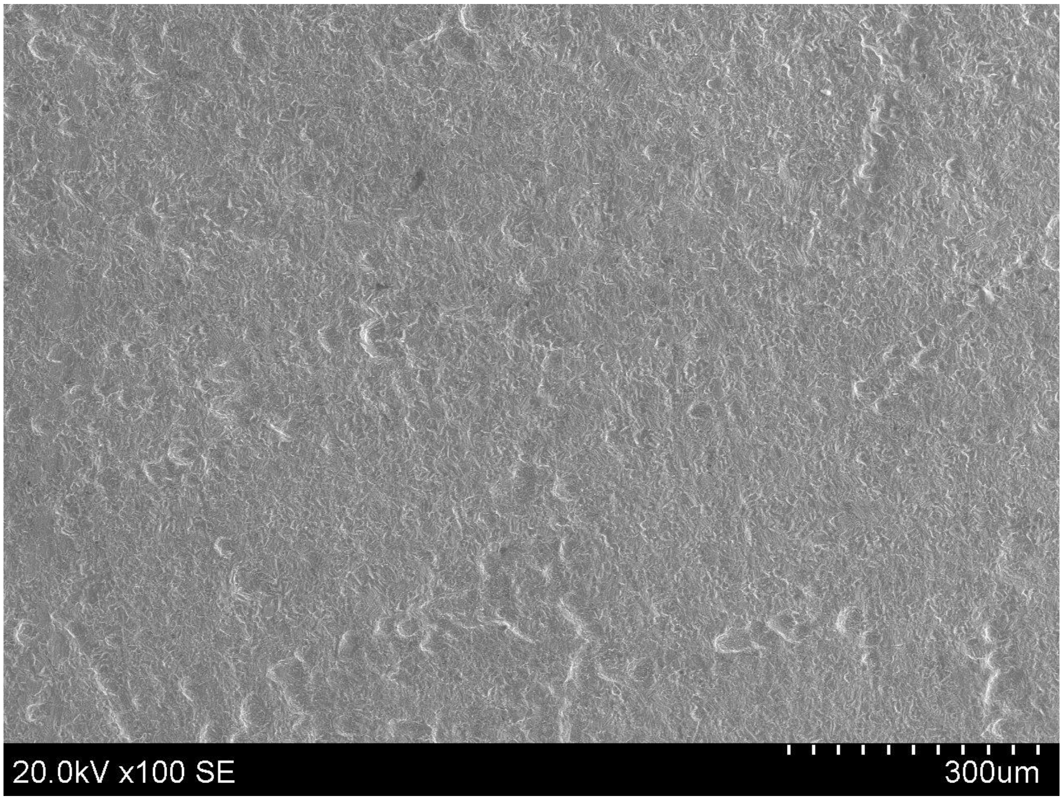


(a) Z-Alloy Coupon 2, Before Cleaning 100X

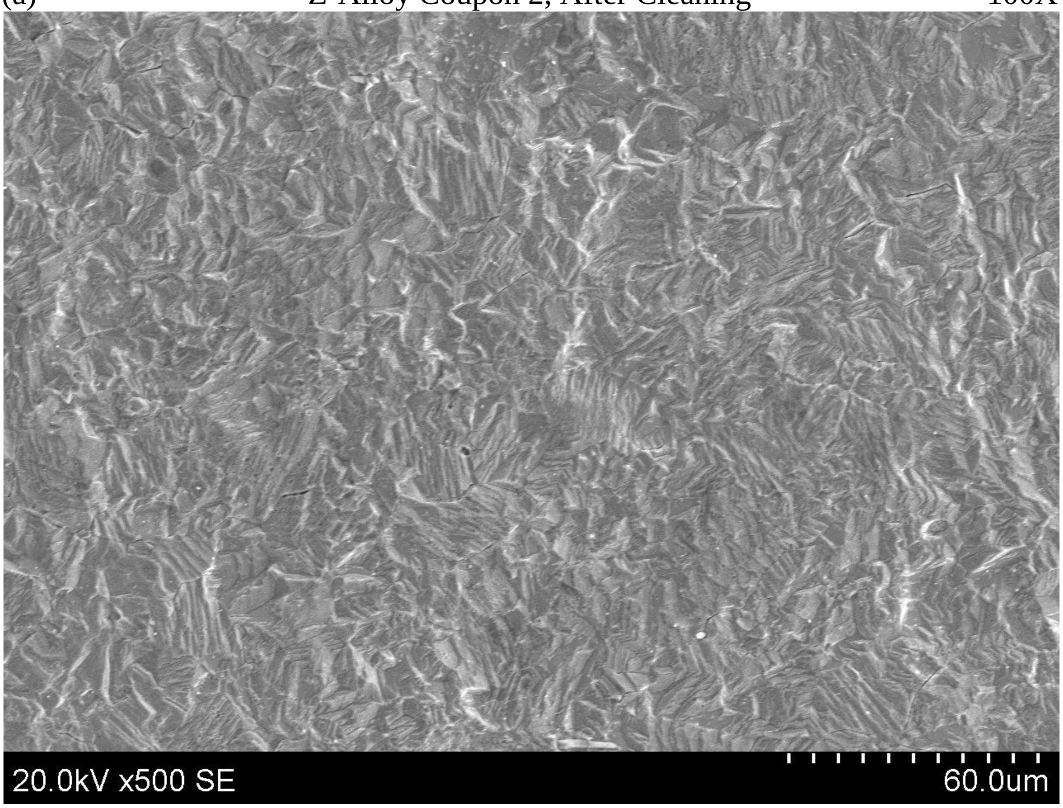


(b) Z-Alloy Coupon 2, Before Cleaning 500X

Figure 29 Scanning electron micrographs of Z-Alloy coupon 2 after a 6 month corrosion test, before cleaning.

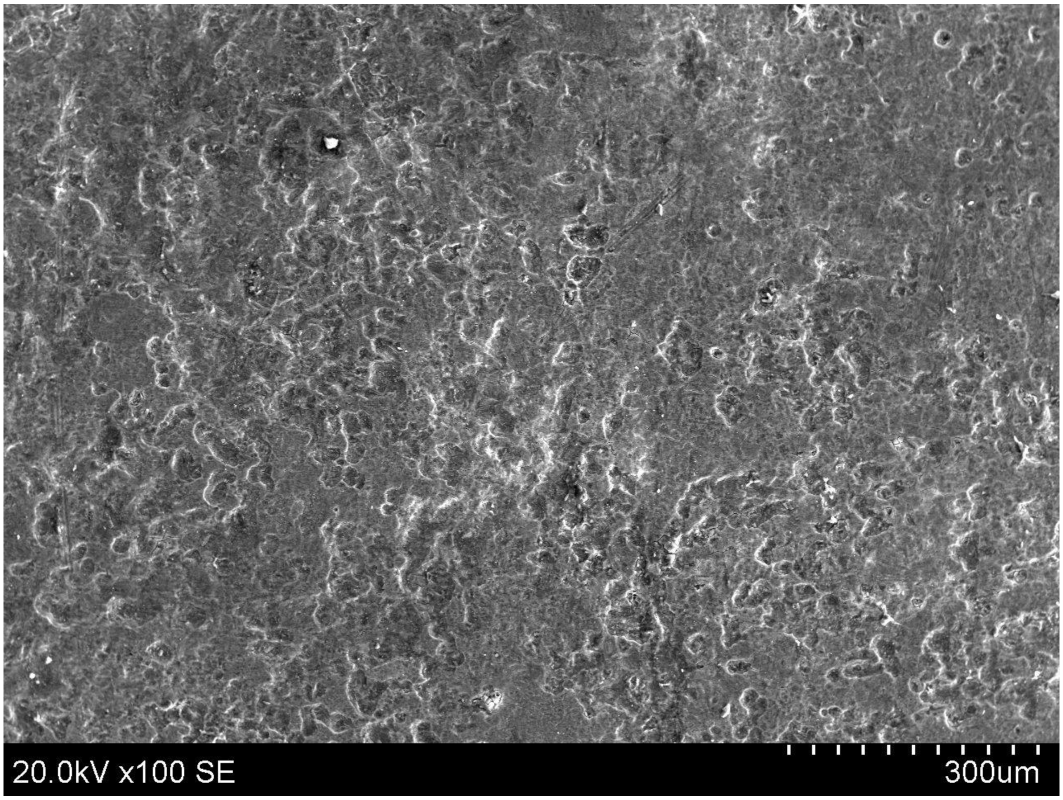


(a) Z-Alloy Coupon 2, After Cleaning 100X

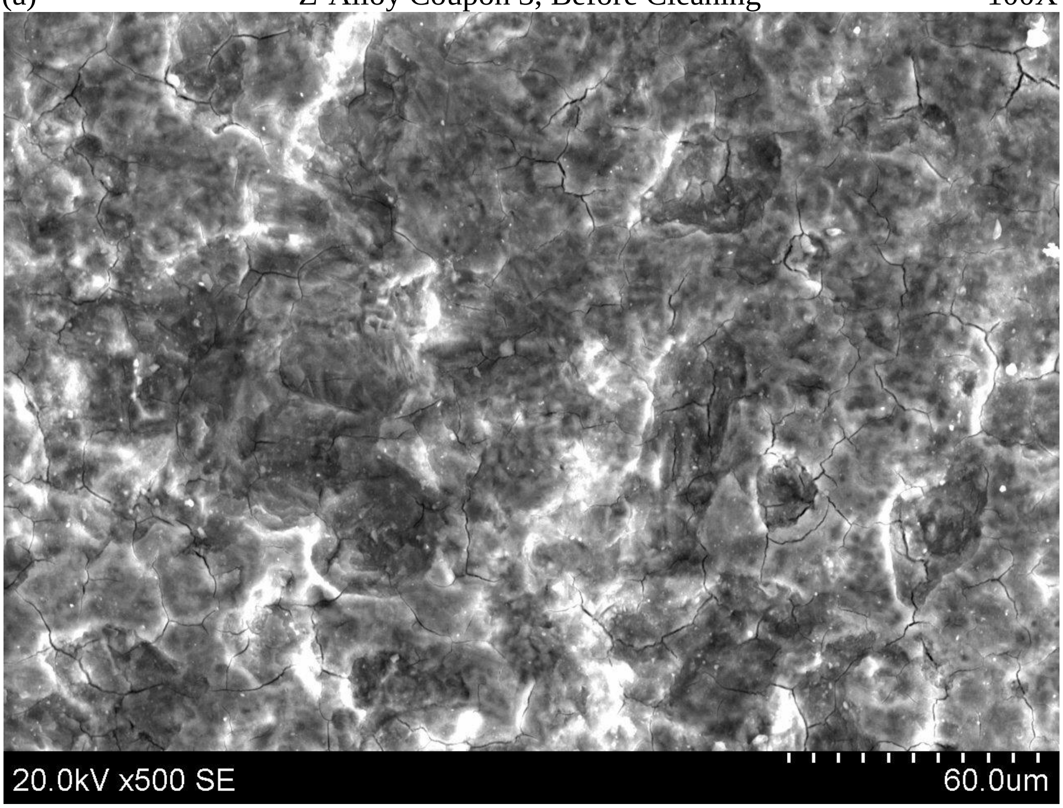


(b) Z-Alloy Coupon 2, After Cleaning 500X

Figure 30 Scanning electron micrographs of Z-Alloy coupon 2 after a 6 month corrosion test, after cleaning.

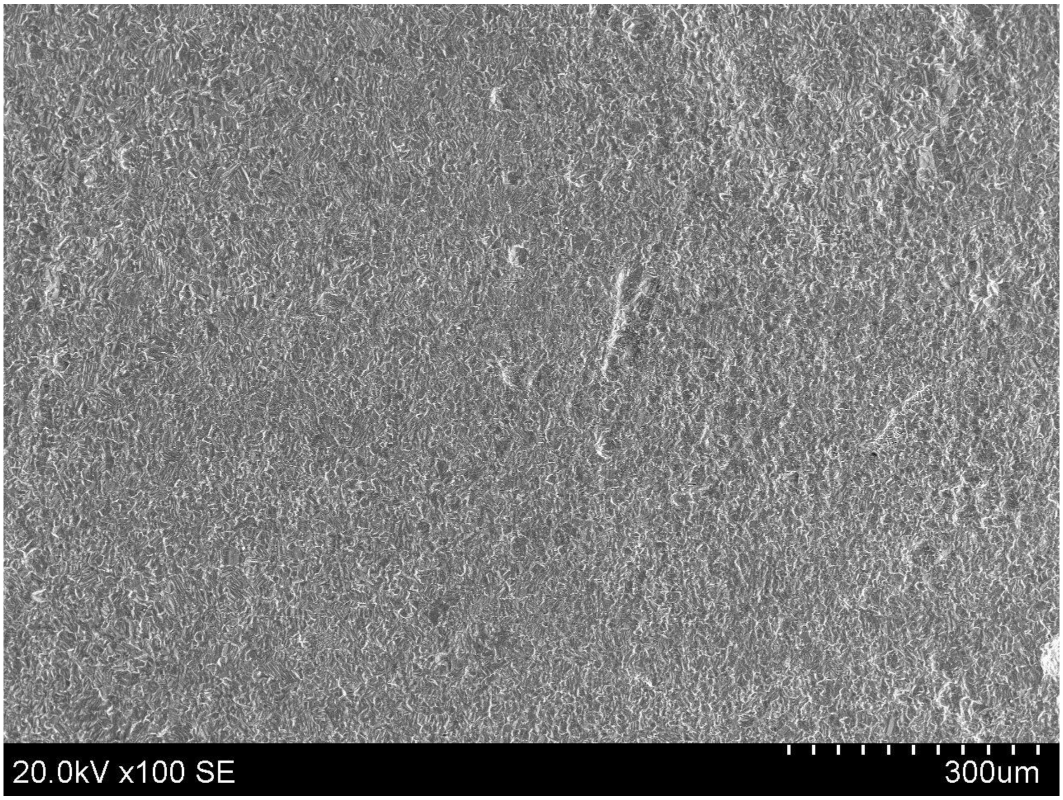


(a) Z-Alloy Coupon 3, Before Cleaning 100X

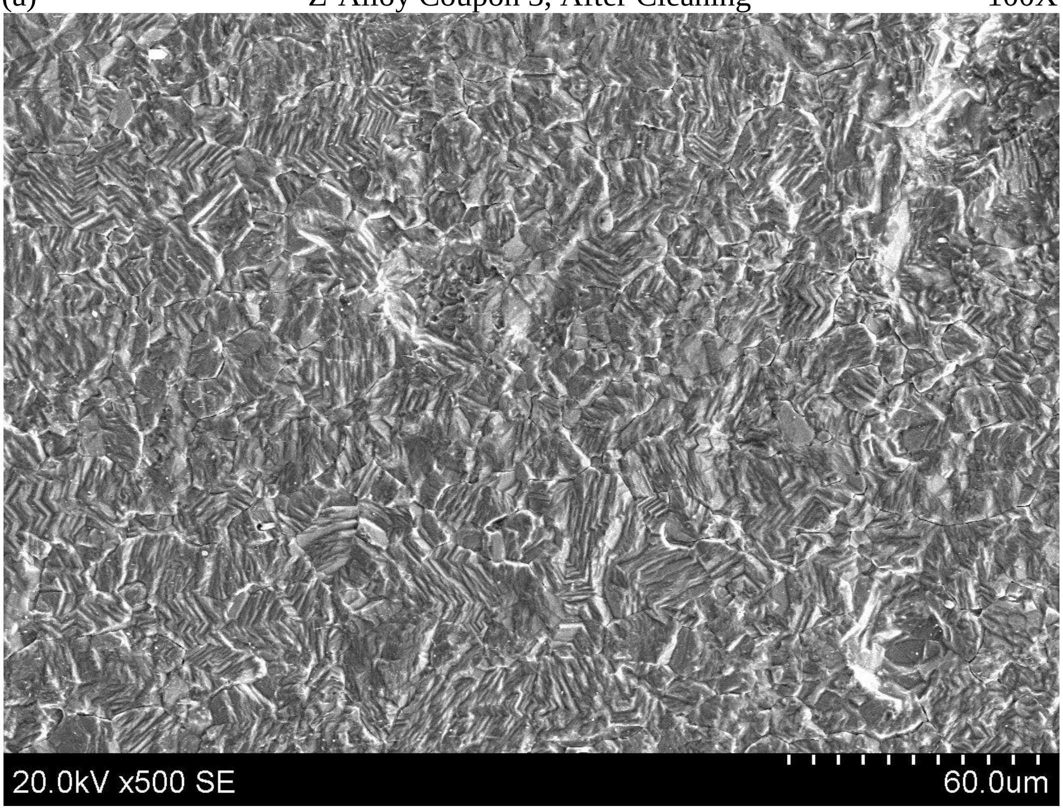


(b) Z-Alloy Coupon 3, Before Cleaning 500X

Figure 31 Scanning electron micrographs of Z-Alloy coupon 3 after a 10 month corrosion test, before cleaning.

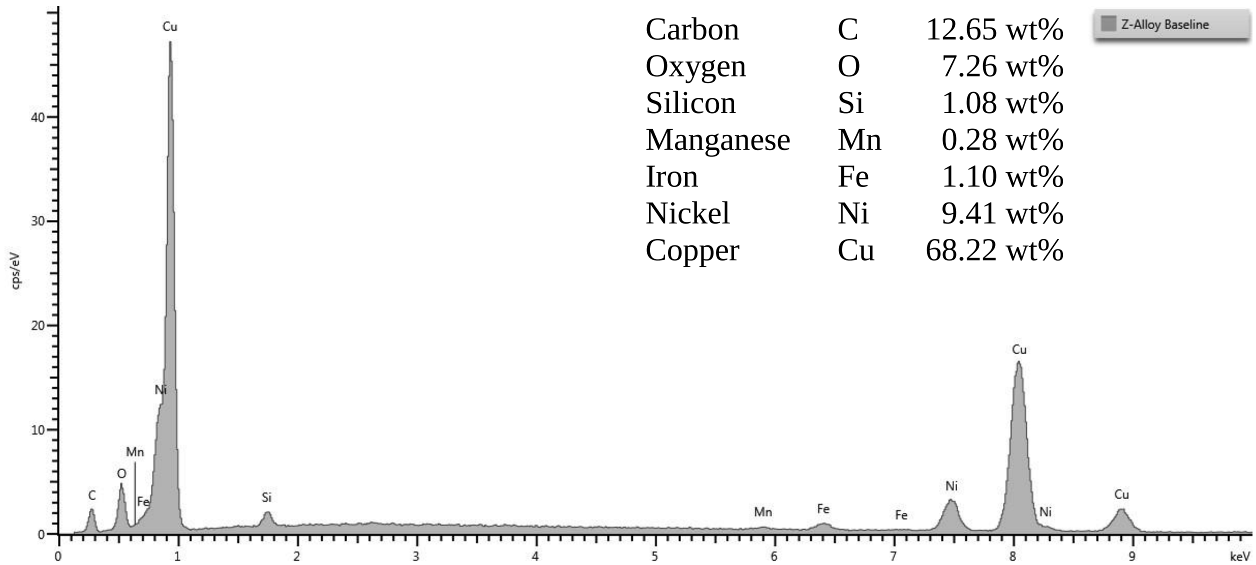


(a) Z-Alloy Coupon 3, After Cleaning 100X



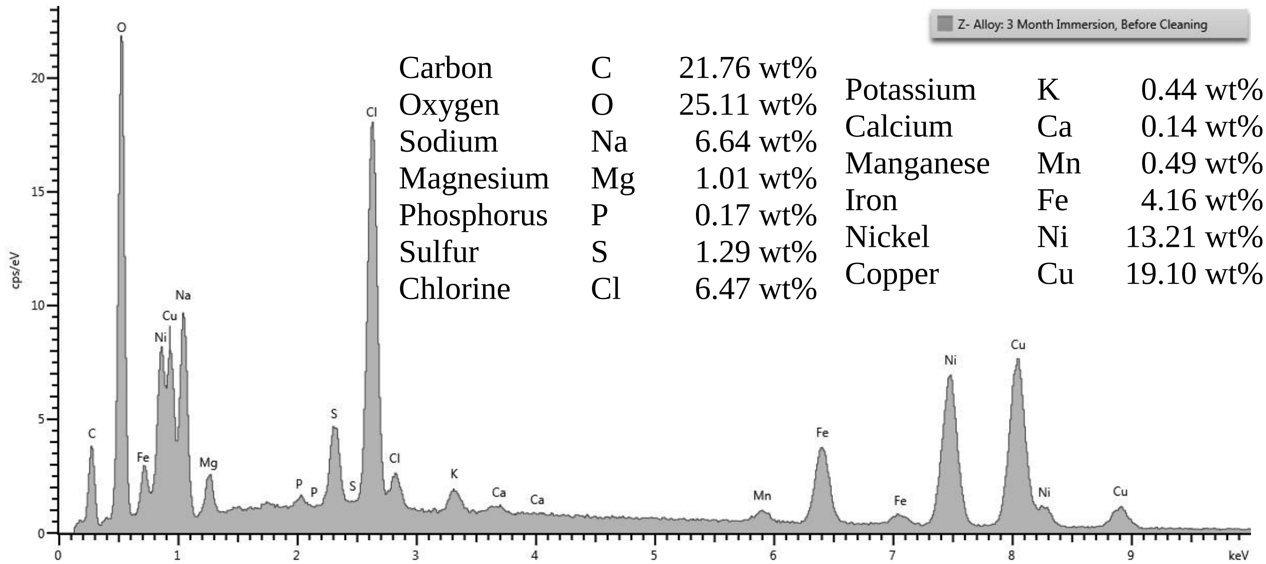
(b) Z-Alloy Coupon 3, After Cleaning 500X

Figure 32 Scanning electron micrographs of Z-Alloy coupon 3 after a 10 month corrosion test, after cleaning.

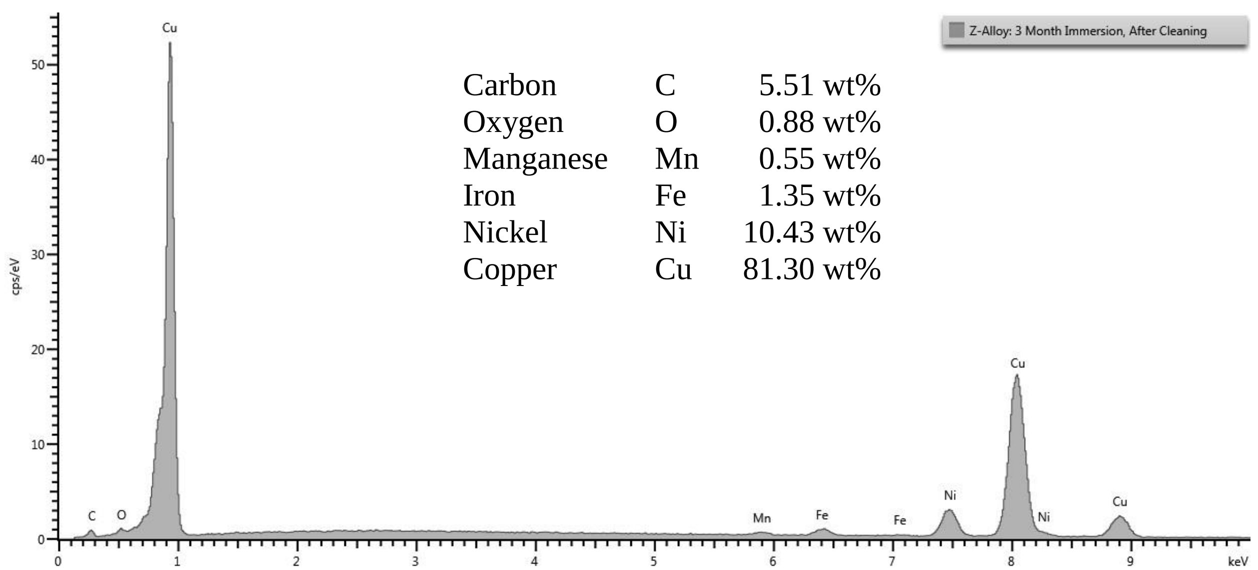


(a) Z-Alloy Baseline Coupon

Figure 33 Energy dispersive x-ray spectra of Z-Alloy baseline coupon 1.

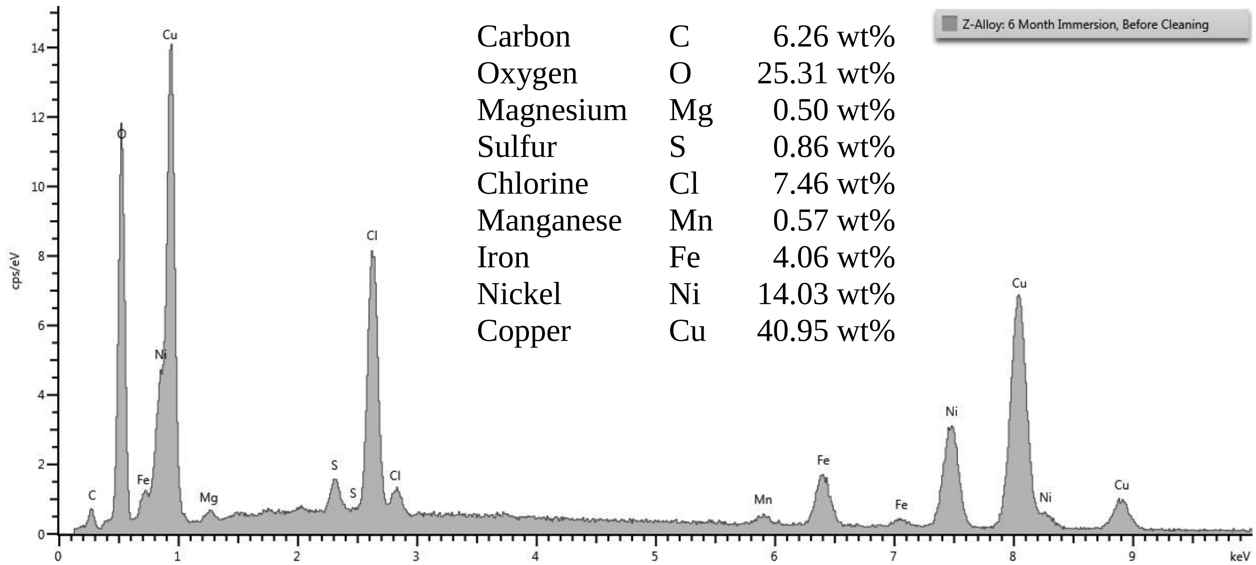


(a) Z-Alloy Coupon 1, Before Cleaning

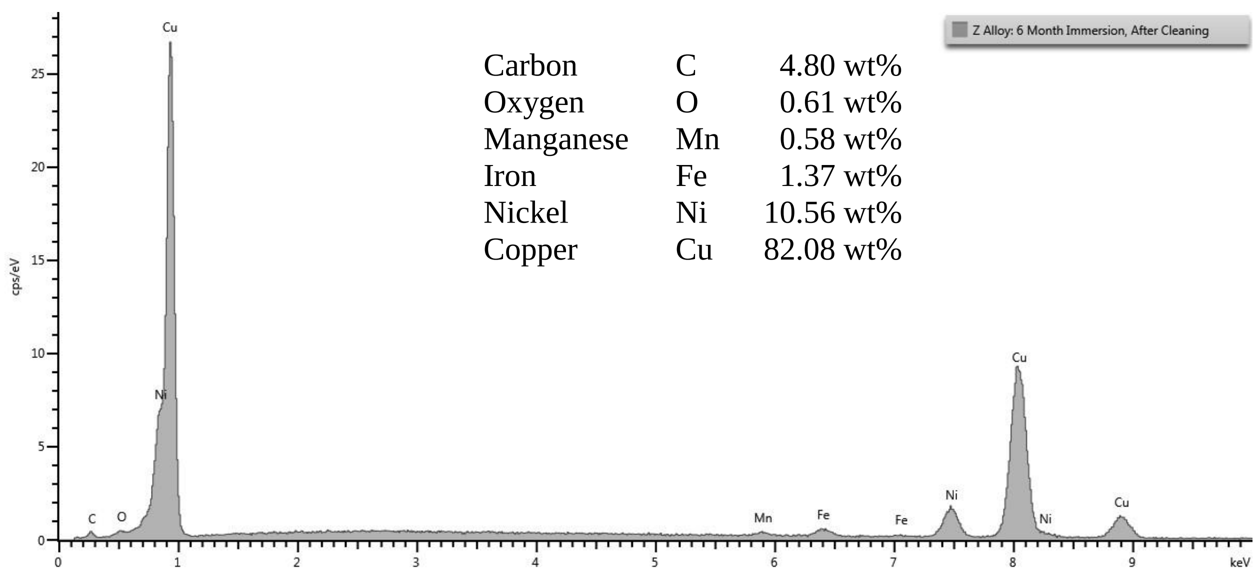


(b) Z-Alloy Coupon 1, After Cleaning

Figure 34 Energy dispersive x-ray spectra of Z-Alloy coupon 1 after a 3 month corrosion test (a) before cleaning and (b) after cleaning.

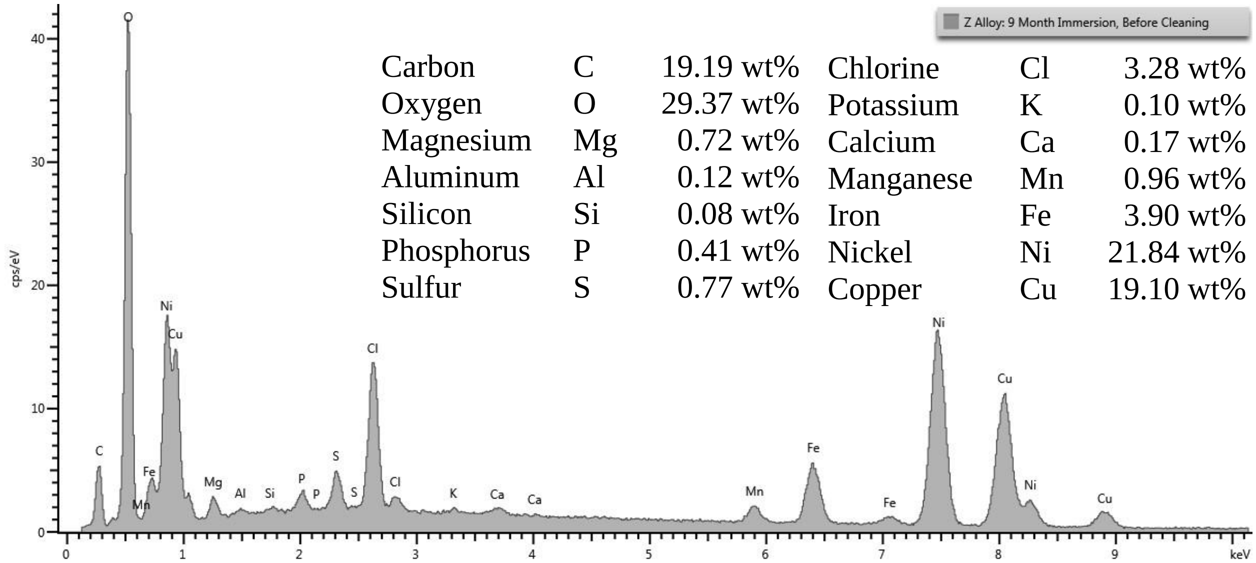


(a) Z-Alloy Coupon 2, Before Cleaning

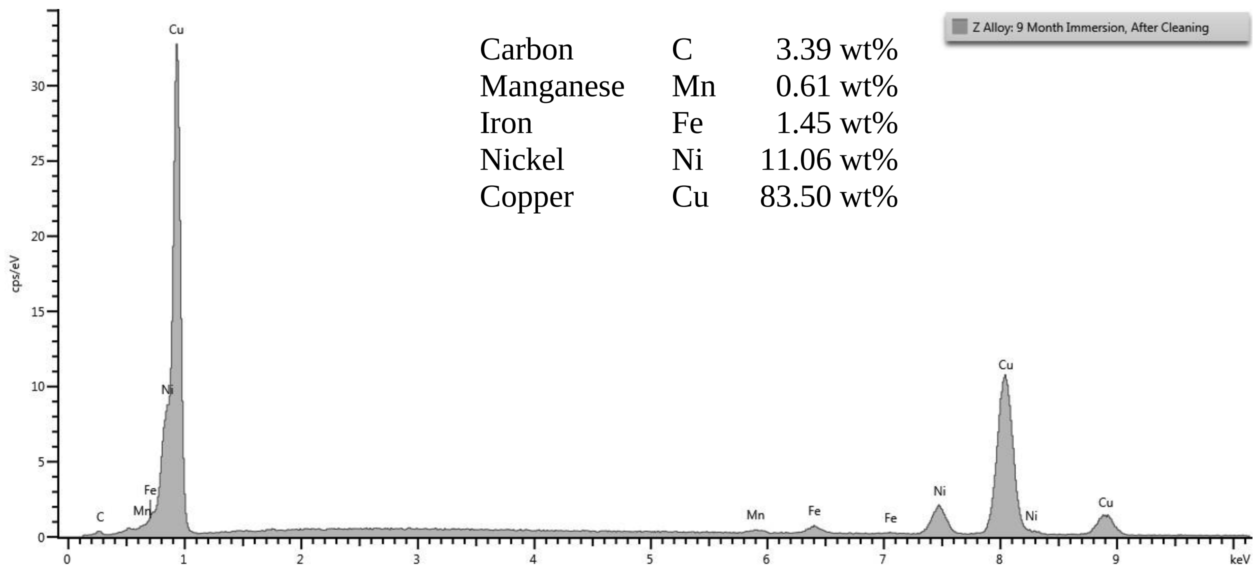


(b) Z-Alloy Coupon 2, After Cleaning

Figure 35 Energy dispersive x-ray spectra of Z-Alloy coupon 2 after a 6 month corrosion test (a) before cleaning and (b) after cleaning.

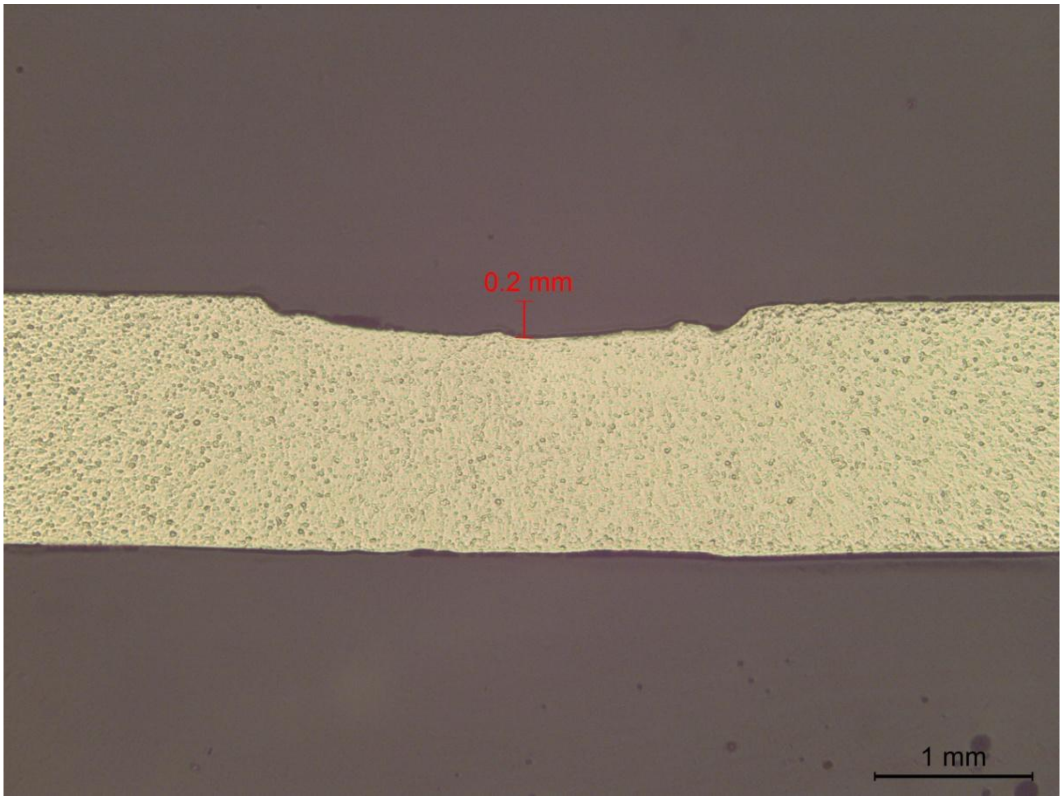


(a) Z-Alloy Coupon 3, Before Cleaning



(b) Z-Alloy Coupon 3, After Cleaning

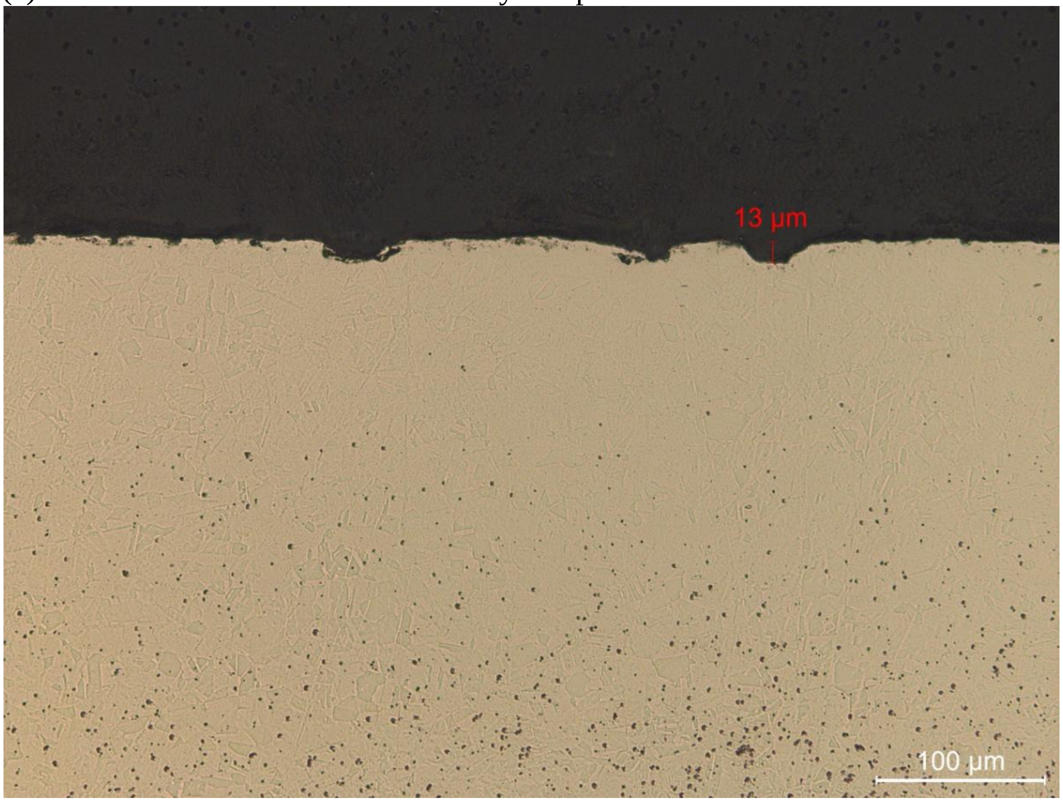
Figure 36 Energy dispersive x-ray spectra of Z-Alloy coupon 3 after a 10 month corrosion test (a) before cleaning and (b) after cleaning.



(a) Z-Alloy Coupon 1 18.75X

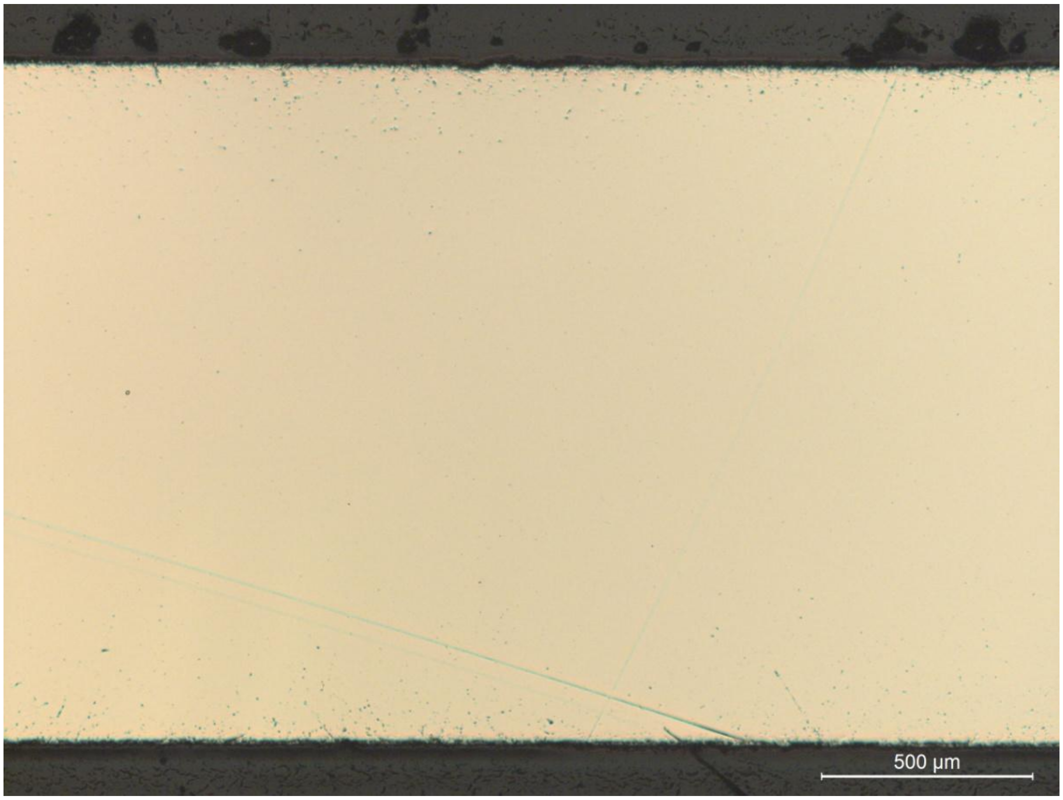
Figure 37 Optical micrograph of Z-Alloy coupon 1.

(a) Z-Alloy Coupon 2 50X

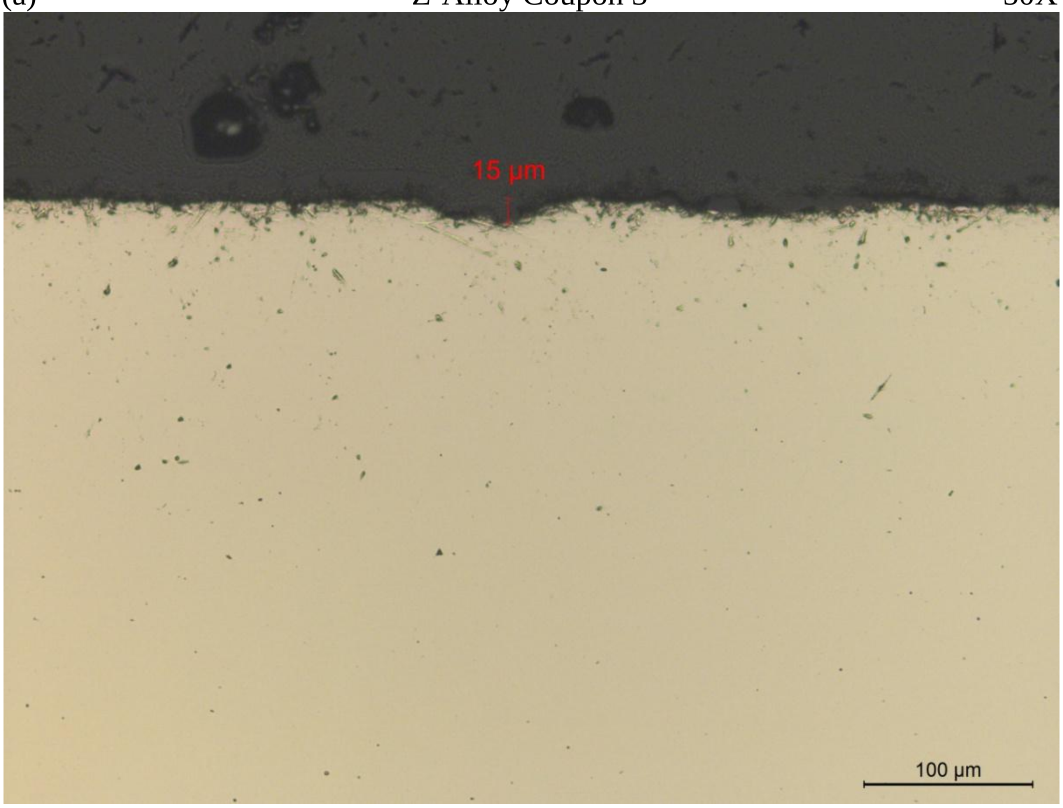


(a) Z-Alloy Coupon 2 200X

Figure 38 Optical micrographs of Z-Alloy coupon 2.



(a) Z-Alloy Coupon 3 50X



(a) Z-Alloy Coupon 3 200X

Figure 39 Optical micrographs of Z-Alloy coupon 3.

WEST BASIN MUNICIPAL WATER DISTRICT OCEAN WATER DESALINATION INTAKE CORROSION STUDY – 12 MONTH RESULTS

Prepared for:

TETRA TECH

Date: August 7, 2015

Prepared by:

V&A

V&A Project No.: 13-0376

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ES EXECUTIVE SUMMARY

West Basin Municipal Water District (West Basin) is pursuing ocean water desalination as an added source of water for its clients. The intent of the study is to measure the extent of corrosion and biofouling on bare and coated metal coupons. Twenty four samples made from four different alloys were identified and installed on a testing apparatus at the West Basin Ocean Water Desalination Intake location near El Segundo, CA. Samples from each alloy were removed after 3, 6, 10 and 12 months and were sent to a laboratory for analysis. The purpose of the corrosion study is the following:

A. To determine the corrosion rates and modes of anticipated corrosion that will occur on the selected materials.
B. To determine the effectiveness of several antifouling control strategies for future design, implementation and operation of intake facilities.
C. To determine the effect that a foul release protective coating will have on biological growth on the test samples.
D. To determine proper material selection, manufacturer quality control, and proper installation of screens.
E. To select materials that are readily available for manufacture of the wedge wire intake screen for use at the full scale West Basin Desalination Plant.
F. To present information with material selection options, showing overall capital cost and O&M costs.

The purpose of this report is to provide the results of the on-site and in-situ testing of metal coupons and wedge wire screen samples after the first 364 days of immersion in the Pacific Ocean seawater. The samples were installed on June 17, 2014 and removed on June 16, 2015. Table ES-1 summarizes the corrosion rate results for four different alloys.

Pitting and general corrosion were the primary mechanisms of corrosion on the coupons. The overall average corrosion rates of the 12-month samples were similar to the 10-month samples. The 12-month overall average corrosion rates were slightly higher than 10-month corrosion rates however the difference was less than 0.0001 inches. This was unlike how the 10-month sample corrosion rates were all lower than the 6-month samples; which in turn had lower corrosion rates than the 3-month samples (except for the 90-10 Cu-Ni coupons).

Figure ES-1 and Table ES-1 summarize the results of the testing.

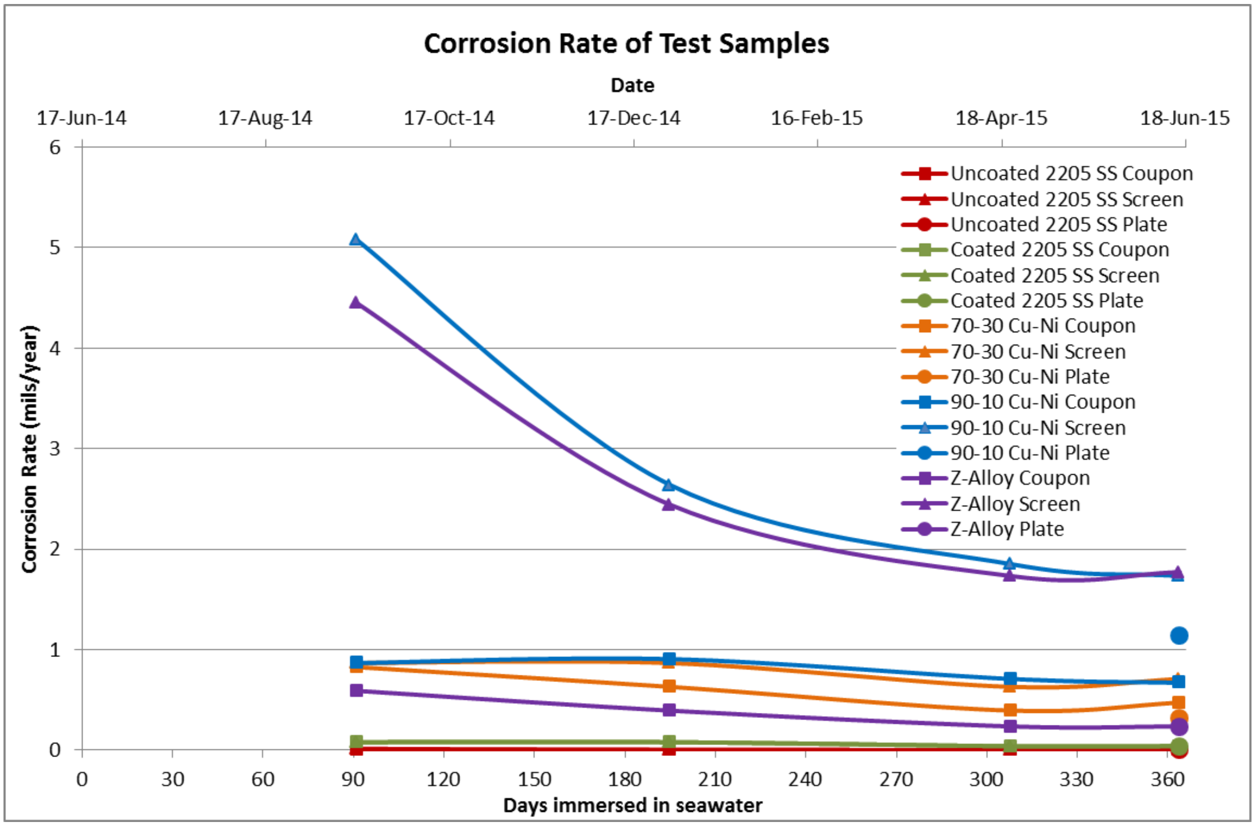

Figure ES-1. Corrosion Rates of Four Alloys after 364 days in Seawater Exposure

Table ES-1. Corrosion Rates of Four Alloys after 364 days in Seawater Exposure

Alloy	Sample Type	Surface Area (sq. in.)	Maximum Pitting Depth over 364 days (mils)	Overall Average Corrosion Rate (mils/year)
2205 Duplex SS Uncoated	1-inch by 3-inch coupon	8.2	1.38	0.0004
	Wedge Wire Screen	96.7	< 20 [A]	0.001
	4-inch by 4-inch plate	33.9	< 20 [A]	0.002
2205 Duplex SS with Foul Release Coating	1-inch by 3-inch coupon	8.2	1.30 [B]	0.039 [B]
	Wedge Wire Screen	96.7	< 20 [A]	0.039 [B]
	4-inch by 4-inch plate	34.6	< 20 [A]	0.039
CDA 715 70-30 Cu-Ni	1-inch by 3-inch coupon	8.2	1.6	0.472
	Wedge Wire Screen	65.0	< 20 [A]	0.709
	4-inch by 4-inch plate	34.4	< 20 [A]	0.315
CDA 706 90-10 Cu-Ni	1-inch by 3-inch coupon	8.2	11.5 (93.4 wide)	0.669
	Wedge Wire Screen	79.1	< 20 [A]	1.732
	4-inch by 4-inch plate	34.1	< 20 [A]	1.142
Z Alloy	1-inch by 3-inch coupon	8.2	0.47	0.236
	Wedge Wire Screen	96.3	< 20 [A]	1.772
	4-inch by 4-inch plate	36.6	< 20 [A]	0.232

[A] Less than detectable/measurable. Only the coupons were metallographically mounted. A pit depth gauge with detection limit 0.5mm ≈ 20mils was used to check the wire screens and plates. In particular, the pits were difficult to measure for pitting depth of the wire screens, but all were less than 20 mils.

[B] Mass loss and corrosion rate includes metal and coating material

Based on the data over 364 days, coated and uncoated 2205 Duplex Stainless Steel has the lowest overall average corrosion rates of the four metal alloys for both the coupons and screens tested in this study. However, the uncoated 2205 Duplex Stainless Steel samples were the most heavily fouled by marine life.

As can be seen in Table ES-1, the highest overall average corrosion rate was observed on the 90-10 Cu-Ni coupon and plate, and the Z Alloy screen. The overall average corrosion rates of the 90-10 Cu-Ni and Z Alloy screens were 3 to 8 times higher than the coupons of the same alloy. The 90-10 Cu-Ni coupons were provided from a different vendor than the screens and they may have a different chemical composition. However the same cannot be said for the Z Alloy samples because they were provided from the same vendor. The 70-30 Cu-Ni samples exhibited slightly more green marine life fouling on the coupons and screens than the Z alloy samples. It is possible that the corrosion rate is reduced by the amount of marine life fouling present on the samples because it limits the exposure of the metal to the seawater. The ability of the metal to create a passivation layer on the surface of each alloy may also affect the corrosion rate.

The highest pitting rate of 11.5 mpy was observed on the 90-10 Cu-Ni coupons followed by 1.6 mpy pitting rate on the 70-30 Cu-Ni coupons. Due to the difficulty of measuring pits on small cross sectional areas, the plates and screens were not sliced into sections. However, the results indicated that all of the pits were much less than 20 mils.

Mechanical damage was observed at each corner of the 70-30 Cu-Ni, 90-10 Cu-Ni, and Z Alloy screens where they were secured to the test rack. The mechanical damage may have been caused by the turbulence in the water and abrasion of the metal by the zip ties that prevented the passivation of the metal at those locations. The exposed metal was corroded and metal loss occurred.

The corrosion rate analysis on the 4-inch by 4-inch flat plates revealed similar results as the screens and coupons. The 90-10 Cu-Ni plate indicated the highest average overall corrosion rate followed by the 70-30 Cu-Ni plate. In general, the copper alloy plates (70-30 Cu-Ni, 90-10 Cu-Ni, and Z Alloy) indicated higher average overall corrosion rates than the coated and uncoated 2205 Duplex Stainless Steel plates. For example, the average overall corrosion rate of the 90-10 Cu-Ni flat plate is over 100 times greater than the average overall corrosion rate of the uncoated 2205 Duplex Stainless Steel. However, the uncoated 2205 Duplex Stainless Steel plate was also heavily fouled with marine life similar to the screens and coupons of the same alloy. There were no detectable corrosion pits measured on the plates.

Based on the conclusions and V&A's experience with similar corrosion studies, the following recommendations are presented for WBMWD to consider for seawater exposures:

1. Intake screens should be manufactured with 70-30 Cu-Ni as it would provide the lowest corrosion rate over a long term service life and would not require a foul release coating.
2. Intake screens manufactured in 2205 Duplex Stainless Steel are recommended if they are coated with a foul-release coating.

1.0 INTRODUCTION

West Basin Municipal Water District (West Basin) is pursuing ocean water desalination as an added source of water for its clients. Four different alloys and one coating system were identified, through review of the literature for similar studies, and installed on a testing apparatus at the West Basin Ocean Water Desalination Intake location near El Segundo, CA. The intent of the study is to measure the extent of corrosion and biofouling on bare and coated metal coupons and wire screens. The samples were installed and a coupon and a wire screen for each material type were removed at 3, 6, 10 and 12 months. The last samples were removed after 12 months. Once removed, the samples were sent to a lab for analysis. The overall objectives for the study are the following:

- To determine the corrosion rates and modes of anticipated corrosion that will occur on the selected materials.
- To determine the effectiveness of several antifouling control strategies for future design, implementation and operation of intake facilities.
- To determine the effect of a foul release that the protective coating will have on biological growth on the test samples. This will substantiate the ultimate selection of intake screen material and the benefit of providing an anti-fouling coating on the intake screen.
- To determine proper material selection, manufacturer quality control, and proper installation of screens.
- To select materials that are readily available for manufacture of the wedge wire intake screen for use at the full scale West Basin Desalination Plant.
- To present information with material selection options, showing overall capital cost, and O&M costs.

The purpose of this report is to provide the results of the on-site and in-situ testing of metal coupons and wedge wire screen samples after 364 days of immersion in the Pacific Ocean seawater.

2.0 METHODS

The purpose of this section of the report is to describe the testing study procedures for on-site and in-situ testing of metal coupons and wedge wire screen samples in order to assess corrosion impact relative to material selection and operating practices. The results presented in this report are for the samples that were removed after 12 months of seawater exposure.

2.1 Procurement of Materials

Twenty-four (24) testing samples were obtained for testing of the corrosion coupons and 24 testing samples were obtained for the wedge wire screens (4 samples for each material type). The metal coupons are 1 inch wide by 3 inches long by 1/16 of an inch thick and the wedge wire screens are 4 inches by 4 inches with 2 mm spacing. The 90-10 Cu-Ni screens have 4 mm spacing, between the screen wires.

V&A coordinated with the coupon vendors and screen manufacturers for the procurement of the testing samples. Metal Samples Company of Munford, Alabama, provided the 1-inch by 3-inch long by 1/16-inch thick coupons in 90-10 Copper-Nickel (Cu-Ni), 70-30 Cu-Ni, and the 2205 Duplex Stainless Steel. Metal Samples also provided the 4-inch by 4-inch by 1/8-inch thick flat plate in the same metal alloys. Holes were made on each 1-inch by 3-inch and 4-inch by 4-inch metal sample in order to secure it to the testing rack with plastic zip ties.

Johnson Screens/Bilfinger Water Technologies of New Brighton, Minnesota provided the 4-inch by 4-inch wedge wire screens in the 90-10 Cu-Ni, 2205 Duplex Stainless Steel, and Z alloys. They also provided the 1-inch by 3-inch by 1/16-inch thick coupons and the 4-inch by 4-inch flat plate in the Z alloy.

Hendrick Screen Company of Owensboro, Kentucky, provided the 4-inch by 4-inch wedge wire screens in 70-30 Cu-Ni.

2.2 Coating for Stainless Steel Screens and Coupons

V&A searched for a coating that would provide an NSF Standard 61-approved coating for drinking water contact and was known to prevent the attachment of marine life on hydraulic structures. V&A identified the following foul release coating system for the stainless steel samples from the literature review and discussions with manufacturers:

A. 1st coat - Sherwin Williams Macropoxy 646 PW immersion grade epoxy primer at 6 mils dry film thickness (dft.)
B. 2nd coat - Sherwin Williams Seaguard Sher-Release beige silicone Tie Coat at 6 mils dft.
C. 3rd coat - Sherwin Williams Seaguard Sher-Release white silicone Surface Coat at 6 mils dft.

The coating was applied by Fuji Hunt Smart Surfaces in Davidsonville, Maryland.

2.3 Lab Analysis

2.3.1 Chemical Analysis by EDS

Anamet, Inc. of Hayward, California, performed a quantitative chemical analysis by Energy Dispersive x-ray Spectra (EDS) on a baseline control sample and on the samples after they were immersed in seawater. Anamet's report contains images of the spectra and is included as Appendix A.

2.3.2 Scanning Electron Microscopy

Anamet, Inc. of Hayward, California, performed Scanning Electron Microscopy (SEM) on the samples. The SEM uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. The signals that derive from electron-sample interactions reveal information about the sample including texture, chemical composition, and crystalline structure.

2.3.3 Metallography

Optical macrographs of the samples were also recorded by Anamet, Inc. before and after cleaning of the samples and are attached in Anamet's reports. A metallographic examination of a cross section of each sample was recorded.

2.3.4 Corrosion Rate Analysis

Samples were weighed by Anamet, Inc. Laboratories in Hayward, CA before they were installed. The samples were analyzed by the lab after they were exposed to the seawater environment per ASTM G1 *Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens* and ASTM D2688 *Standard Test Method for Corrosivity of Water in the Absence of Heat Transfer (Weight Loss Method)*. The samples were cleaned with either nitric acid or hydrochloric acid. Plots of mass loss versus cleaning cycles for each sample are attached in Anamet's report. Pitting examination was performed per ASTM G46 *Standard Guide for Examination and Evaluation of Pitting Corrosion*.

2.4 Procedures

After the initial baseline parameters were obtained, the samples were shipped to Tenera Environmental for installation at the project site. Tenera Environmental assembled the testing rack

and affixed the coupons and wedge wire screens prior to immersion in the ocean source water. The wedge wire screens were secured to the testing rack with plastic zip ties. There was one test rack for each set of samples to be removed at each specified interval.

The testing samples consisted of metal coupons, wedge wire screens and flat plates (coated and uncoated) for installation on the in-situ testing apparatus installed by Tenera Environmental divers.
Samples and cleaning were performed per ASTM G-1 *Preparing, Cleaning, and Evaluating Corrosion Test Specimens* and ASTM D2688 *Standard Test Method for Corrosivity of Water in the Absence of Heat Transfer (Weight Loss Method)*. ASTM G-1 includes procedures in Sections 14.10 through 14.14 that involve weighing and classifying the types of pits. This test method covers the determination of the corrosivity of water by evaluating pitting and by measuring the weight loss of metal specimens. Pitting is a form of localized corrosion: weight loss is a measure of the average corrosion rate.

A metallographic examination was performed per ASTM E3 *Standard Guide for Preparation of Metallographic Specimens*. The primary objective of metallographic examinations is to reveal the constituents and structure of metals and their alloys by means of a light optical or scanning electron microscope.

Before installation the samples were examined for the following baseline parameters:

1. Weigh all samples per ASTM G1. Samples to be coated will be weighed before and after coating application.
2. Examine samples visually to 40X
3. Color photograph, one of each material type
4. Photomicrograph @ 10X, one of each material type
5. Photomicrograph @ 50X, one of each material type
6. Scanning Electron Micrograph (SEM) @ 100X, one of each material type
7. Energy Dispersive Spectroscopy (EDS), one of each material type

Samples removed after 3, 6, 10 and 12 months of exposure have been and will be examined for the following:

1. Sample cleaning and weighing per ASTM G1 and ASTM D2688
2. Pitting examination per ASTM G46
3. Dimensional inspection (micrometers or NOGO gauge): Wedge wire and gap dimensions.
4. Photomicrograph @ 10X, one of each material type After Cleaning (AC)
5. Photomicrograph @ 50X, one of each material type AC
6. Scanning Electron Micrograph @ 100X, one of each material type AC
7. Elemental analysis with EDS, one of each material type AC
8. Metallographic examination per ASTM E3, one of each material type

2.5 Corrosion Mechanisms

Corrosion is an electrochemical phenomenon that takes place at the interface of the metal and electrolyte, which in this case is seawater. When the metal is in contact with the electrolyte, a difference in potential develops at the electrolyte/metal interface. When corrosion reactions take place, they generate a current between two points on the metal surface with current flow through the electrolyte. Factors that may impact the corrosion rate include the following:

- Presence of inclusions in the metal or a Heat Affected Zone due to welding
- Mechanical stresses caused by welding, forming or temperature
- Water velocity and tidal fluctuations at the surface of the coupon (not possible to simulate in a lab)
- Alloy resistance to corrosion due to high chloride concentrations in seawater
- Water temperature, dissolved oxygen, sulfates, and chlorides. Water temperature data was collected at the intake to better understand and account for how temperature may impact the corrosion rate.

The following sections explain some possible corrosion mechanisms for the metals based on V&A's research.

2.5.1 Uniform Corrosion

If all metal surfaces are attacked via corrosion at an equal rate, the corrosion is termed uniform. As far as failure rate, the uniform corrosion rate is expressed in terms of pipe penetrating rates (rate of pipe wall loss) in thousandths of inches (mils) per year (mpy).

2.5.2 Localized and Pitting Corrosion

When corrosion of the metal surface is localized, the surface under the most aggressive attack becomes recessed with respect to the rest of the pipe surface and visible pits are formed. In such instances, the attack is said to be non-uniform, localized, or pitting corrosion. Theoretically, corrosion pitting in metals is divided into two phases: pit initiation and propagation.

2.5.3 Stress Corrosion Cracking

The occurrence of stress corrosion cracking (SCC) depends on the simultaneous achievement of three requirements: 1) a susceptible material; 2) a chemical environment that causes SCC for that material and 3) sufficient tensile (mechanical) stress within the material. The mechanical stresses may be caused by welding, forming, applied loads, and temperature.

Photo 2-1 and Photo 2-2 show samples of the cracking that might occur for copper alloys and duplex stainless steel under mechanical and chemical stresses. These photos are not of the metal samples that are part of this study and are presented for demonstrative purposes only.

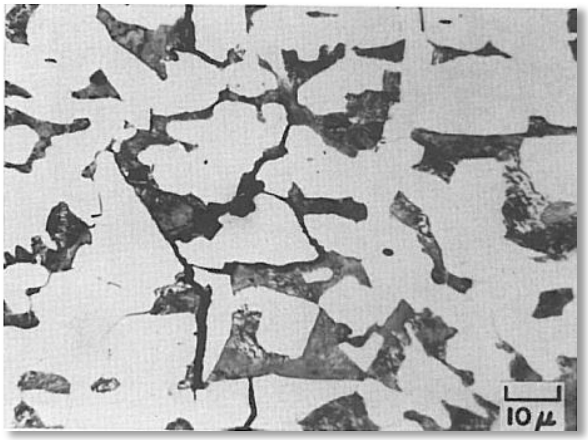

Photo 2-1. Intergranular Stress Corrosion Cracking in a Steel Pipe.[1]

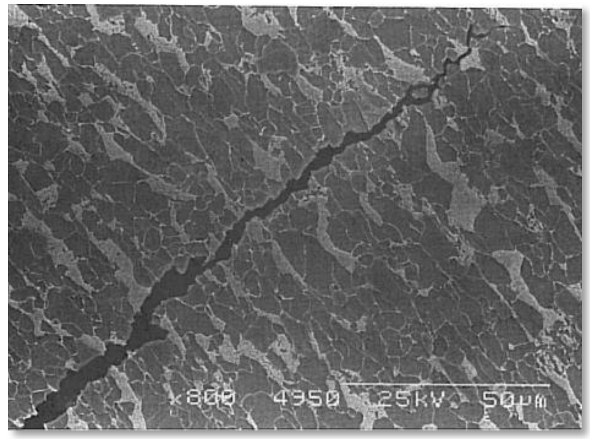

Photo 2-2. Transgranular Stress Corrosion Cracking in a Steel Pipe.[2]

2.6 Reference Corrosion Rates from Studies Performed by Others

V&A researched seawater corrosion rates for the alloys in this study to compare the corrosion rate of the alloys with the results of this study. Table 2-1 summarizes the information found in corrosion control literature.

Table 2-1. Average Corrosion Rates from Literature Review for Alloys in Seawater

Material	UNS	Corrosion Rate (mils/yr.)	Reference
2205 duplex stainless steel	S32205	0.03	McGuire, Stainless Steels for Design Engineers, p. 101, 2008
70-30 Cu-Ni	C71500	0.13	ASM Volume 13B p. 140 Fig 14 (Efird & Anderson, Mater. Perform., 1975)
90-10 Cu-Ni	C70600	0.15	ASM Volume 13B p.140, Fig 13 (Efird & Anderson, Mater. Perform., 1975)

1 Revie, R. Winston. Uhlig's Corrosion Handbook. 2nd Edition, John Wiley and Sons, Inc. New York, 2000, p. 194.
2 Ibid.

Figure 2-1 shows a graph of the average corrosion rates for several metal alloys in seawater. As seen in the graph, 70-30 Cu-Ni and 90-10 Cu-Ni have a corrosion rate of 0.15 to 0.5 mils per year.

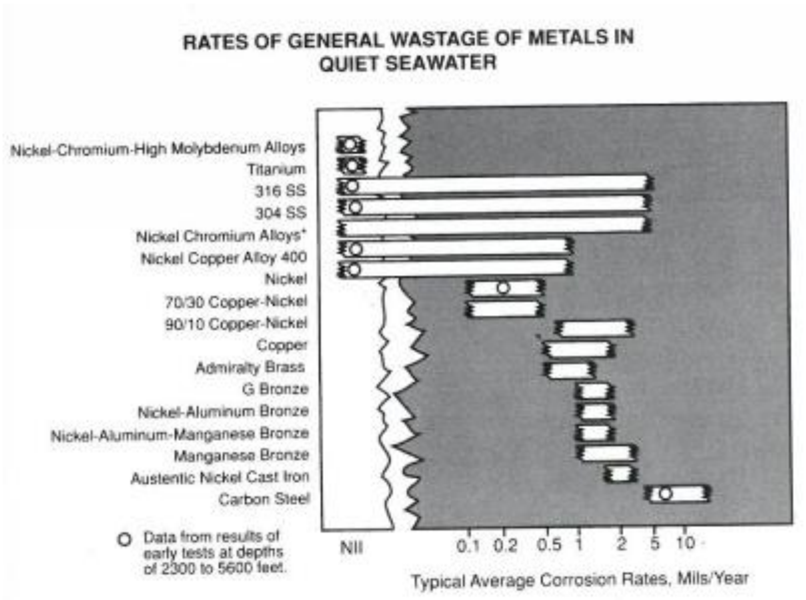

Figure 2-1. Graph of Average Corrosion Rates of Different Alloys in Seawater[3]

[3] NACE Corrosion Engineer's Reference Book, 2nd Ed. (1991) R.S. Treseder (editor)

3.0 FINDINGS

The fourth set of 15 3-inch by 1-inch coupons, 4-inch by 4-inch flat plates and screens was installed on Tuesday, June 17, 2014, and retrieved after 364 days on Tuesday, June 16, 2015. Photographic documentation and lab results and analysis are presented below.

3.1 Photos of Samples after 12 Months of Exposure

Photo 3-1 through Photo 3-20 show the samples before they were cleaned or analyzed.

Photo 3-10, Photo 3-15, and Photo 3-20 show some typical mechanical damage to the screen wires that was observed on the 70-30 Cu-Ni, 90-10 Cu-Ni, and Z Alloy screens. The damage was observed at each corner of the screen where the screens were secured to the test rack. The mechanical damage may have been caused by the turbulence in the water and the abrasion by the zip ties that prevented the passivation of the metal at those locations. The exposed metal was corroded and metal loss occurred.

Photo 3-8, Photo 3-11, Photo 3-13, Photo 3-17 and Photo 3-18 show some further oxidation and discoloration of the copper alloy sample surfaces after being exposed to the atmosphere for up to 7 days. These photos are courtesy of Anamet, Inc. and are included in the reports in Appendix A.

Photo 3-1. Marine life attached to uncoated 2205 Duplex stainless steel coupon with a weld.

Photo 3-2. Marine life attached to uncoated 2205 Duplex stainless steel flat plate.

Photo 3-3. Marine life attached to uncoated 2205 Duplex stainless steel wedge wire screen.

Photo 3-4. Slight damage to coating on edge and initiation of biofouling on corner of coated 2205 Duplex stainless steel coupon.

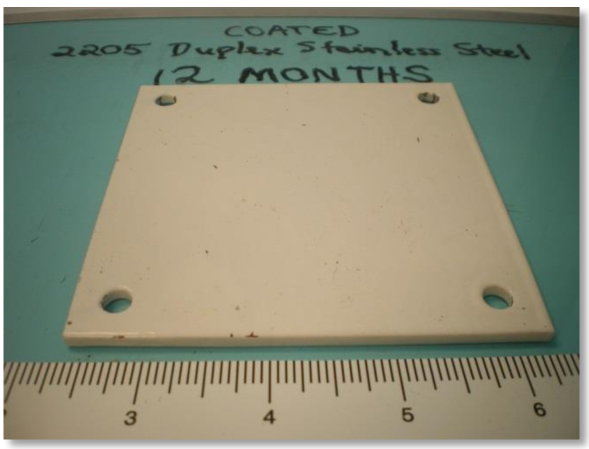

Photo 3-5. Coated 2205 Duplex stainless steel flat plate in good condition

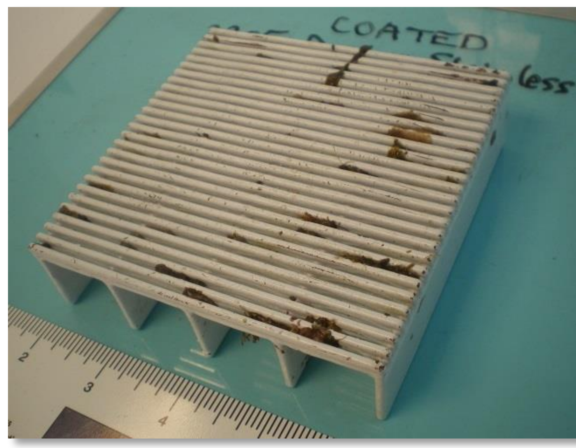

Photo 3-6. Coating damage to coated 2205 Duplex Stainless Steel wedge wire sample.

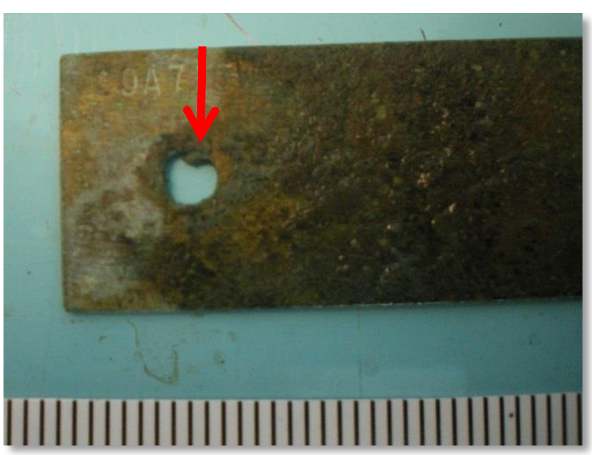

Photo 3-7. Detail view of hole and surface of 70-30 Cu-Ni coupon.

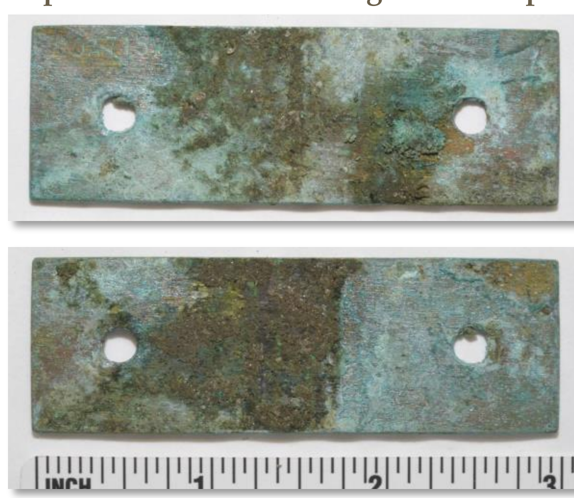

Photo 3-8. Development of copper patina on 70-30 Cu-Ni coupon, front (top), back (bottom).

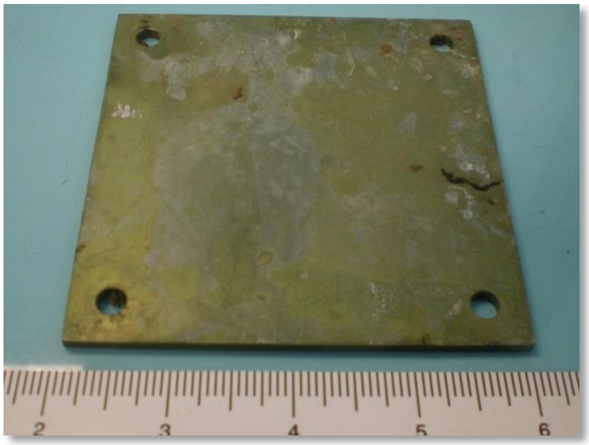

Photo 3-9. Surface discoloration of 70-30 Cu-Ni flat plate.

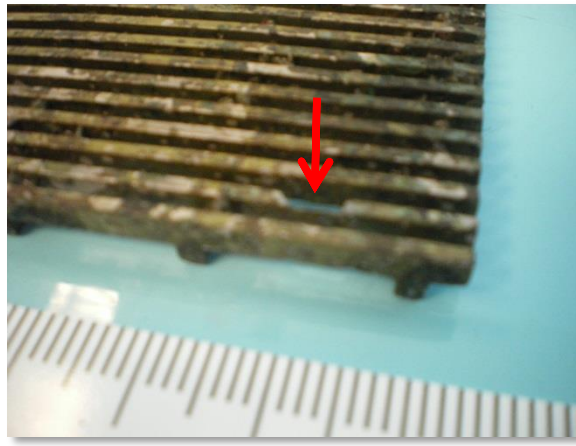

Photo 3-10. Mechanical damage to 70-30 Cu-Ni wedge wire screen.

Photo 3-11. 70-30 Cu-Ni wire screen at 10x magnification, pitting and discoloration.

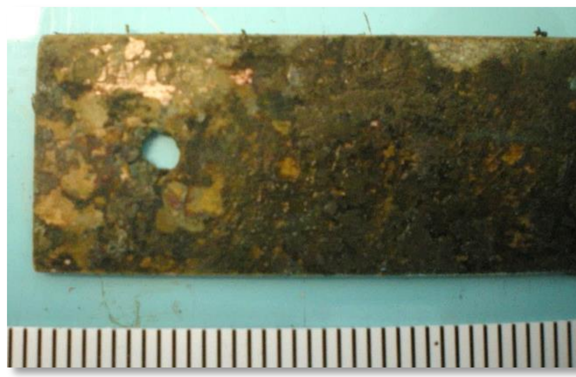

Photo 3-12. Detail view of 90-10 Cu-Ni 1-inch by 3-inch coupon with weld.

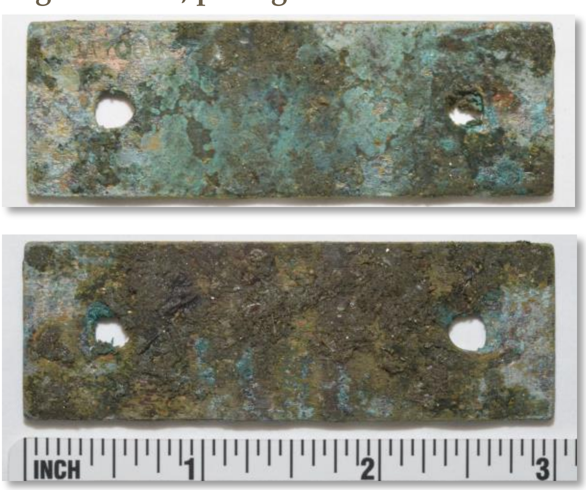

Photo 3-13. Development of patina on 90-10 Cu-Ni coupon, front (top), back (bottom).

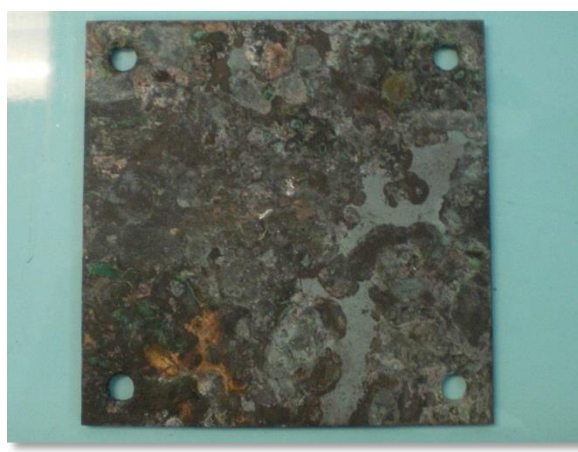

Photo 3-14. 90-10 Cu-Ni plate.

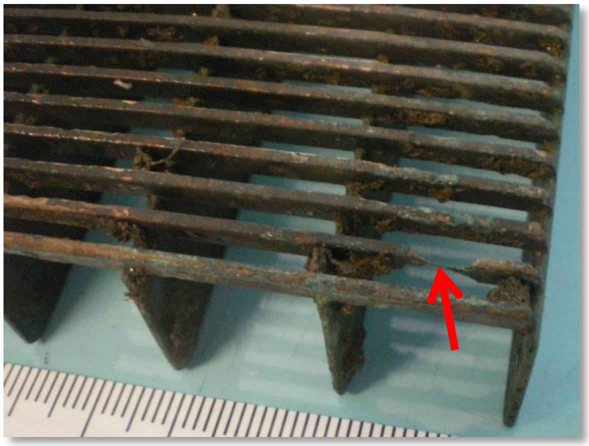

Photo 3-15. Mechanical damage to 90-10 Cu-Ni wedge wire screen.

Photo 3-16. Z alloy 1-inch by 3-inch coupon with weld (front).

Photo 3-17. Surface discoloration of Z alloy coupon, front (top), back (bottom).

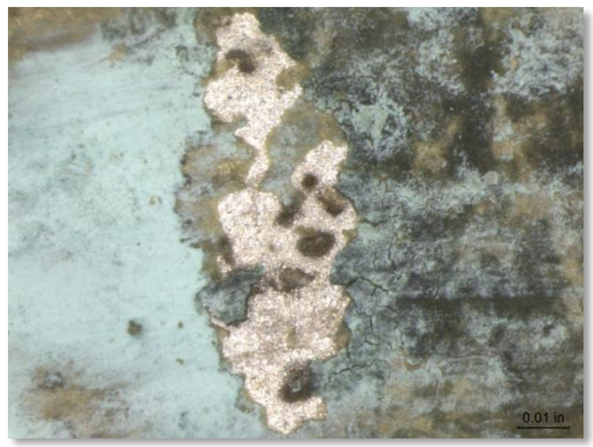

Photo 3-18. Surface discoloration of Z alloy coupon, shown at 50x magnification

Photo 3-19. Minimal corrosion was observed on the Z alloy flat plate.

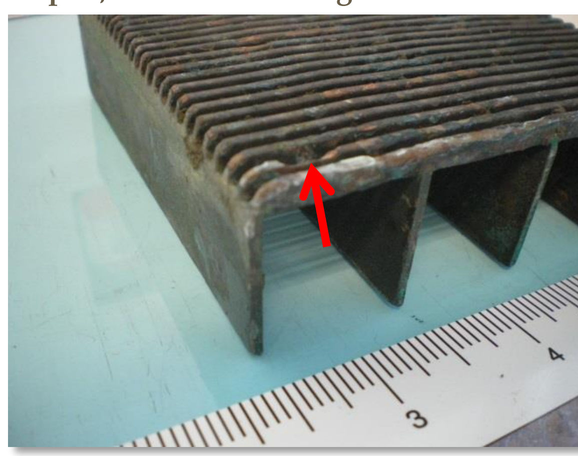

Photo 3-20. Mechanical damage to Z Alloy wedge wire screen.

3.2 Corrosion Rates after 364 Days

Table 3-1 summarizes the results of the corrosion rate analysis conducted by Anamet, Inc. after the samples were exposed to seawater for 364 days starting on June 17, 2014.

Table 3-1. Corrosion Rates of Four Alloys after 364 days in Seawater Exposure

Alloy	Sample Type	Surface Area (sq. in.)	Maximum Pitting Depth over 364 days (mils)	Overall Average Corrosion Rate (mils/year)
2205 Duplex SS Uncoated	1-inch by 3-inch coupon	8.2	1.38	0.0004
	Wedge Wire Screen	96.7	< 20 [A]	0.001
	4-inch by 4-inch plate	33.9	< 20 [A]	0.002
2205 Duplex SS with Foul Release Coating	1-inch by 3-inch coupon	8.2	1.30 [B]	0.039 [B]
	Wedge Wire Screen	96.7	< 20 [A]	0.039 [B]
	4-inch by 4-inch plate	34.6	< 20 [A]	0.039
CDA 715 70-30 Cu-Ni	1-inch by 3-inch coupon	8.2	1.57	0.472
	Wedge Wire Screen	65.0	< 20 [A]	0.709
	4-inch by 4-inch plate	34.4	< 20 [A]	0.315
CDA 706 90-10 Cu-Ni	1-inch by 3-inch coupon	8.2	11.45 (93.4 wide)	0.669
	Wedge Wire Screen	79.1	< 20 [A]	1.732
	4-inch by 4-inch plate	34.1	< 20 [A]	1.142
Z Alloy	1-inch by 3-inch coupon	8.2	0.47	0.236
	Wedge Wire Screen	96.3	< 20 [A]	1.772
	4-inch by 4-inch plate	36.6	< 20 [A]	0.232

[A] Less than detectable/measurable. Only the coupons were metallographically mounted. A pit depth gauge with detection limit 0.5mm ≈ 20mils was used to check the wire screens and plates. In particular, the pits were difficult to measure for pitting depth of the wire screens, but all were less than 20 mils.

[B] Mass loss and corrosion rate includes metal and coating material

3.2.1 Corrosion Rate over Time

Figure 3-1 summarizes the results of the corrosion rate analysis over 12 months of testing.

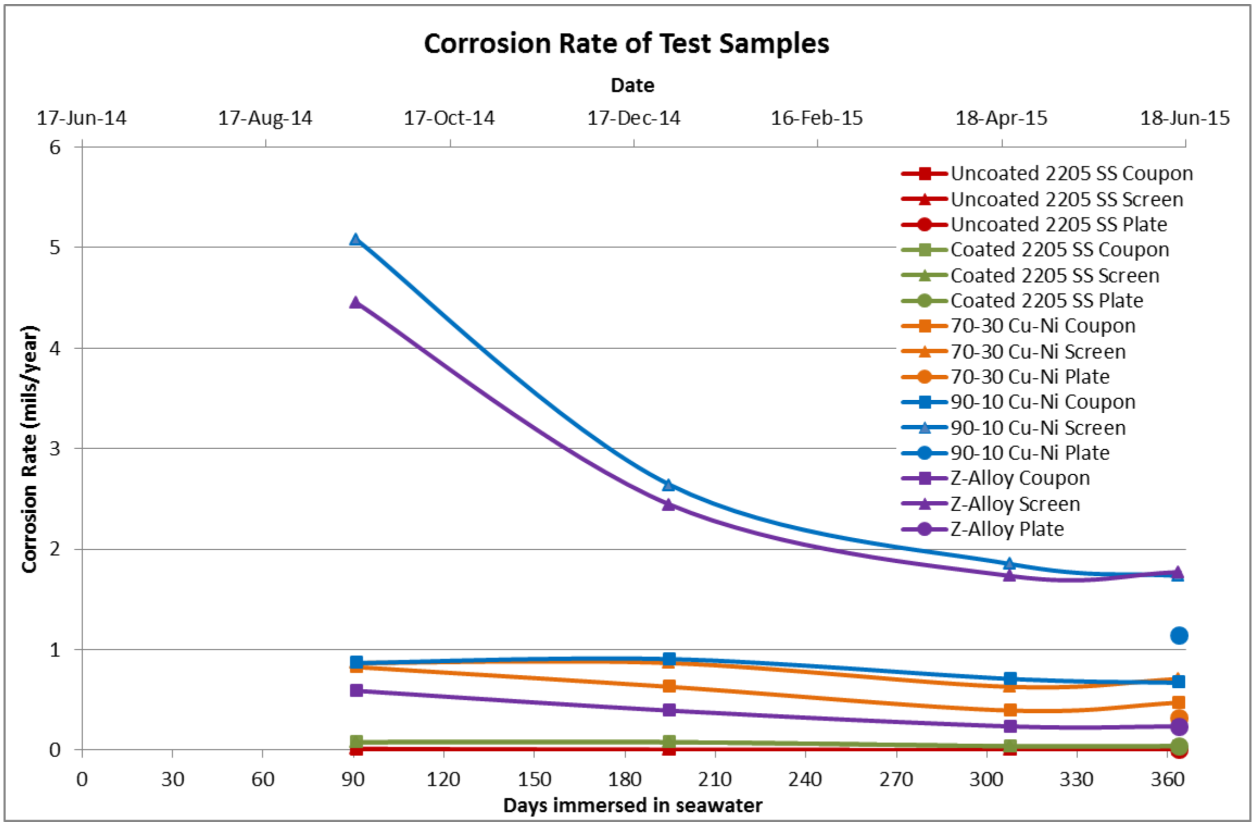

Figure 3-1. Corrosion Rates of Four Alloys over 12 months in Seawater Exposure

The average corrosion rates of the 12-month samples were similar to the 10-month samples; approximately half even had slightly higher rates however the difference was less than 0.0001 inches. This was unlike how the 10-month sample corrosion rates were all lower than the 6-month samples; which in turn had lower corrosion rates than the 3-month samples (except for the 3 and 6-month 90-10 Cu-Ni coupons).

3.2.2 Water Temperature

The corrosion rates may have also been affected by the seasonal water temperature changes. Figure 3-2 graphs the water temperature data collected at the intake throughout the course of the study.

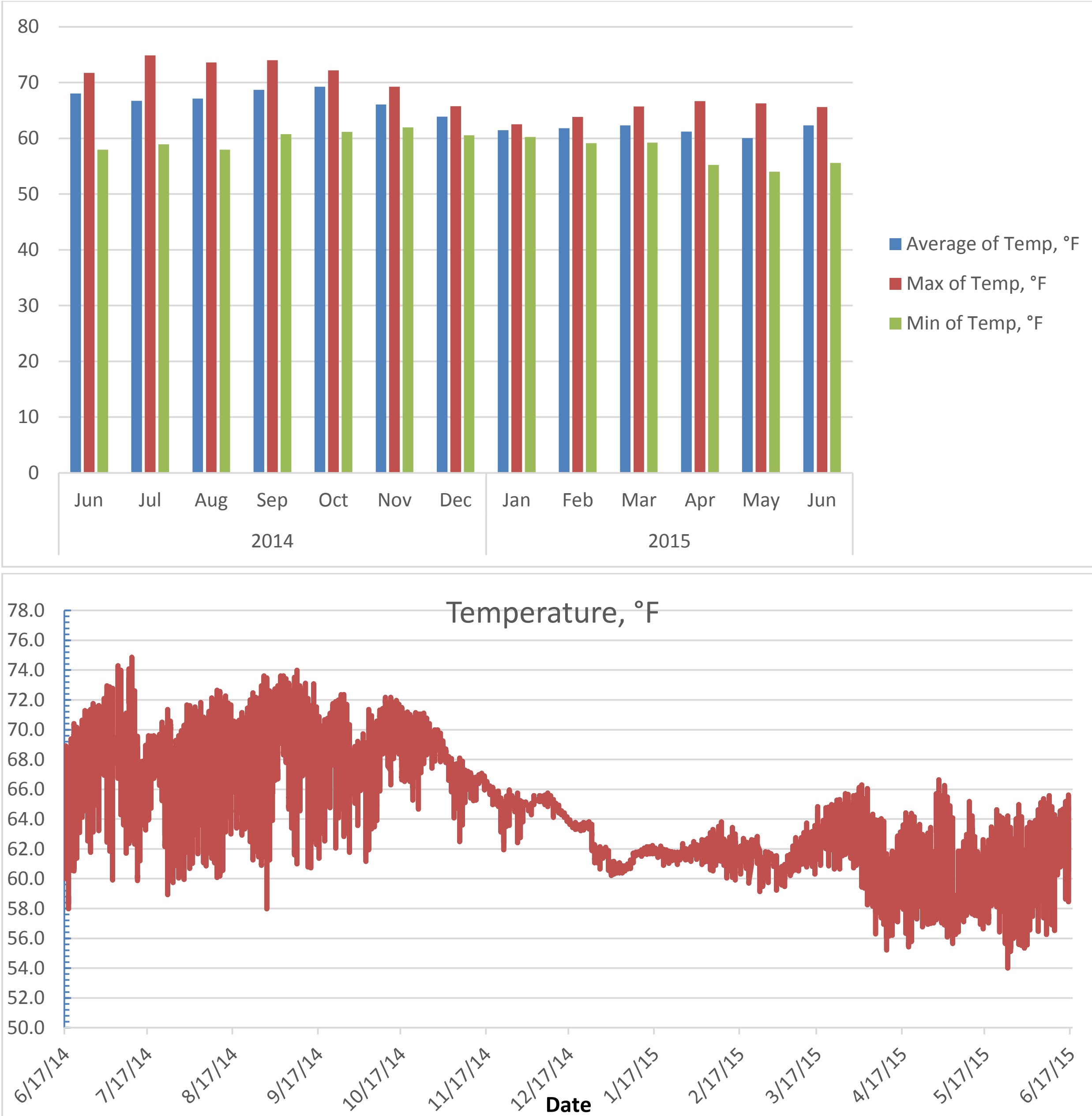

Figure 3-2. Water Temperature at Intake

The water temperature for all of the months was an average of 64 degrees Fahrenheit, minimum 54 degrees Fahrenheit and maximum 75 degrees Fahrenheit.

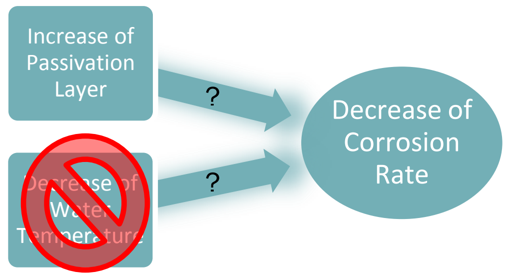

Figure 3-3. Potential Corrosion Rate Factors

The lower corrosion rate appears to coincide with lower water temperatures. However the lower corrosion rate also coincided with a more developed passivation layer. The causal influence of each factor cannot be separated in this study, but the decrease in temperature was minimal compared to the amount of passivation layer visible. Therefore the increase of passivation layer probably had a larger effect than the temperature change.

3.2.3 Comparison between the Different Material Types

Based on the data over 364 days, coated and uncoated 2205 Duplex Stainless Steel has the lowest average corrosion rates of the four metal alloy coupons, screens, and flat plates tested in this study. However, the uncoated 2205 Duplex Stainless Steel samples were the most heavily fouled by marine life.

Of the copper alloy coupon samples, the Z alloy 1-inch by 3-inch coupon indicated the lowest overall average corrosion rate and the 90-10 Cu-Ni coupon had the highest corrosion rate. However, the Z alloy screen had the highest corrosion rate of all of the screens after 364 days of exposure. The overall average corrosion rates of the 90-10 Cu-Ni and Z Alloy screens were 3 to 8 times higher than the coupons of the same alloy. The 90-10 Cu-Ni coupons were provided from a different vendor than the screens and they may have a different chemical composition. However the same cannot be said for the Z Alloy samples because they were provided by the same vendor. The 70-30 and 90-10 Cu-Ni samples exhibited slightly more green marine life fouling on the coupons and screens than the Z alloy samples (see Photo 3-16Photo 3-7 through Photo 3-20). It is possible that the corrosion rate is reduced by the amount of marine life fouling present on the samples because it limits the exposure of the metal to the seawater. The ability of the metal to create a passivation layer on the surface of each alloy may also affect the corrosion rate.

The highest pitting rate was observed on the 90-10 Cu-Ni coupon. Pits on the small cross sectional areas of the wire screens were difficult to measure, but were all less than 20 mils and appears to follow the same trend between the different alloys as the coupons. The plates were also not metallographically mounted, but all pits were less than 20 mils.

The corrosion rate analysis on the 4-inch by 4-inch flat plates revealed similar results as the screens and coupons. The 90-10 Cu-Ni plate indicated the highest average overall corrosion rate followed by the 70-30 Cu-Ni plate. In general, the copper alloy plates (70-30 Cu-Ni, 90-10 Cu-Ni, and Z Alloy) indicated higher average overall corrosion rates than the coated and uncoated 2205 Duplex Stainless Steel plates. For example, the average overall corrosion rate of the 90-10 Cu-Ni flat plate is over 100 times greater than the average overall corrosion rate of the uncoated 2205 Duplex Stainless Steel. However, the uncoated 2205 Duplex Stainless Steel plate was also heavily fouled with marine life similar to the screens and coupons of the same alloy. There were no detectable corrosion pits measured on the plates.

Photo 3-21 through Photo 3-35 show the surfaces of the samples under magnification. Photos are courtesy of Anamet, Inc. and are included in the reports in Appendix A.

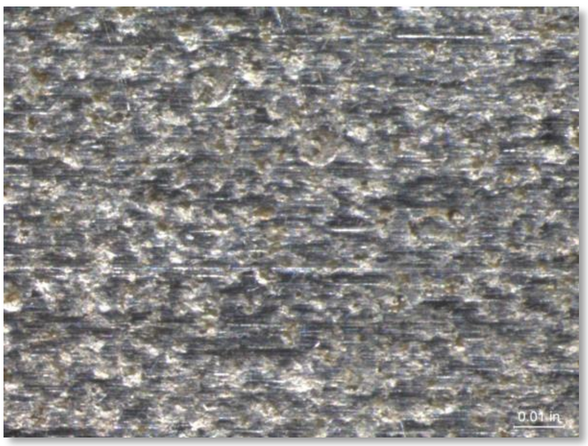

Photo 3-21. Uncoated 2205 Duplex SS coupon surface after cleaning at 50X magnification.

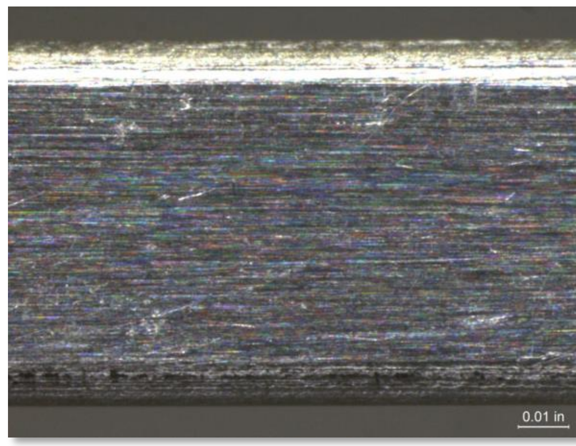

Photo 3-22. Uncoated 2205 Duplex SS screen surface after cleaning at 50X magnification.

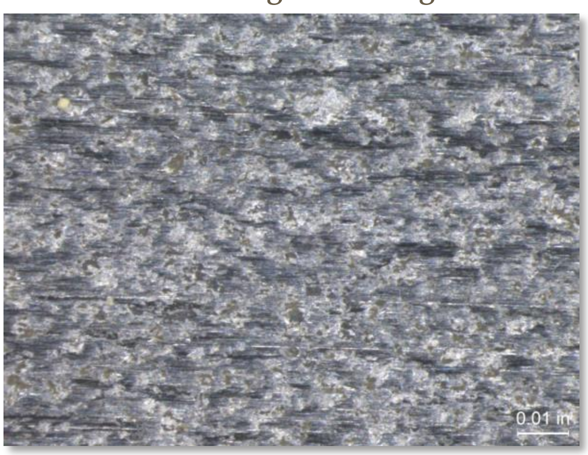

Photo 3-23. Uncoated 2205 Duplex SS plate surface after cleaning at 50X magnification.

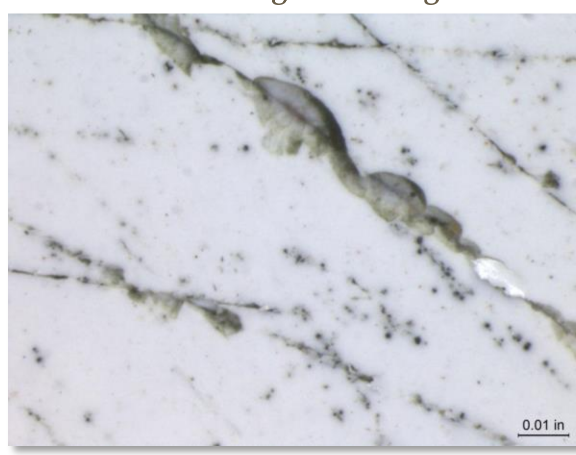

Photo 3-24. 2205 Duplex SS coupon surface at an area of coating damage.

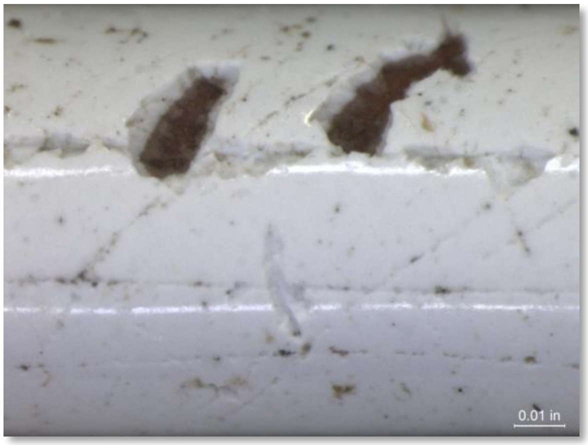

Photo 3-25. 2205 Duplex SS wedge wire screen surface exposed at an area of coating damage.

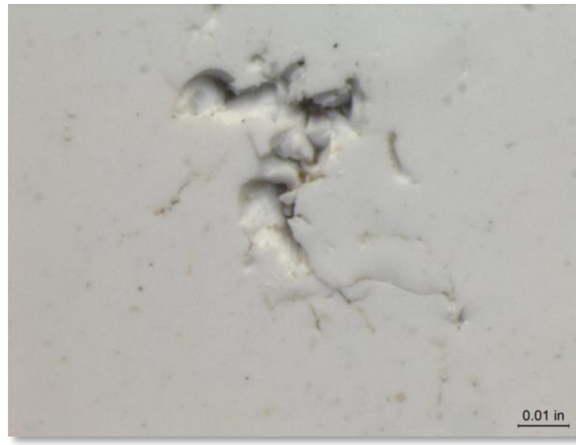

Photo 3-26. 2205 Duplex SS plate surface at an area of coating damage.

Photo 3-27. CDA 715 coupon at 50x magnification after cleaning

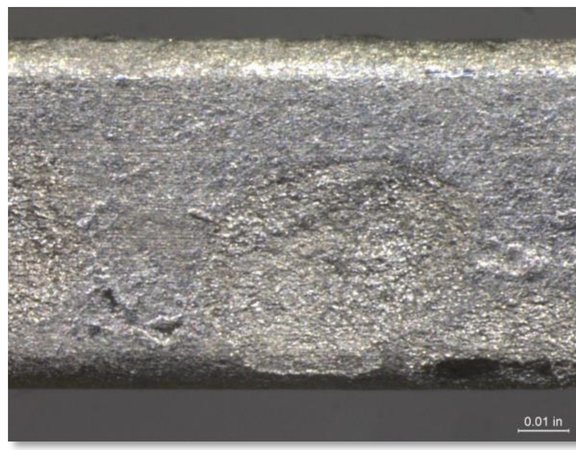

Photo 3-28. CDA 715 Screen at 50X magnification after cleaning.

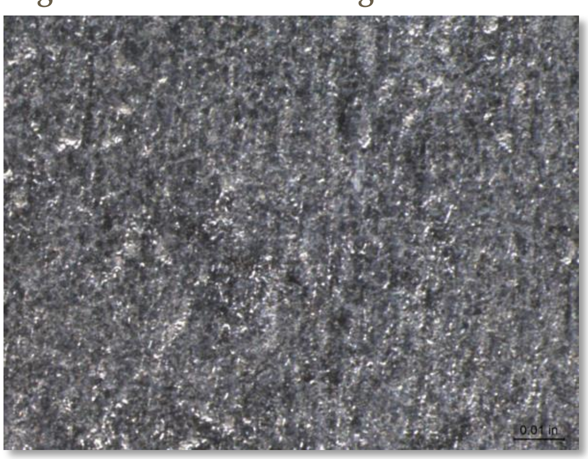

Photo 3-29. CDA 715 plate at 50x magnification after cleaning

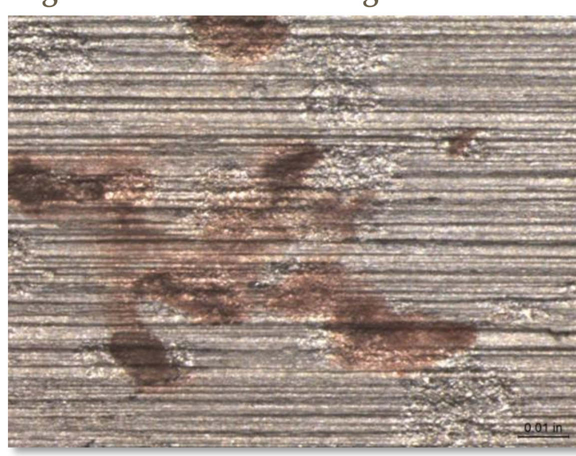

Photo 3-30. CDA 706 coupon at 50X magnification after cleaning.

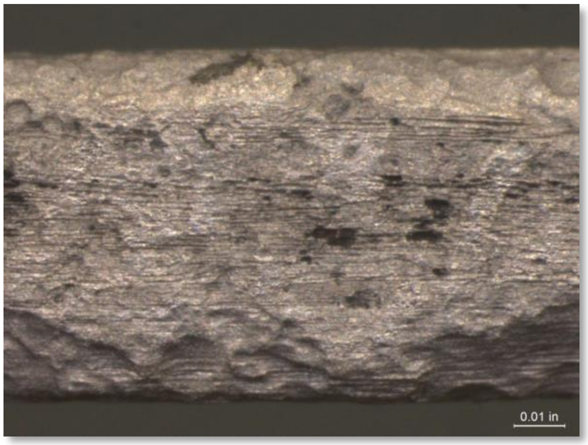

Photo 3-31. CDA 706 screen at 50X magnification after cleaning.

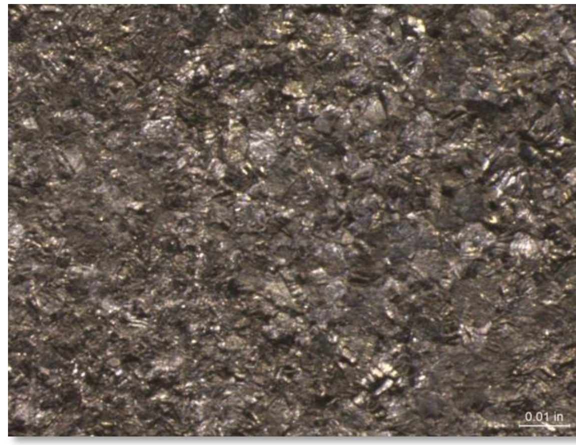

Photo 3-32. CDA 706 plate at 50X magnification after cleaning.

Photo 3-33. Z Alloy coupon at 50X magnification after cleaning.

Photo 3-34. Z Alloy Screen at 50X magnification after cleaning.

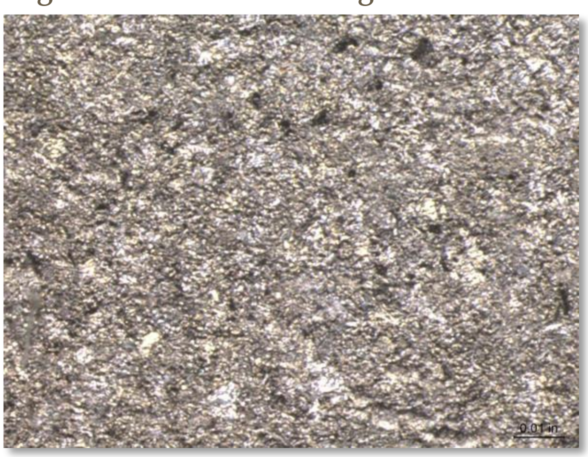

Photo 3-35. Z Alloy plate at 50X magnification after cleaning.

4.0 CONCLUSIONS

4.1 Coupons

1. The average corrosion rates of the 12-month samples were similar to the 10-month samples. The passivation layer that was building up during the first 10 months is no longer increasing.
2. The average corrosion rate of the uncoated and coated 2205 Duplex Stainless Steel coupons was the lowest of the four alloys that were included in this study.
3. The greatest amount of biofouling was observed on the uncoated 2205 Duplex Stainless Steel coupons.
4. The average corrosion rate of the 90-10 Cu-Ni coupons was the highest of the four alloys that were included in this study.
5. The lowest coupon pitting depth was measured on the Z Alloy coupons after 364 days of exposure in seawater.
6. The highest pitting depth was measured on the 90-10 Cu-Ni coupon after 364 days of exposure in seawater.
7. Pitting and general corrosion were the primary modes of corrosion on the coupons.
8. There is a large difference in the overall corrosion rate between the coupons and screens for the 90-10 Cu-Ni and Z Alloy samples.
9. The overall average corrosion rates of the 90-10 Cu-Ni and Z Alloy screens were 3 to 8 times higher than the coupons of the same alloy.
10. The overall average corrosion rates were higher than the data found in the literature summarized in Table 2-1.

4.2 Screens

1. The average corrosion rate of the uncoated 2205 Duplex Stainless Steel screens was the lowest of the four alloys after 364 days of exposure.
2. The greatest amount of biofouling was observed on the uncoated 2205 Duplex Stainless Steel wedge wire screens.
3. The average corrosion rate of the Z Alloy screens was the highest of the four alloys that were included in this study.
4. Pitting, erosion corrosion, and general corrosion were the primary modes of corrosion on the screens.
5. The maximum pitting depth of the screens appears to follow the same trend between the different alloys as the coupons, but was difficult to measure due to the clearance between the wires.

6. The overall average corrosion rates of the 90-10 Cu-Ni and Z Alloy screens were 3 to 8 times higher than the coupons of the same alloy.
7. The overall average corrosion rates were higher than the data found in the literature summarized in Table 2-1.
8. Mechanical damage was observed at each corner of the 70-30 Cu-Ni, 90-10 Cu-Ni, and Z Alloy screens where they were secured to the test rack. The mechanical damage may have been caused by the turbulence in the water and abrasion of the metal by the zip ties that prevented the passivation of the metal at those locations. The exposed metal was corroded and metal loss occurred.

4.3 Flat Plates

1. The average corrosion rate of the uncoated 2205 Duplex Stainless Steel 4-inch by 4-inch flat plates was the lowest of the four alloys after 364 days of exposure.
2. The greatest amount of biofouling was observed on the uncoated 2205 Duplex Stainless Steel wedge wire screens.
3. The overall average corrosion rate of the 90-10 Cu-Ni flat plates was the highest of the four alloys that were included in this study.
4. The lowest average corrosion rate was measured on the 2205 Duplex Stainless Steel after 364 days of exposure in seawater.
5. In general, the copper alloy plates (70-30 Cu-Ni, 90-10 Cu-Ni, and Z Alloy) indicated higher average overall corrosion rates than the coated and uncoated 2205 Duplex Stainless Steel plates. For example, the average overall corrosion rate of the 90-10 Cu-Ni flat plate is over 100 times greater than the average overall corrosion rate of the uncoated 2205 Duplex Stainless Steel.

5.0 RECOMMENDATIONS

Based on the conclusions and V&A's experience with similar corrosion studies, the following recommendations are presented for WBMWD to consider for seawater exposures:

3. Intake screens should be manufactured with 70-30 Cu-Ni as it would provide the lowest corrosion rate over a long term service life and would not require a foul release coating.
4. The foul-release-coated 2205 Duplex Stainless Steel screens would also provide a long term service based on the results of the study.
5. If intake screens are manufactured by 2205 Duplex Stainless Steel the following coating should be applied to the screens:
    a. 1st coat - Sherwin Williams Macropoxy 646 PW immersion grade epoxy primer at 6 mils dry film thickness (dft.)
    b. 2nd coat - Sherwin Williams Seaguard Sher-Release beige silicone Tie Coat at 6 mils dft.
    c. 3rd coat - Sherwin Williams Seaguard Sher-Release white silicone Surface Coat at 6 mils dft.
6. Foul-release coated screens should be inspected every 5 years to determine if repairs are required. The foul release coating will need to be removed from immersion service and repaired while the surfaces are dry.

APPENDIX A. LAB ANALYSIS REPORTS

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Report No. 5005.0361B **July 17, 2015**

CORROSION EVALUATION OF 2205 DUPLEX STAINLESS STEEL COUPONS AND SCREENS

Customer Authorization: Verbal

Report To: V & A Engineering
Attn: Manuel Najar
155 Grand Avenue, Suite 700
Oakland, CA 94612

1.0 INTRODUCTION

Five coupons, five wedge wire screens, and one plate made from a 2205 duplex stainless steel alloy were submitted by V&A Engineering for corrosion evaluation. The coupons were 1-inch by 3-inches by ¼-inch thick. The wedge wire screens were 4-inches by 4-inches by 1-inch tall with 4 mm spacing. The plate was 4-inches by 4-inches by 1/8-inch thick.

Four coupons, four screens, and one plate were to be placed in seawater for a period up to one year. After every 3 month interval, one coupon and one screen were to be removed from the test system and examined for corrosion. After 12 months, the plate was removed from the test system and examined for corrosion. The purpose of this evaluation was to document the samples in the baseline as-received condition, then again after 3, 6, 10, and 12 months of water exposure, record any loss in mass, examine for any pitting corrosion, and estimate the corrosion rate.

The samples were evaluated by the following laboratory procedures:

1) Visual examination and weighing
2) Cleaning per ASTM G1[1]
3) Scanning electron microscopy and energy dispersive x-ray spectroscopy
4) Metallography

The results of the evaluation showed minimal mass loss and corrosion for the coupon and screen after 3, 6, 10, and 12 months of corrosion testing. The coupons and screens, after 3, 6, 10, and 12 months of corrosion testing, had a corrosion rate less than 0.0005 millimeters per year. The plate, after 12 month of corrosion test, had a corrosion rate less than 0.0005 millimeters per year. The coupons lost the same amount of material over time while the screens lost less material over time, but both the coupons and screens exhibited very little mass loss and thus had a consistent corrosion rate of less than 0.005 millimeters per year over the duration of the corrosion test.

[1] G1: Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

2.0 EVALUATION[2]

2.1 Visual Examination

The sample identifications for the coupons and wedge wire screens and their corresponding immersion times are shown in Table 1. The coupons had identification numbers stamped on the front face by V&A Engineering. A number of notches, corresponding to the sample number, were sawed at the edge of each screen for identification after the corrosion test. The weights of the samples were recorded. Coupons 6 – 9 and screens 1 – 5 were sent back to V&A for corrosion testing. Coupon 10 was the baseline sample and documented by photography, optical stereoscopy and scanning electron microscopy for comparison to the tested samples. Screen 5 was documented as a baseline by photography and optical stereoscopy, and then sent to V&A for testing.

Photographs of the baseline coupon are shown in Figure 1. Photographs of coupons 1 – 4, after 3, 6, 10, and 12 months of corrosion testing, are shown in Figures 2 – 5. A photograph of the baseline screen is shown in Figure 6. Photographs of screens 1 – 4, after 3, 6, 10, and 12 months of corrosion testing, are shown in Figures 7 – 10. A photograph of the baseline plate is shown in Figure 11 and a photograph of the plate after 12 months of corrosion testing is shown in Figure 12.

2.2 Cleaning

The coupon and screen were cleaned with solution C.7.1 per ASTM G1.[3] One cleaning cycle was approximately 10 minutes. After each cleaning cycle, the samples were rinsed in water, dried, and weighed. The cleaning and weighing cycle was completed five times for the coupon and screen. The weights of the samples as-received, after corrosion testing but before cleaning, and after each cleaning cycle are presented in Table 2.

Optical macrographs of the baseline coupon, screen, and plate are shown in Figures 13, 22, and 31, respectively. Representative optical macrographs of coupons 6 – 9 after 3, 6, 10, and 12 months of corrosion testing, before and after cleaning, are shown in Figures 14 – 21. Representative optical macrographs of screens 1 – 4 after 3, 6, 10, and 12 months of corrosion testing, before and after cleaning, are shown in Figures 23 – 30. Representative optical macrographs of the plate after 12 months of corrosion testing, before and after cleaning, are shown in Figures 32 – 33.

The mass loss versus the number of cleaning cycles were plotted to determine the mass loss of the samples due to corrosion, shown in Figures 34 – 38. The equations for best fit lines AB and BC, calculated using IGOR Pro, are listed in Table 3. Point B, indicated by the red circle in each plot, corresponds to the mass loss due to corrosion for each sample. This mass loss was subtracted from the weight of the sample before cleaning and from the weight of the sample as-received to determine the total mass loss from corrosion. The corrosion rate of each sample was determined by the formula specified in Section 8.1 of ASTM G1:

[2] The magnifications of the optical and scanning electron micrographs in this report are approximate and should not be used as a basis for dimensional analyses unless otherwise indicated.
[3] 100 mL nitric acid + 900 ml reagent water.

$$Corrosion\ Rate = \frac{K\ x\ W}{A\ x\ T\ x\ D}$$

where K = 8.76 x 10^4, T = time of exposure in hours, A = area in cm^2, W = mass loss in grams, and D = density in g/cm^3. The density of the Z-Alloy was determined by cutting a section out of the baseline coupon, measuring the length, width, and thickness, and weighing the section with a balance. The total mass loss from corrosion and the calculated corrosion rate of each sample is shown in Table 4.

2.3 Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy

The baseline coupon and coupons 6 – 9 were examined with a scanning electron microscope. Representative scanning electron micrographs of the baseline coupon are shown in Figure 39. Representative scanning electron micrographs of coupons 6 – 9, after cleaning, are shown in Figures 40 – 43. Energy dispersive x-ray spectra of the baseline coupon and coupons 6 – 9, after cleaning, are shown in Figures 44 – 46. The coupons were not analyzed by scanning electron microscopy and energy dispersive x-ray spectroscopy before cleaning due to the amount of biological products on it.

2.4 Metallography

Cross sections were taken from the coupon and prepared for a metallographic examination. Optical micrographs of the surfaces for coupons 6 – 9 are shown in Figures 47 – 50. Small, narrow pits were observed in all samples, the deepest of which measured 35 μm.

3.0 DISCUSSION

The coupon and screen showed minimal mass loss and pitting overall after 3, 6, 10, and 12 months of corrosion testing. The weight loss of the coupons was less than the measurement capabilities of the balance; the calculated corrosion rate was consistent over the duration of the corrosion test.

4.0 CONCLUSIONS[4]

The following conclusions are based upon the submitted samples and the evidence gathered:

1. The coupons, after 3, 6, 10, and 12 months of corrosion testing, had a mass loss less than 0.001 grams. The coupons had consistent mass loss over the duration of the corrosion test.

2. The coupons, after 3, 6, 10, and 12 months of corrosion testing, had a corrosion rate less than 0.0005 mm / year. The coupons had a consistent corrosion rate over the duration of the corrosion test.

3. The screens, after 3, 6, 10, and 12 months of corrosion testing, had a mass loss of 0.04 grams, 0.02 grams, < 0.001 grams, and < 0.001 grams, respectively. The screens had less mass loss over the duration of the corrosion test.

4. The screens, after 3, 6, 10, and 12 months of corrosion testing, had a corrosion rate less than 0.0005 mm / year. The screens had a consistent corrosion rate over the duration of the corrosion test.

5. The plate, after 12 months of corrosion testing, had a mass loss of 0.01 grams and a corrosion rate less than 0.0005 mm / year.

Prepared by:	Reviewed by:
Norman Yuen	Audrey A. Fasching
Norman Yuen Materials Engineer	Audrey A. Fasching, Ph.D., P.E. Senior Materials Engineer

[4] The conclusions in this report are based upon the available information and evidence provided by the client and gathered by Anamet, within the scope of work authorized by the client, and they are hereby presented by Anamet to a reasonable degree of engineering and scientific certainty. Anamet reserves the right to amend or supplement its conclusions or opinions presented in this report should additional data or information become available, or further work be approved by the client.

Table 1
Sample Identifications

Description: Alloy	Description: Part	V&A Engineering Identification (As-Received)	Anamet Identification (in report)	Notes
2205 Duplex Stainless Steel	**Flat Plate** 4-inch x 4-inch x 1/8-inch	2205 2	Plate	None
	Coupon 1-inch x 3-inch x 1/8-inch with autogenous weld bead	2205W 6	Coupon 6	3 Month Immersion
		2205W 7	Coupon 7	6 Month Immersion
		2205W 8	Coupon 8	10 Month Immersion
		2205W 9	Coupon 9	12 Month Immersion
		2205W 10	Coupon 10	Baseline Sample (no exposure)
	Wedge Wire Screen 4-inch x 4-inch x 1-inch with 2 mm spacing	None	Screen 1	3 Month Immersion
		None	Screen 2	6 Month Immersion
		None	Screen 3	10 Month Immersion
		None	Screen 4	12 Month Immersion
		None	Screen 5	12 Month Immersion

Table 2
Sample Weights

Sample	Baseline Measurement	Measurements after 3 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 6	22.1525	22.1531	22.1529	22.1527	22.1515	22.1514	22.1513
Screen 1	311.70	311.78	311.66	311.66	311.66	311.67	311.67

Sample	Baseline Measurement	Measurements after 6 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 7	22.0018	22.0018	22.0017	22.0015	22.0016	-	-
Screen 2	313.62	313.60	313.59	313.60	313.58	-	-

Sample	Baseline Measurement	Measurements after 10 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 8	22.0012	22.0010	22.0011	22.0008	22.0006	-	-
Screen 3	312.36	312.36	312.36	312.35	312.34	-	-

Sample	Baseline Measurement	Measurements after 12 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 9	21.8006	21.8002	21.8000	21.7998	21.8001	-	-
Screen 4	311.84	311.84	311.83	311.83	-	-	-
Plate	237.34	237.33	237.33	237.33	-	-	-

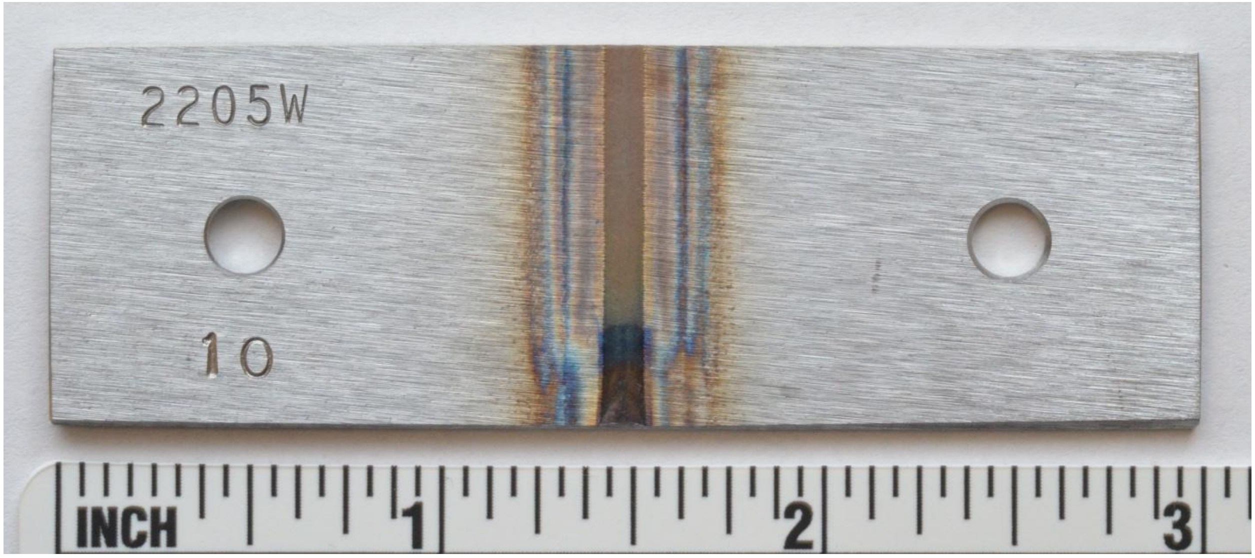
Table 3
Equations of Lines AB and BC for Corrosion Testing Samples

Sample	Line AB	Line BC	Point B (Approximate Mass Loss from Corrosion)
Coupon 6	y = 0.0004x	N/A	0 grams
Coupon 7	N/A	y = 0.0001x	0 grams
Coupon 8	N/A	y = 0.0001x	0 grams
Coupon 9	N/A	y = 0.0001x	0 grams
Screen 1	y = 0.12x	y = 0.120	0.12 grams
Screen 2	N/A	y = 0.007x	0 grams
Screen 3	N/A	y = 0.010x	0 grams
Screen 4	y = 0.01x	y = 0.01	0.01 grams
Plate	N/A	N/A	0 grams

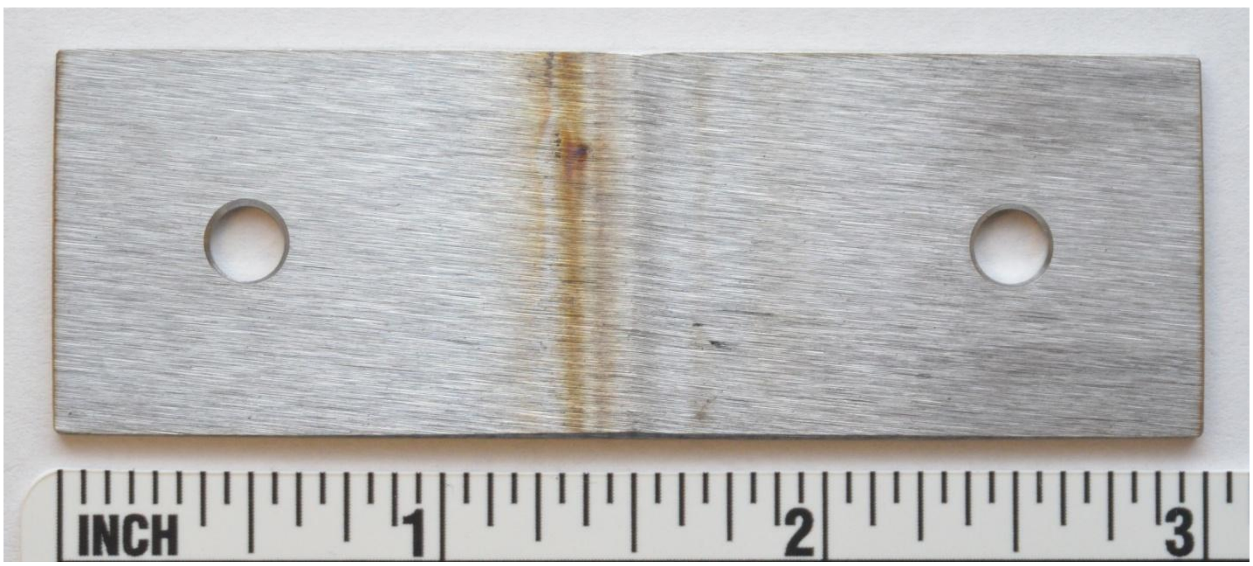
Table 4
Total Mass Loss from Corrosion and Corrosion Rate

Sample	Total Mass Loss from Corrosion*	Corrosion Rate
Coupon 6	< 0.001 grams	< 0.0005 mm / year
Coupon 7	< 0.001 grams	< 0.0005 mm / year
Coupon 8	< 0.001 grams	< 0.0005 mm / year
Coupon 9	< 0.001 grams	< 0.0005 mm / year
Screen 1	0.04 grams	< 0.0005 mm / year
Screen 2	0.02 grams	< 0.0005 mm / year
Screen 3	0.00 grams	< 0.0005 mm / year
Screen 4	0.01 grams	< 0.0005 mm / year
Plate	0.01 grams	< 0.0005 mm / year

* Weight As-Received – (Weight Before Cleaning – Mass Loss from Corrosion During Cleaning)



(a) Duplex 2205 Stainless Steel Baseline Coupon, Front Side



(b) Duplex 2205 Stainless Steel Baseline Coupon, Back Side

Figure 1 Photographs of the duplex 2205 stainless steel baseline coupon (a) front and (b) back side.

(a) Duplex 2205 Stainless Steel Coupon 6, Front Side

(b) Duplex 2205 Stainless Steel Coupon 6, Back Side

Figure 2 Photographs of duplex 2205 stainless steel coupon 6 (a) front and (b) back side after a 3 month corrosion test.

(a) Duplex 2205 Stainless Steel Coupon 7, Front Side

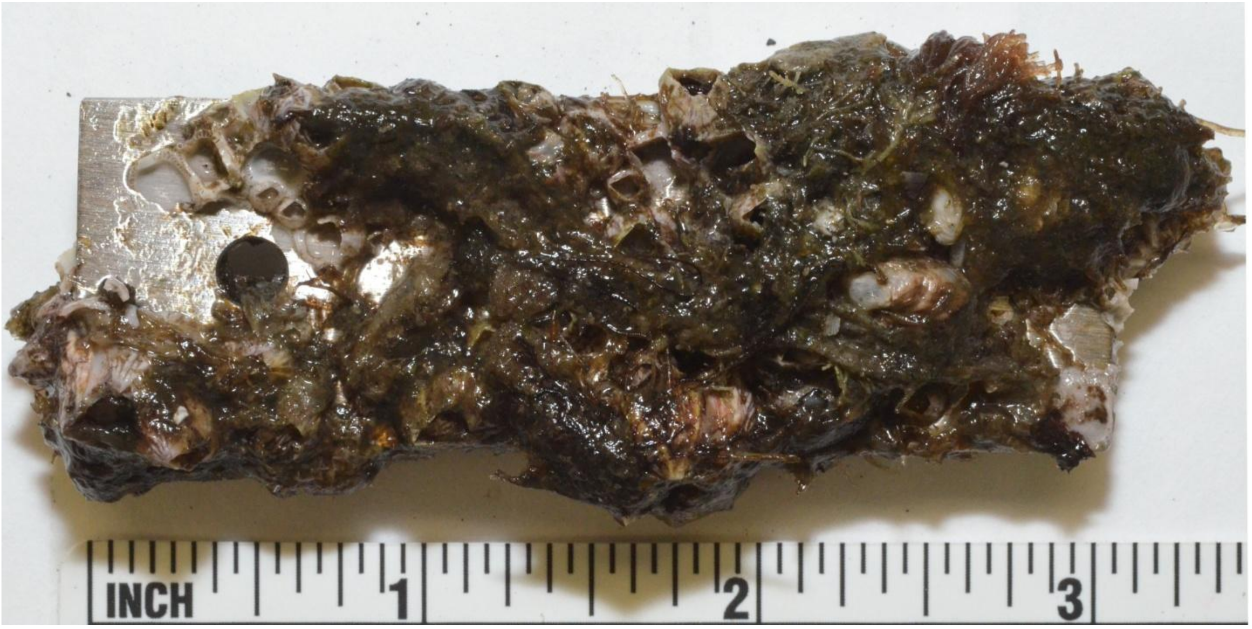
(b) Duplex 2205 Stainless Steel Coupon 7, Back Side

Figure 3 Photographs of duplex 2205 stainless steel coupon 7 (a) front and (b) back side after a 6 month corrosion test.

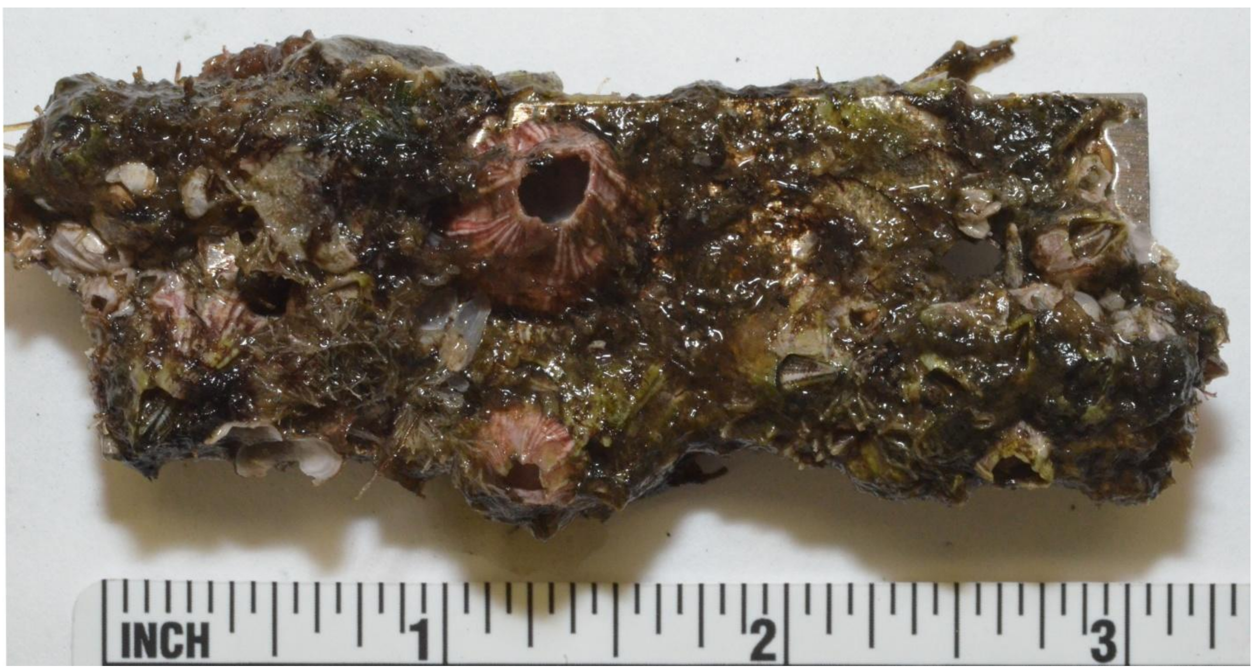
(a) Duplex 2205 Stainless Steel Coupon 8, Front Side

(b) Duplex 2205 Stainless Steel Coupon 8, Back Side

Figure 4 Photographs of duplex 2205 stainless steel coupon 8 (a) front and (b) back side after a 10 month corrosion test.



(a) Duplex 2205 Stainless Steel Coupon 9, Front Side



(b) Duplex 2205 Stainless Steel Coupon 9, Back Side

Figure 5 Photographs of duplex 2205 stainless steel coupon 9 (a) front and (b) back side after a 12 month corrosion test.

(a) Duplex 2205 Stainless Steel Baseline Screen

Figure 6 Photograph of the duplex 2205 stainless steel baseline screen.

(a) Duplex 2205 Stainless Steel Screen 1

Figure 7 Photograph of duplex 2205 stainless steel screen 1 after a 3 month corrosion test.

(a) Duplex 2205 Stainless Steel Screen 2

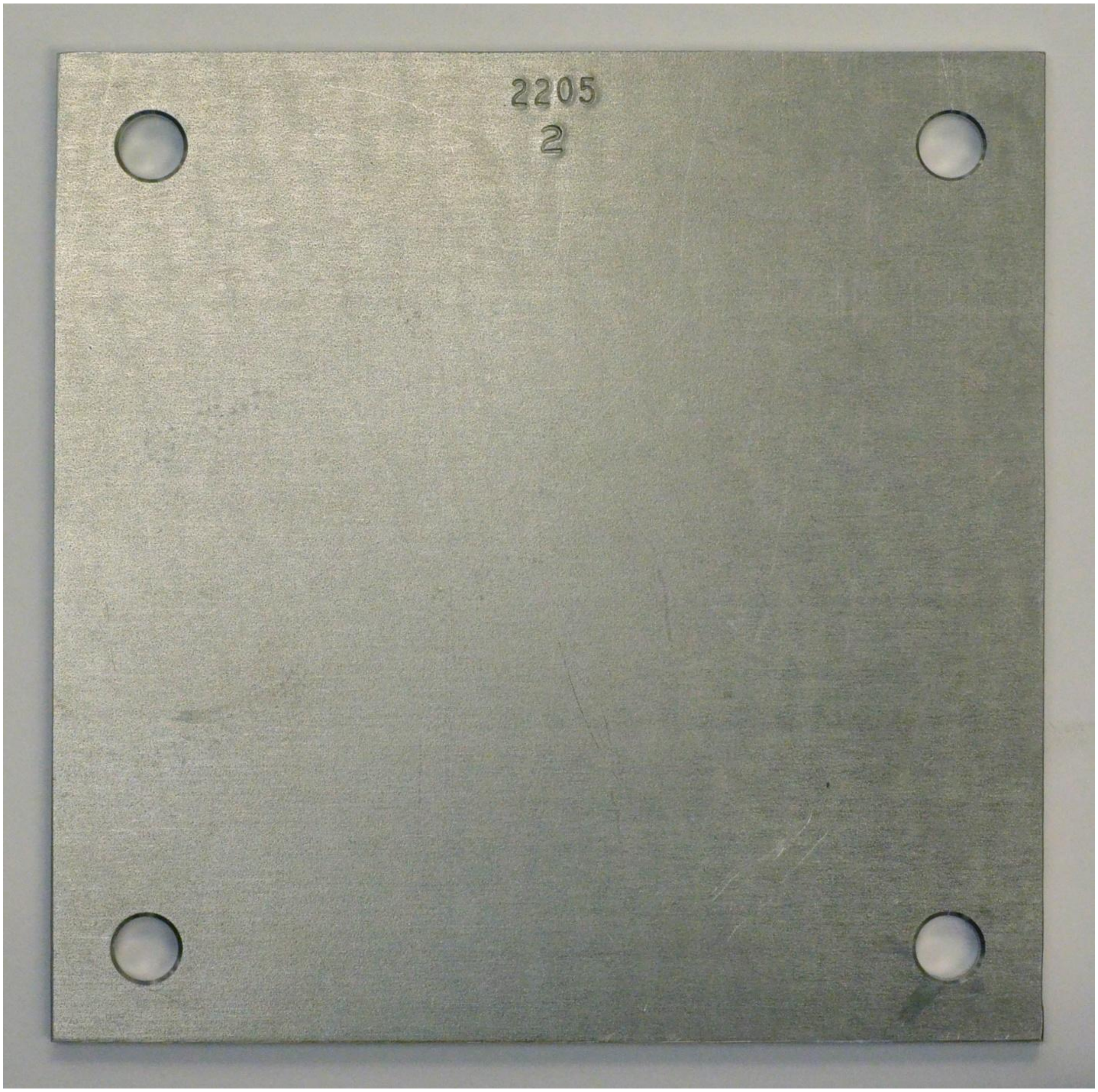
Figure 8 Photograph of duplex 2205 stainless steel screen 2 after a 6 month corrosion test.

(a) Duplex 2205 Stainless Steel Screen 3

Figure 9 Photograph of duplex 2205 stainless steel screen 3 after a 10 month corrosion test.

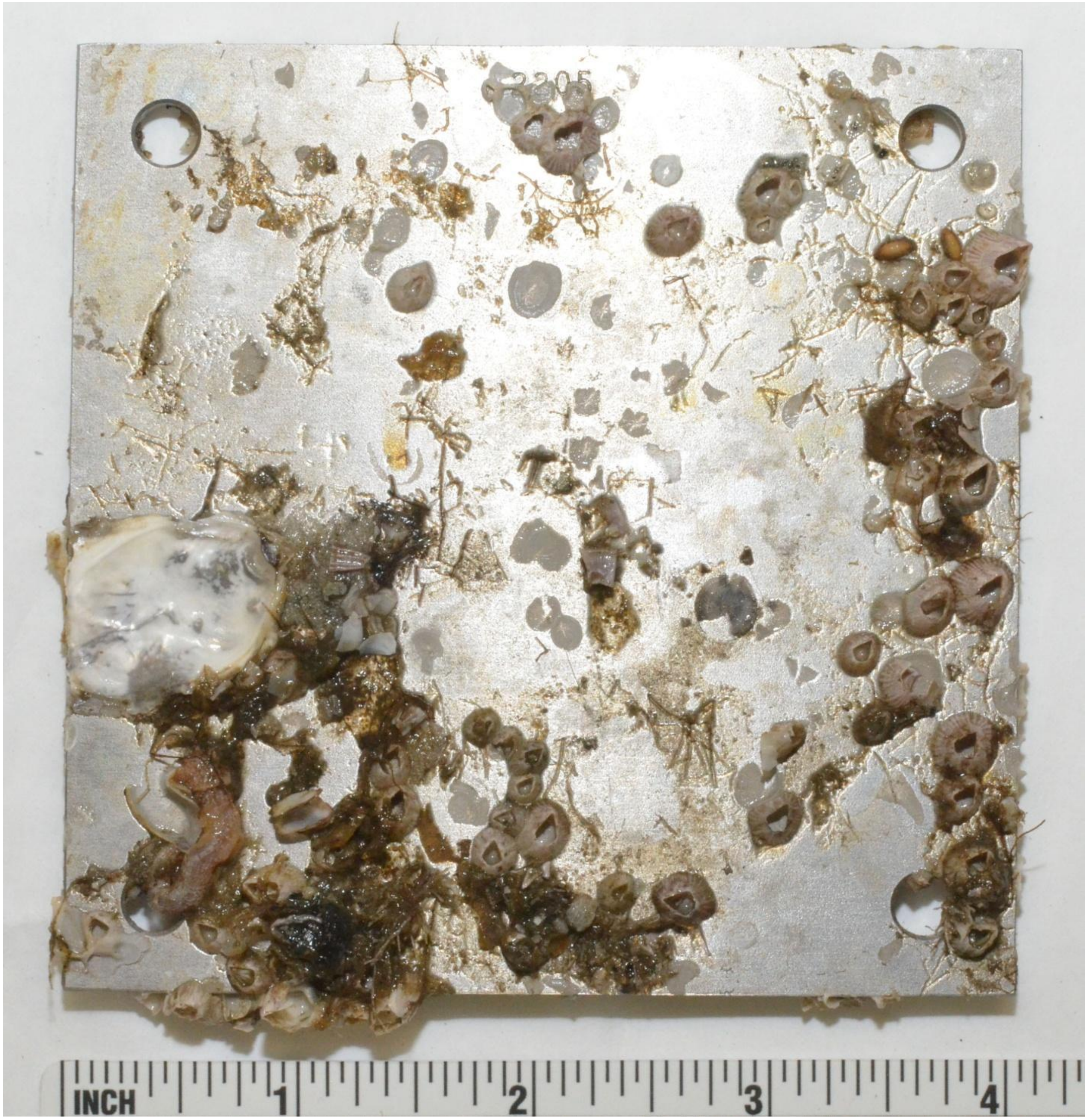
(a) Duplex 2205 Stainless Steel Screen 4

Figure 10 Photograph of duplex 2205 stainless steel screen 4 after a 12 month corrosion test.



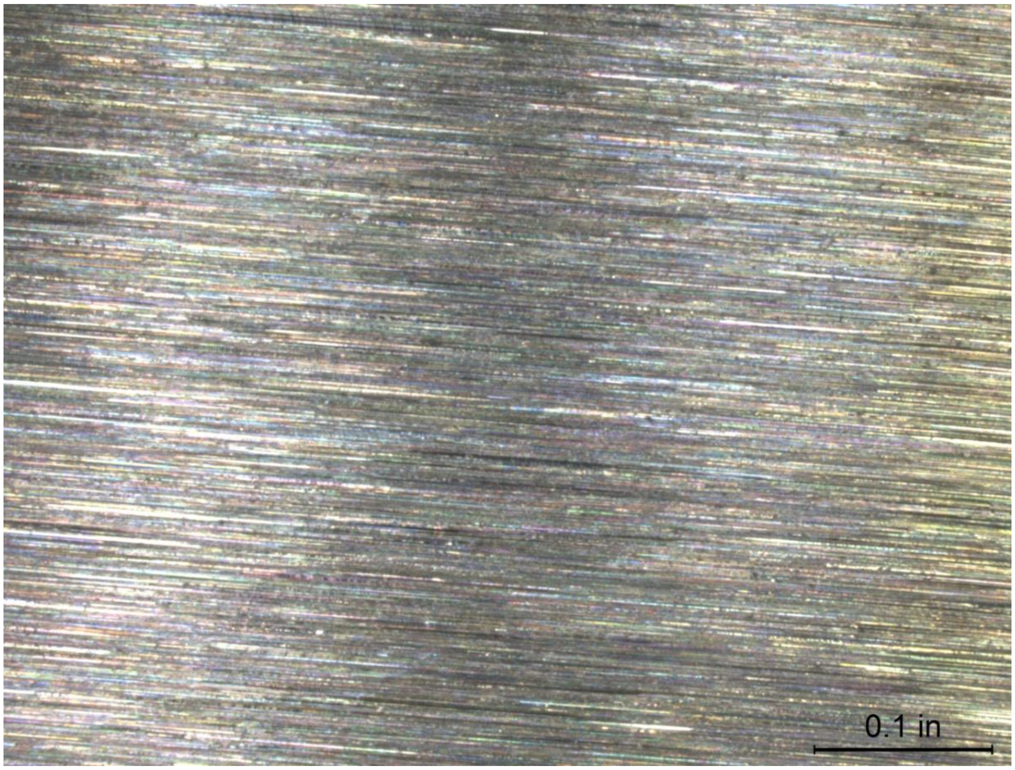
(a) Duplex 2205 Stainless Steel Baseline Plate

Figure 11 Photograph of the duplex 2205 stainless steel baseline plate.

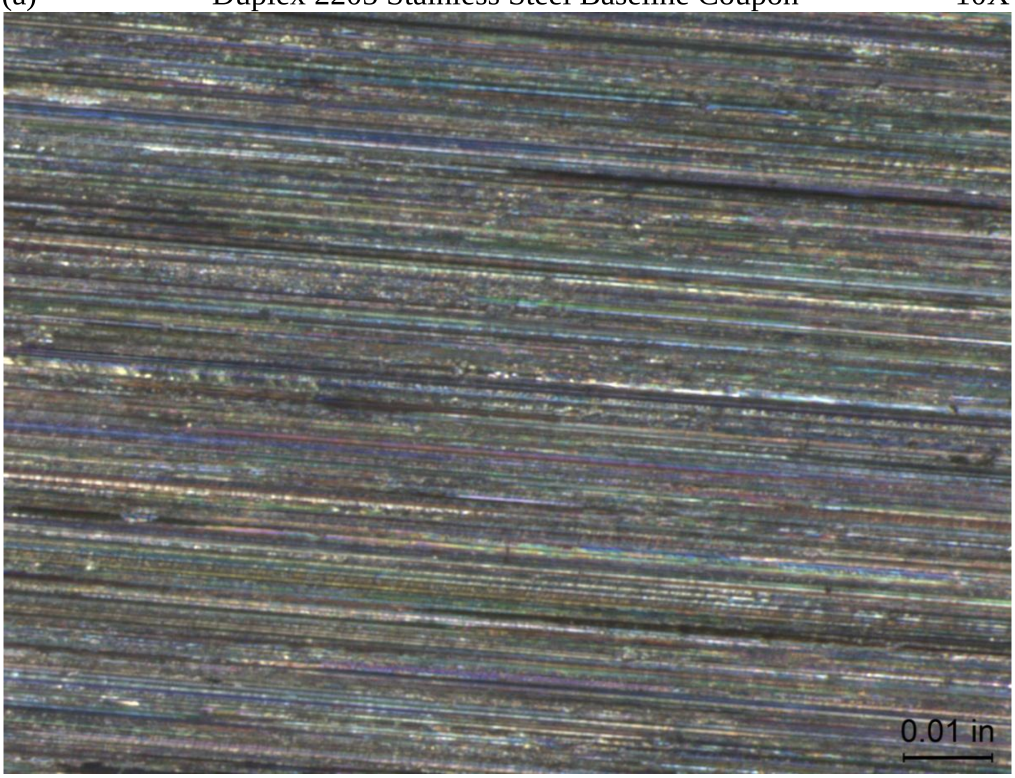


(a) Duplex 2205 Stainless Steel Plate

Figure 12 Photograph of duplex 2205 stainless steel plate after a 12 month corrosion test.



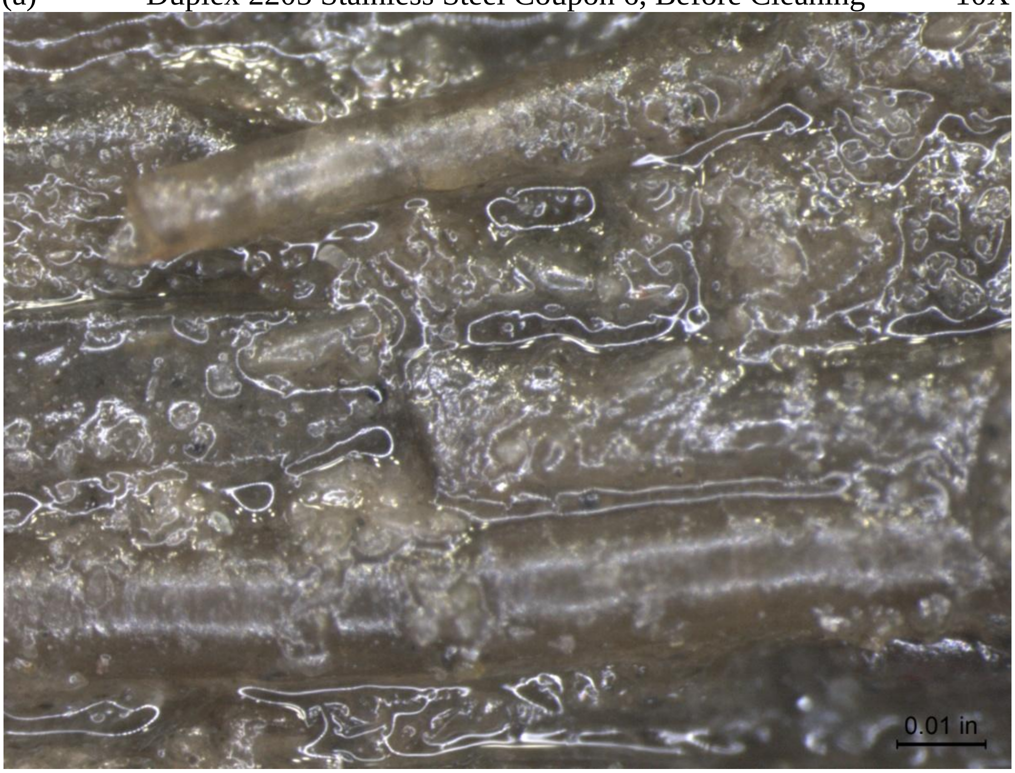
(a) Duplex 2205 Stainless Steel Baseline Coupon 10X



(b) Duplex 2205 Stainless Steel Baseline Coupon 50X

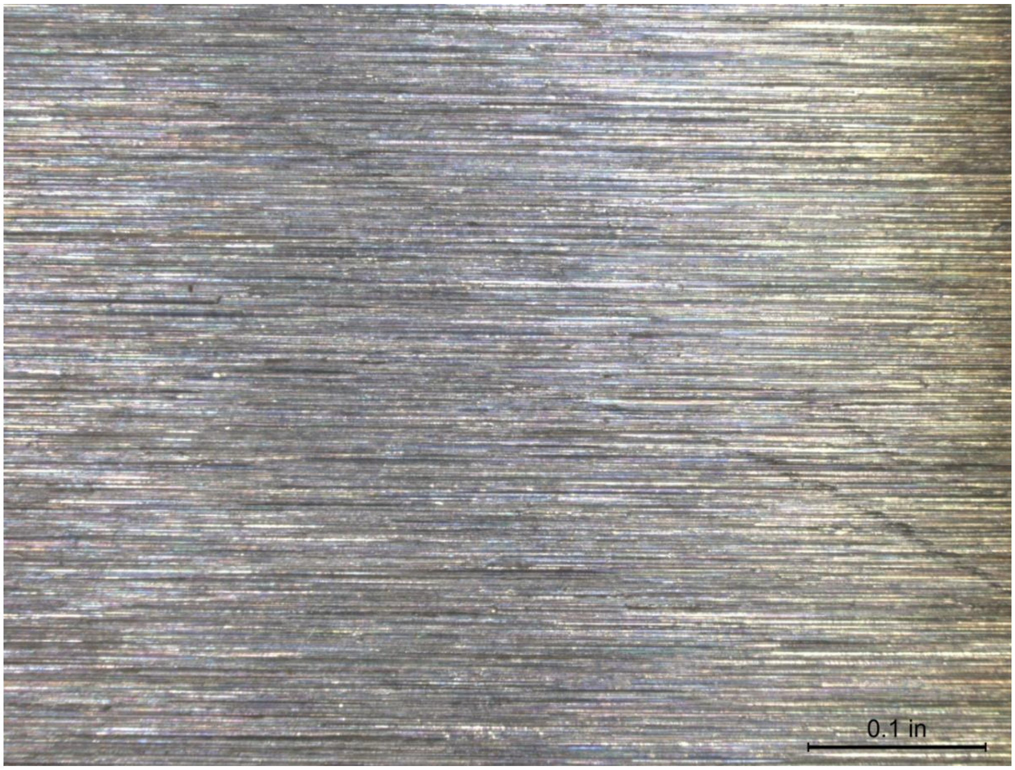
Figure 13 Optical macrographs of the duplex 2205 stainless steel baseline coupon.

(a) Duplex 2205 Stainless Steel Coupon 6, Before Cleaning 10X

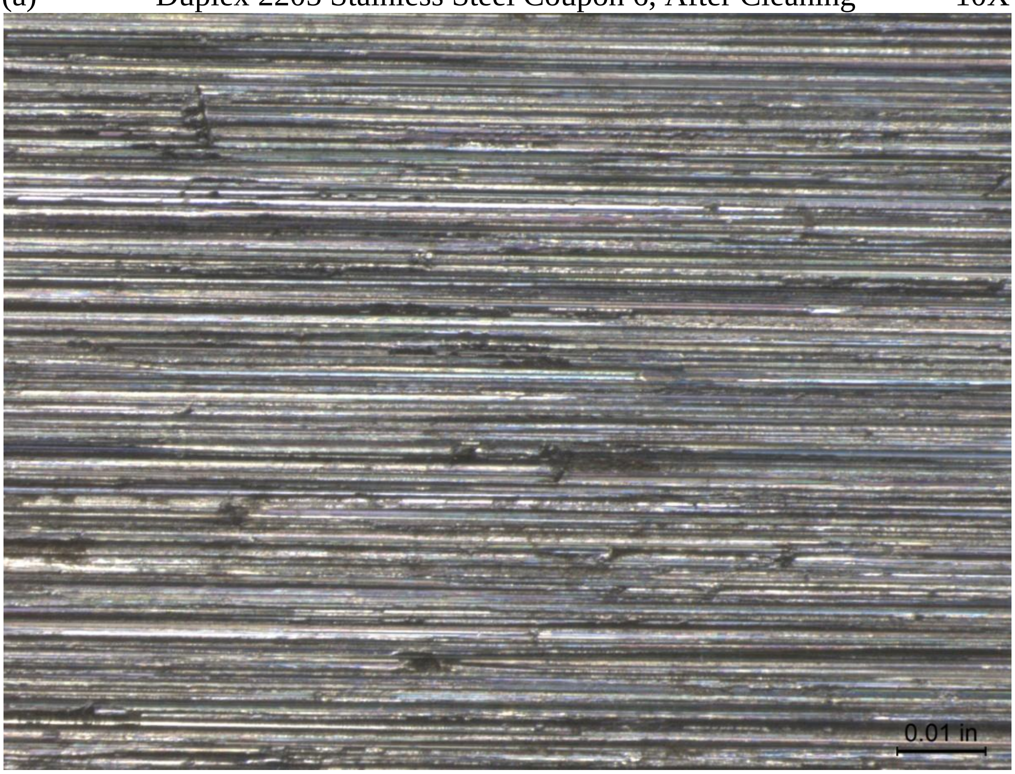


(b) Duplex 2205 Stainless Steel Coupon 6, Before Cleaning 50X

Figure 14 Optical macrographs of duplex 2205 stainless steel coupon 6 after a 3 month corrosion test, before cleaning.



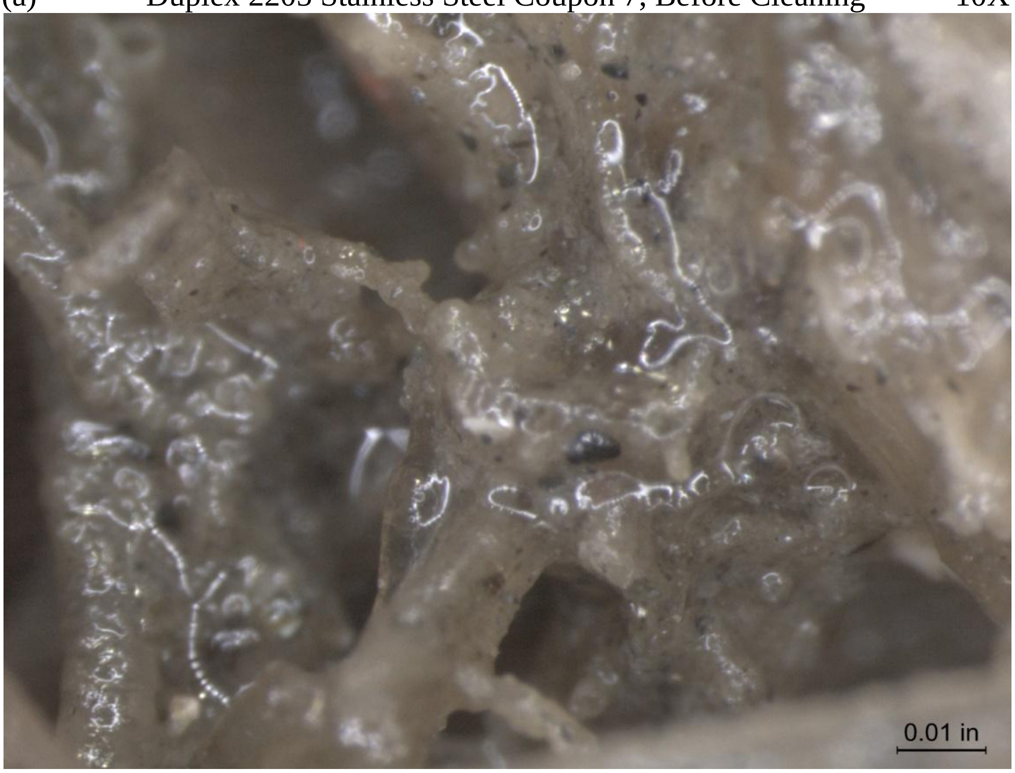
(a) Duplex 2205 Stainless Steel Coupon 6, After Cleaning 10X



(b) Duplex 2205 Stainless Steel Coupon 6, After Cleaning 50X

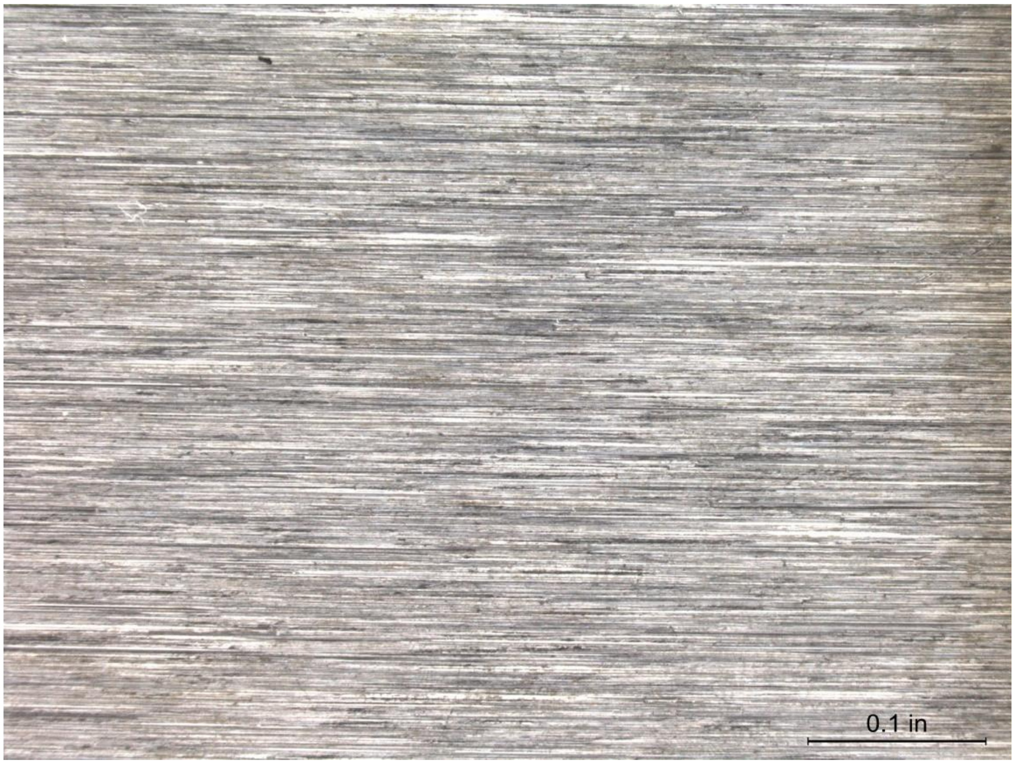
Figure 15 Optical macrographs of duplex 2205 stainless steel coupon 6 after a 3 month corrosion test, after cleaning.

(a) Duplex 2205 Stainless Steel Coupon 7, Before Cleaning 10X

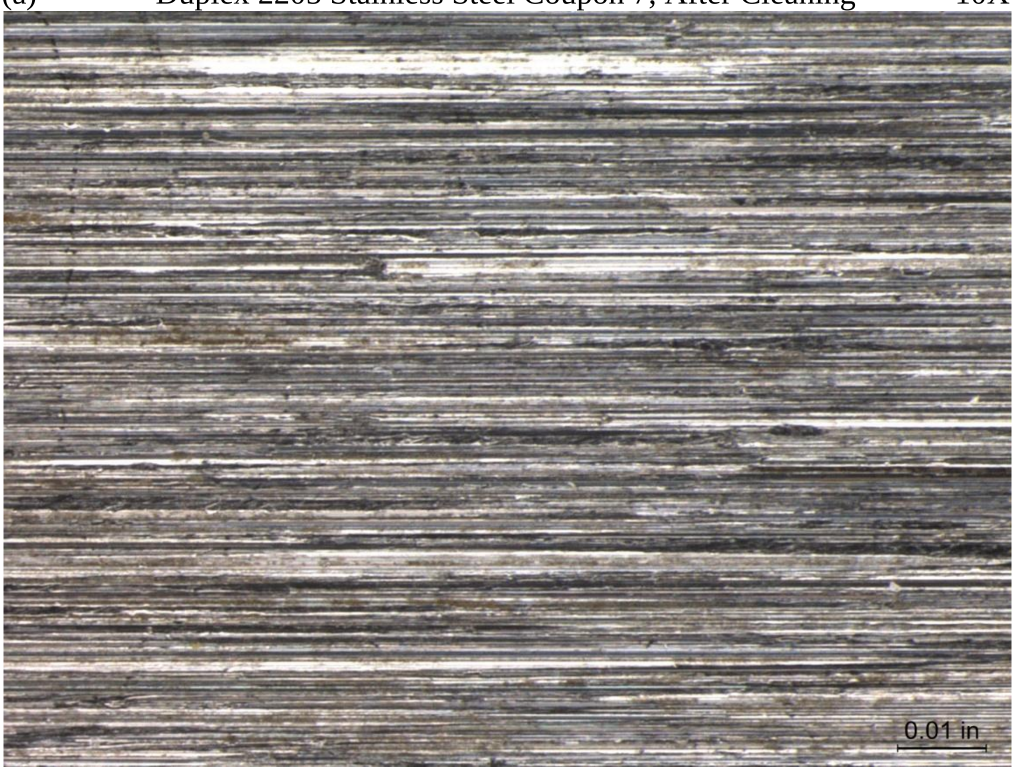


(b) Duplex 2205 Stainless Steel Coupon 7, Before Cleaning 50X

Figure 16 Optical macrographs of duplex 2205 stainless steel coupon 7 after a 6 month corrosion test, before cleaning.



(a) Duplex 2205 Stainless Steel Coupon 7, After Cleaning 10X



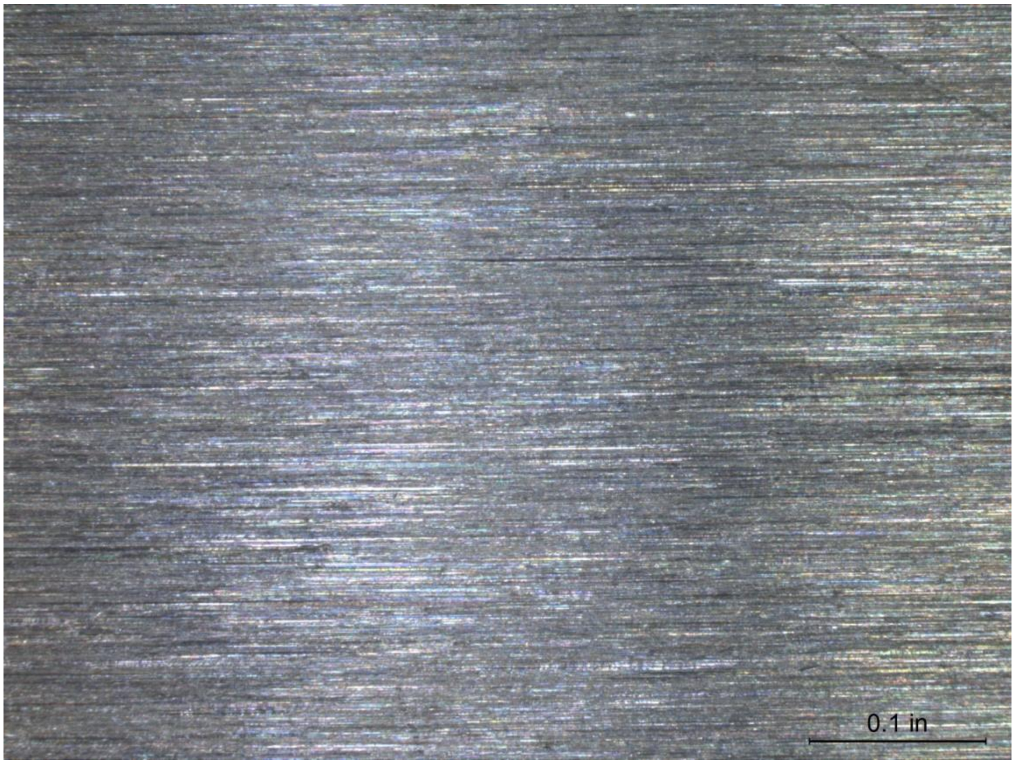
(b) Duplex 2205 Stainless Steel Coupon 7, After Cleaning 50X

Figure 17 Optical macrographs of duplex 2205 stainless steel coupon 7 after a 6 month corrosion test, after cleaning.

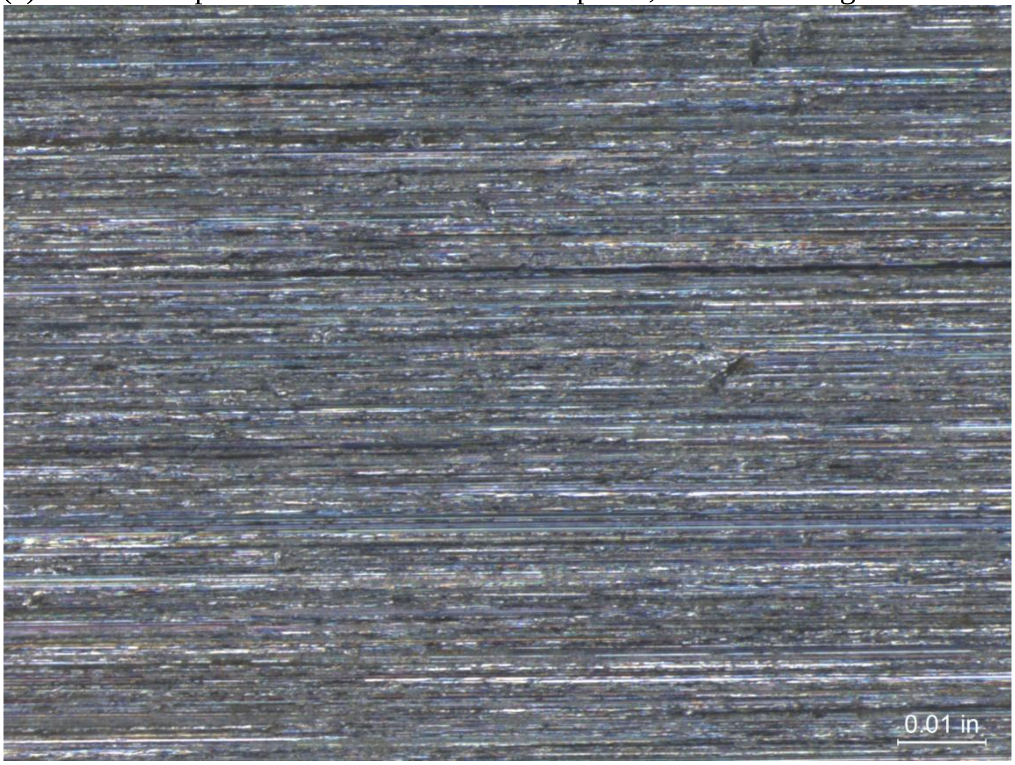
(a) Duplex 2205 Stainless Steel Coupon 8, Before Cleaning 10X

(b) Duplex 2205 Stainless Steel Coupon 8, Before Cleaning 50X

Figure 18 Optical macrographs of duplex 2205 stainless steel coupon 8 after a 10 month corrosion test, before cleaning.

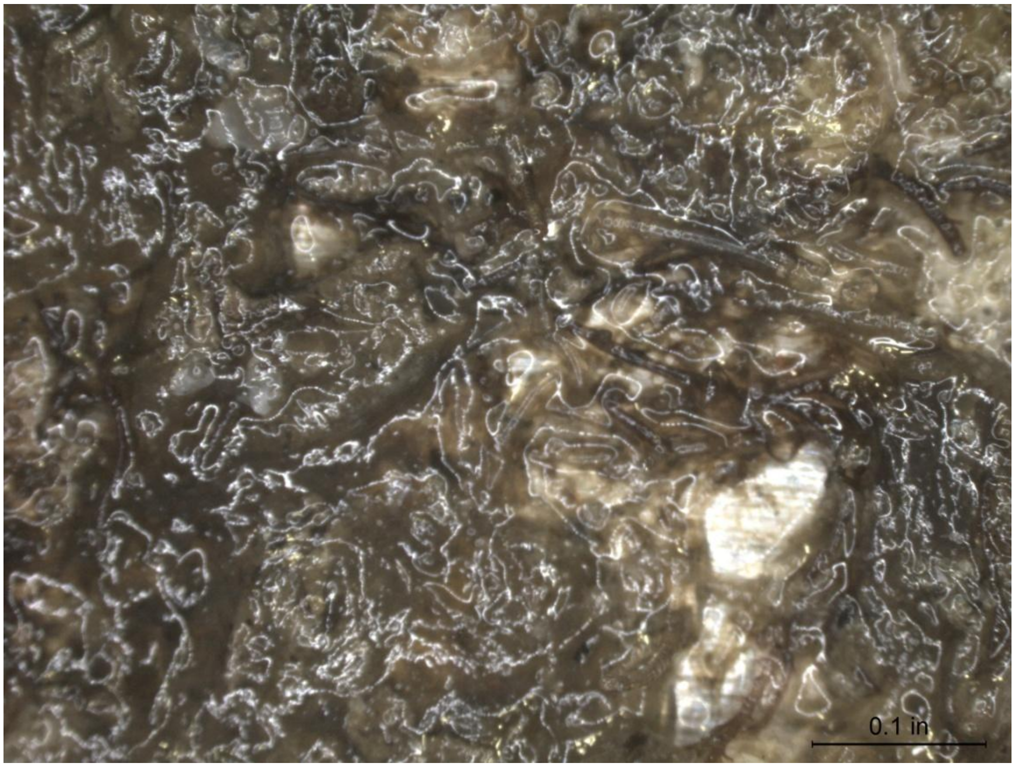


(a) Duplex 2205 Stainless Steel Coupon 8, After Cleaning 10X

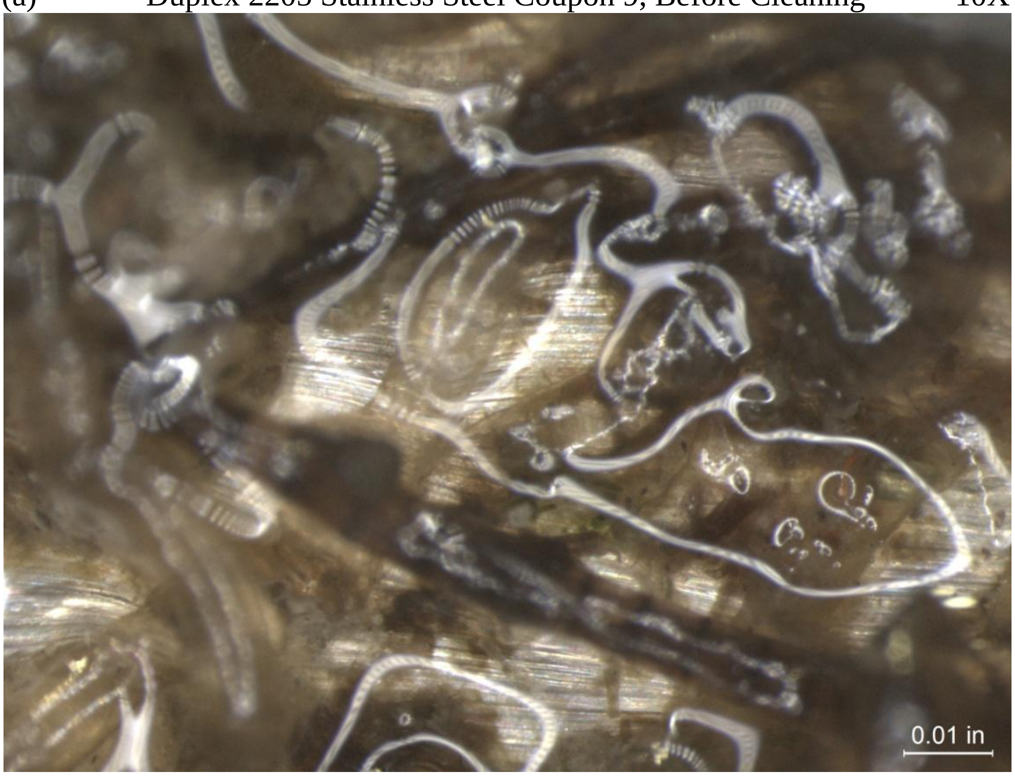


(b) Duplex 2205 Stainless Steel Coupon 8, After Cleaning 50X

Figure 19 Optical macrographs of duplex 2205 stainless steel coupon 8 after a 10 month corrosion test, after cleaning.

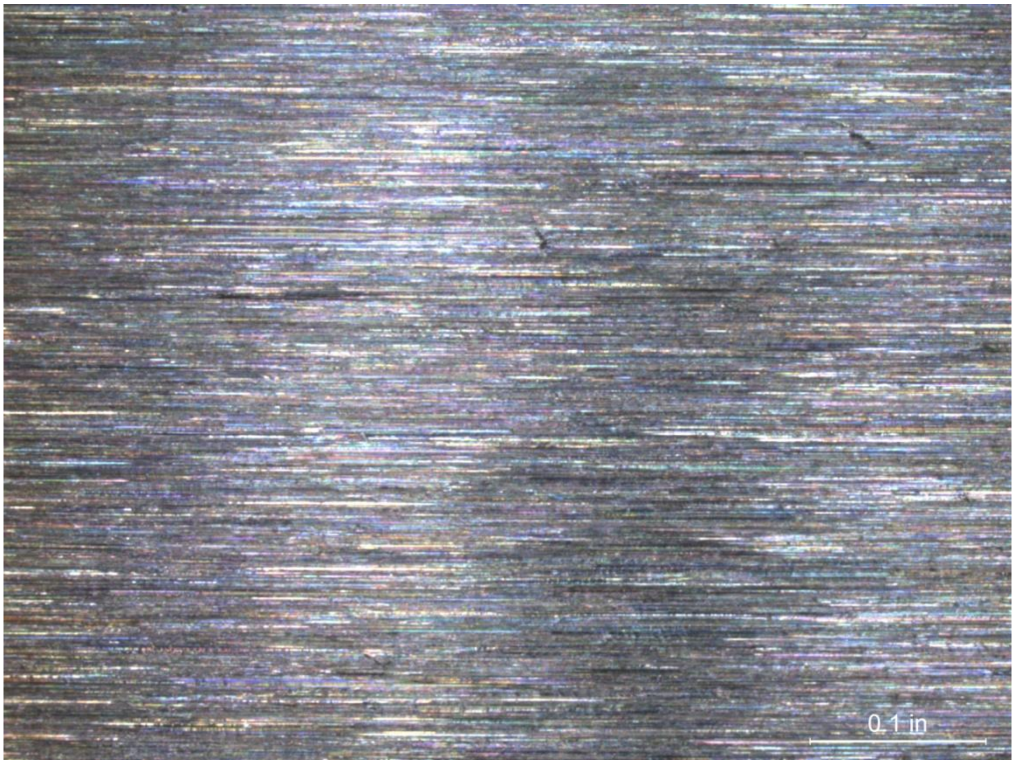


(a) Duplex 2205 Stainless Steel Coupon 9, Before Cleaning 10X

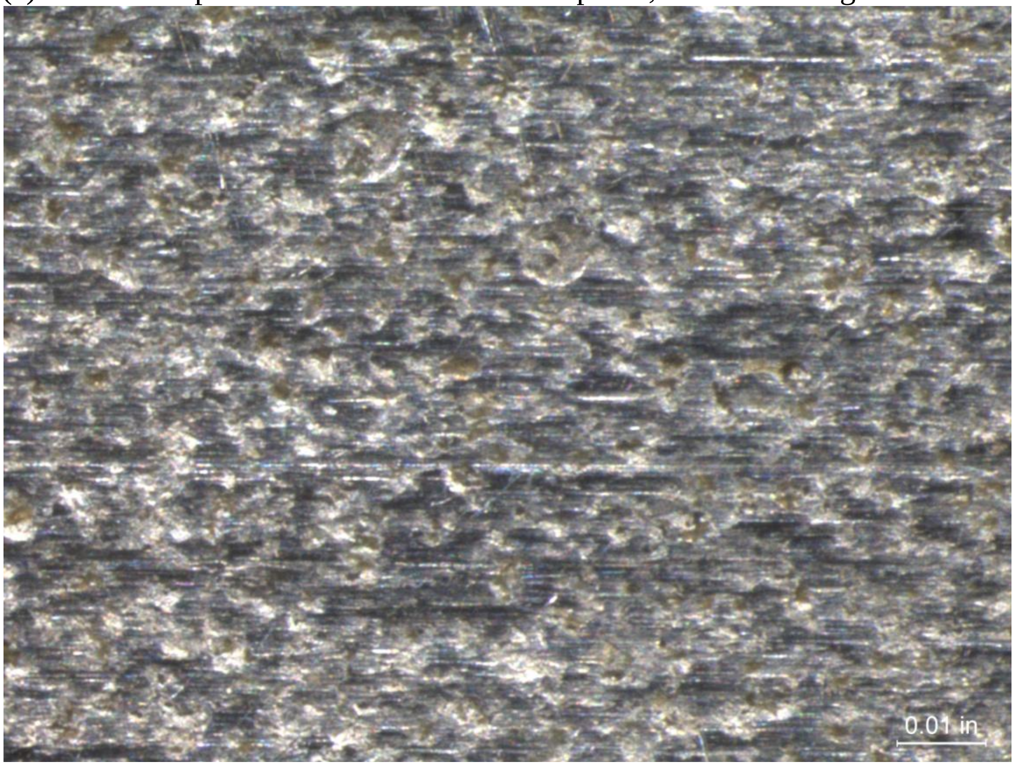


(b) Duplex 2205 Stainless Steel Coupon 9, Before Cleaning 50X

Figure 20 Optical macrographs of duplex 2205 stainless steel coupon 9 after a 12 month corrosion test, before cleaning.

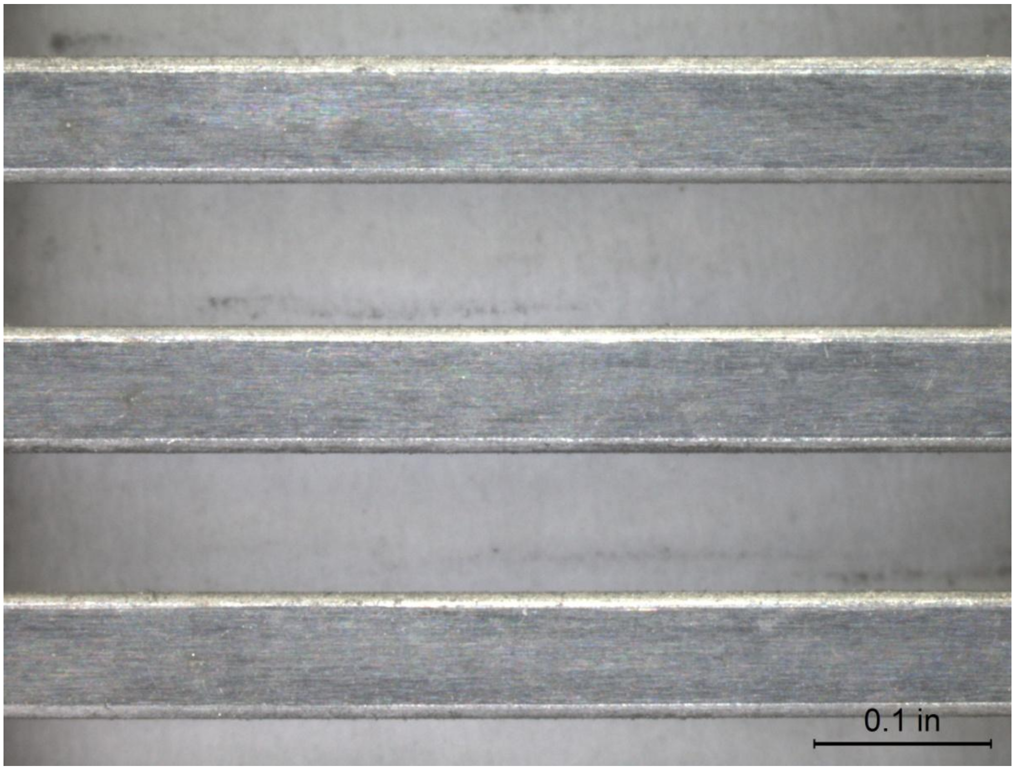


(a) Duplex 2205 Stainless Steel Coupon 9, After Cleaning 10X

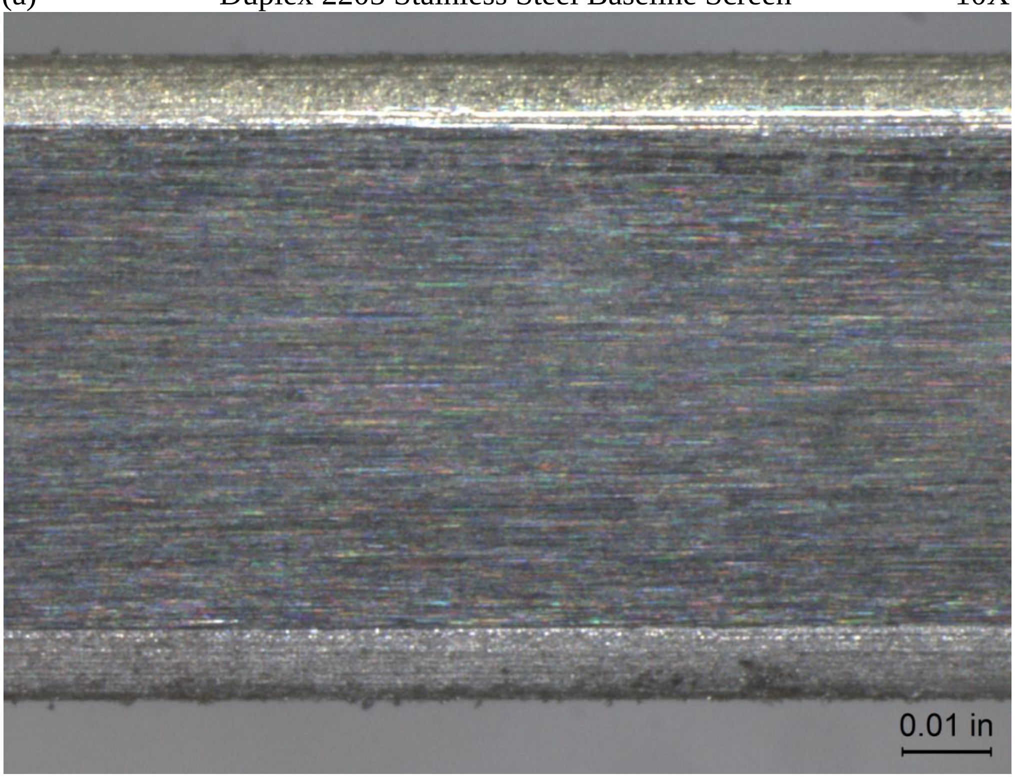


(b) Duplex 2205 Stainless Steel Coupon 9, After Cleaning 50X

Figure 21 Optical macrographs of duplex 2205 stainless steel coupon 9 after a 12 month corrosion test, after cleaning.

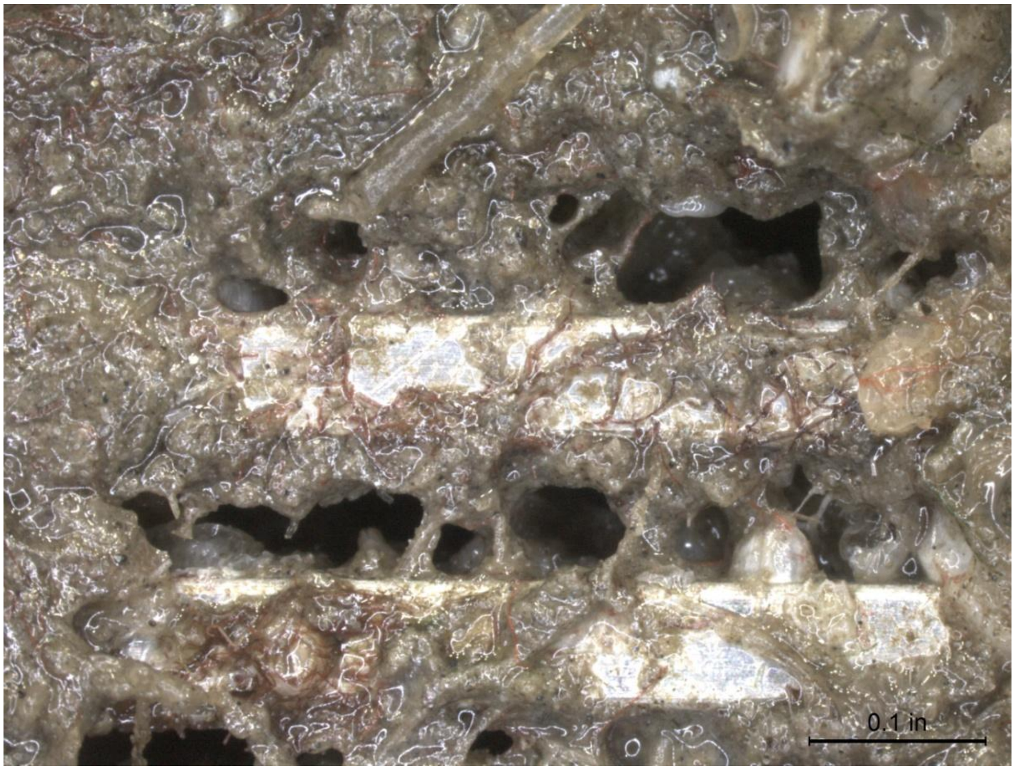


(a) Duplex 2205 Stainless Steel Baseline Screen 10X

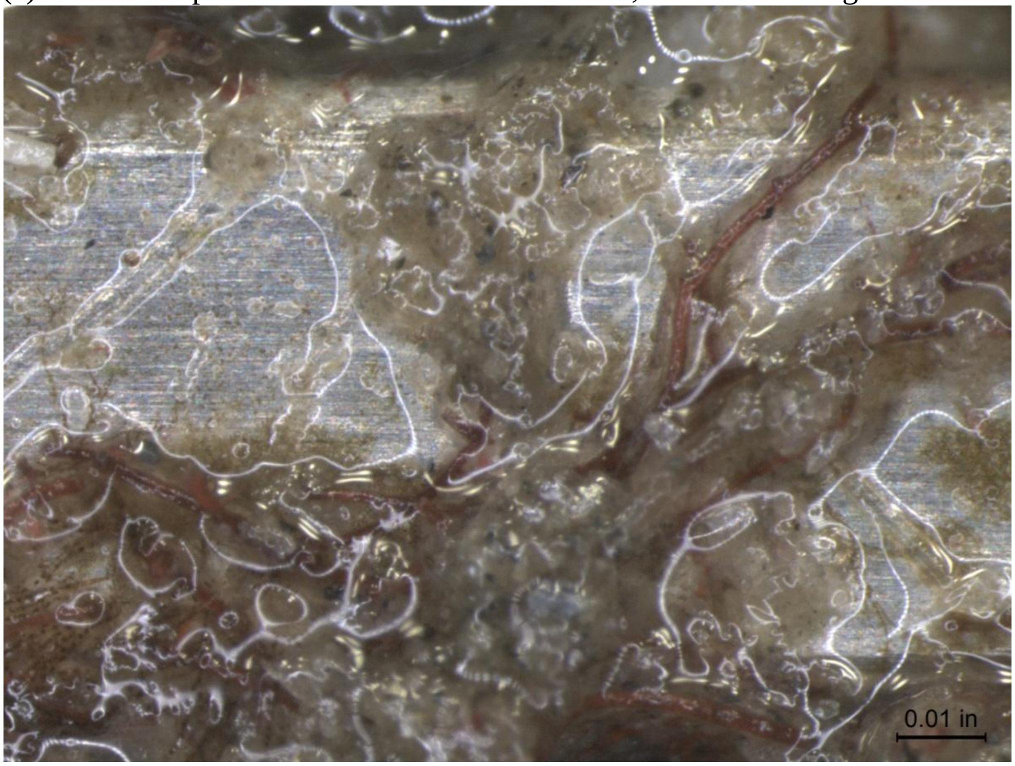


(b) Duplex 2205 Stainless Steel Baseline Screen 50X

Figure 22 Optical macrographs of the duplex 2205 stainless steel baseline screen.

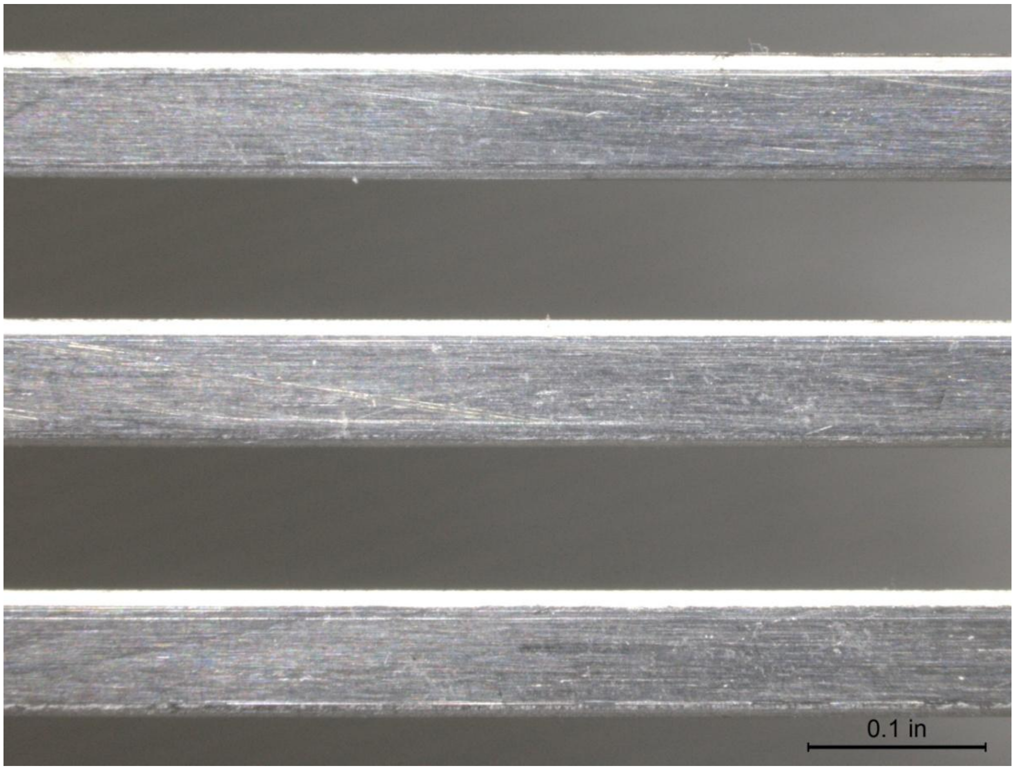


(a) Duplex 2205 Stainless Steel Screen 1, Before Cleaning 10X

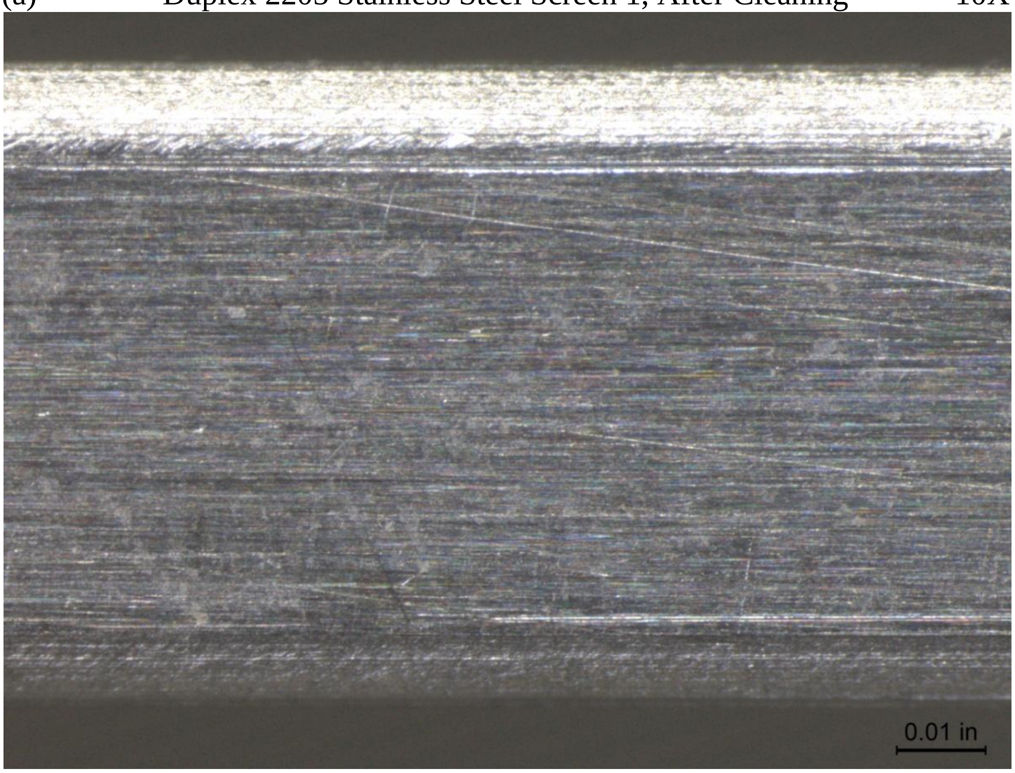


(b) Duplex 2205 Stainless Steel Screen 1, Before Cleaning 50X

Figure 23 Optical macrographs of duplex 2205 stainless steel screen 1 after a 3 month corrosion test, before cleaning.



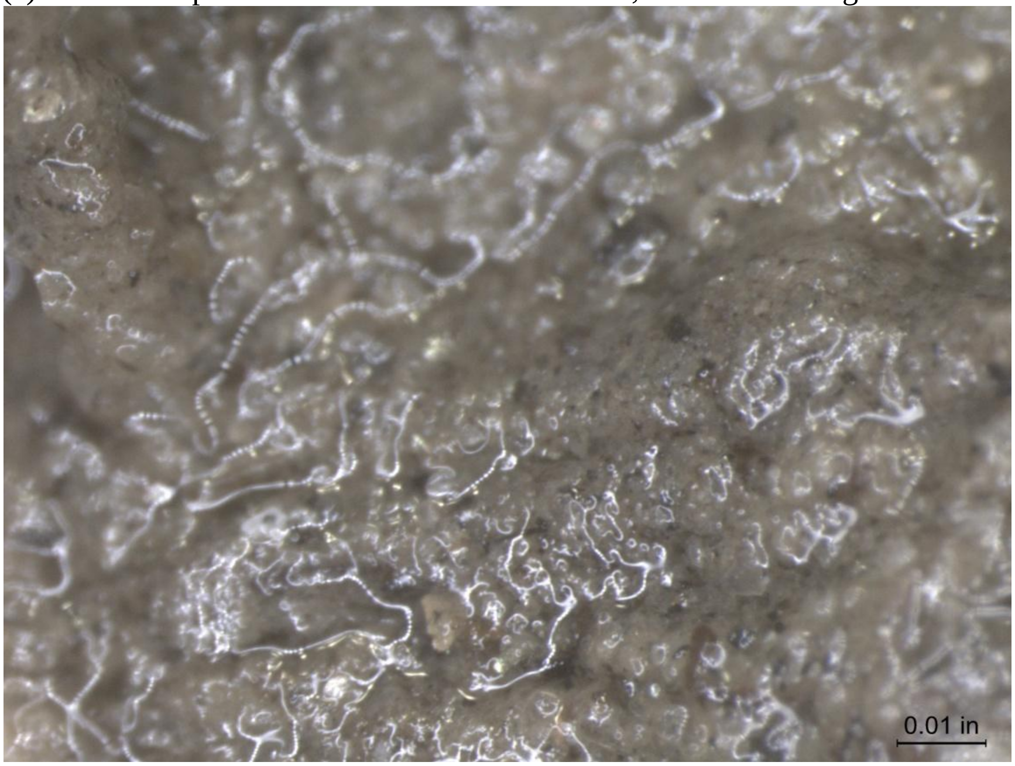
(a) Duplex 2205 Stainless Steel Screen 1, After Cleaning 10X



(b) Duplex 2205 Stainless Steel Screen 1, After Cleaning 50X

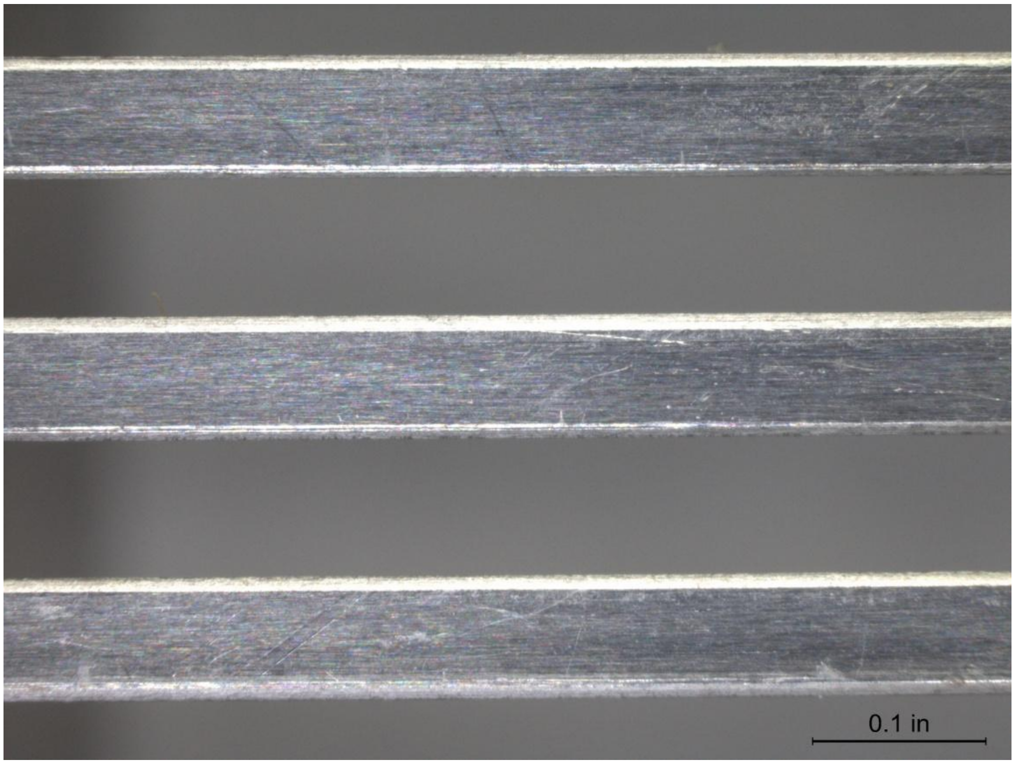
Figure 24 Optical macrographs of duplex 2205 stainless steel screen 1 after a 3 month corrosion test, after cleaning.

(a) Duplex 2205 Stainless Steel Screen 2, Before Cleaning 10X

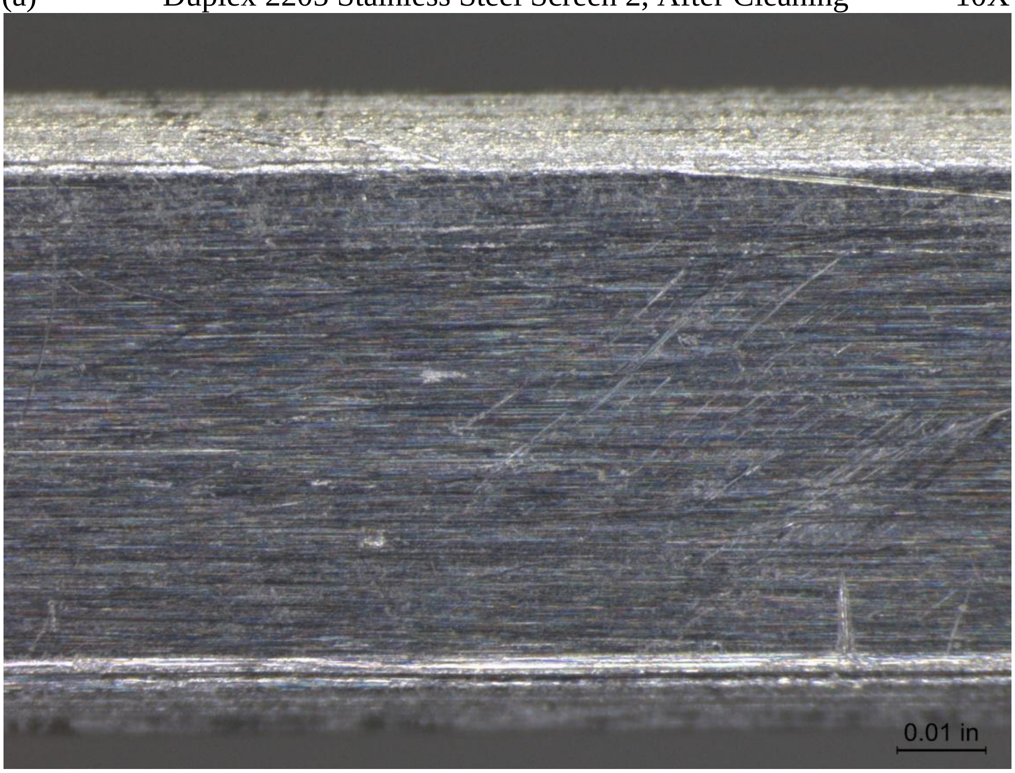


(b) Duplex 2205 Stainless Steel Screen 2, Before Cleaning 50X

Figure 25 Optical macrographs of duplex 2205 stainless steel screen 2 after a 6 month corrosion test, before cleaning.

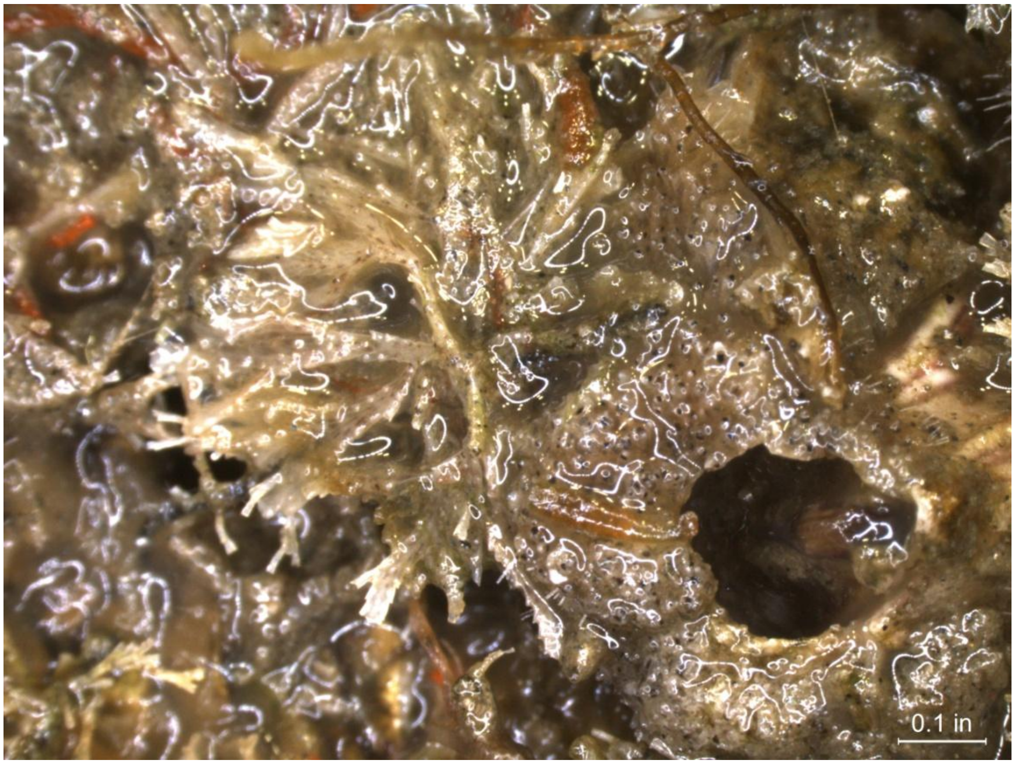


(a) Duplex 2205 Stainless Steel Screen 2, After Cleaning 10X



(b) Duplex 2205 Stainless Steel Screen 2, After Cleaning 50X

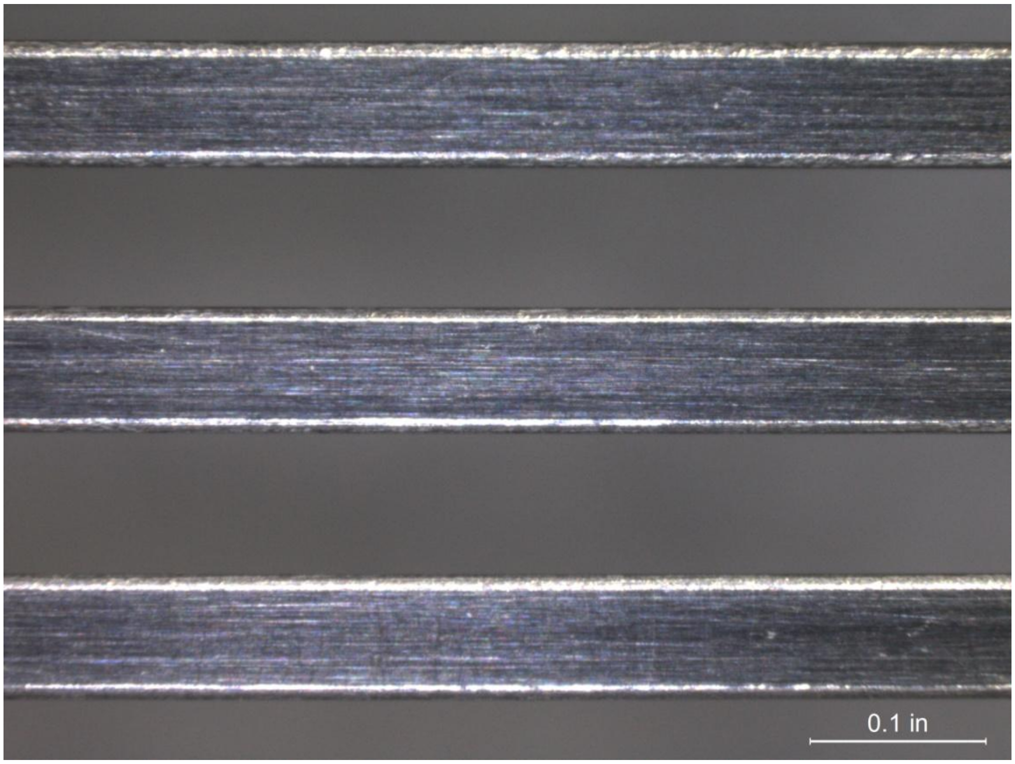
Figure 26 Optical macrographs of duplex 2205 stainless steel screen 2 after a 6 month corrosion test, after cleaning.



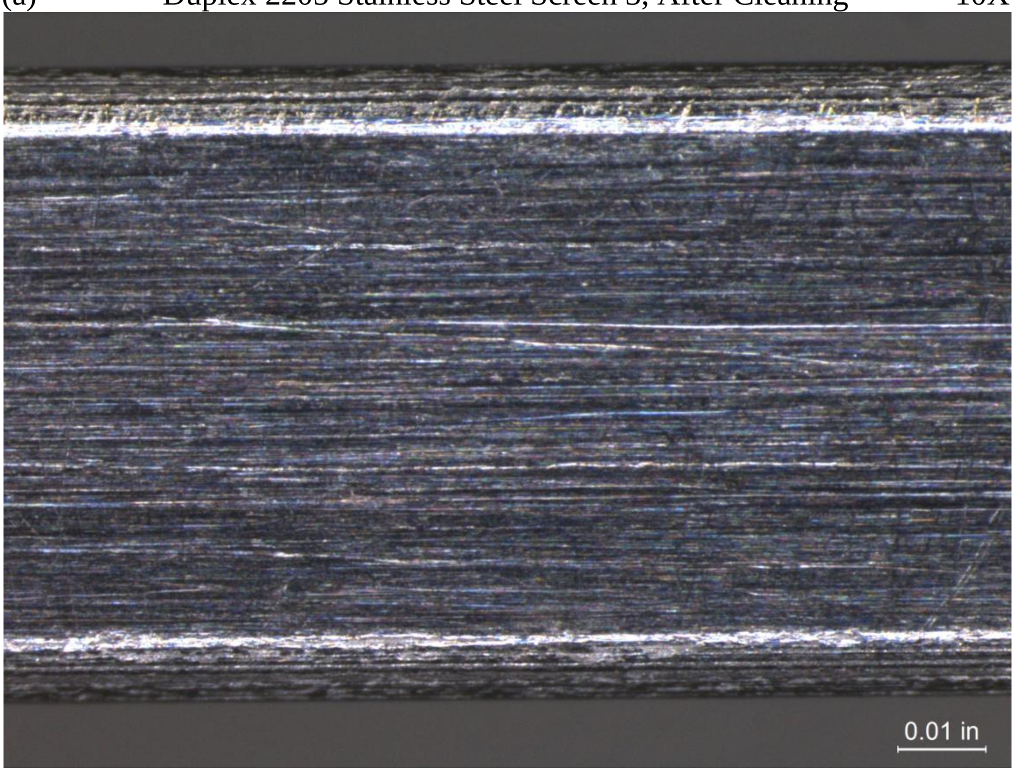
(a) Duplex 2205 Stainless Steel Screen 3, Before Cleaning 10X

(b) Duplex 2205 Stainless Steel Screen 3, Before Cleaning 50X

Figure 27 Optical macrographs of duplex 2205 stainless steel screen 3 after a 10 month corrosion test, before cleaning.



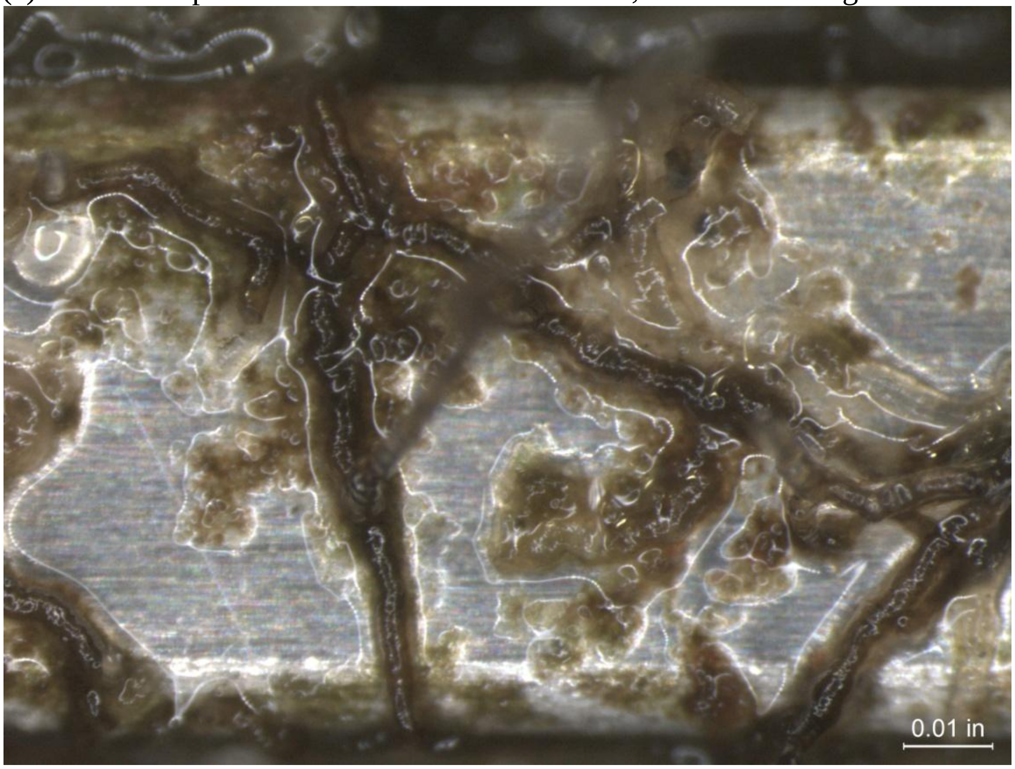
(a) Duplex 2205 Stainless Steel Screen 3, After Cleaning 10X



(b) Duplex 2205 Stainless Steel Screen 3, After Cleaning 50X

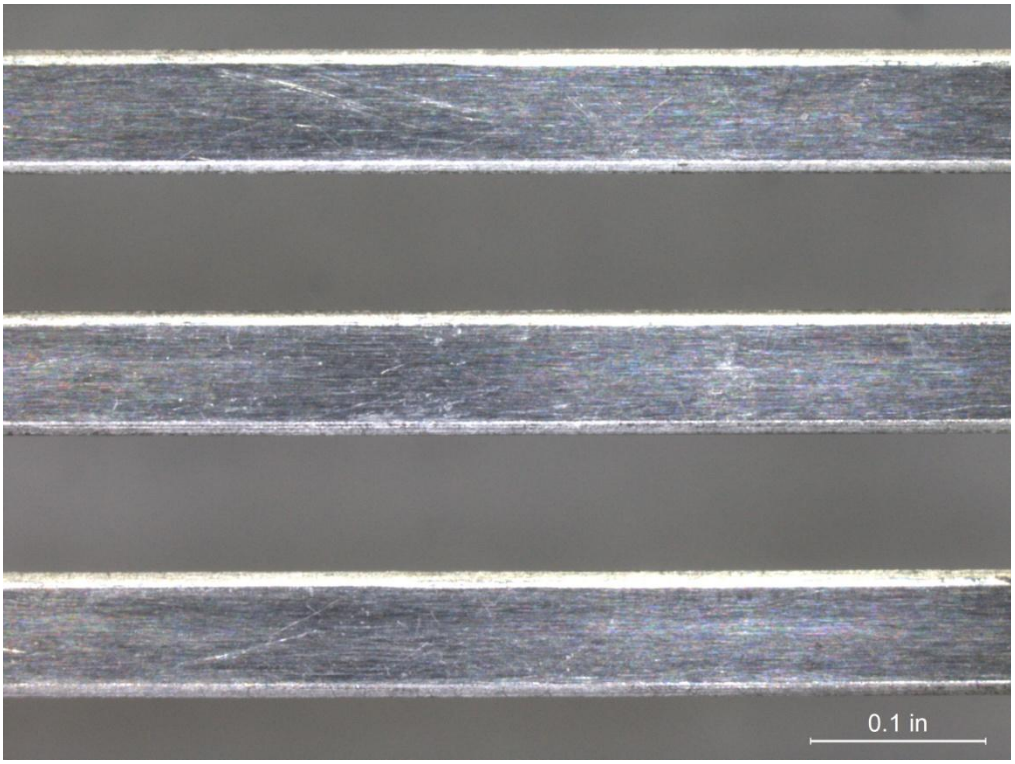
Figure 28 Optical macrographs of duplex 2205 stainless steel screen 3 after a 10 month corrosion test, after cleaning.

(a) Duplex 2205 Stainless Steel Screen 4, Before Cleaning 10X

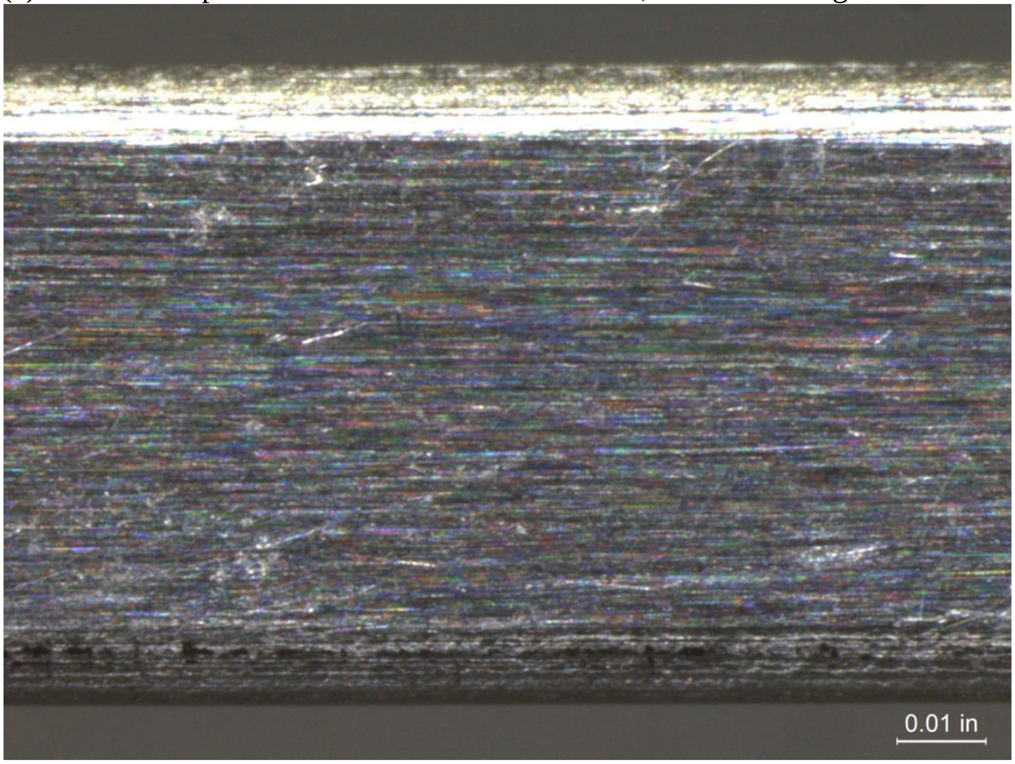


(b) Duplex 2205 Stainless Steel Screen 4, Before Cleaning 50X

Figure 29 Optical macrographs of duplex 2205 stainless steel screen 4 after a 12 month corrosion test, before cleaning.



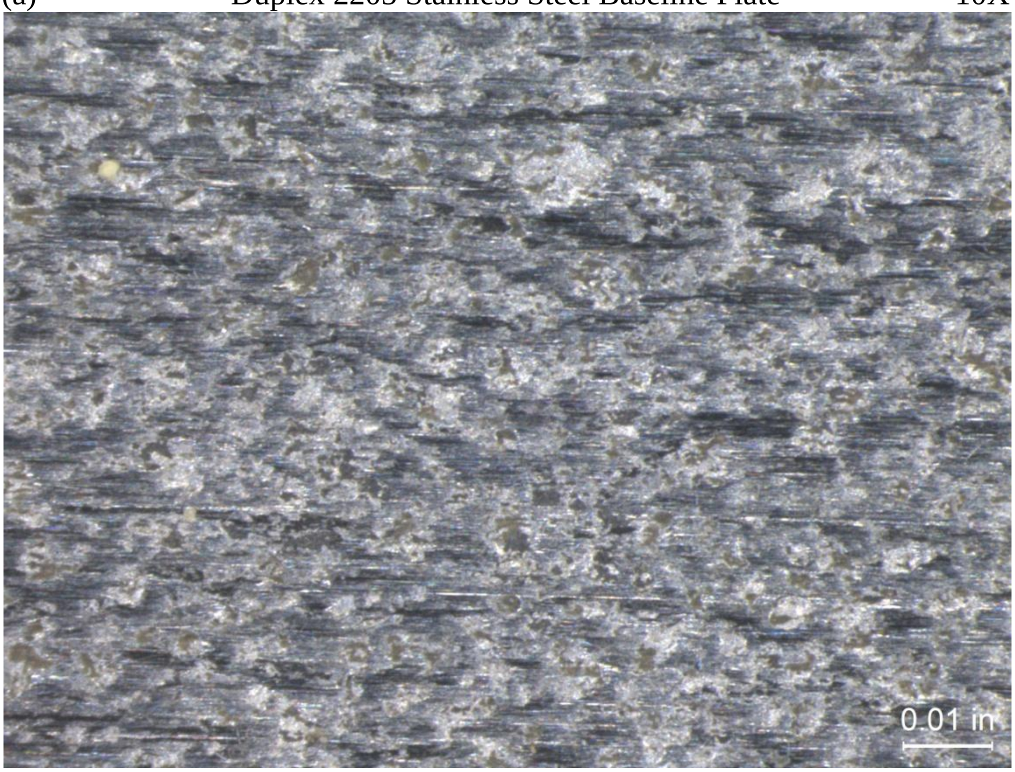
(a) Duplex 2205 Stainless Steel Screen 4, After Cleaning 10X



(b) Duplex 2205 Stainless Steel Screen 4, After Cleaning 50X

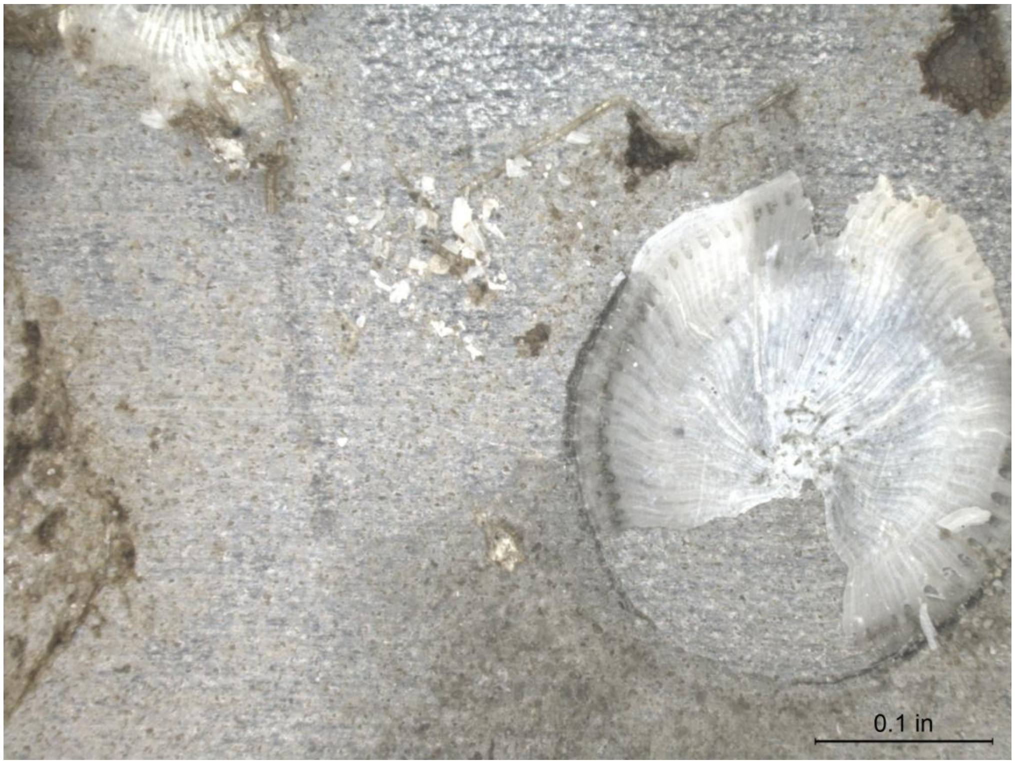
Figure 30 Optical macrographs of duplex 2205 stainless steel screen 4 after a 12 month corrosion test, after cleaning.

(a) Duplex 2205 Stainless Steel Baseline Plate 10X

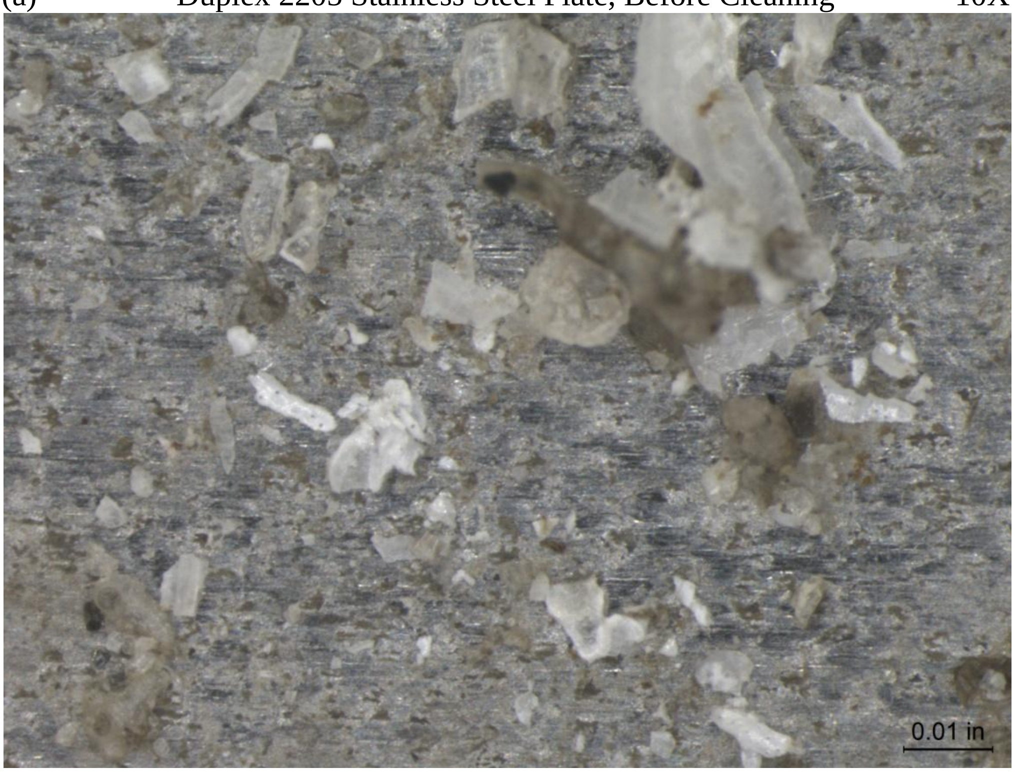


(b) Duplex 2205 Stainless Steel Baseline Plate 50X

Figure 31 Optical macrographs of the duplex 2205 stainless steel baseline plate.



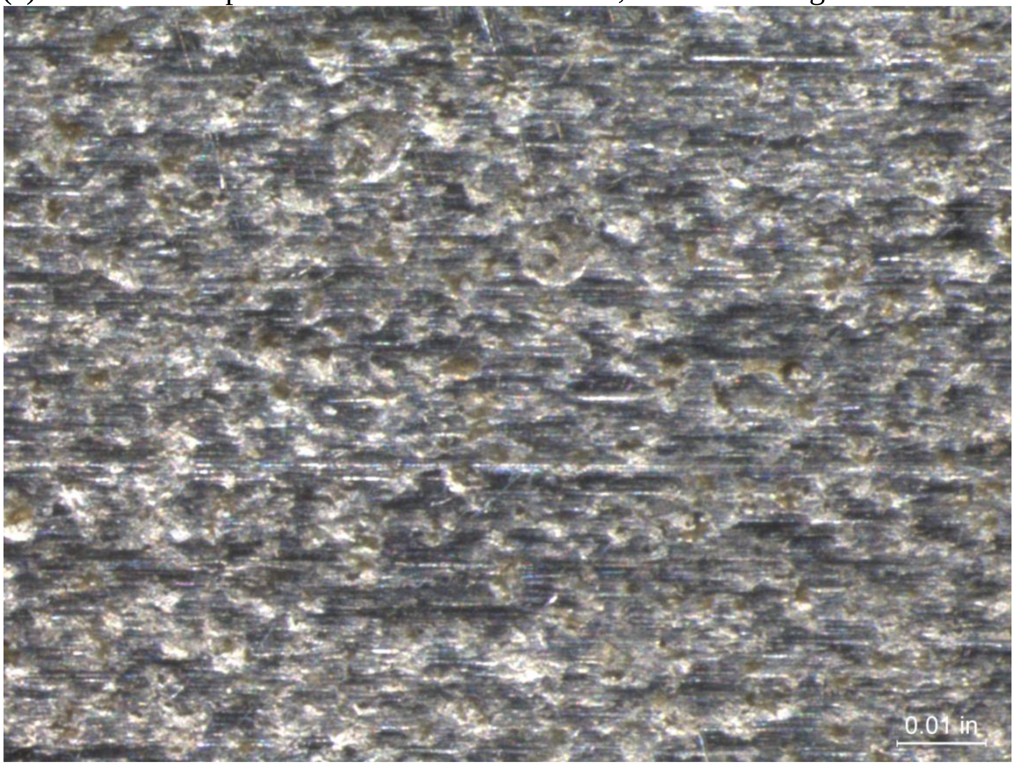
(a) Duplex 2205 Stainless Steel Plate, Before Cleaning 10X



(b) Duplex 2205 Stainless Steel Plate, Before Cleaning 50X

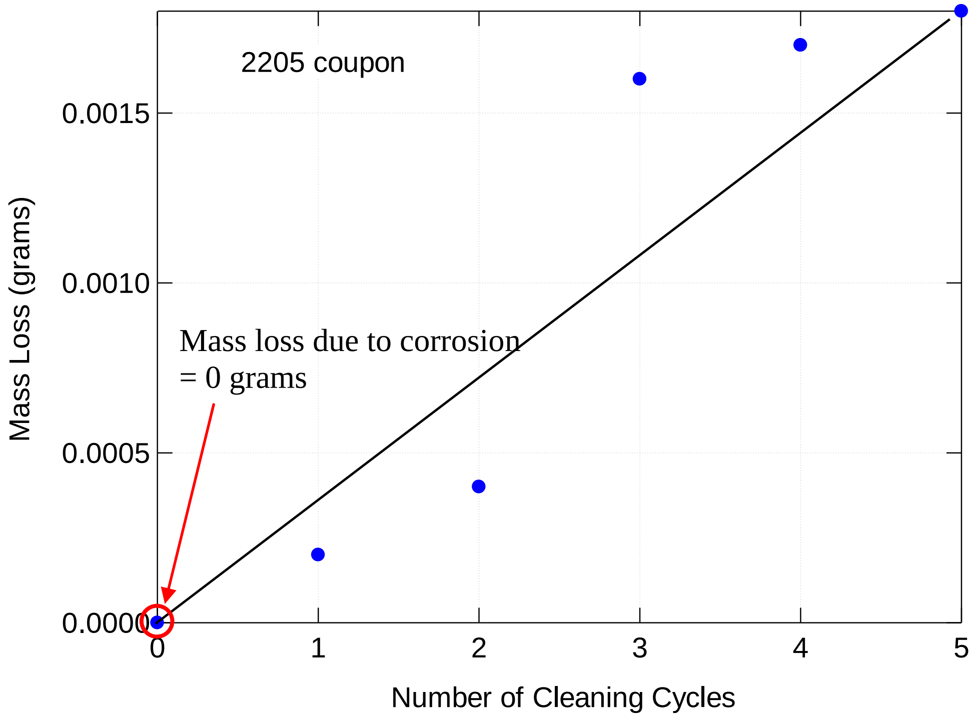
Figure 32 Optical macrographs of duplex 2205 stainless steel plate after a 12 month corrosion test, before cleaning.

(a) Duplex 2205 Stainless Steel Plate, After Cleaning 10X

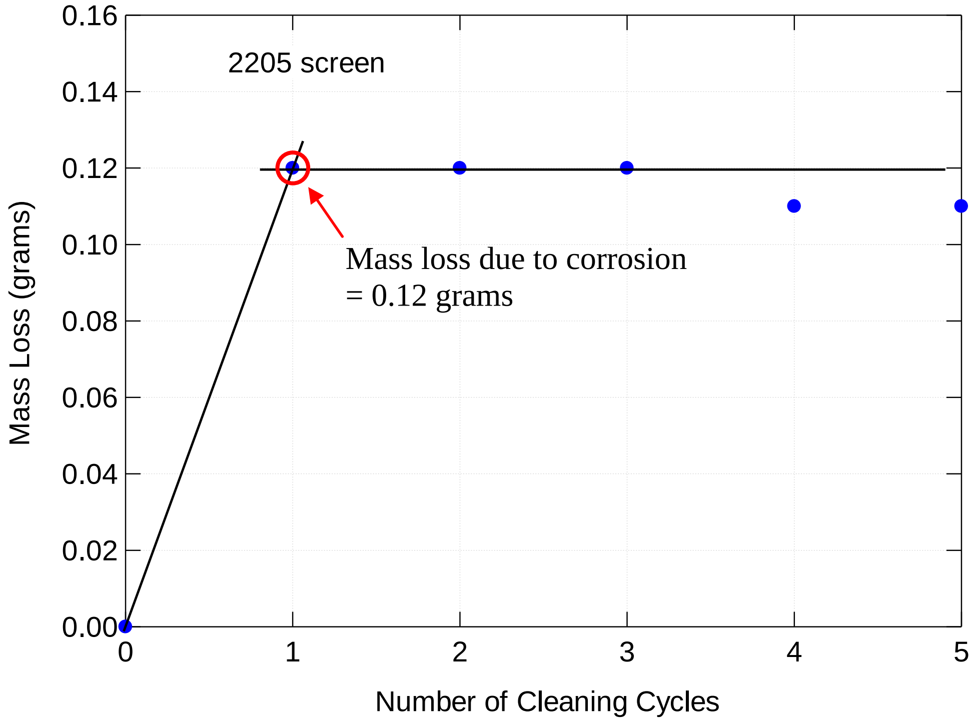


(b) Duplex 2205 Stainless Steel Plate, After Cleaning 50X

Figure 33 Optical macrographs of duplex 2205 stainless steel plate after a 12 month corrosion test, after cleaning.

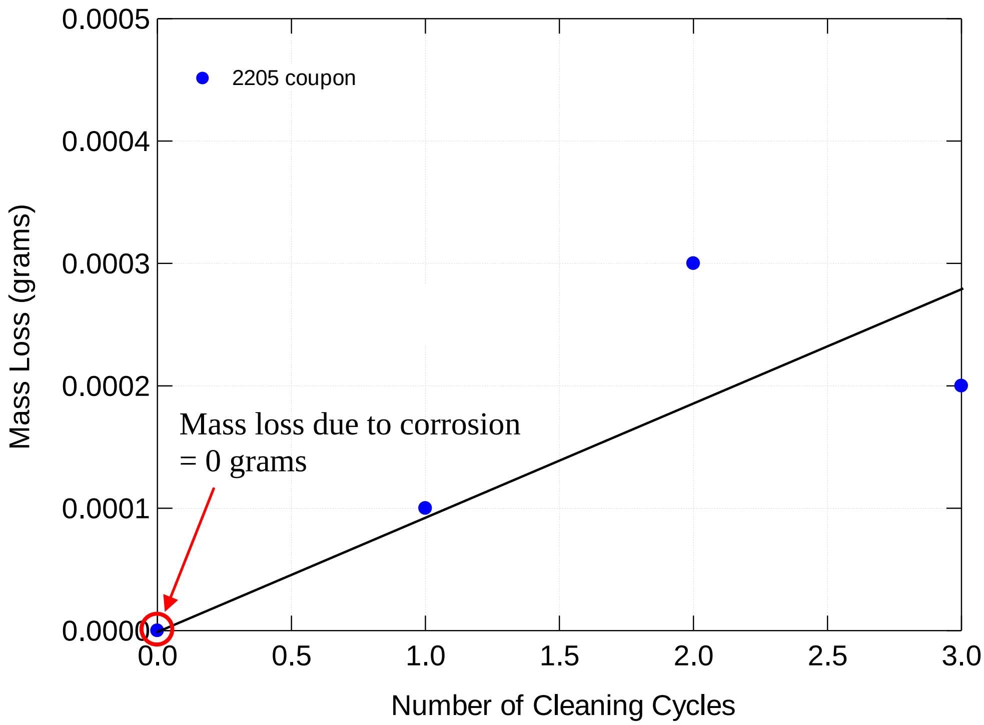


(a)

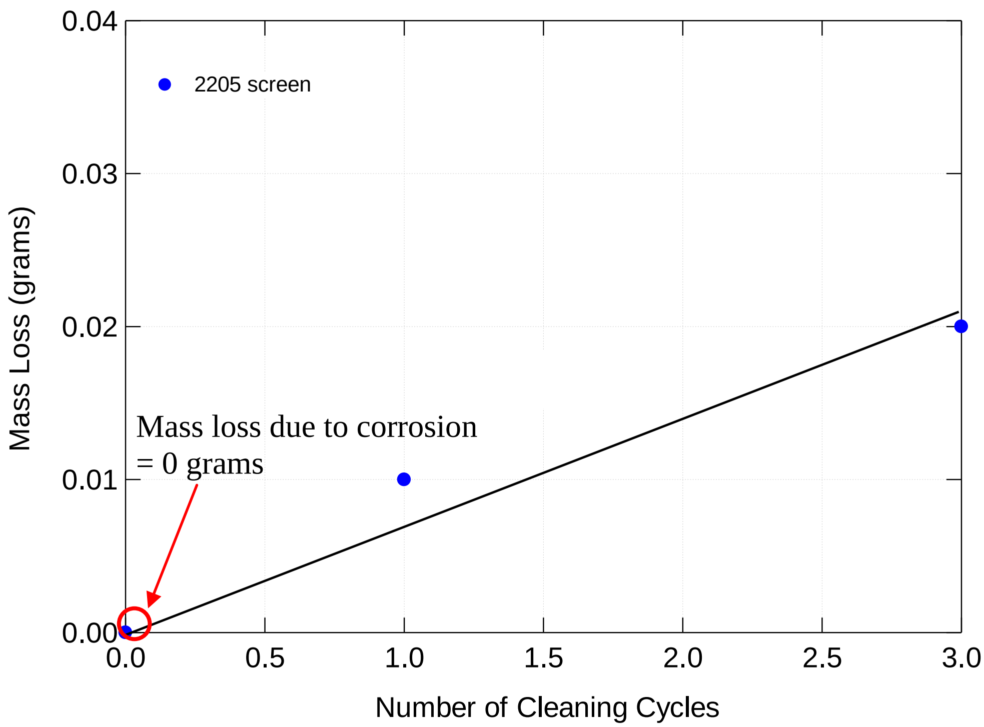


(b)

Figure 34 Mass loss of the duplex 2205 stainless steel (a) coupon 6 and (b) screen 1 during cleaning.

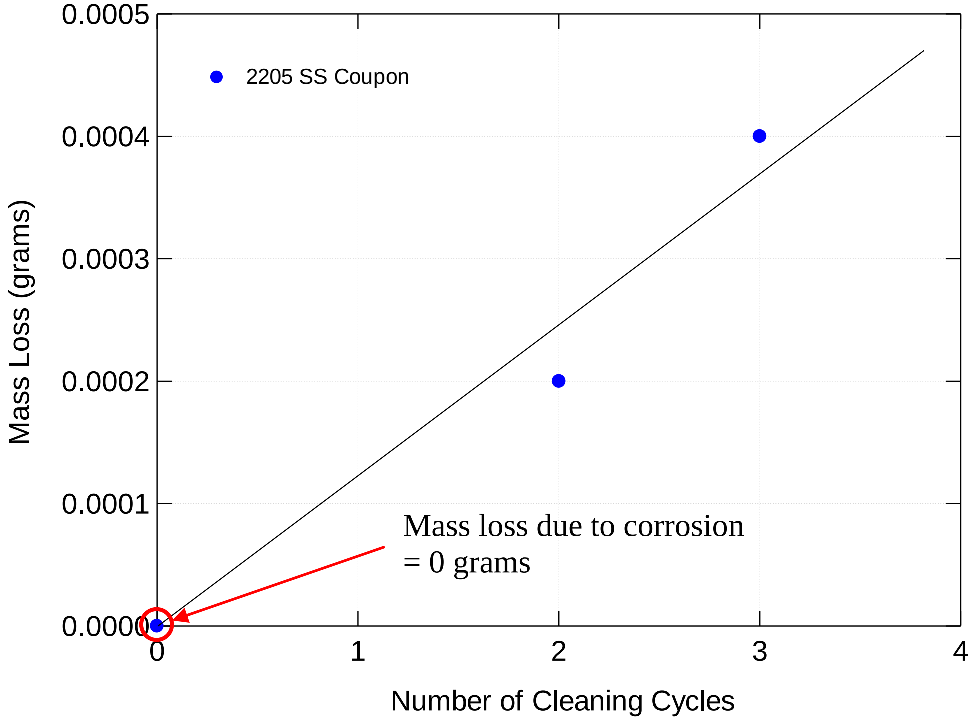


(a)

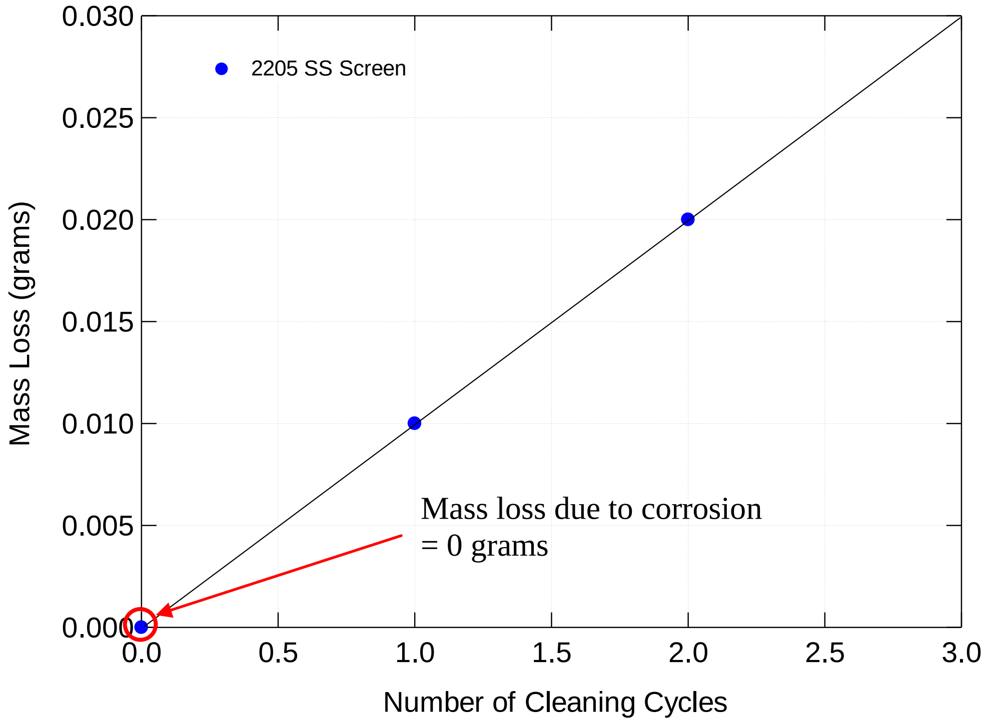


(b)

Figure 35 Mass loss of the duplex 2205 stainless steel (a) coupon 7 and (b) screen 2 during cleaning.

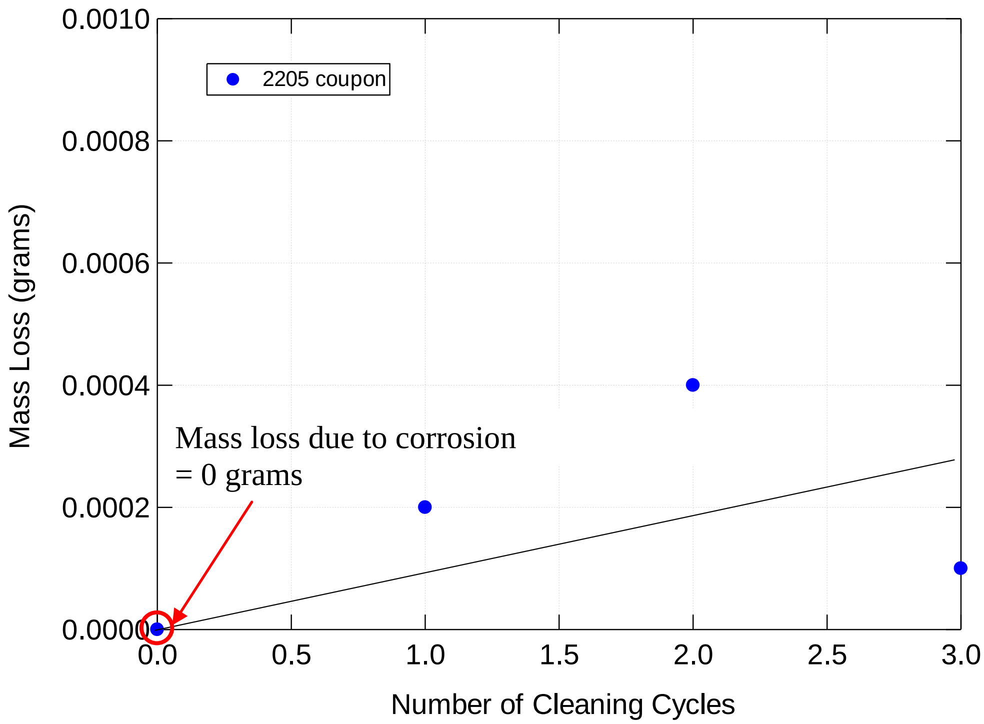


(a)

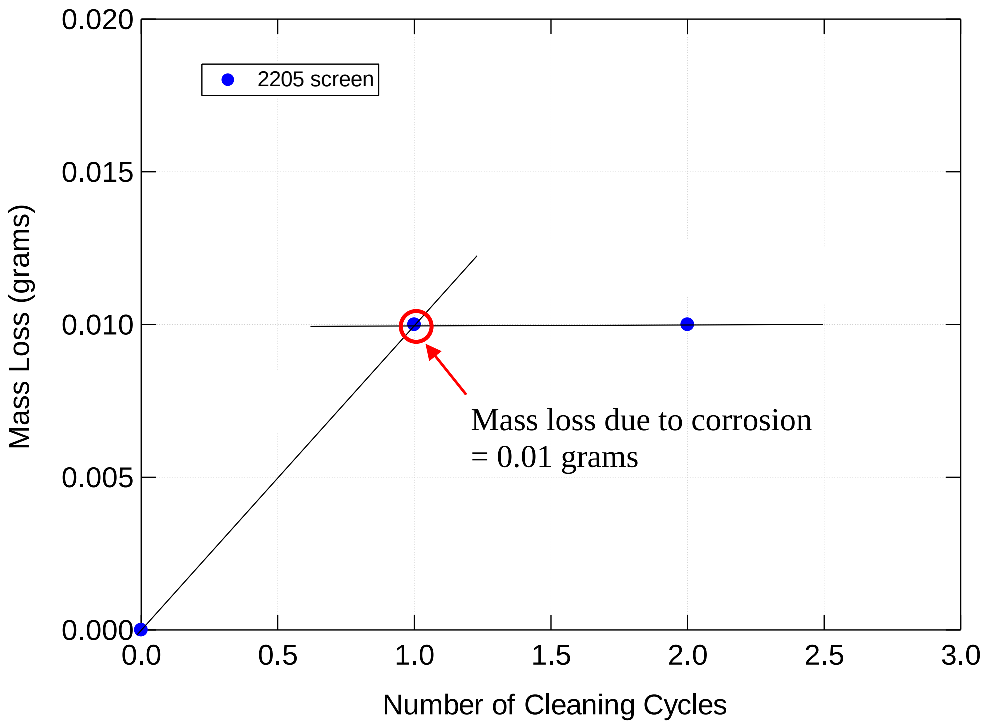


(b)

Figure 36 Mass loss of the duplex 2205 stainless steel (a) coupon 8 and (b) screen 3 during cleaning.

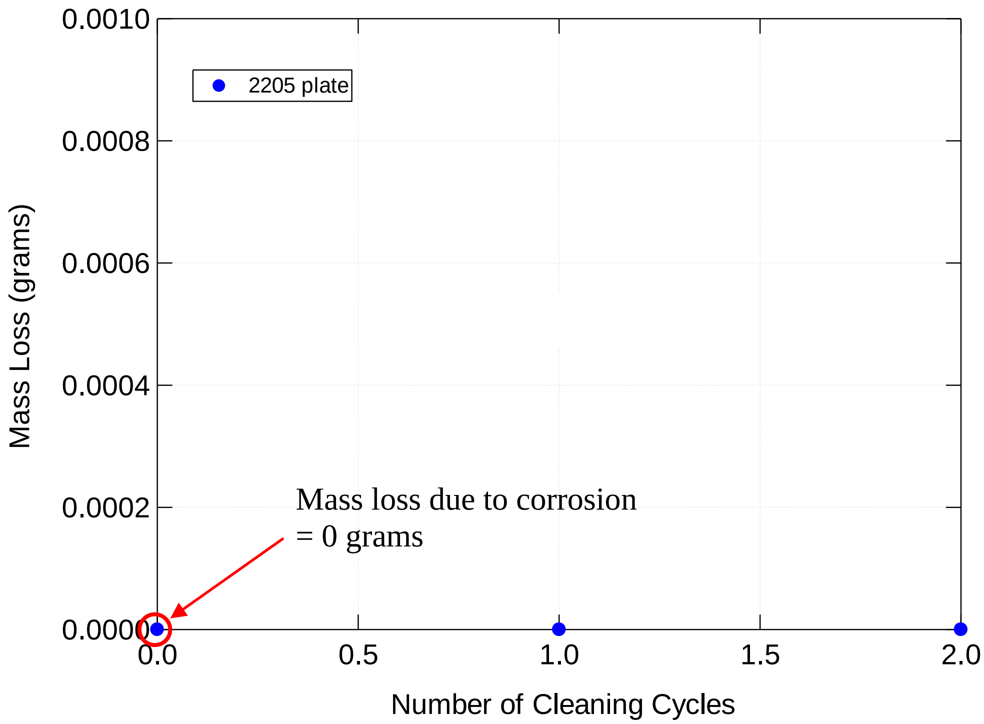


(a)



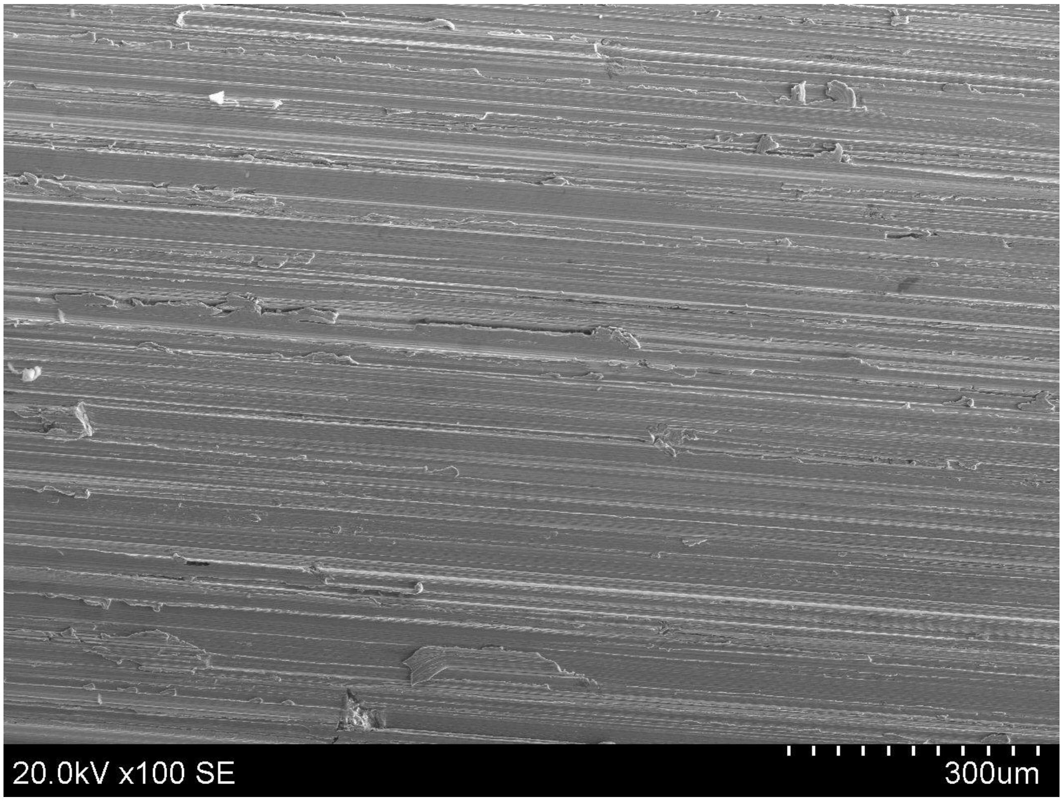
(b)

Figure 37 Mass loss of the duplex 2205 stainless steel (a) coupon 9 and (b) screen 4 during cleaning.

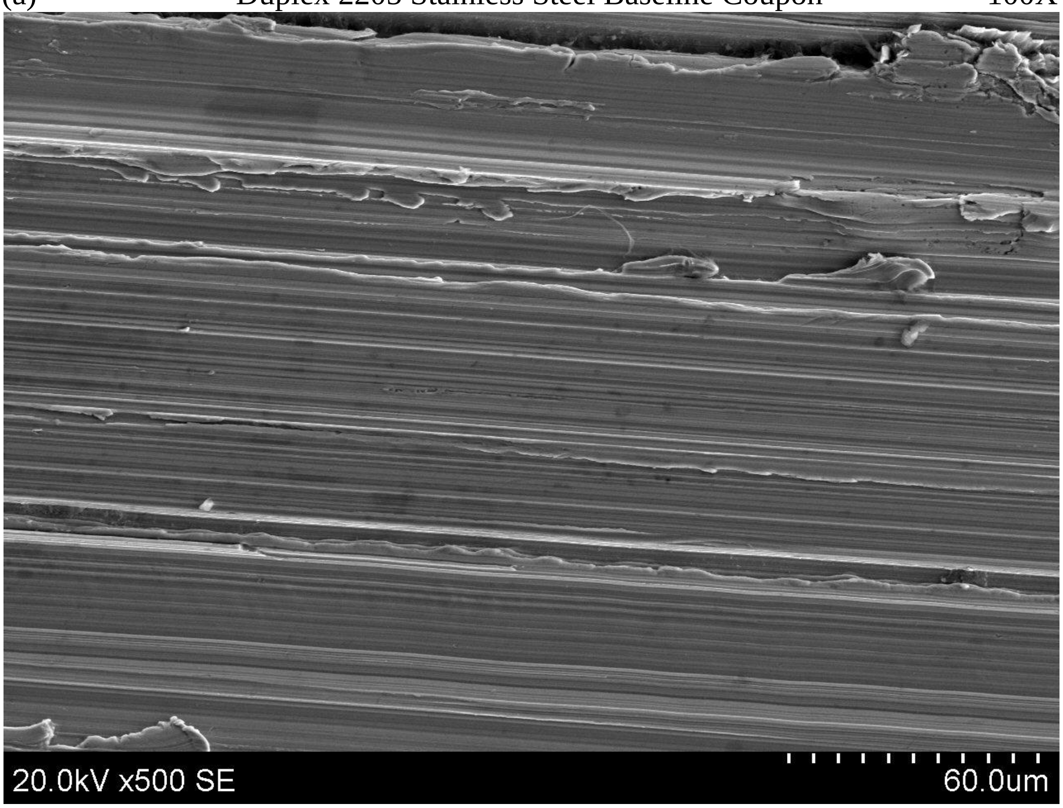


(b)

Figure 38 Mass loss of the duplex 2205 stainless steel plate during cleaning.

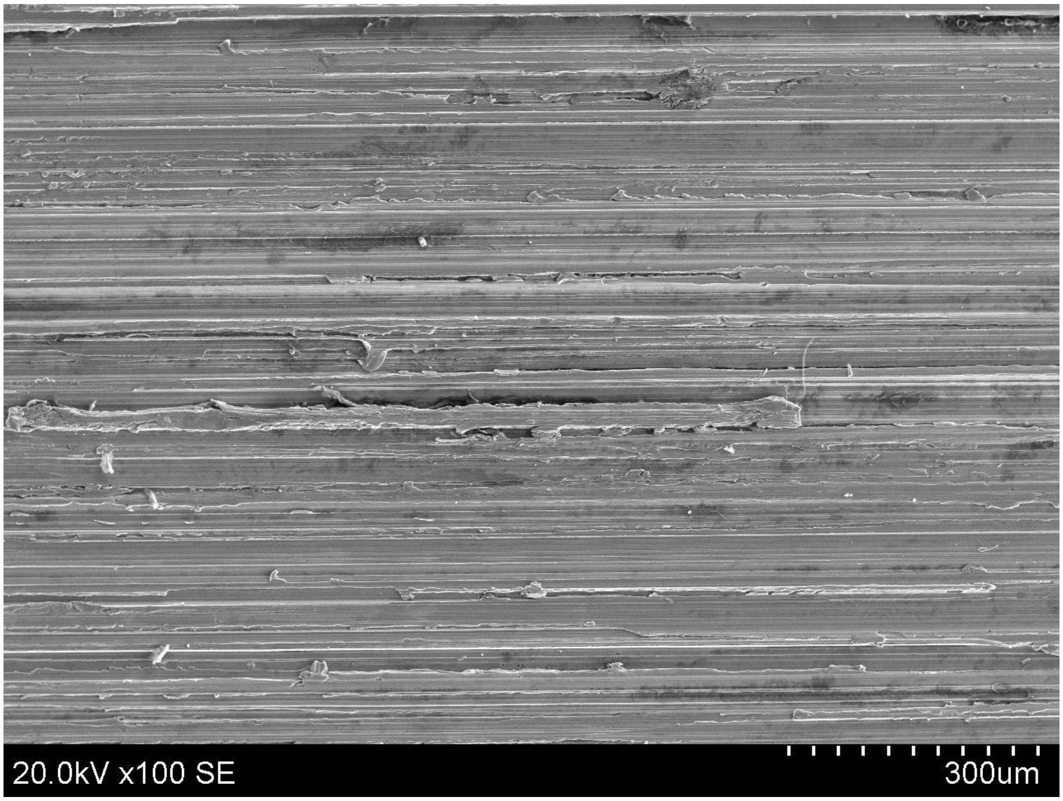


(a) Duplex 2205 Stainless Steel Baseline Coupon 100X

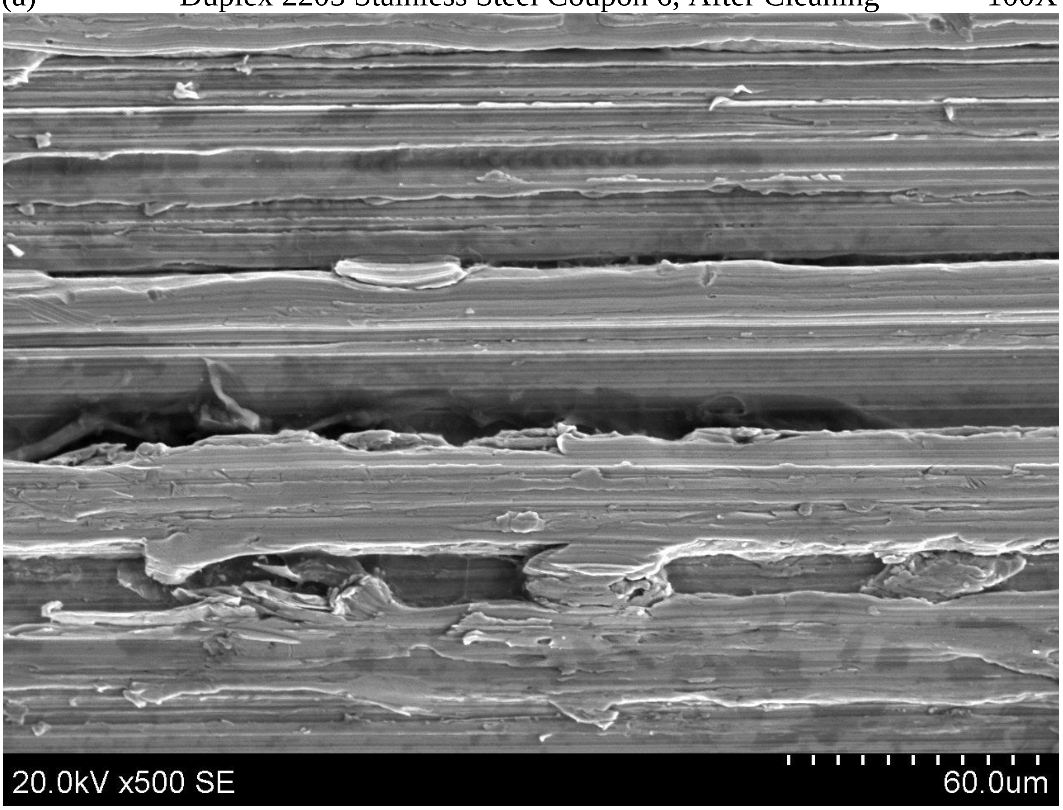


(b) Duplex 2205 Stainless Steel Baseline Coupon 500X

Figure 39 Scanning electron micrographs of the duplex 2205 stainless steel baseline coupon.

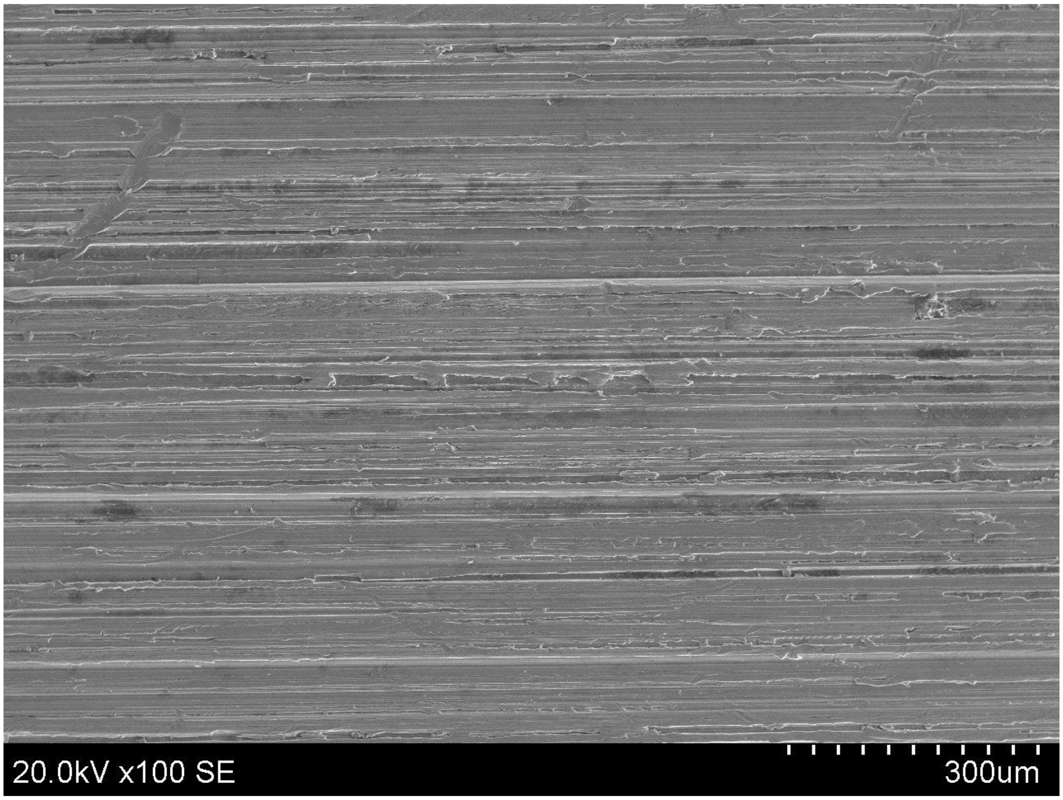


(a) Duplex 2205 Stainless Steel Coupon 6, After Cleaning 100X

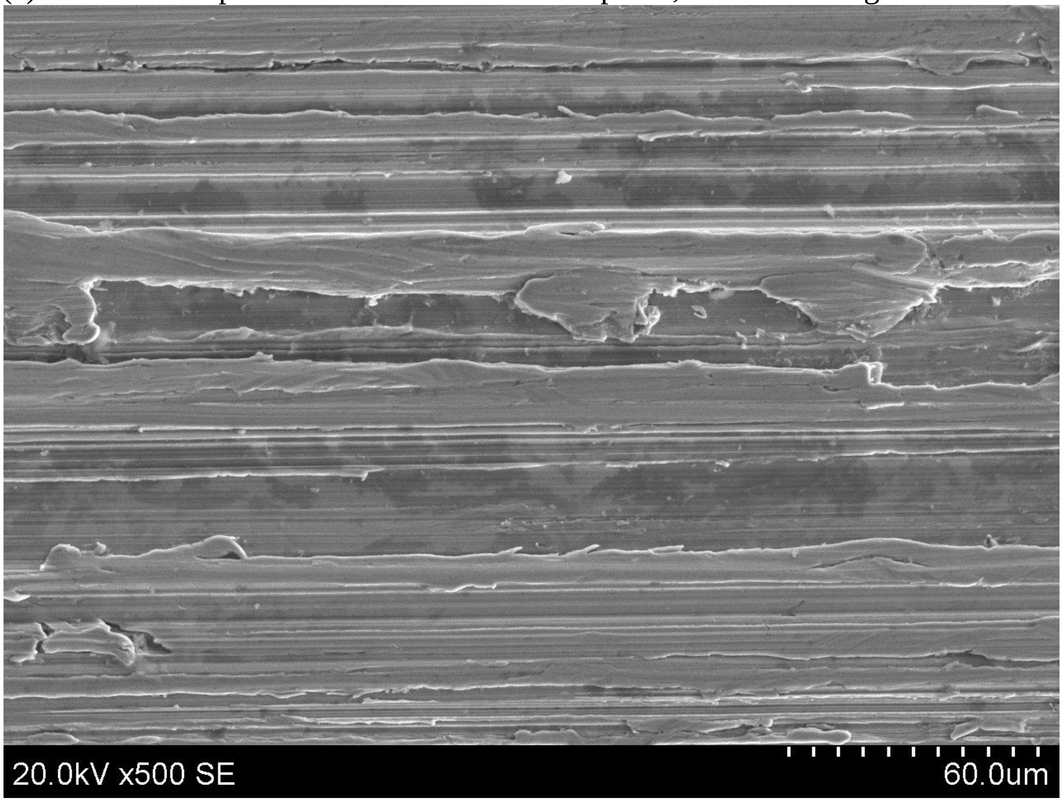


(b) Duplex 2205 Stainless Steel Coupon 6, After Cleaning 500X

Figure 40 Scanning electron micrographs of duplex stainless steel coupon 6 after a 3 month corrosion test, after cleaning.

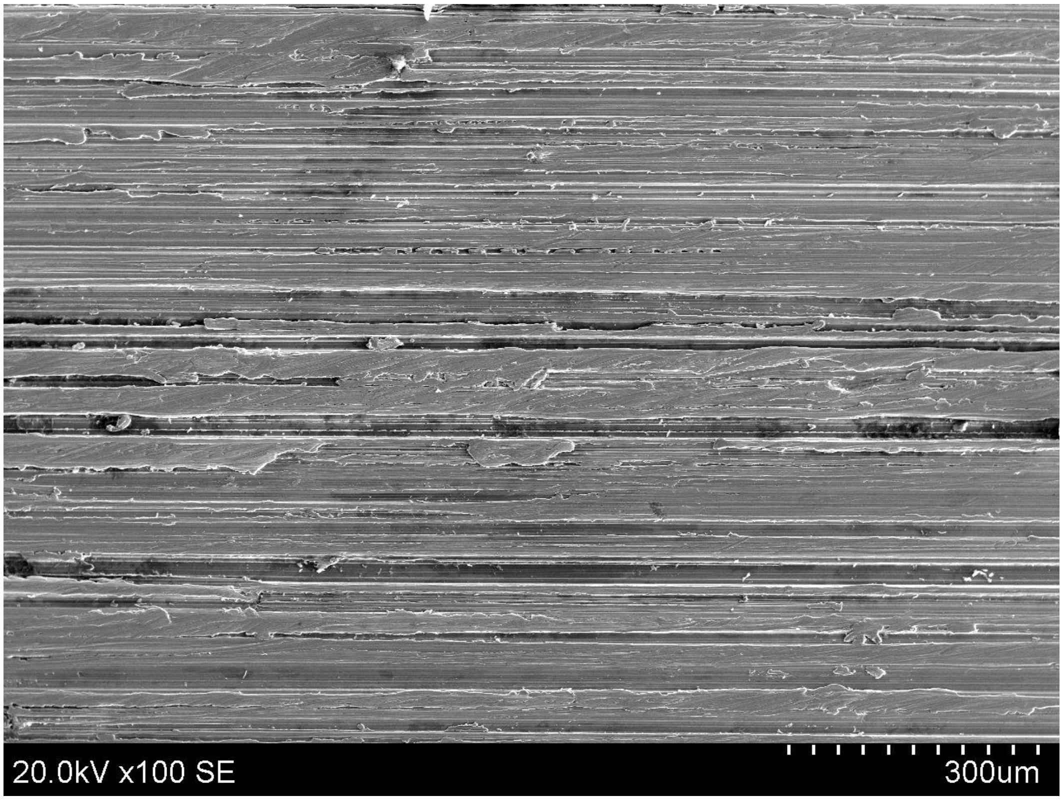


(a) Duplex 2205 Stainless Steel Coupon 7, After Cleaning 100X

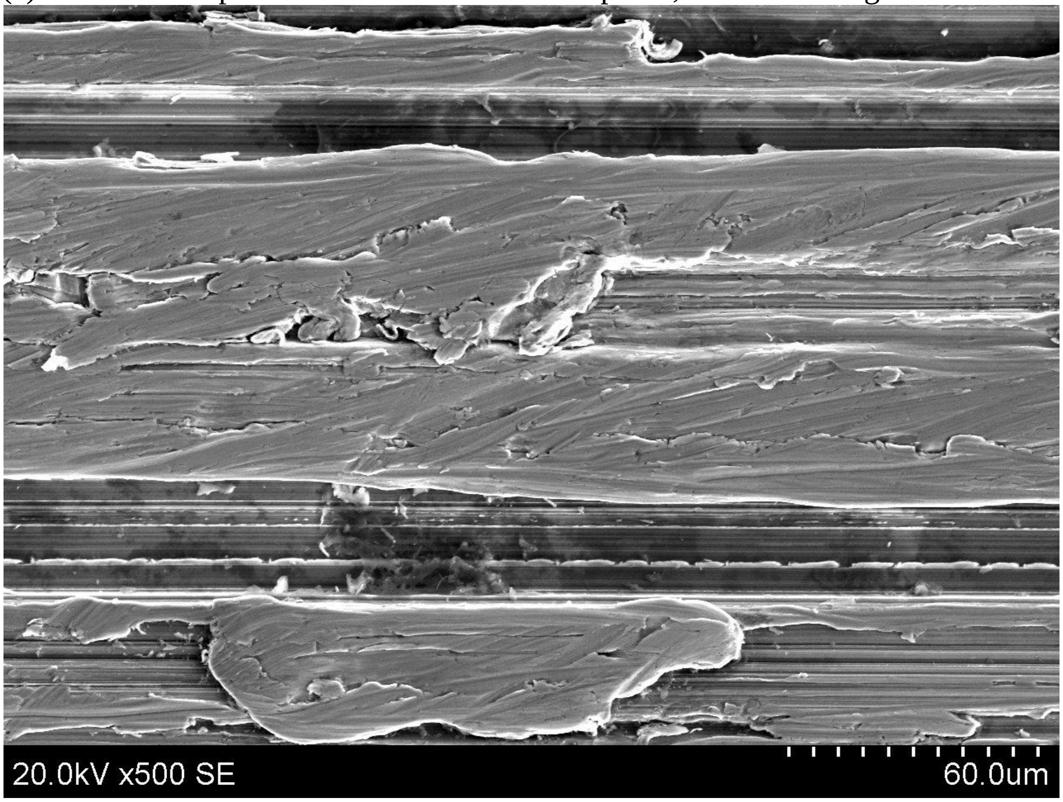


(b) Duplex 2205 Stainless Steel Coupon 7, After Cleaning 500X

Figure 41 Scanning electron micrographs of duplex stainless steel coupon 7 after a 6 month corrosion test, after cleaning.

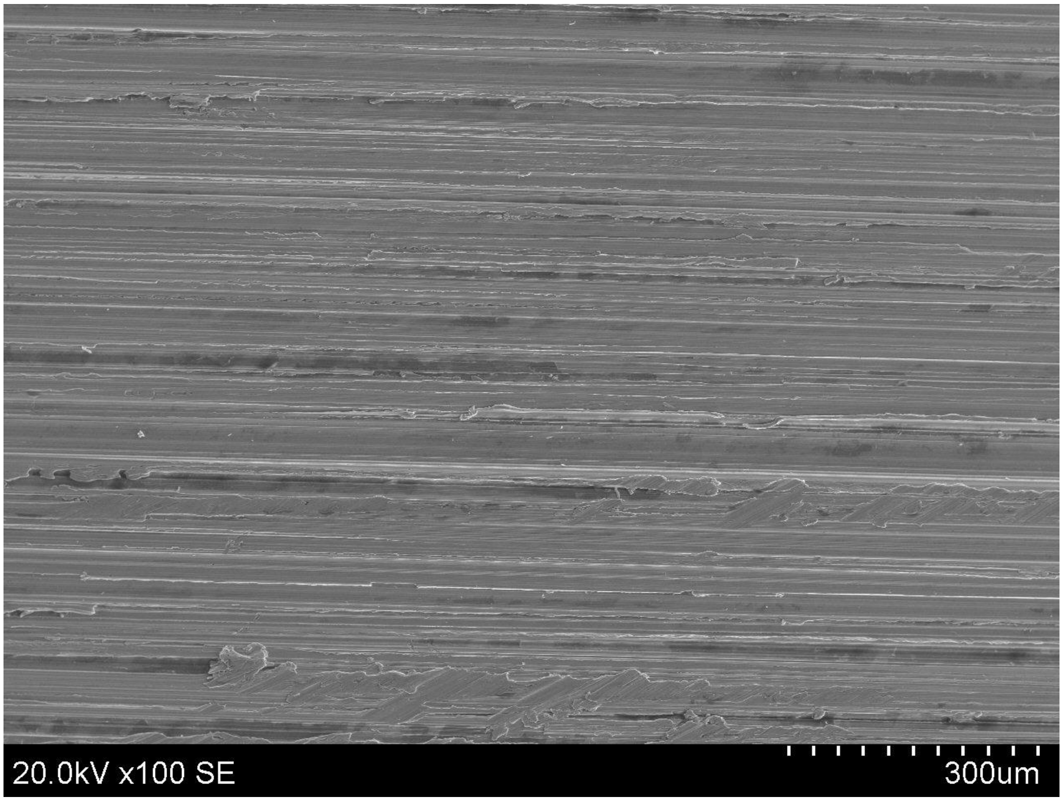


(a) Duplex 2205 Stainless Steel Coupon 8, After Cleaning 100X



(b) Duplex 2205 Stainless Steel Coupon 8, After Cleaning 500X

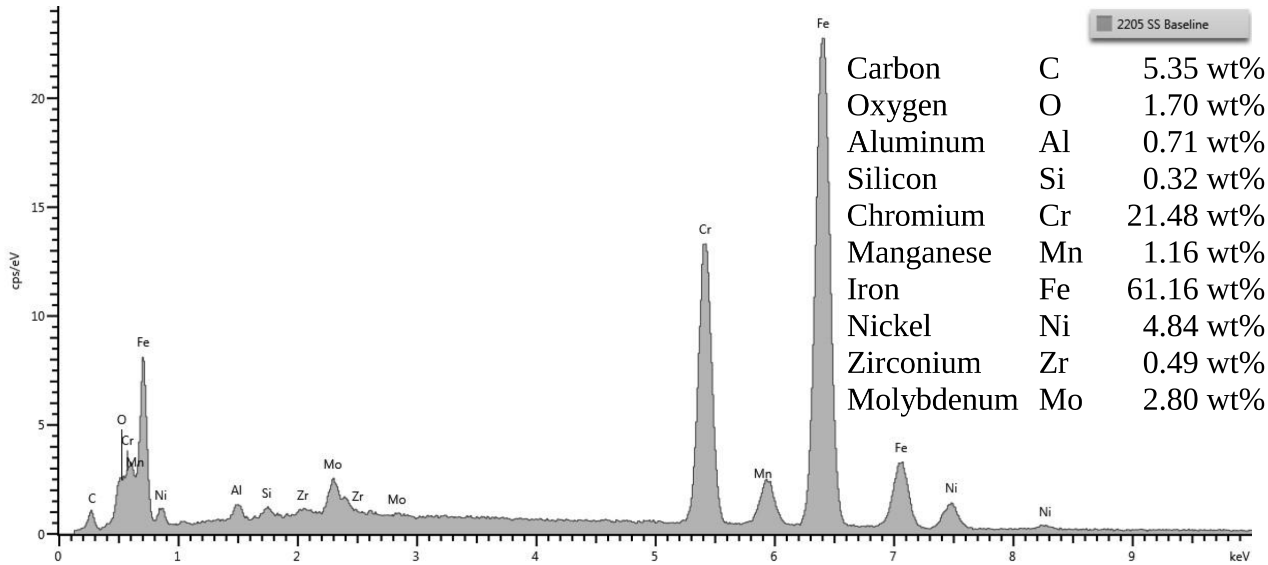
Figure 42 Scanning electron micrographs of duplex stainless steel coupon 8 after a 10 month corrosion test, after cleaning.



(a) Duplex 2205 Stainless Steel Coupon 9, After Cleaning 100X

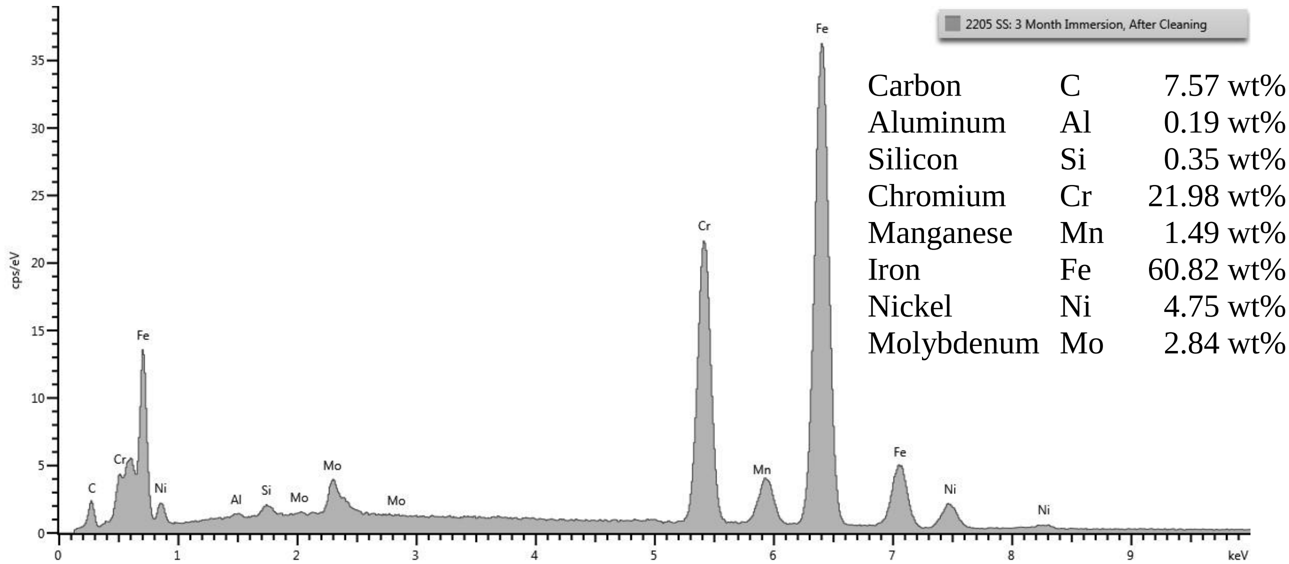
(b) Duplex 2205 Stainless Steel Coupon 9, After Cleaning 500X

Figure 43 Scanning electron micrographs of duplex stainless steel coupon 9 after a 12 month corrosion test, after cleaning.

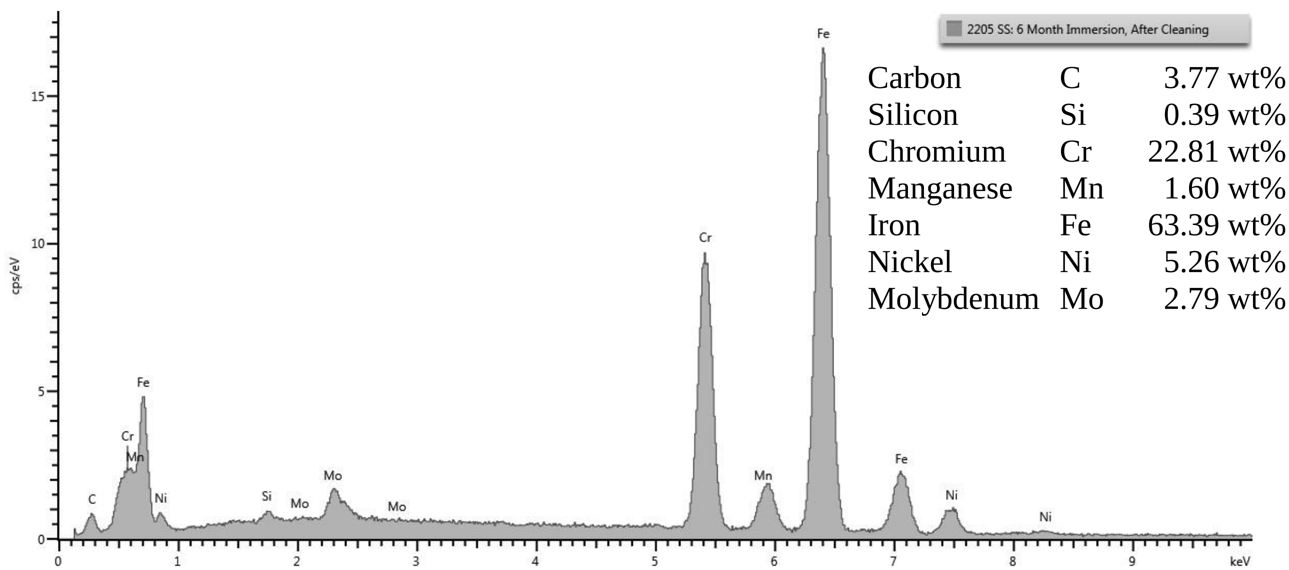


(a) Duplex 2205 Stainless Steel Baseline Coupon

Figure 44 Energy dispersive x-ray spectra of the duplex 2205 stainless steel baseline coupon.

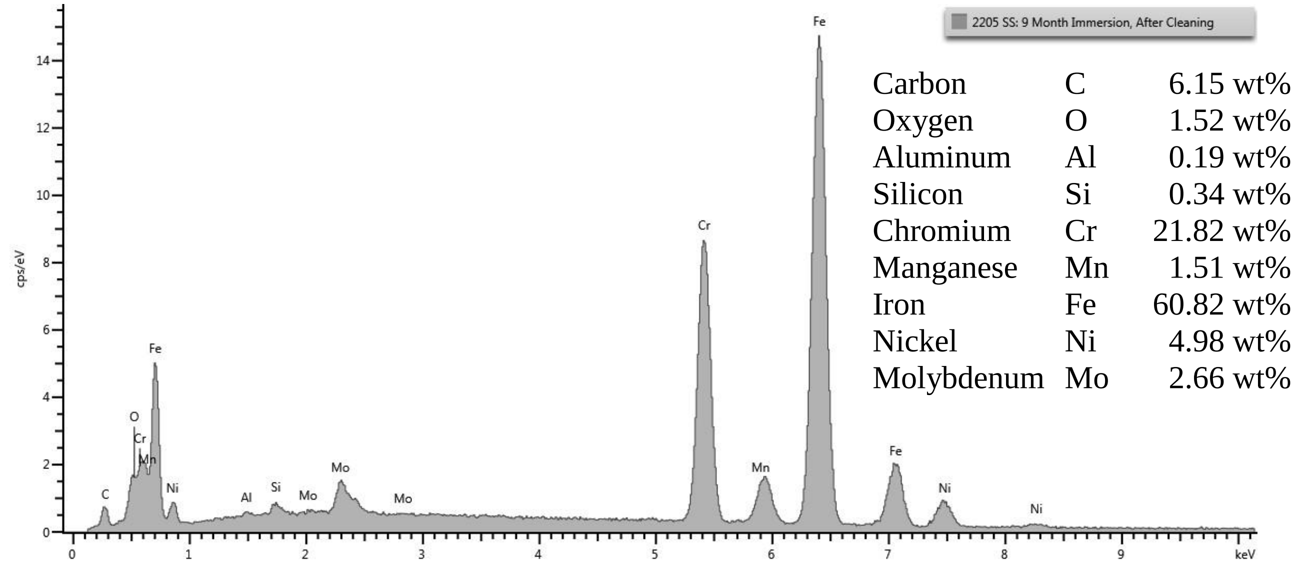


(a) Duplex 2205 Stainless Steel Coupon 6, After Cleaning

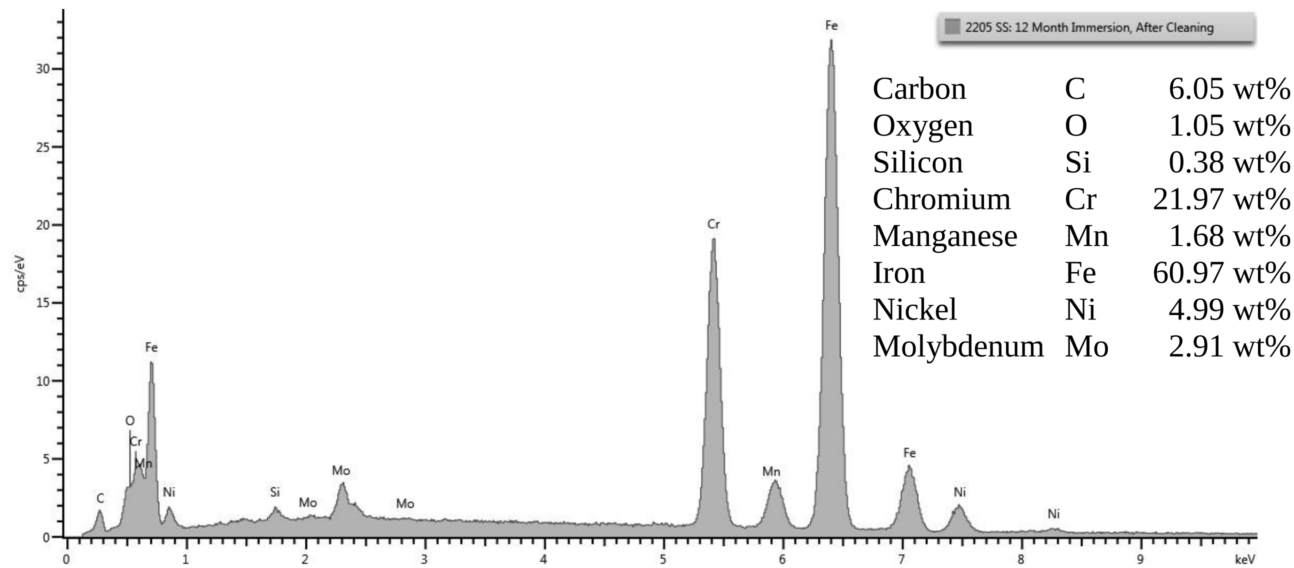


(b) Duplex 2205 Stainless Steel Coupon 7, After Cleaning

Figure 45 Energy dispersive x-ray spectra of (a) coupon 6 after a 3 month corrosion test and (b) coupon 7 after a 6 month corrosion test, after cleaning. Both coupons were not analyzed by energy dispersive x-ray spectroscopy before cleaning due to the marine life on the surface of the coupon.

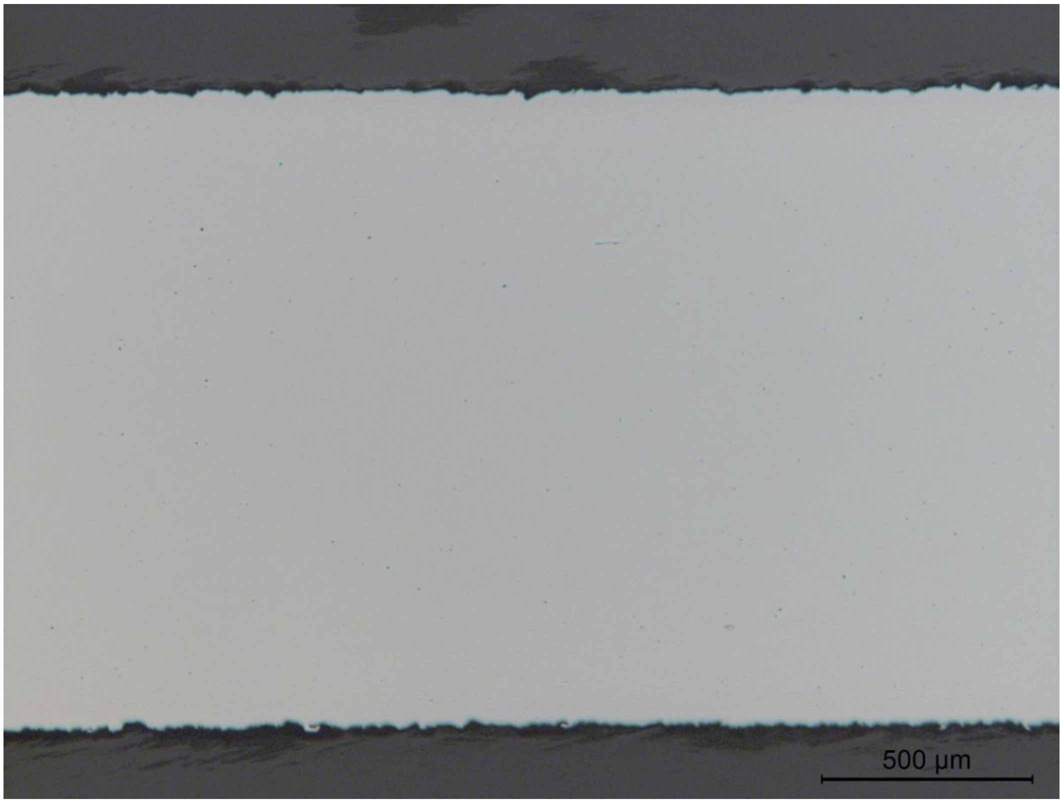


(a) Duplex 2205 Stainless Steel Coupon 8, After Cleaning



(b) Duplex 2205 Stainless Steel Coupon 9, After Cleaning

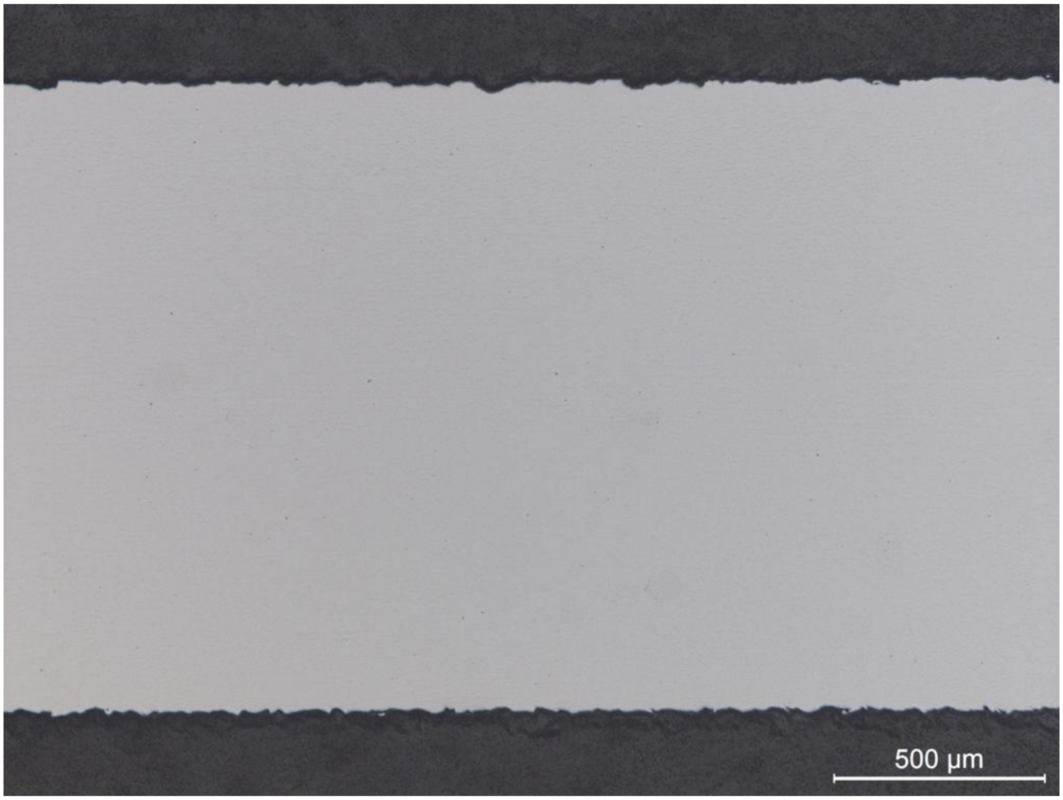
Figure 46 Energy dispersive x-ray spectra of (a) coupon 8 after a 10 month corrosion test and (b) coupon 9 after a 12 month corrosion test, after cleaning. Both coupons were not analyzed by energy dispersive x-ray spectroscopy before cleaning due to the marine life on the surface of the coupon.



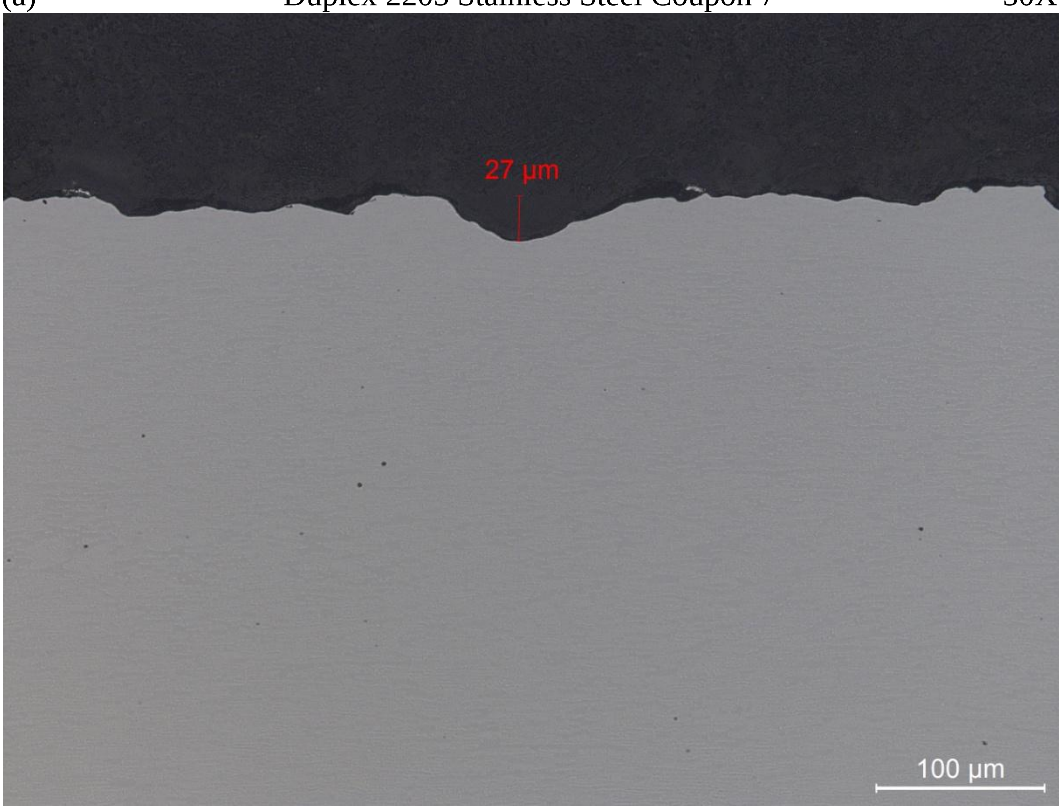
(a) Duplex 2205 Stainless Steel Coupon 6 50X

(b) Duplex 2205 Stainless Steel Coupon 6 200X

Figure 47 Optical micrographs of duplex stainless steel coupon 6.

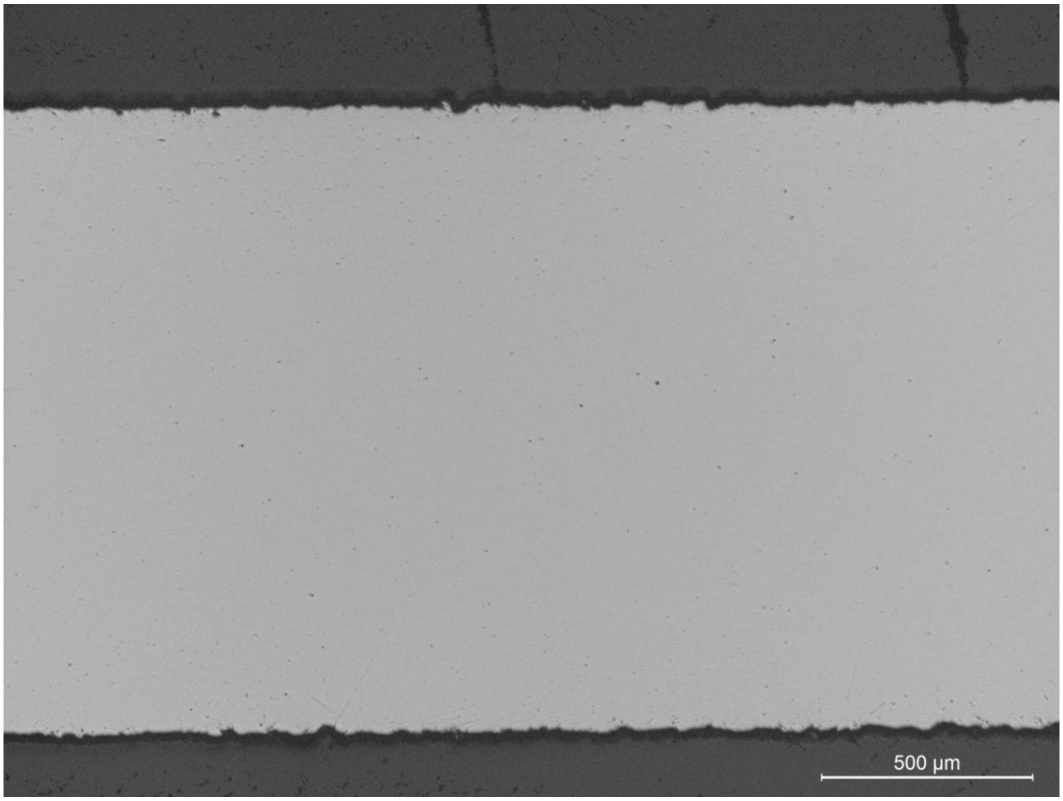


(a) Duplex 2205 Stainless Steel Coupon 7 50X

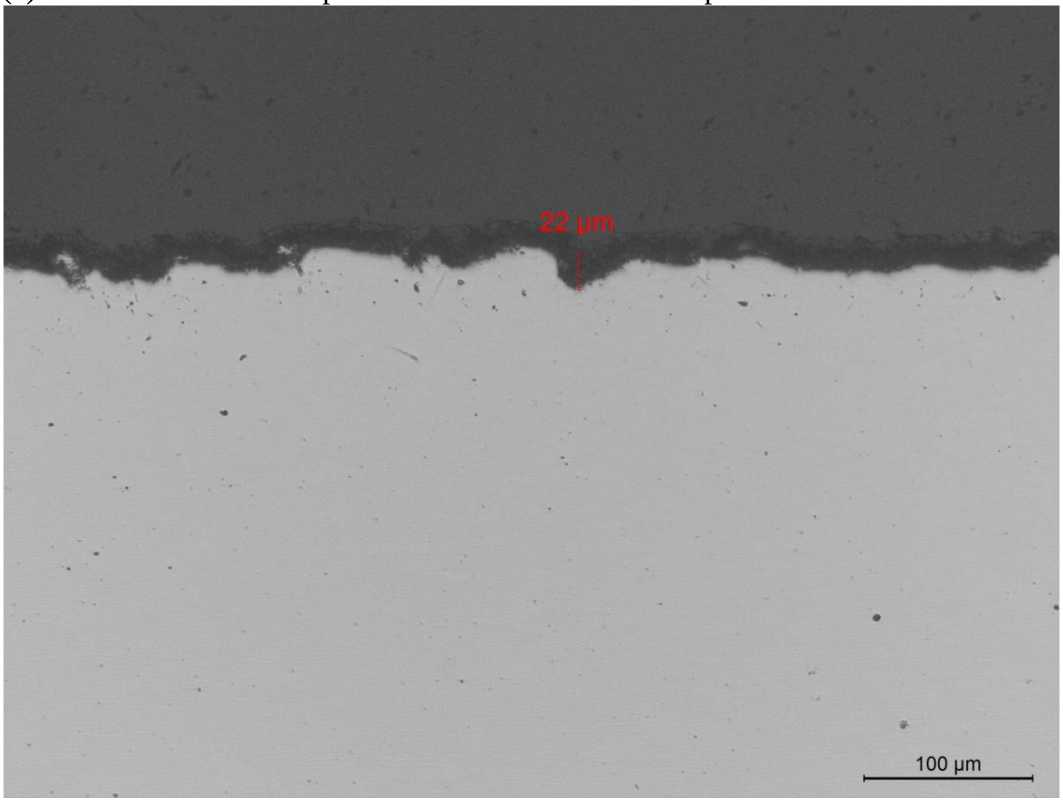


(b) Duplex 2205 Stainless Steel Coupon 7 200X

Figure 48 Optical micrographs of duplex stainless steel coupon 7.

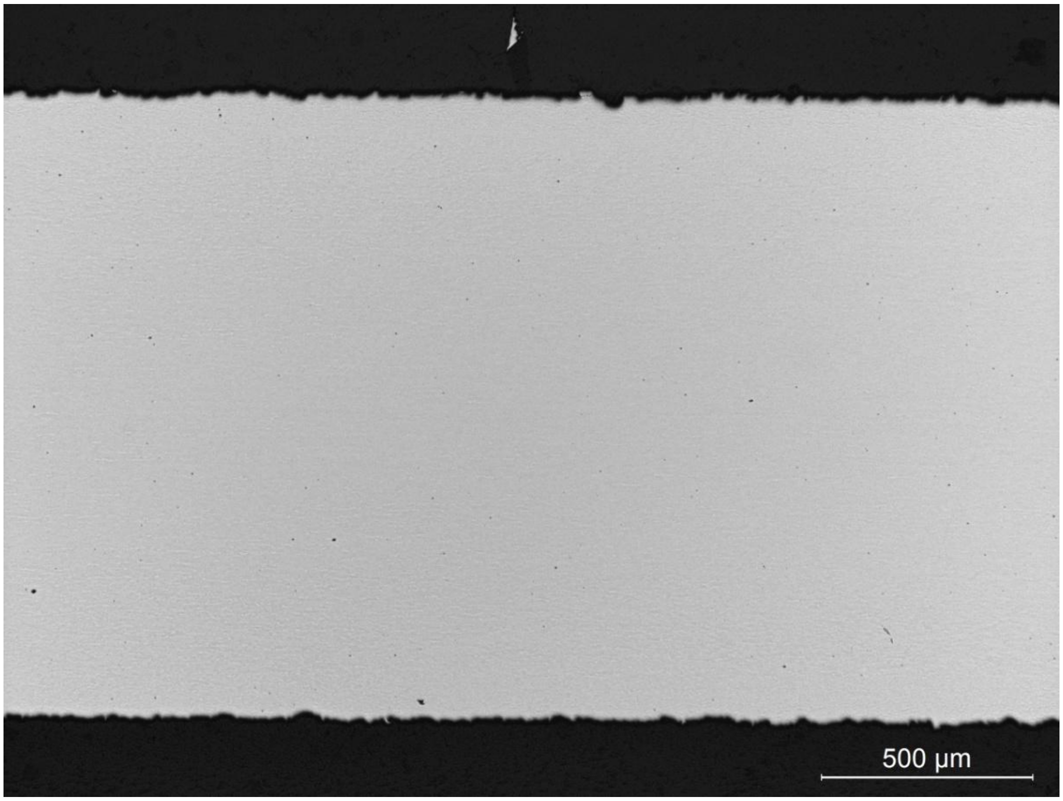


(a) Duplex 2205 Stainless Steel Coupon 8 50X

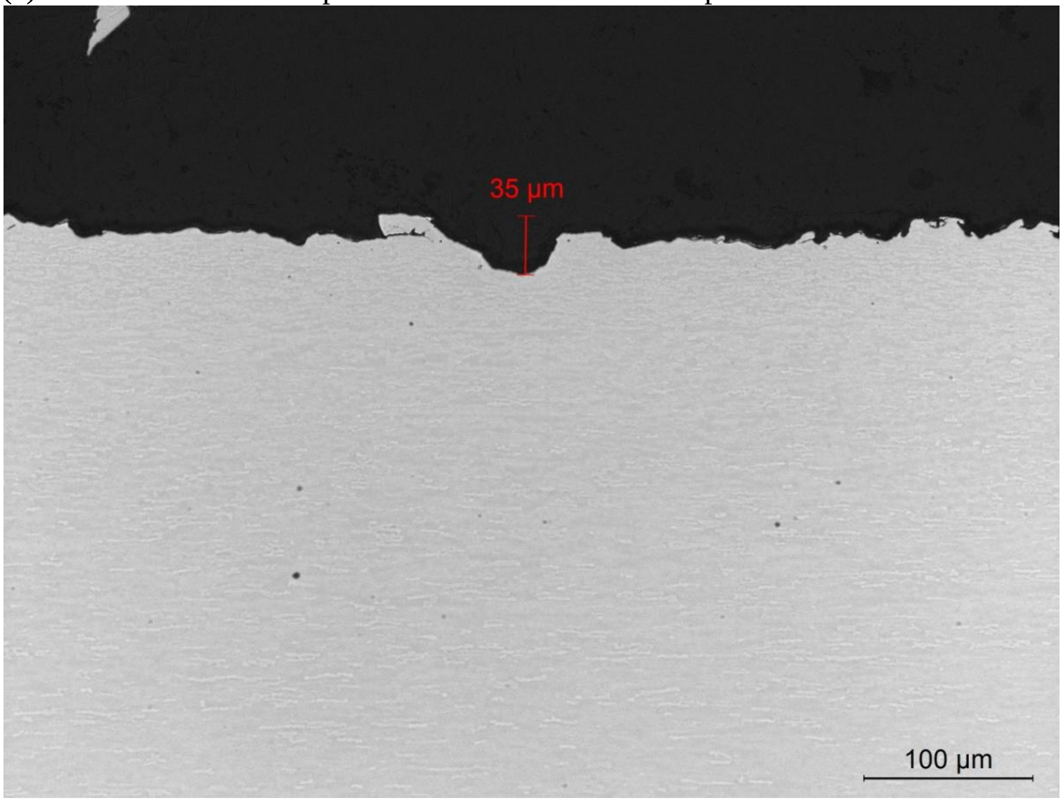


(b) Duplex 2205 Stainless Steel Coupon 8 200X

Figure 49 Optical micrographs of duplex stainless steel coupon 8.



(a) Duplex 2205 Stainless Steel Coupon 9 50X



(b) Duplex 2205 Stainless Steel Coupon 9 200X

Figure 50 Optical micrographs of duplex stainless steel coupon 9.

Report No. 5005.0361A **July 17, 2015**

CORROSION EVALUATION OF 2205 DUPLEX STAINLESS STEEL COUPONS AND SCREENS WITH ANTI-BIOFOULING COATING

Customer Authorization: Verbal

Report To: V & A Engineering
Attn: Manuel Najar
155 Grand Avenue, Suite 700
Oakland, CA 94612

1.0 INTRODUCTION

Five coupons, five wedge wire screens, and one plate of 2205 duplex stainless steel with a bio-fouling coating were submitted by V&A Engineering for corrosion evaluation. The coupons were 1-inch by 3-inches by ¼-inch thick. The wedge wire screens were 4-inches by 4-inches by 1-inch tall with 2 mm spacing. The plate was 4-inches by 4-inches by 1/8-inch thick.

Four coupons, four screens, and one plate were to be placed in seawater for a period up to one year. After every 3 month interval, one coupon and one screen were to be removed from the test system and examined for corrosion. After 12 months, the plate was removed from the test system and examined for corrosion. The purpose of this evaluation was to document the samples in the baseline as-received condition, then again after 3, 6, 10, and 12 months of water exposure, record any loss in mass, examine for any pitting corrosion, and estimate the corrosion rate.

The samples were evaluated by the following laboratory procedures:

1) Visual examination and weighing
2) Cleaning per ASTM G1[1]
3) Scanning electron microscopy
4) Metallography

The results of the evaluation showed minimal mass loss and corrosion for the coupon and screen after 3, 6, 10, and 12 months of corrosion testing. The coupons, after 3, 6, 10, and 12 months of corrosion testing, had a corrosion rate of 0.002, 0.002, 0.001 and 0.001 millimeters per year, respectively. The screens, after 3, 6, 10, and 12 months of corrosion testing, had a corrosion rate of 0.002, 0.002, 0.001 and 0.001 millimeters per year, respectively. The plate, after 12 months of corrosion testing, had a corrosion rate of 0.001 millimeters per year. The coupons and screens lost more material over time, but the corrosion rate decreased as the exposure time increased.

[1] G1: Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

2.0 EVALUATION[2]

2.1 Visual Examination

The sample identifications for the coupons and wedge wire screens and their corresponding immersion times are shown in Table 1. The coupons had identification numbers stamped on the front face by V&A Engineering. A number of notches, corresponding to the sample number, were sawed at the edge of each screen for identification after the corrosion test. The weights of the samples were recorded. Coupons 6 – 9 and screens 1 – 5 were sent back to V&A for corrosion testing. Coupon 10 was the baseline sample and documented by photography, optical stereoscopy and scanning electron microscopy for comparison to the tested samples. Screen 5 was documented as a baseline by photography and optical stereoscopy, and then sent to V&A for testing.

Photographs of the baseline coupon are shown in Figure 1. Photographs of coupons 1 – 4, after 3, 6, 10, and 12 months of corrosion testing, are shown in Figures 2 – 5. A photograph of the baseline screen is shown in Figure 6. Photographs of screens 1 – 4, after 3, 6, 10, and 12 months of corrosion testing, are shown in Figures 7 – 10. A photograph of the baseline plate is shown in Figure 11 and a photograph of the plate after 12 months of corrosion testing is shown in Figure 12.

2.2 Cleaning

The coupon and screen were cleaned with solution C.7.1 per ASTM G1.[3] One cleaning cycle was approximately 5 minutes. After each cleaning cycle, the samples were rinsed in water, dried, and weighed. The cleaning and weighing cycle was completed five times for the coupon and screen. The weights of the samples as-received, after corrosion testing but before cleaning, and after each cleaning cycle are presented in Table 2.

Optical macrographs of the baseline coupon, screen, and plate are shown in Figures 13, 22, and 31, respectively. Representative optical macrographs of coupons 1 – 4 after 3, 6, 10, and 12 months of corrosion testing, before and after cleaning, are shown in Figures 14 – 21. Representative optical macrographs of screens 1 – 4 after 3, 6, 10, and 12 months of corrosion testing, before and after cleaning, are shown in Figures 23 – 30. Representative optical macrographs of the plate after 12 months of corrosion testing, before and after cleaning, are shown in Figures 32 – 33.

The mass loss versus the number of cleaning cycles was plotted, shown in Figure 34 – 38. The equations for best fit lines AB and BC, calculated using IGOR Pro, are listed in Table 3. Point B, indicated by the red circle in each plot, corresponds to the mass loss due to corrosion during the cleaning process for each sample. This mass loss was subtracted from the weight of the sample before cleaning and from the weight of the sample as-received to determine the total mass loss from corrosion. The corrosion rate of each sample was determined by the formula specified in Section 8.1 of ASTM G1:

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[2] The magnifications of the optical and scanning electron micrographs in this report are approximate and should not be used as a basis for dimensional analyses unless otherwise indicated.
[3] 100 mL nitric acid + 900 ml reagent water.

$$Corrosion\ Rate = \frac{K\ x\ W}{A\ x\ T\ x\ D}$$

where K = 8.76 x 10^4, T = time of exposure in hours, A = area in cm^2, W = mass loss in grams, and D = density in g/cm^3. The total mass loss from corrosion and the calculated corrosion rate of each sample is shown in Table 4.

2.3 Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy

The baseline coupon and coupons 1 – 4 were examined with a scanning electron microscope. Representative scanning electron micrographs of the baseline coupon are shown in Figure 39. Representative scanning electron micrographs of coupons 1 – 4, before and after cleaning, are shown in Figures 40 – 47. Energy dispersive x-ray spectra of the baseline coupon and coupons 1 – 4, before and after cleaning, are shown in Figures 48 – 52.

2.4 Metallography

Cross sections were taken from the coupon and prepared for a metallographic examination. Optical micrographs of the surface for coupons 1 – 4 are shown in Figures 53 – 56. Small, shallow pits were observed in coupons 1, 3, and 4, the deepest of which measured 33 µm. Sharp narrow pits were observed in coupon 2, the deepest measured 34 µm.

3.0 DISCUSSION

The coupons and screens showed minimal mass loss and pitting overall after 3, 6, 10, and 12 months of corrosion testing. The coupons and screens had more material loss over time but had a decreasing consistent corrosion rate over the duration of the corrosion test.

4.0 CONCLUSIONS[4]

The following conclusions are based upon the submitted samples and the evidence gathered:

1. The coupon, after 3, 6, 10, and 12 months of corrosion testing, had a mass loss of 0.023 grams, 0.031 grams, 0.035 grams, and 0.046 grams, respectively. The coupons had more mass loss over the duration of the corrosion test.

2. The coupons, after 3, 6, 10, and 12 months of corrosion testing, had a corrosion rate of 0.002 mm / year, 0.002 mm / year, 0.001 mm / year, and 0.001 mm / year, respectively. The coupons had a decreasing corrosion rate over the duration of the corrosion test.

3. The screens, after 3, 6, 10, and 12 months of corrosion testing, had a mass loss of 0.25 grams, 0.43 grams, 0.60 grams, and 0.60 grams, respectively. The screens had more mass loss over the duration of the corrosion test.

4. The screens, after 3, 6, 10, and 12 months of corrosion testing, had a corrosion rate of 0.002 mm / year, 0.002 mm / year, 0.001 mm / year, and 0.001 mm / year, respectively. The screens had a decreasing corrosion rate over the duration of the corrosion test.

5. The plate, after 12 months of corrosion testing, had a mass loss of 0.21 grams and a corrosion rate of 0.001 mm / year.

Prepared by:	Reviewed by:
Norman Yuen	Audrey A. Fasching
Norman Yuen Materials Engineer	Audrey A. Fasching, Ph.D., P.E. Senior Materials Engineer

[4] The conclusions in this report are based upon the available information and evidence provided by the client and gathered by Anamet, within the scope of work authorized by the client, and they are hereby presented by Anamet to a reasonable degree of engineering and scientific certainty. Anamet reserves the right to amend or supplement its conclusions or opinions presented in this report should additional data or information become available, or further work be approved by the client.

Table 1
Sample Identifications

<table>
<tr><th colspan="2">Description</th><th rowspan="2">V&A Engineering Identification (As-Received)</th><th rowspan="2">Anamet Identification (in report)</th><th rowspan="2">Notes</th></tr>
<tr><th>Alloy</th><th>Part</th></tr>
<tr><td rowspan="11">2205 Duplex Stainless Steel with anti-biofouling coating</td><td>Flat Plate
4-inch x 4-inch x 1/8-inch</td><td>None</td><td>Plate</td><td>None</td></tr>
<tr><td rowspan="5">Coupon
1-inch x 3-inch x 1/8-inch with autogenous weld bead</td><td>2205 SS 1</td><td>Coupon 1*</td><td>3 Month Immersion</td></tr>
<tr><td>2205 SS 2</td><td>Coupon 2*</td><td>6 Month Immersion</td></tr>
<tr><td>2205 SS 3</td><td>Coupon 3*</td><td>10 Month Immersion</td></tr>
<tr><td>2205 SS 4</td><td>Coupon 4*</td><td>12 Month Immersion</td></tr>
<tr><td>2205 SS 5</td><td>Coupon 5</td><td>Baseline Sample (no exposure)</td></tr>
<tr><td rowspan="5">Wedge Wire Screen
4-inch x 4-inch x 1-inch with 2 mm spacing</td><td>None</td><td>Screen 1*</td><td>3 Month Immersion</td></tr>
<tr><td>None</td><td>Screen 2*</td><td>6 Month Immersion</td></tr>
<tr><td>None</td><td>Screen 3*</td><td>10 Month Immersion</td></tr>
<tr><td>None</td><td>Screen 4*</td><td>12 Month Immersion</td></tr>
<tr><td>None</td><td>Screen 5*</td><td>12 Month Immersion</td></tr>
</table>

* Cable ties were attached to each sample to designate sample identification. The number of cable ties per sample corresponded to the sample number.

Table 2
Sample Weights

Sample	Baseline Measurement	Measurements after 3 Months Corrosion Testing				
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)
Coupon 1	24.1892	24.1683	24.1668	24.1666	24.1665	-
Screen 1	339.91	340.03	339.70	339.66	339.63	339.63

Sample	Baseline Measurement	Measurements after 6 Months Corrosion Testing				
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)
Coupon 2	24.2019	24.1714	24.1711	24.1701	24.1694	24.1691
Screen 2	341.67	341.34	341.24	341.24	341.25	-

Sample	Baseline Measurement	Measurements after 10 Months Corrosion Testing				
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)
Coupon 3	24.2035	24.1681	24.1675	24.1668	24.1661	-
Screen 3	338.80	338.24	338.20	338.20	338.21	-

Sample	Baseline Measurement	Measurements after 12 Months Corrosion Testing				
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)
Coupon 4	24.5101	24.4673	24.4667	24.4643	24.4634	24.4633
Screen 4	337.91	337.78	337.30	337.31	337.30	-
Plate	250.11	249.91	249.90	249.90	249.91	-

Table 3
Equations of Lines AB and BC for Corrosion Testing Samples

Sample	Line AB	Line BC	Point B (Approximate Mass Loss from Corrosion During Cleaning)
Coupon 1	y = 0.0015x	y = 0.0001x + 0.0015	0.0016 grams
Coupon 2	N/A	y = 0.0006x	0 grams
Coupon 3	N/A	y = 0.0006x	0 grams
Coupon 4	y = 0.001x	y = 0.004	0.004 grams
Screen 1	y = 0.33x	y = 0.02x + 0.35	0.37 grams
Screen 2	y = 0.10x	y = 0.10	0.10 grams
Screen 3	y = 0.02x	y = 0.04	0.04 grams
Screen 4	y = 0.49x	y = 0.01x + 0.460	0.47 grams
Plate	y = 0.01x	y = 0.01	0.01 grams

Table 4
Total Mass Loss from Corrosion and Corrosion Rate

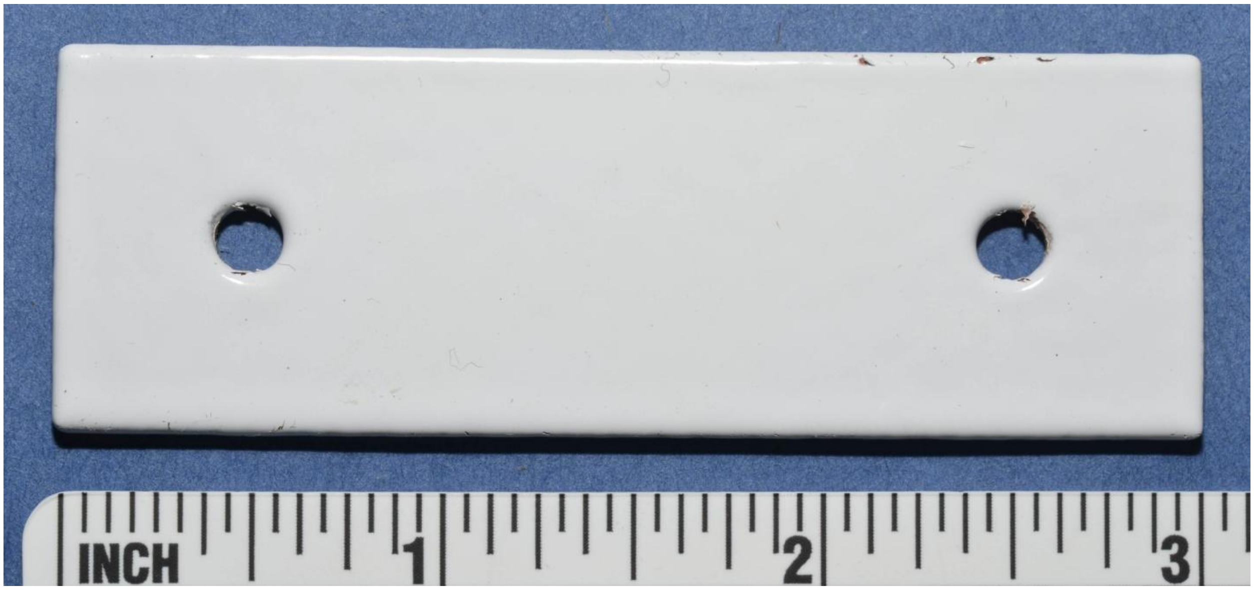
Sample	Total Mass Loss from Corrosion*	Corrosion Rate
Coupon 1	0.023 grams	0.002 mm / year
Coupon 2	0.031 grams	0.002 mm / year
Coupon 3	0.035 grams	0.001 mm / year
Coupon 4	0.046 grams	0.001 mm / year
Screen 1	0.25 grams	0.002 mm / year
Screen 2	0.43 grams	0.002 mm / year
Screen 3	0.60 grams	0.001 mm / year
Screen 4	0.60 grams	0.001 mm / year
Plate	0.21 grams	0.001 mm / year

* Weight As-Received – (Weight Before Cleaning – Mass Loss from Corrosion During Cleaning)

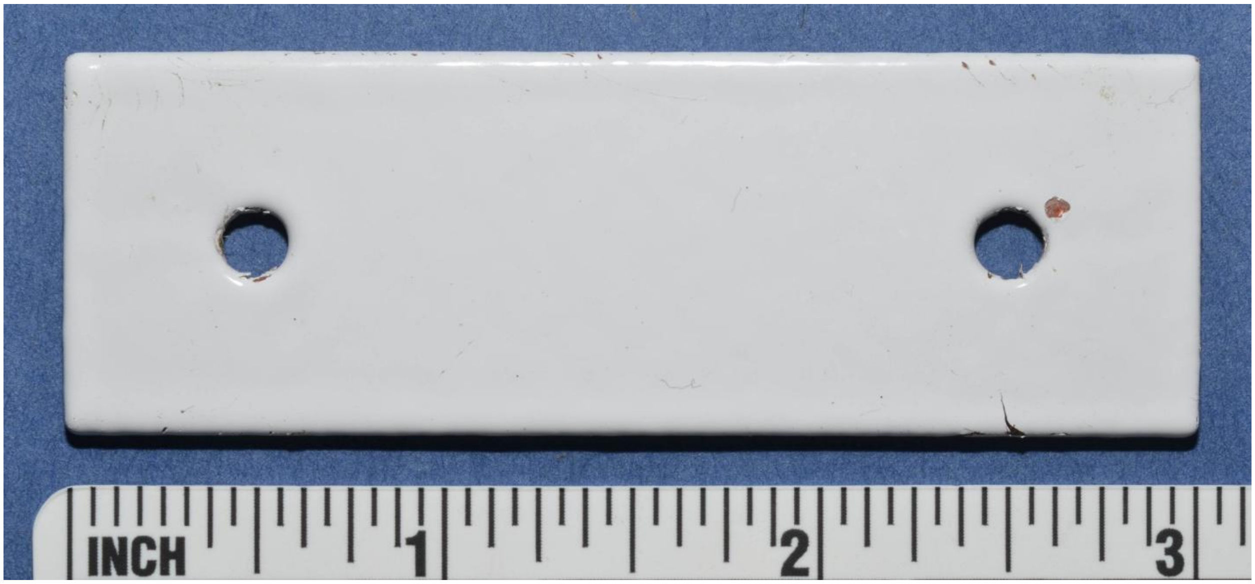
(a) Coated Duplex 2205 Stainless Steel Baseline Coupon, Front Side

(b) Coated Duplex 2205 Stainless Steel Baseline Coupon, Back Side

Figure 1 Photographs of the duplex 2205 stainless steel with anti-biofouling coating baseline coupon (a) front and (b) back side.



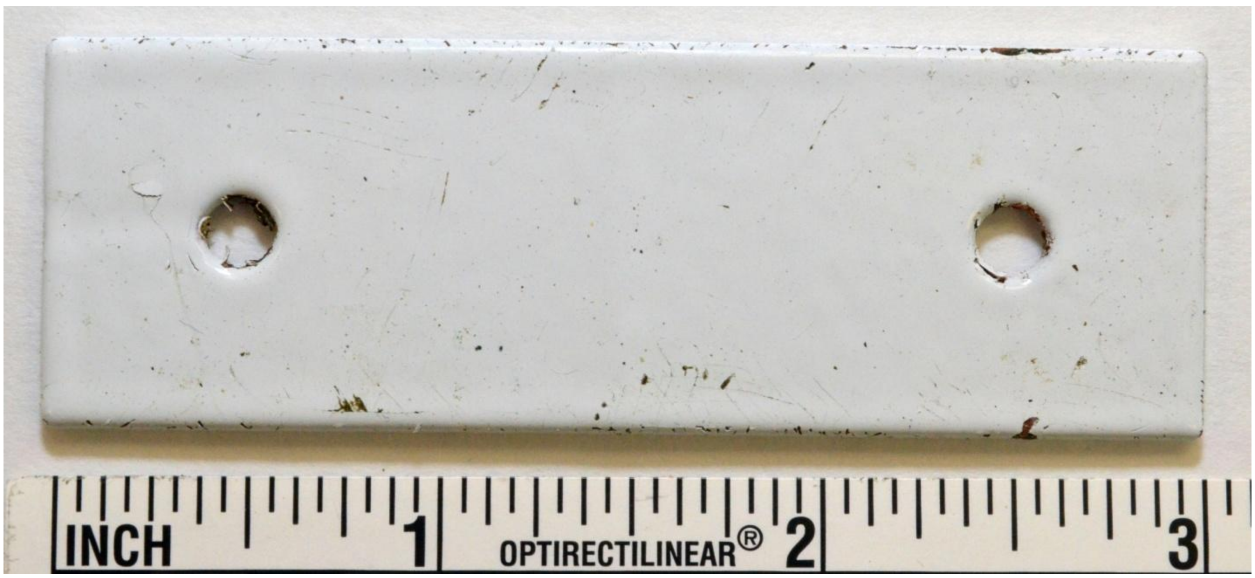
(a) Coated Duplex 2205 Stainless Steel Coupon 1, Front Side



(b) Coated Duplex 2205 Stainless Steel Coupon 1, Back Side

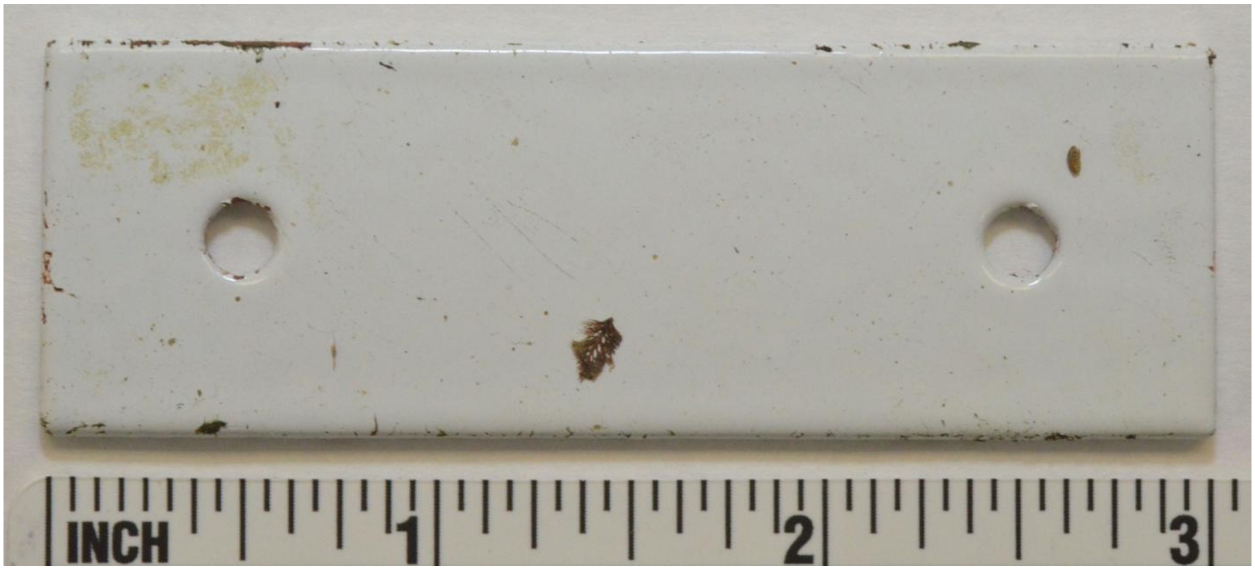
Figure 2 Photographs of duplex 2205 stainless steel with anti-biofouling coating coupon 1 (a) front and (b) back side after a 3 month corrosion test.

(a) Coated Duplex 2205 Stainless Steel Coupon 2, Front Side



(b) Coated Duplex 2205 Stainless Steel Coupon 2, Back Side

Figure 3 Photographs of duplex 2205 stainless steel with anti-biofouling coating coupon 2 (a) front and (b) back side after a 6 month corrosion test.

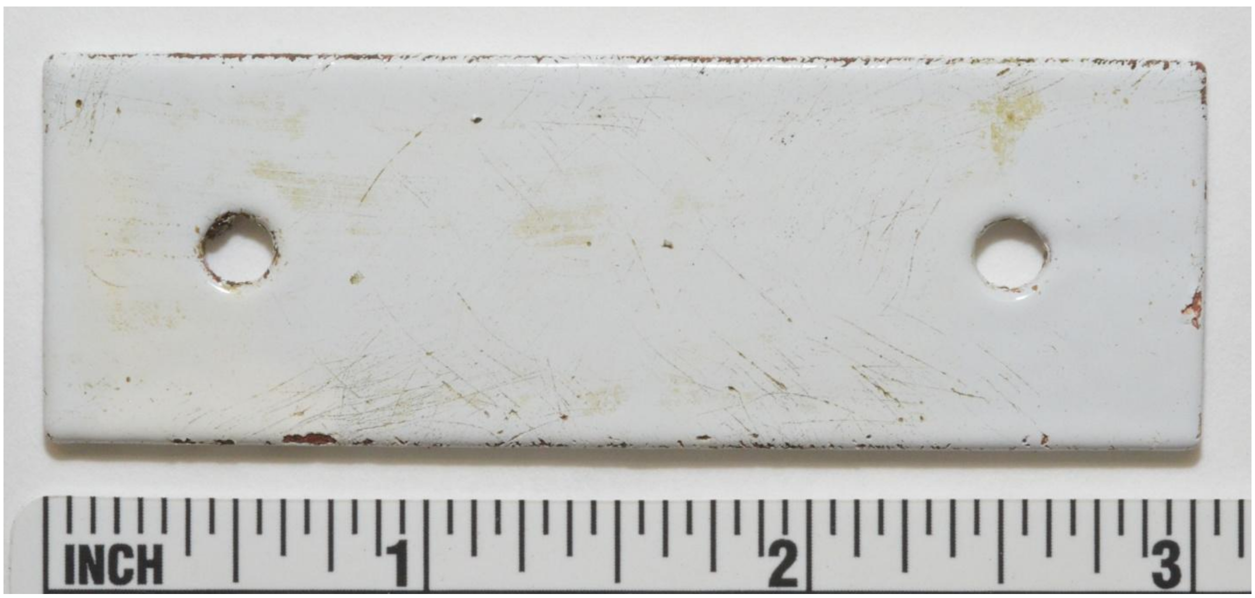


(a) Coated Duplex 2205 Stainless Steel Coupon 3, Front Side

(b) Coated Duplex 2205 Stainless Steel Coupon 3, Back Side

Figure 4 Photographs of duplex 2205 stainless steel with anti-biofouling coating coupon 3 (a) front and (b) back side after a 10 month corrosion test.

(a) Coated Duplex 2205 Stainless Steel Coupon 4, Front Side



(b) Coated Duplex 2205 Stainless Steel Coupon 4, Back Side

Figure 5 Photographs of duplex 2205 stainless steel with anti-biofouling coating coupon 4 (a) front and (b) back side after a 12 month corrosion test.

(a) Coated Duplex 2205 Stainless Steel Baseline Screen

Figure 6 Photograph of the duplex 2205 stainless steel with anti-biofouling coating baseline screen.

(a) Coated Duplex 2205 Stainless Steel Screen 1

Figure 7 Photograph of duplex 2205 stainless steel with anti-biofouling coating screen 1 after a 3 month corrosion test.

(a) Coated Duplex 2205 Stainless Steel Screen 2

Figure 8 Photograph of duplex 2205 stainless steel with anti-biofouling coating screen 2 after a 6 month corrosion test.

(a) Coated Duplex 2205 Stainless Steel Screen 3

Figure 9 Photograph of duplex 2205 stainless steel with anti-biofouling coating screen 3 after a 10 month corrosion test.

(a) Coated Duplex 2205 Stainless Steel Screen 4

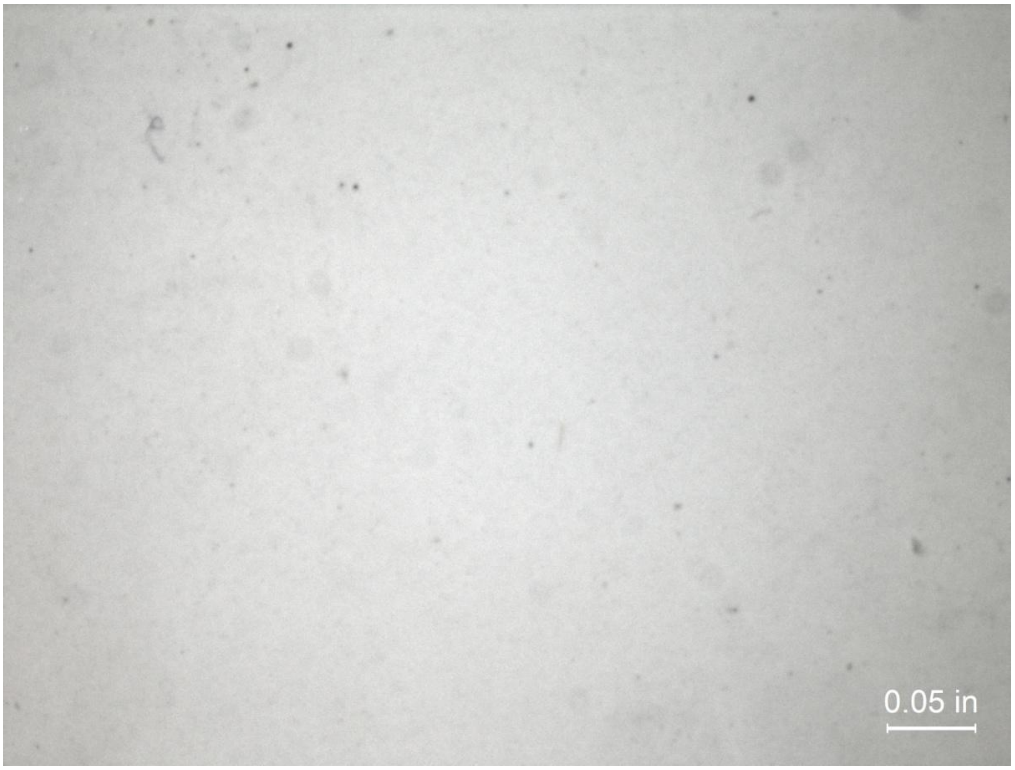
Figure 10 Photograph of duplex 2205 stainless steel with anti-biofouling coating screen 4 after a 12 month corrosion test.

(a) Coated Duplex 2205 Stainless Steel Baseline Plate

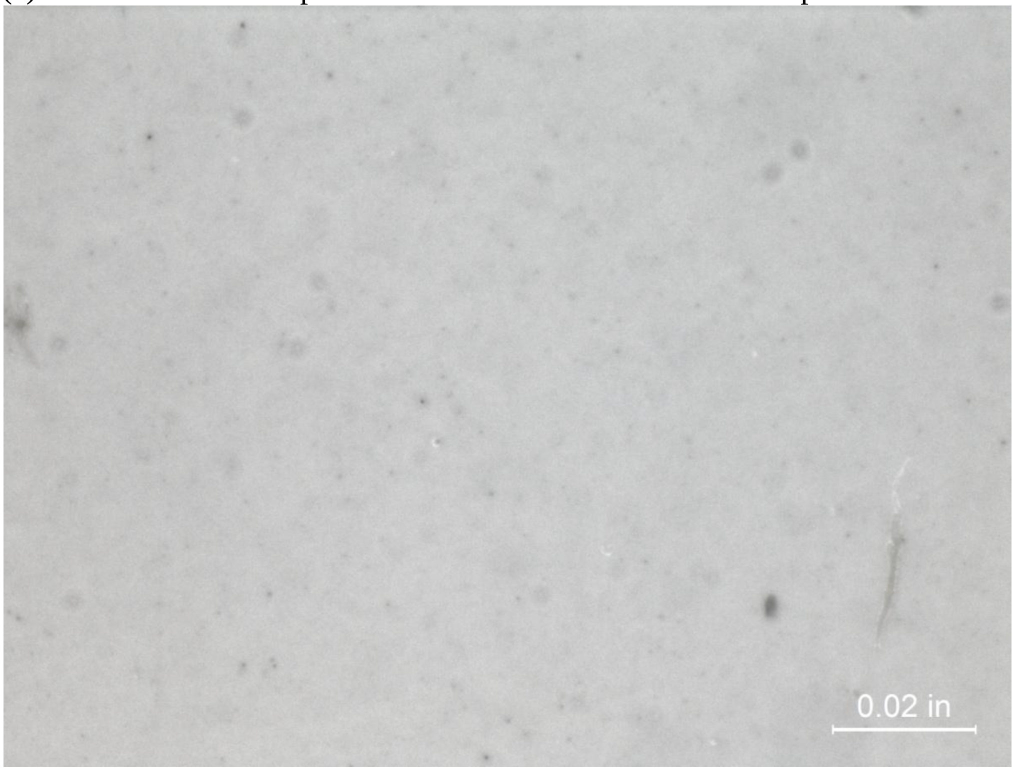
Figure 11 Photograph of the duplex 2205 stainless steel with anti-biofouling coating baseline plate.

(a) Coated Duplex 2205 Stainless Steel Plate

Figure 12 Photograph of duplex 2205 stainless steel with anti-biofouling coating plate after a 12 month corrosion test.

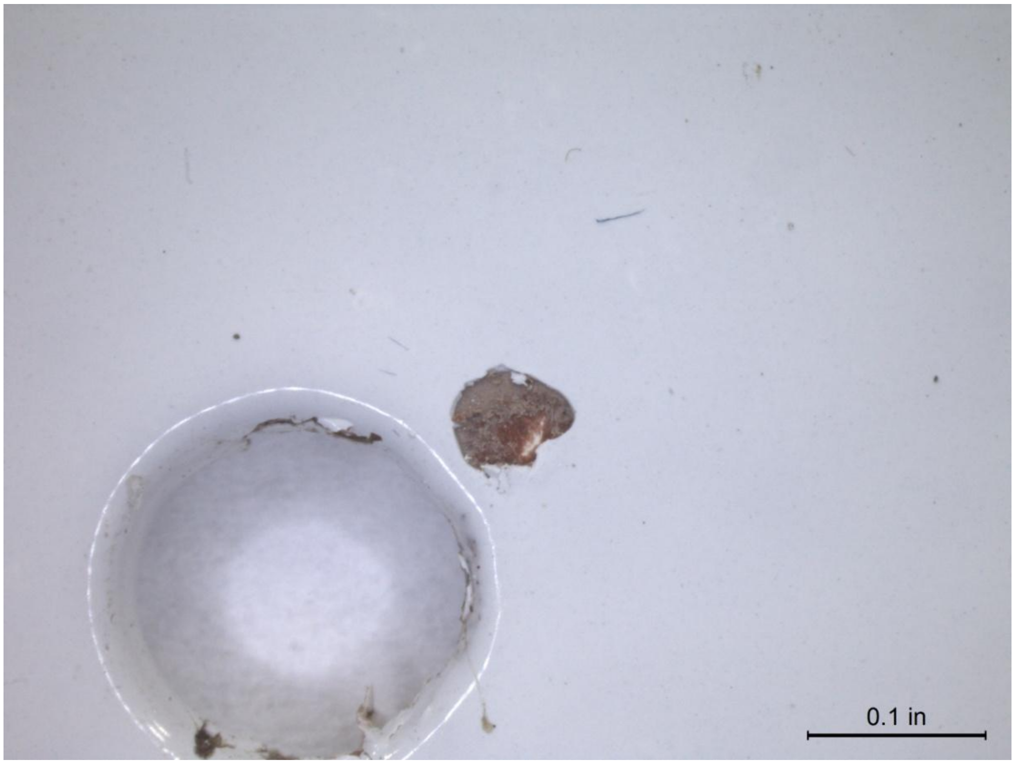


(a) Coated Duplex 2205 Stainless Steel Baseline Coupon 10X

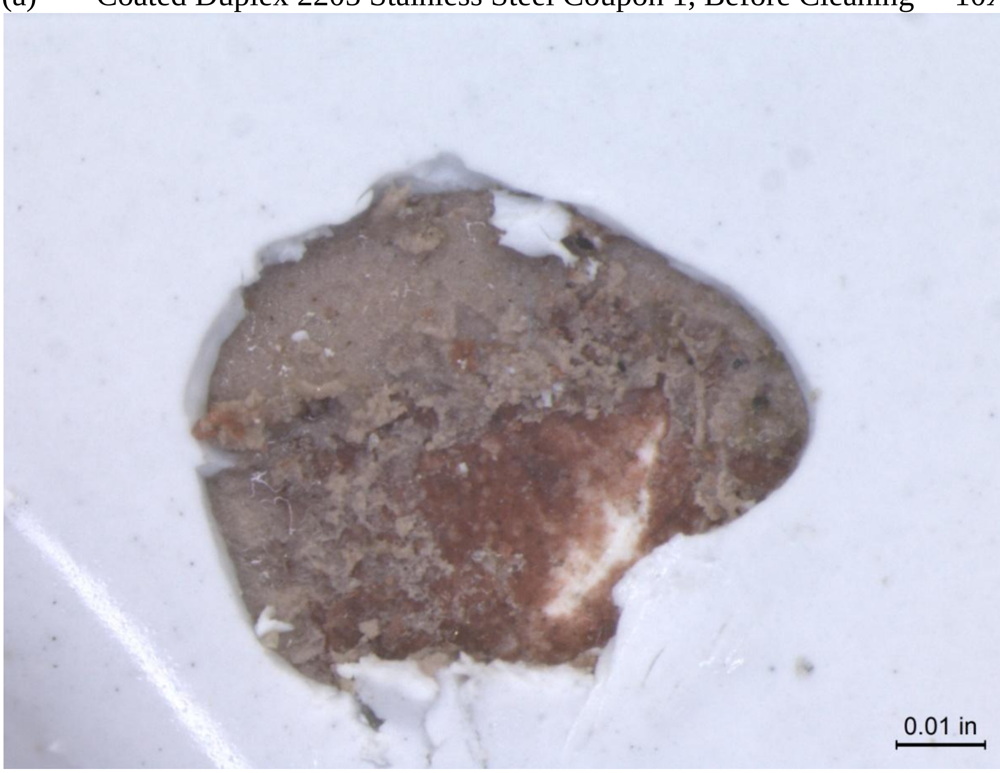


(b) Coated Duplex 2205 Stainless Steel Baseline Coupon 40X

Figure 13 Optical macrographs of the duplex 2205 stainless steel with anti-biofouling coating baseline coupon.

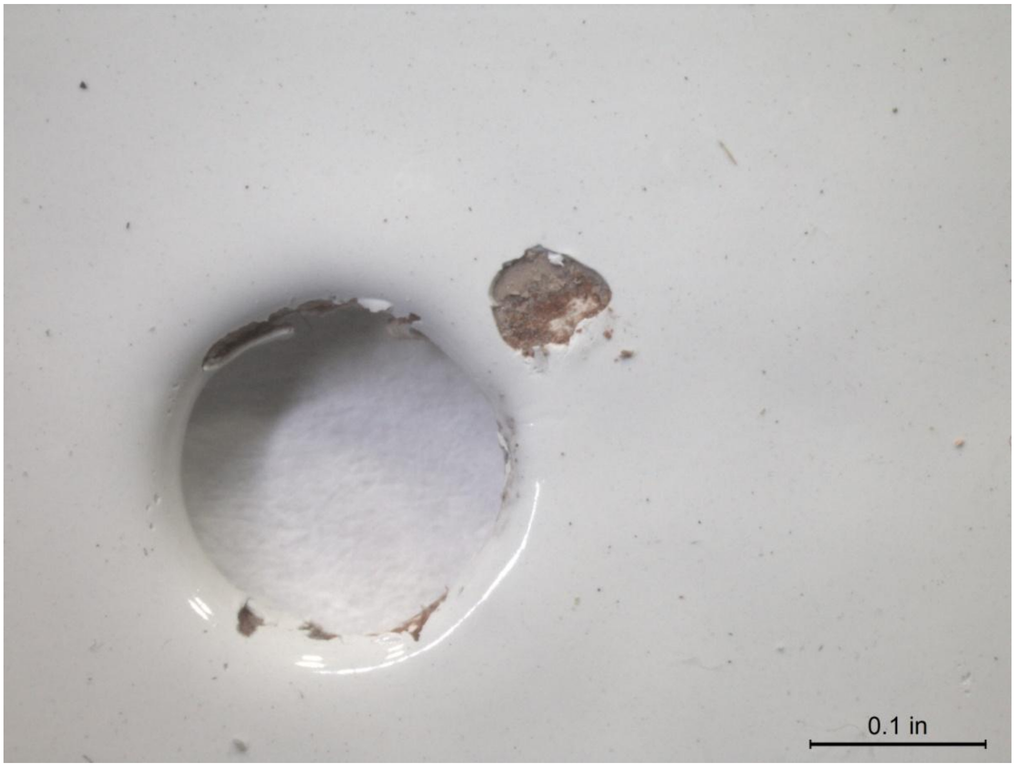


(a) Coated Duplex 2205 Stainless Steel Coupon 1, Before Cleaning 10X

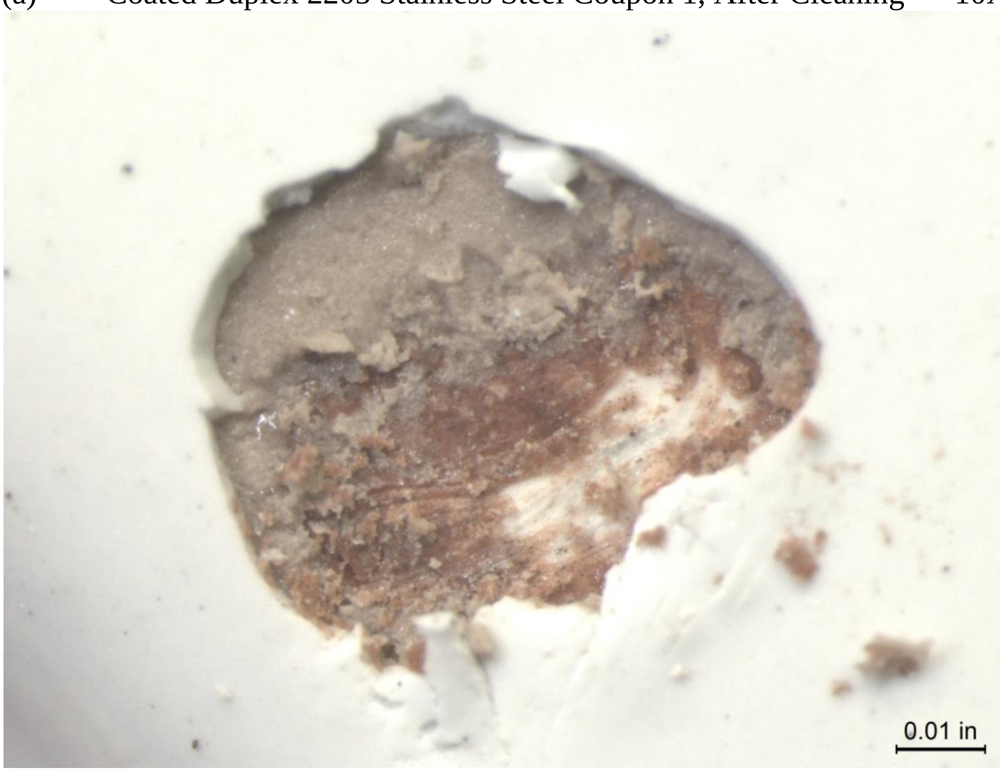


(b) Coated Duplex 2205 Stainless Steel Coupon 1, Before Cleaning 50X

Figure 14 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 1 after a 3 month corrosion test, before cleaning.

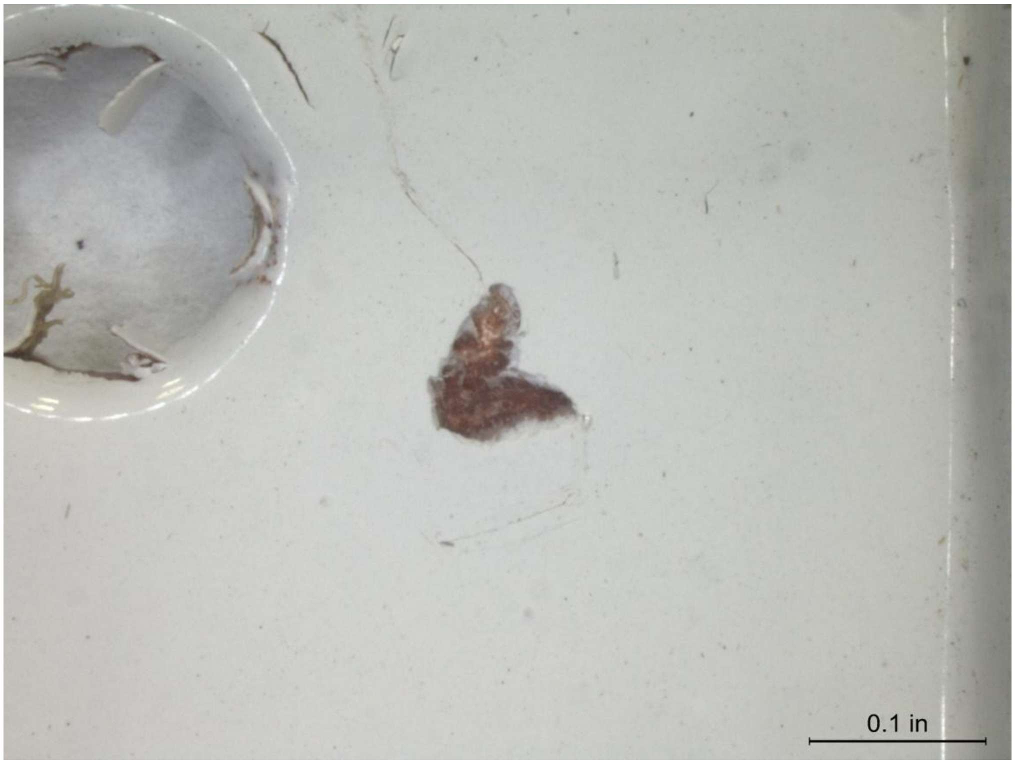


(a) Coated Duplex 2205 Stainless Steel Coupon 1, After Cleaning 10X

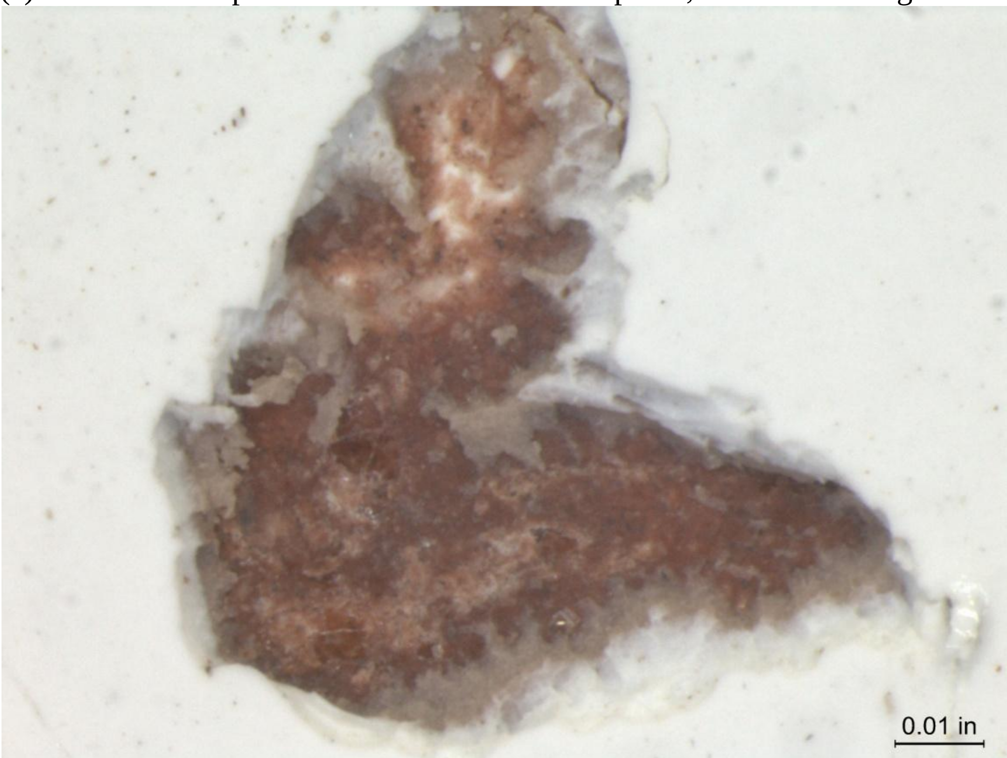


(b) Coated Duplex 2205 Stainless Steel Coupon 1, After Cleaning 50X

Figure 15 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 1 after a 3 month corrosion test, after cleaning.

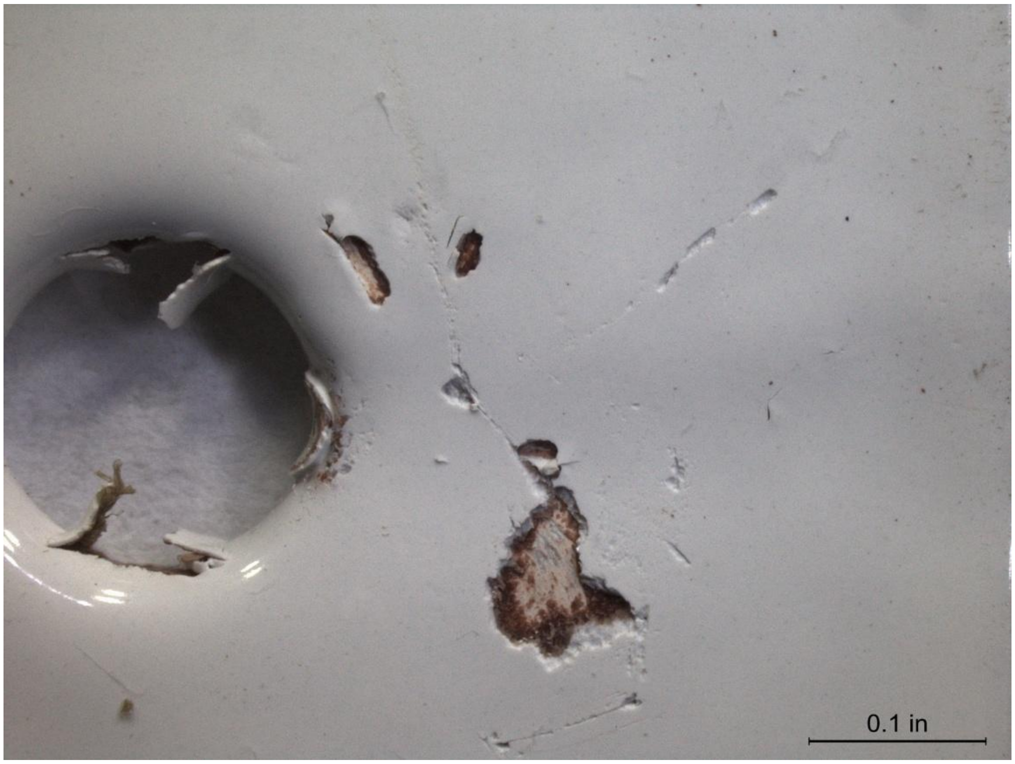


(a) Coated Duplex 2205 Stainless Steel Coupon 2, Before Cleaning 10X



(b) Coated Duplex 2205 Stainless Steel Coupon 2, Before Cleaning 50X

Figure 16 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 2 after a 6 month corrosion test, before cleaning.

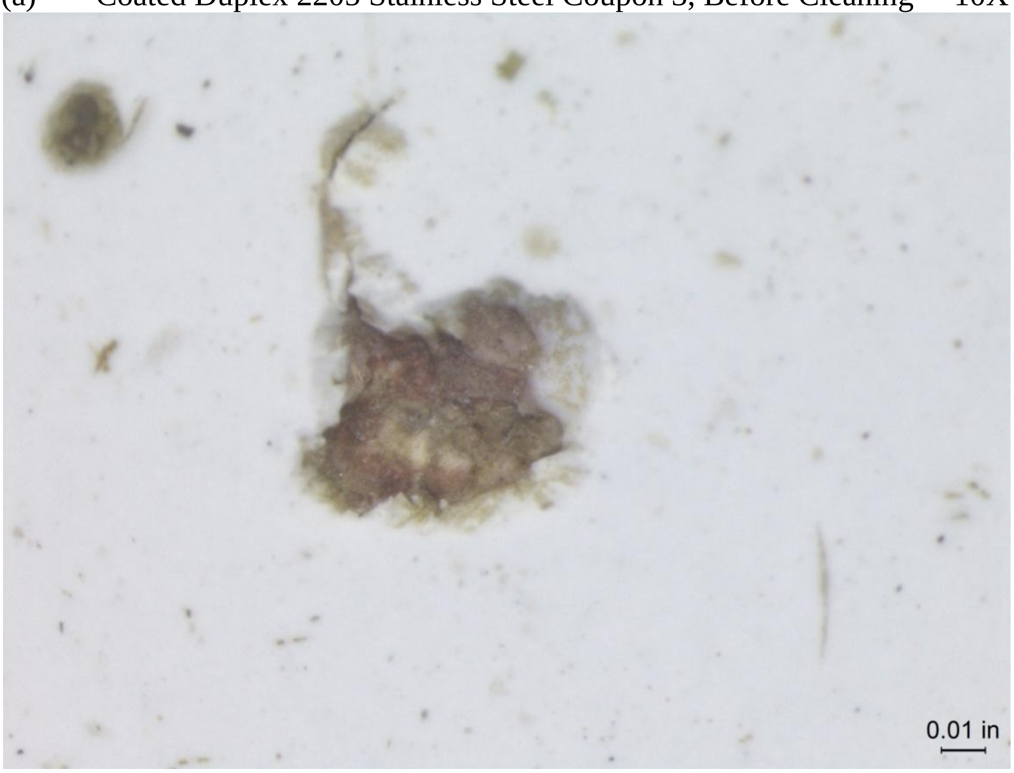


(a) Coated Duplex 2205 Stainless Steel Coupon 2, After Cleaning 10X

(b) Coated Duplex 2205 Stainless Steel Coupon 2, After Cleaning 50X

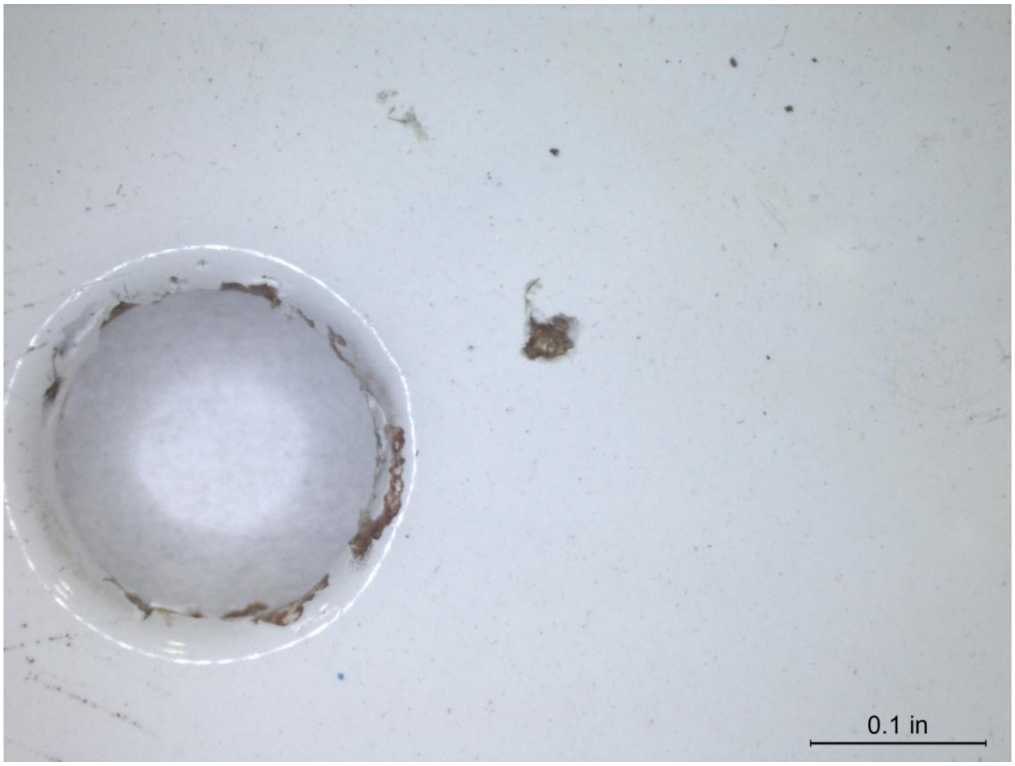
Figure 17 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 2 after a 6 month corrosion test, after cleaning.

(a) Coated Duplex 2205 Stainless Steel Coupon 3, Before Cleaning 10X

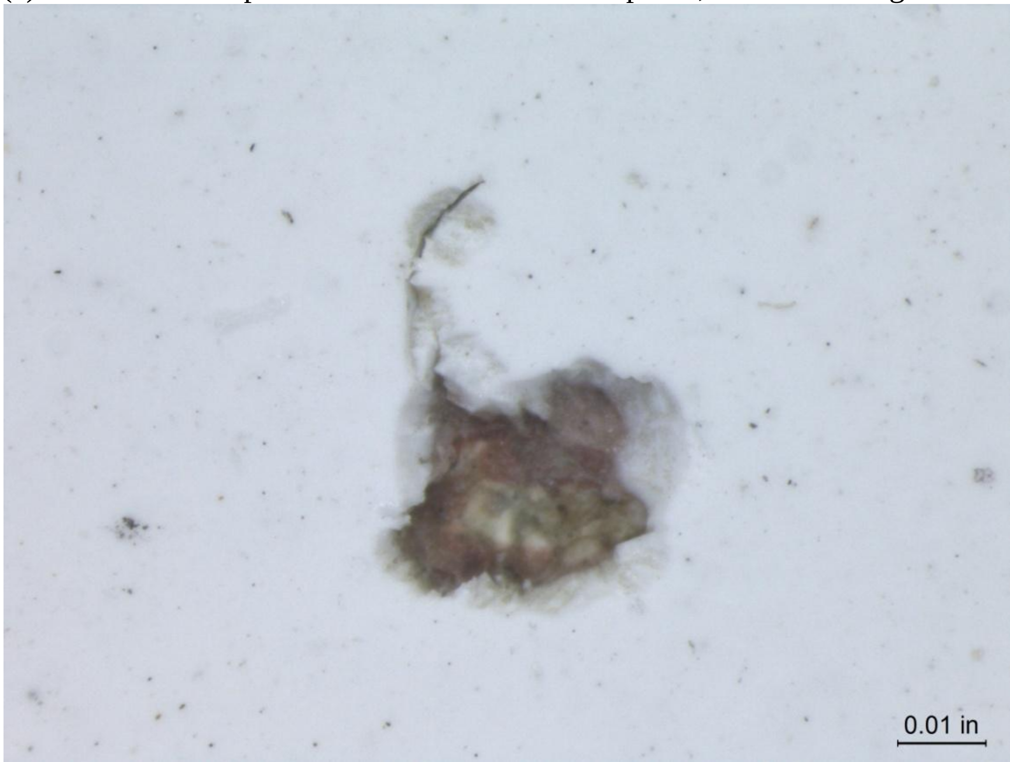


(b) Coated Duplex 2205 Stainless Steel Coupon 3, Before Cleaning 50X

Figure 18 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 3 after a 10 month corrosion test, before cleaning.

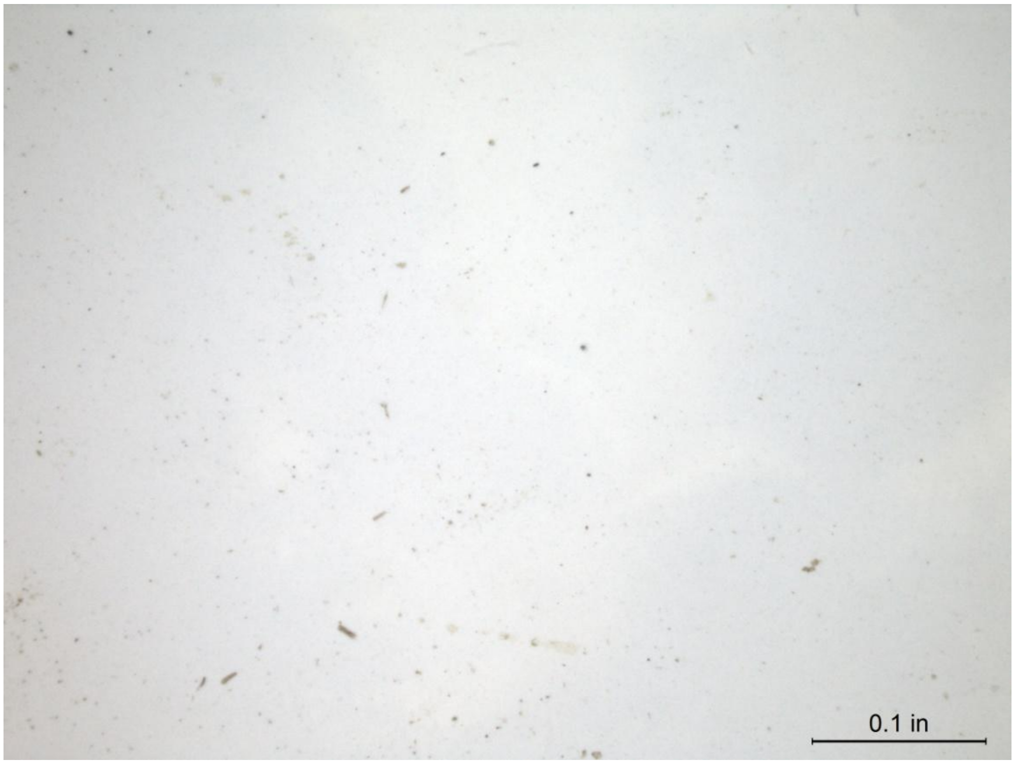


(a) Coated Duplex 2205 Stainless Steel Coupon 3, After Cleaning 10X

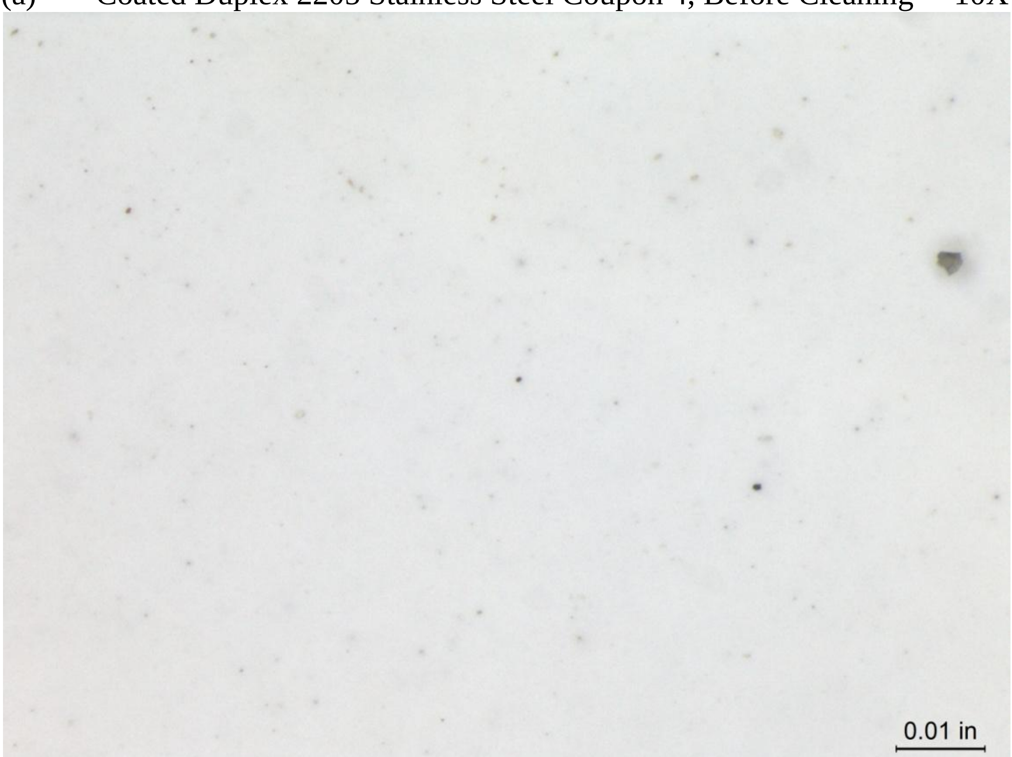


(b) Coated Duplex 2205 Stainless Steel Coupon 3, After Cleaning 50X

Figure 19 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 3 after a 10 month corrosion test, after cleaning.

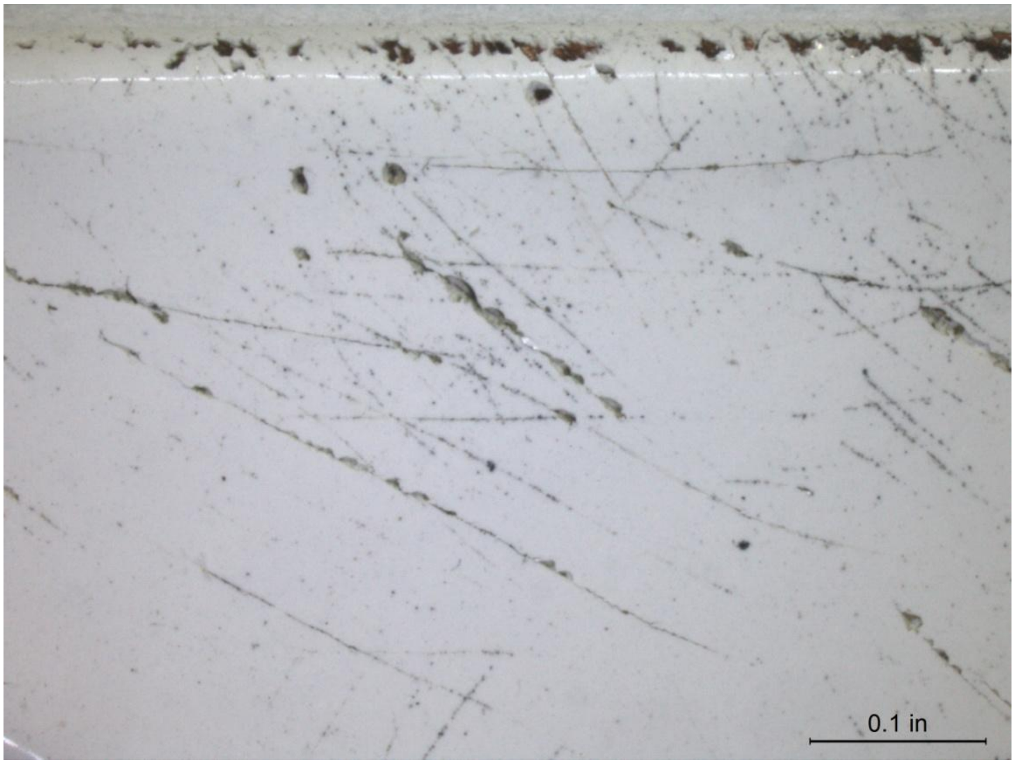


(a) Coated Duplex 2205 Stainless Steel Coupon 4, Before Cleaning 10X

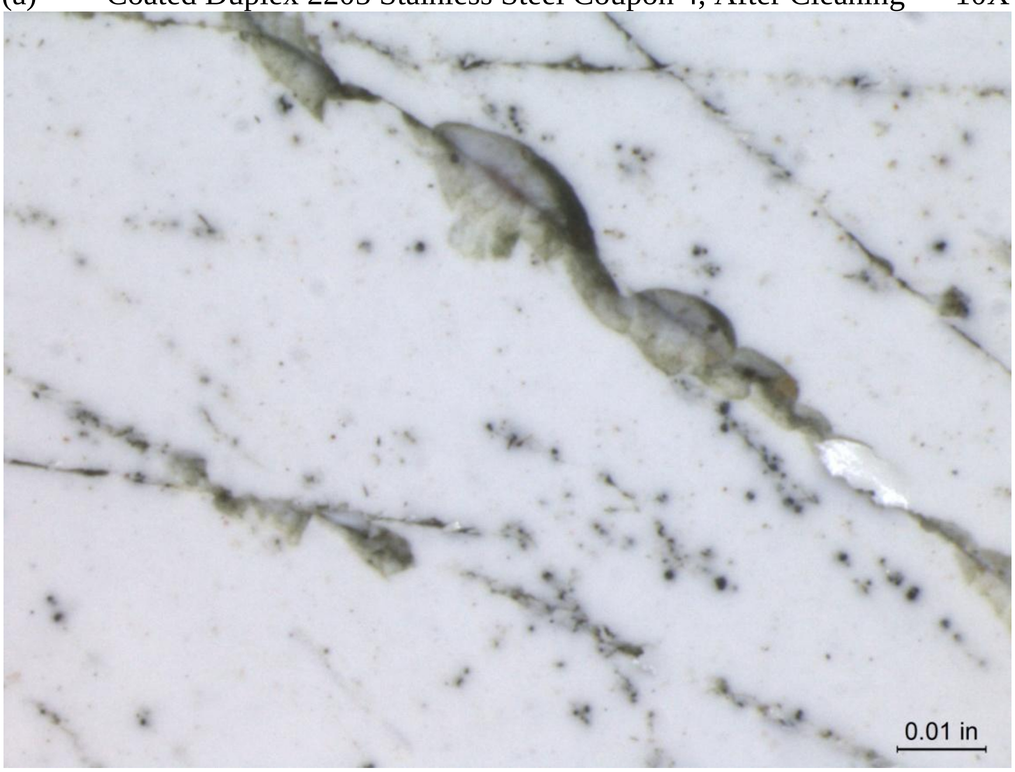


(b) Coated Duplex 2205 Stainless Steel Coupon 4, Before Cleaning 50X

Figure 20 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 4 after a 12 month corrosion test, before cleaning.

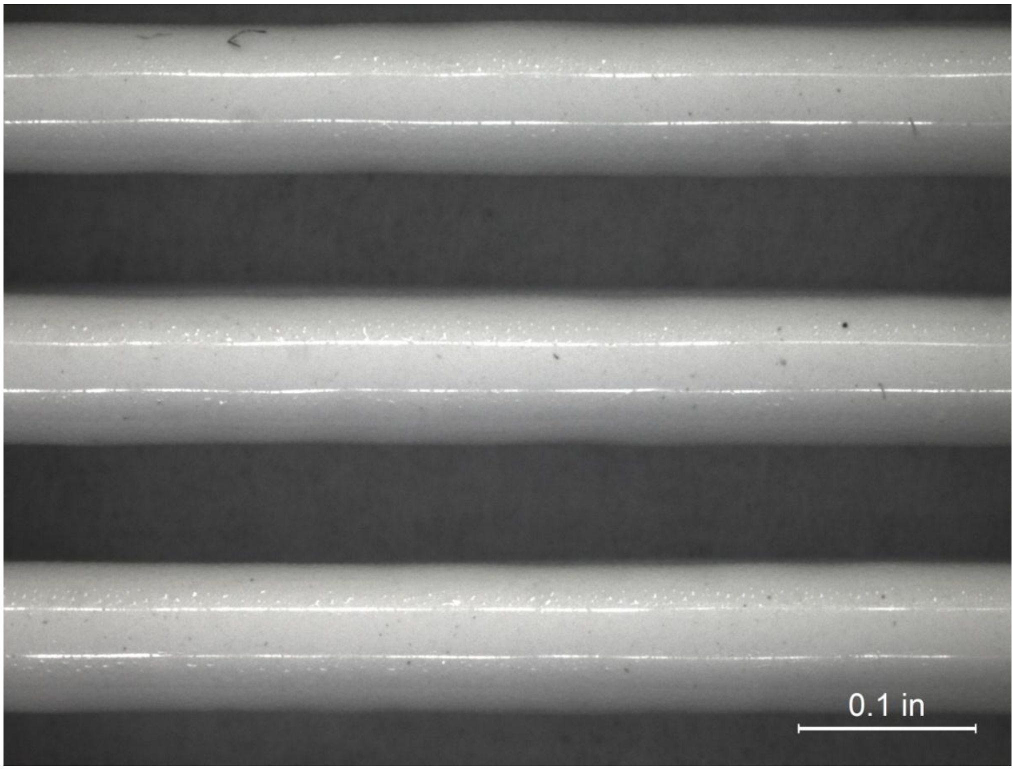


(a) Coated Duplex 2205 Stainless Steel Coupon 4, After Cleaning 10X



(b) Coated Duplex 2205 Stainless Steel Coupon 4, After Cleaning 50X

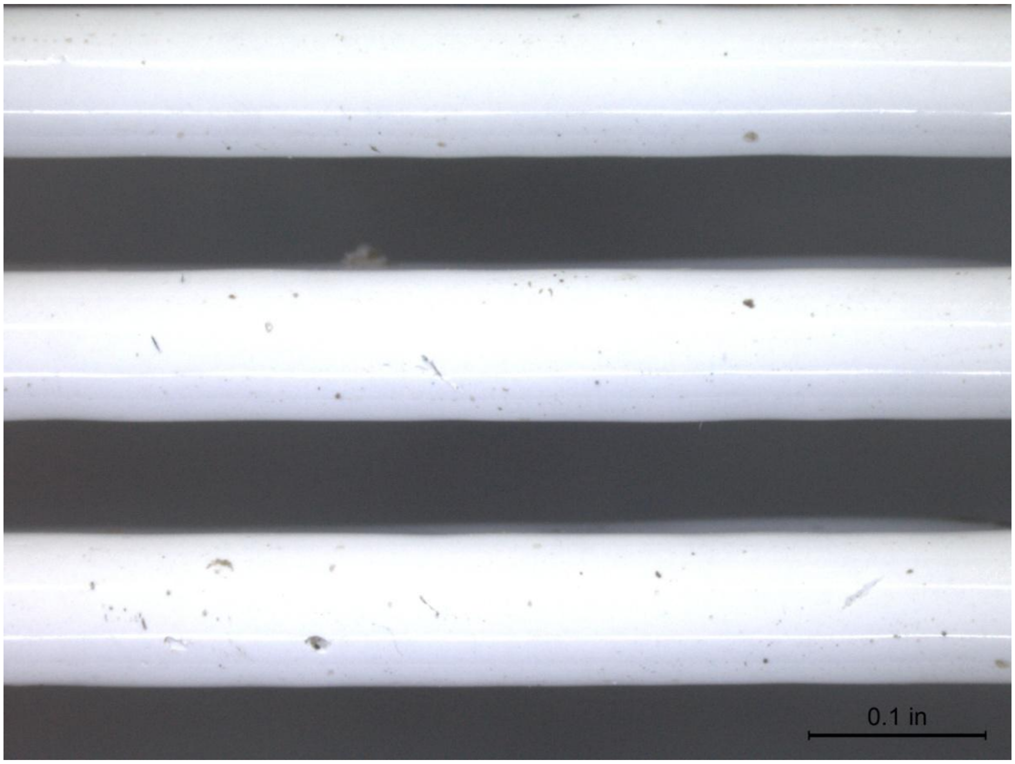
Figure 21 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 4 after a 12 month corrosion test, after cleaning.



(a) Coated Duplex 2205 Stainless Steel Baseline Screen 10X

(b) Coated Duplex 2205 Stainless Steel Baseline Screen 50X

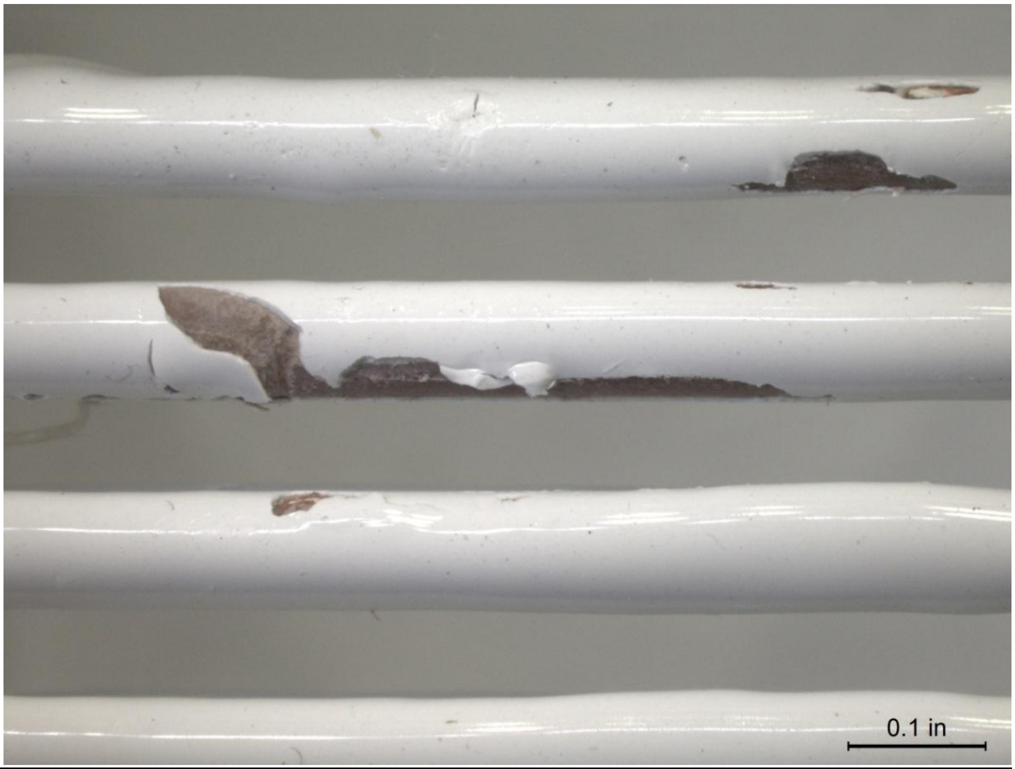
Figure 22 Optical macrographs of the duplex 2205 stainless steel with anti-biofouling coating baseline screen.



(a) Coated Duplex 2205 Stainless Steel Screen 1, Before Cleaning 10X

(b) Coated Duplex 2205 Stainless Steel Screen 1, Before Cleaning 50X

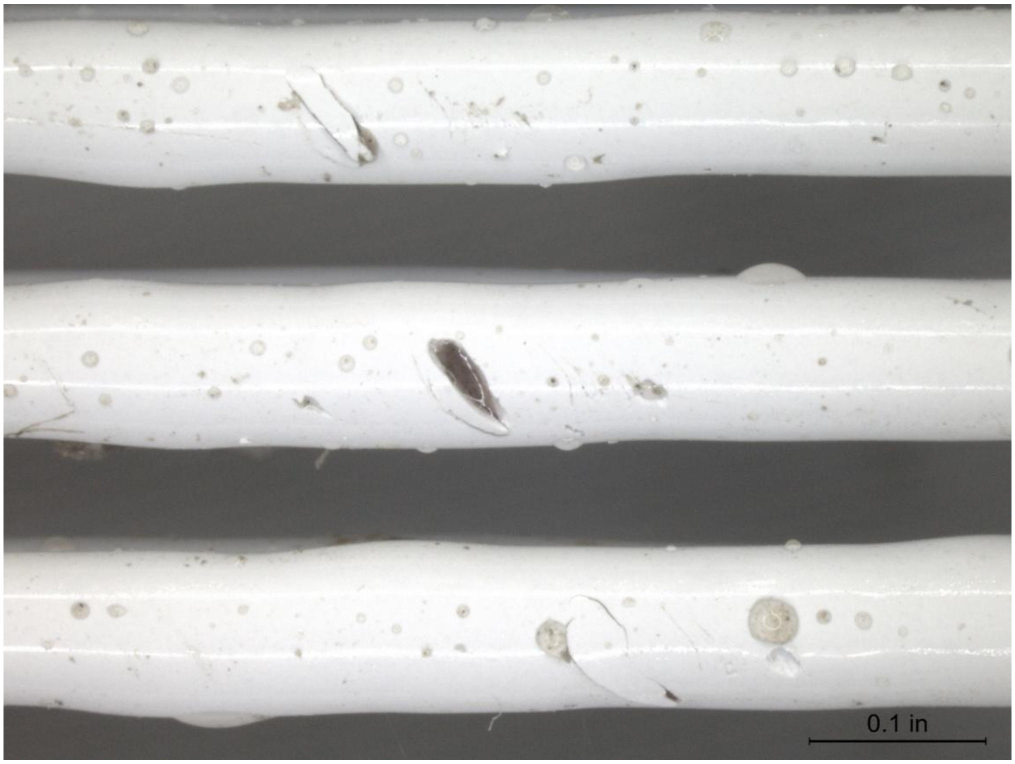
Figure 23 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating screen 1 after a 3 month corrosion test, before cleaning.



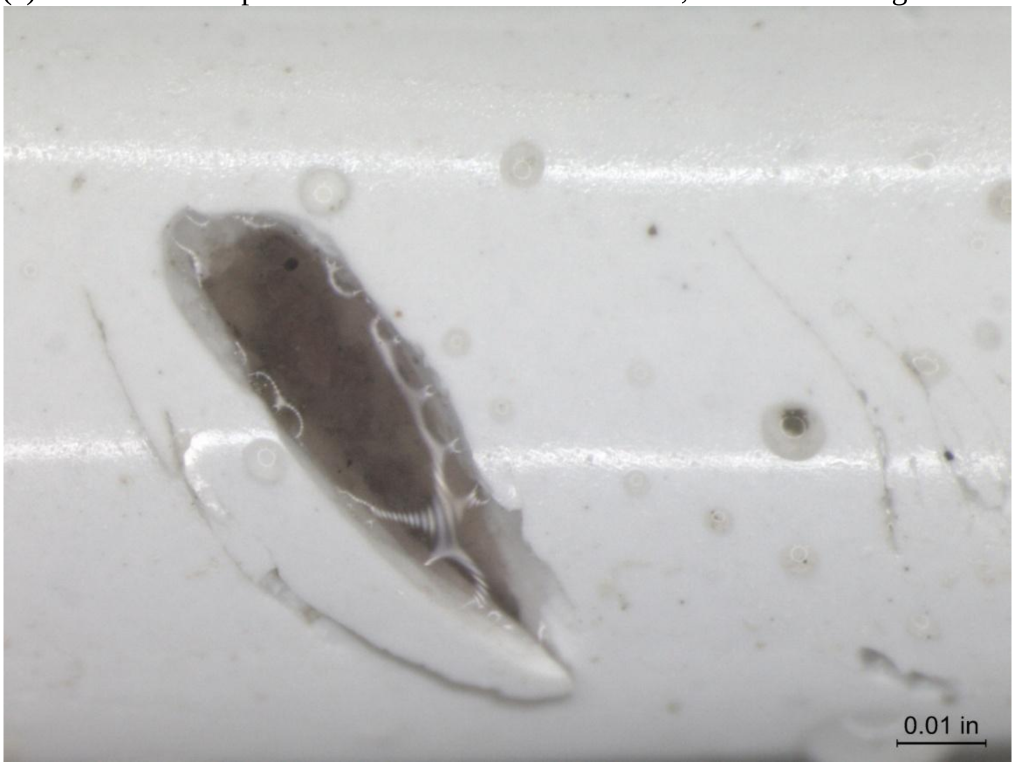
(a) Coated Duplex 2205 Stainless Steel Screen 1, After Cleaning 10X

(b) Coated Duplex 2205 Stainless Steel Screen 1, After Cleaning 50X

Figure 24 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating screen 1 after a 3 month corrosion test, after cleaning.

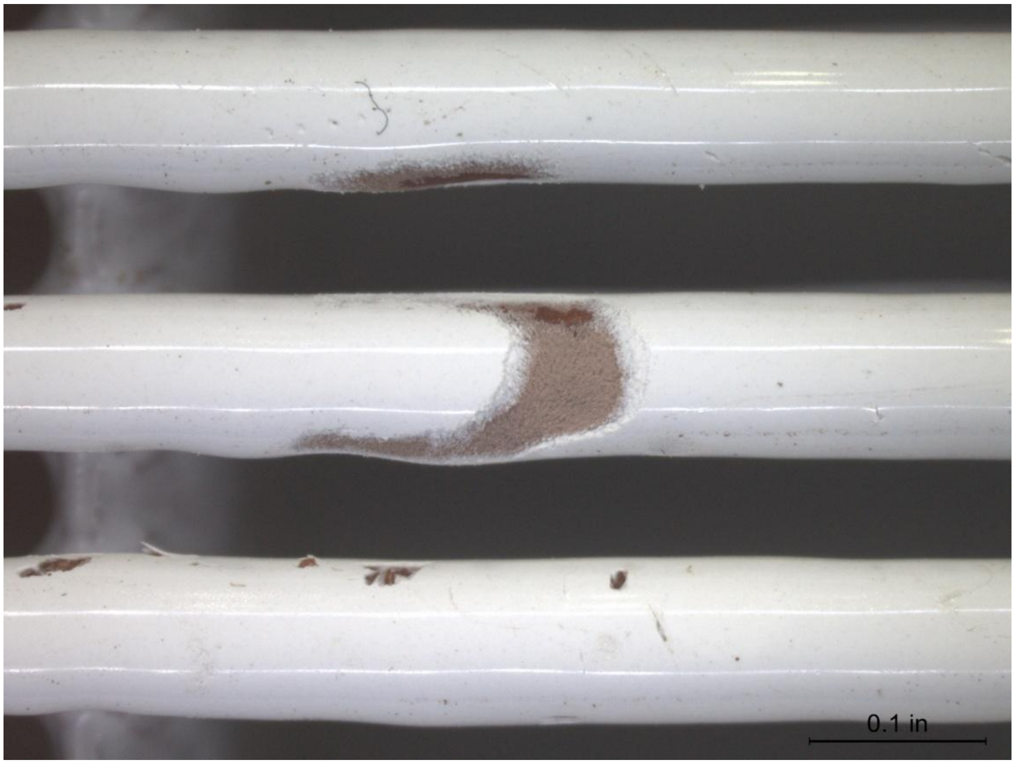


(a) Coated Duplex 2205 Stainless Steel Screen 2, Before Cleaning 10X



(b) Coated Duplex 2205 Stainless Steel Screen 2, Before Cleaning 50X

Figure 25 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating screen 2 after a 6 month corrosion test, before cleaning.



(a) Coated Duplex 2205 Stainless Steel Screen 2, After Cleaning 10X

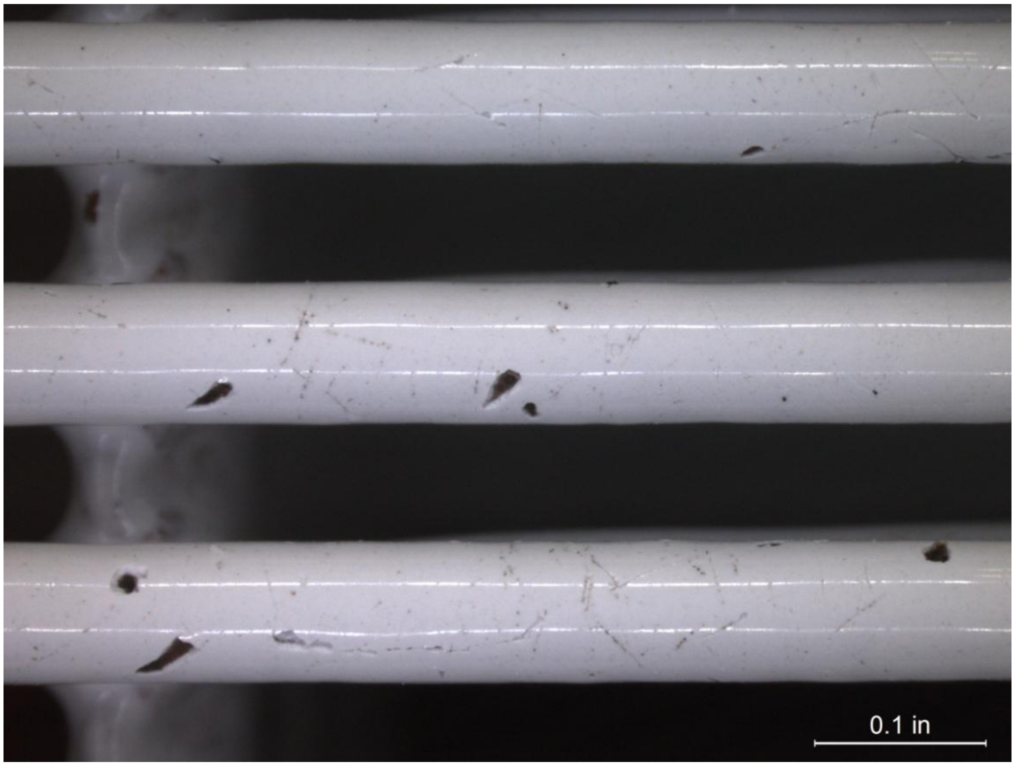
(b) Coated Duplex 2205 Stainless Steel Screen 2, After Cleaning 50X

Figure 26 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating screen 2 after a 6 month corrosion test, after cleaning.

(a) Coated Duplex 2205 Stainless Steel Screen 3, Before Cleaning 10X

(b) Coated Duplex 2205 Stainless Steel Screen 3, Before Cleaning 50X

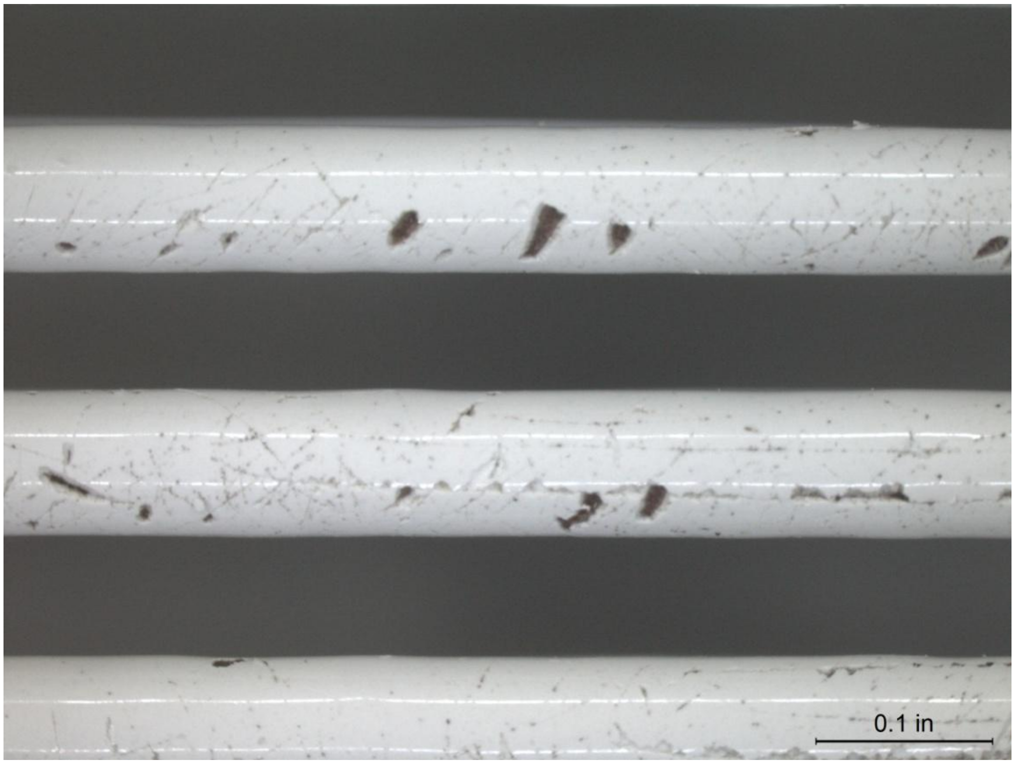
Figure 27 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating screen 3 after a 10 month corrosion test, before cleaning.



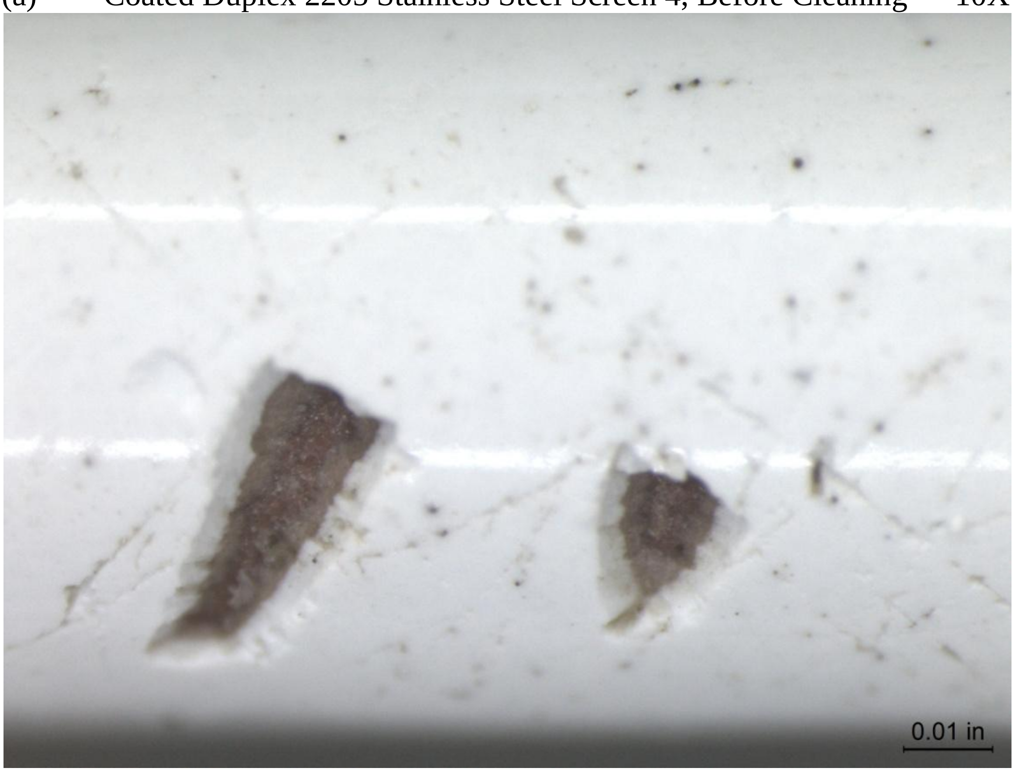
(a) Coated Duplex 2205 Stainless Steel Screen 3, After Cleaning 10X

(b) Coated Duplex 2205 Stainless Steel Screen 3, After Cleaning 50X

Figure 28 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating screen 3 after a 10 month corrosion test, after cleaning.

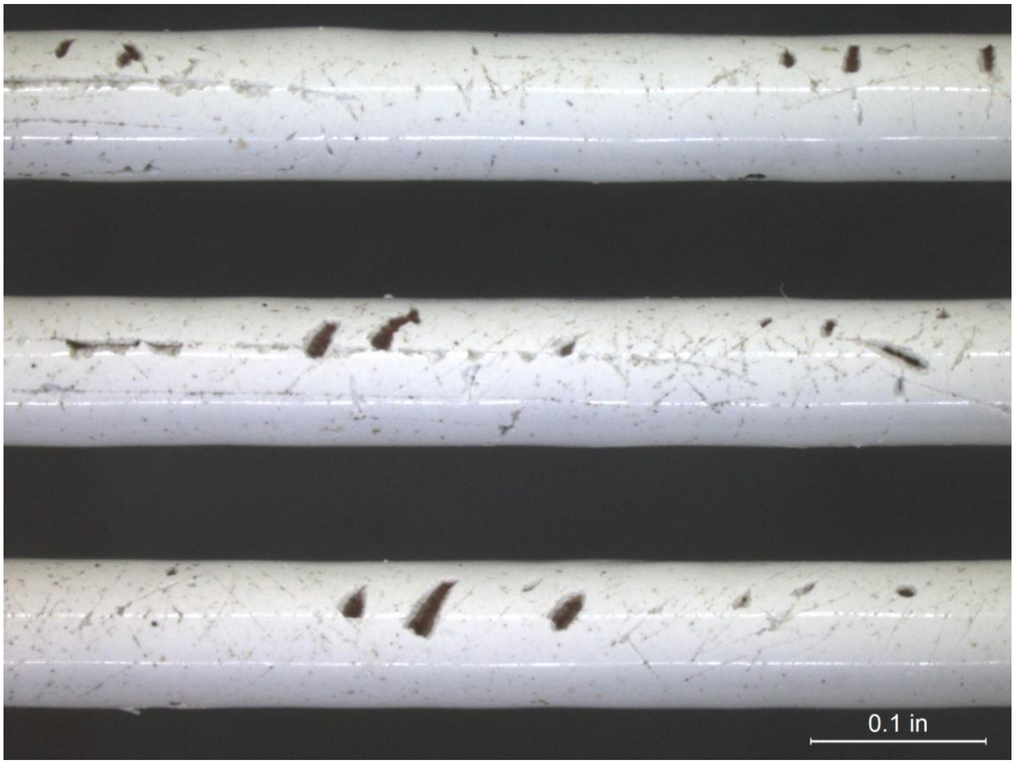


(a) Coated Duplex 2205 Stainless Steel Screen 4, Before Cleaning 10X

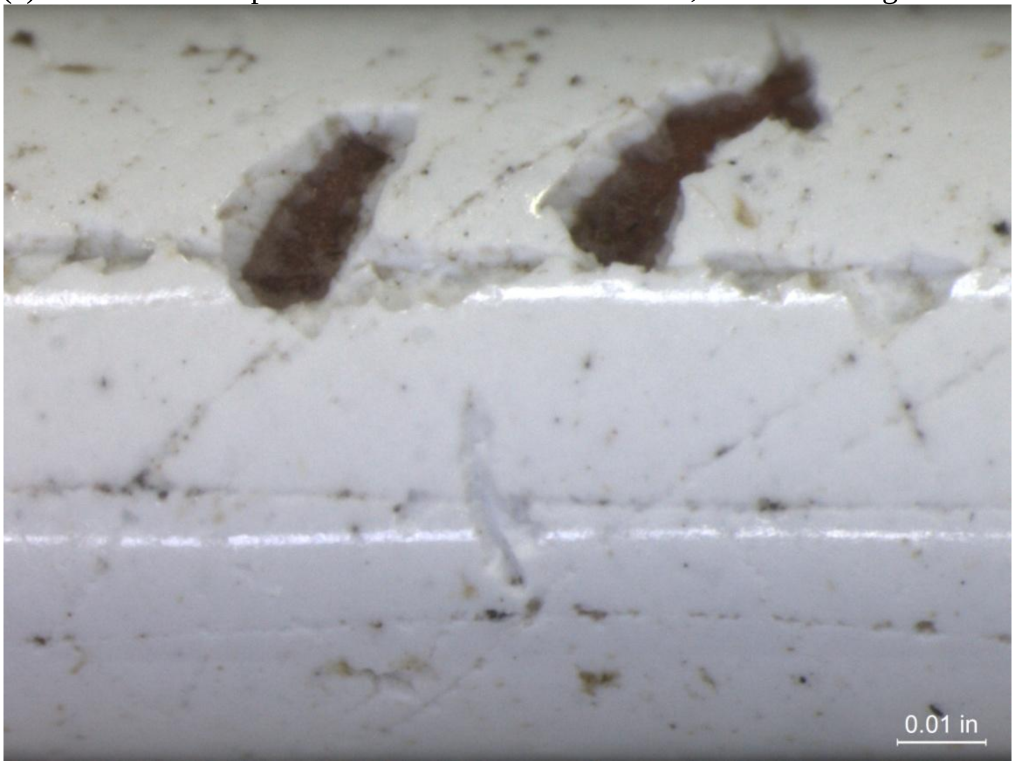


(b) Coated Duplex 2205 Stainless Steel Screen 4, Before Cleaning 50X

Figure 29 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating screen 4 after a 12 month corrosion test, before cleaning.

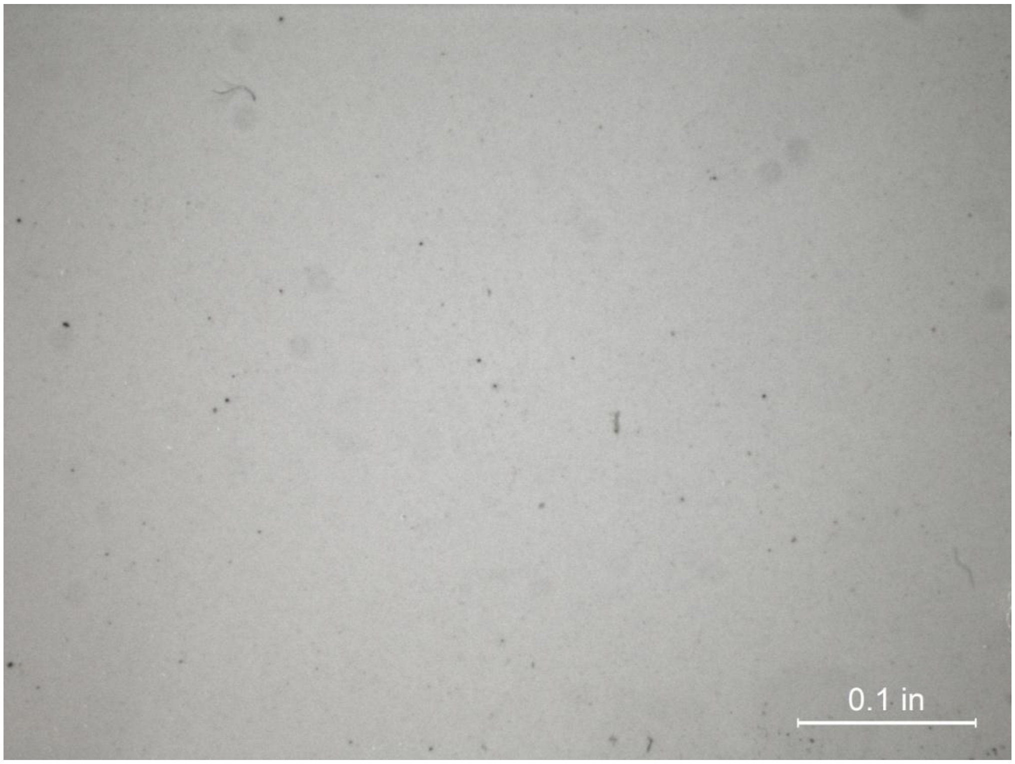


(a) Coated Duplex 2205 Stainless Steel Screen 4, After Cleaning 10X

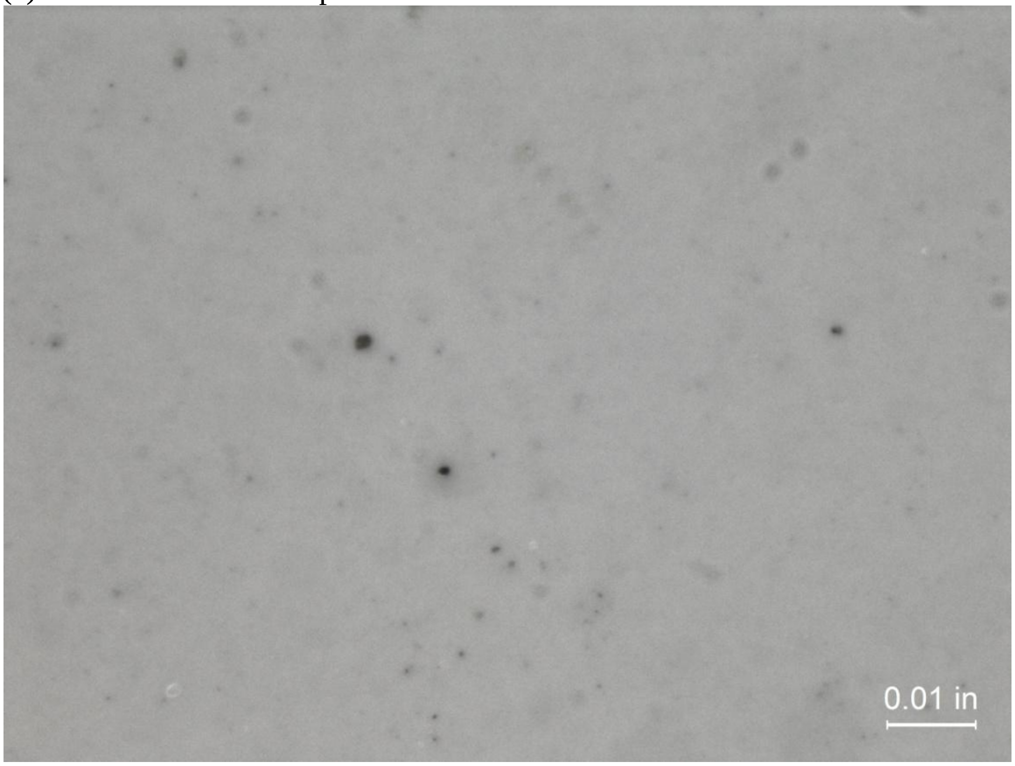


(b) Coated Duplex 2205 Stainless Steel Screen 4, After Cleaning 50X

Figure 30 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating screen 4 after a 12 month corrosion test, after cleaning.

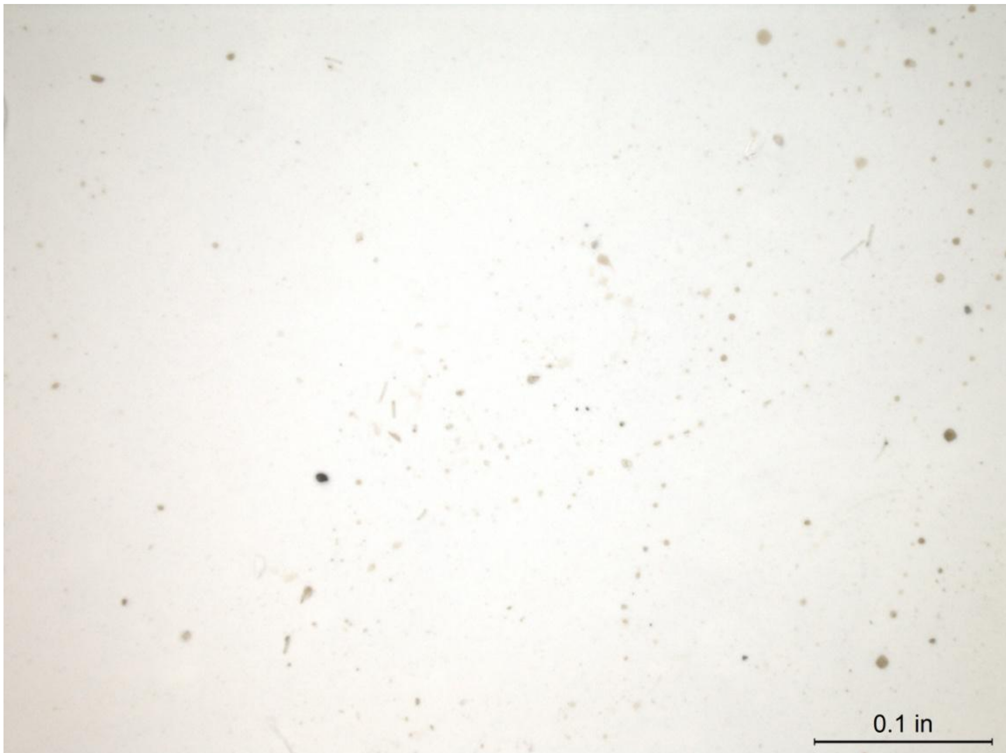


(a) Coated Duplex 2205 Stainless Steel Baseline Plate 10X

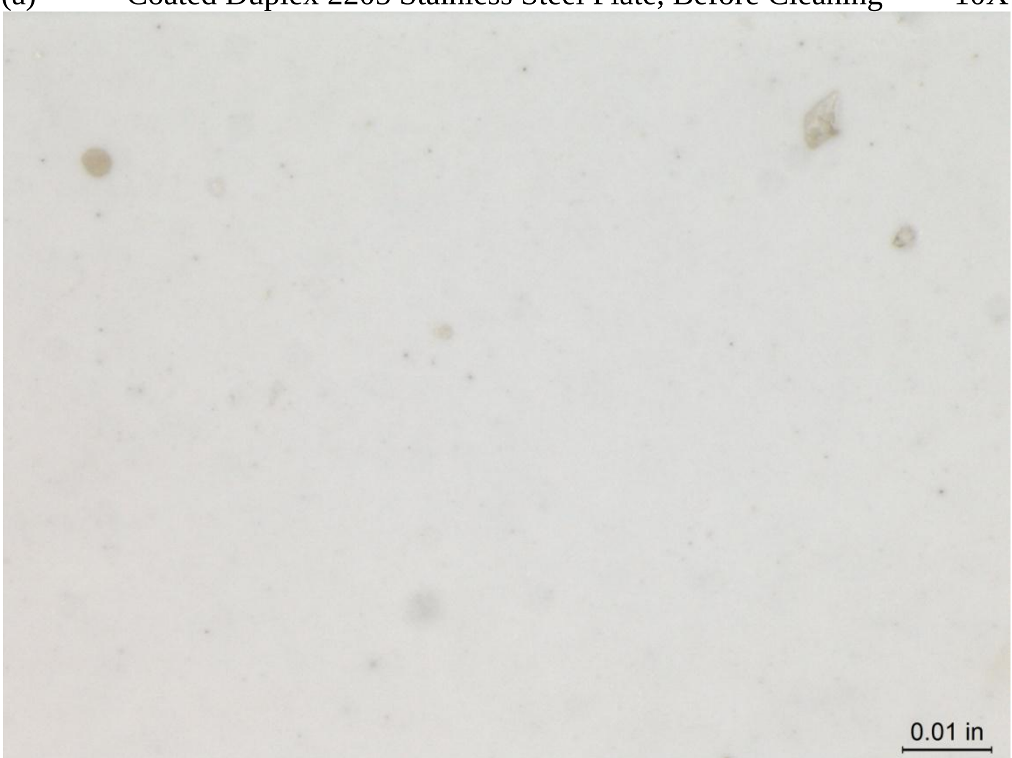


(b) Coated Duplex 2205 Stainless Steel Baseline Plate 50X

Figure 31 Optical macrographs of the duplex 2205 stainless steel with anti-biofouling coating baseline plate.

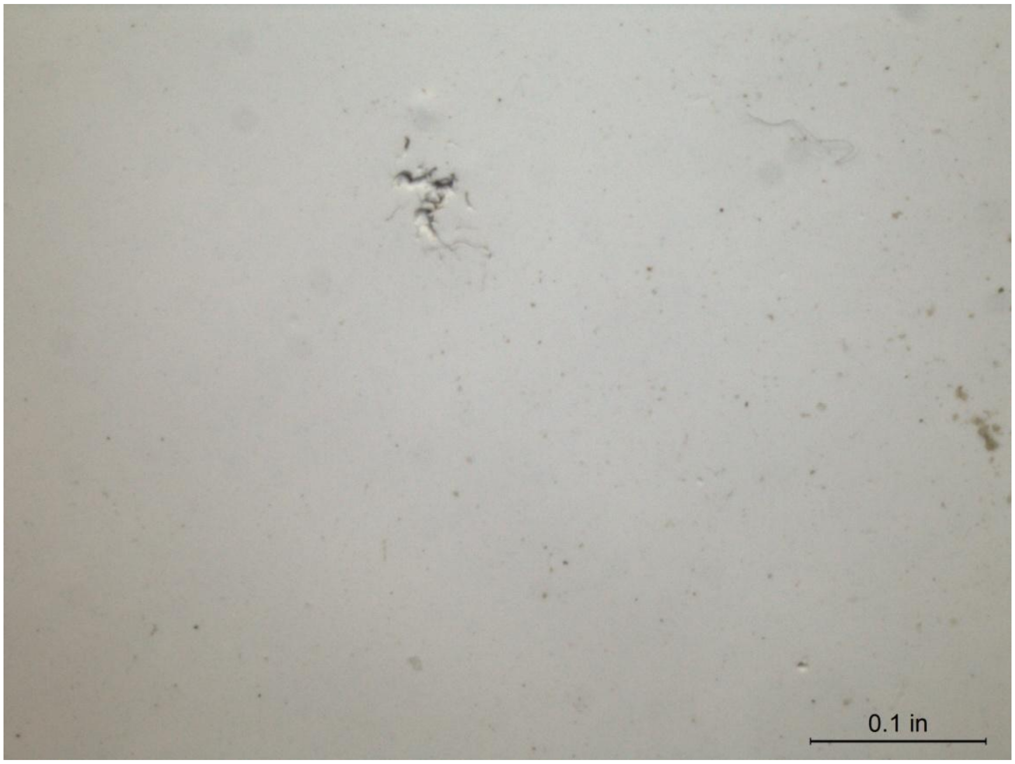


(a) Coated Duplex 2205 Stainless Steel Plate, Before Cleaning 10X

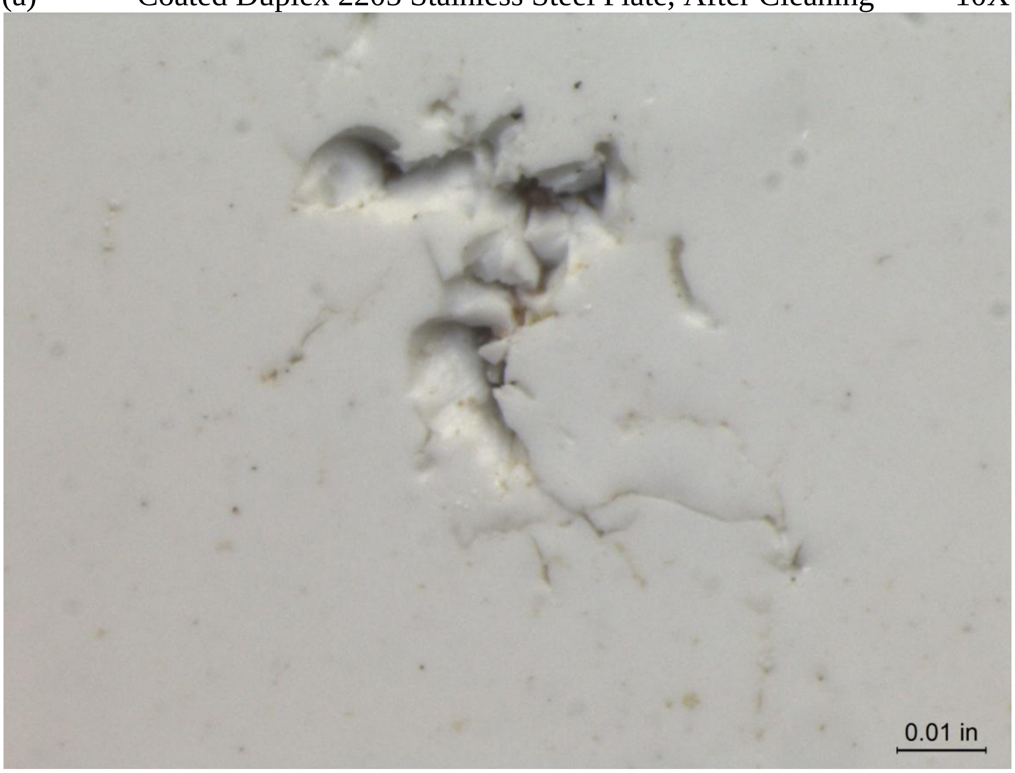


(b) Coated Duplex 2205 Stainless Steel Plate, Before Cleaning 50X

Figure 32 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating plate after a 12 month corrosion test, before cleaning.

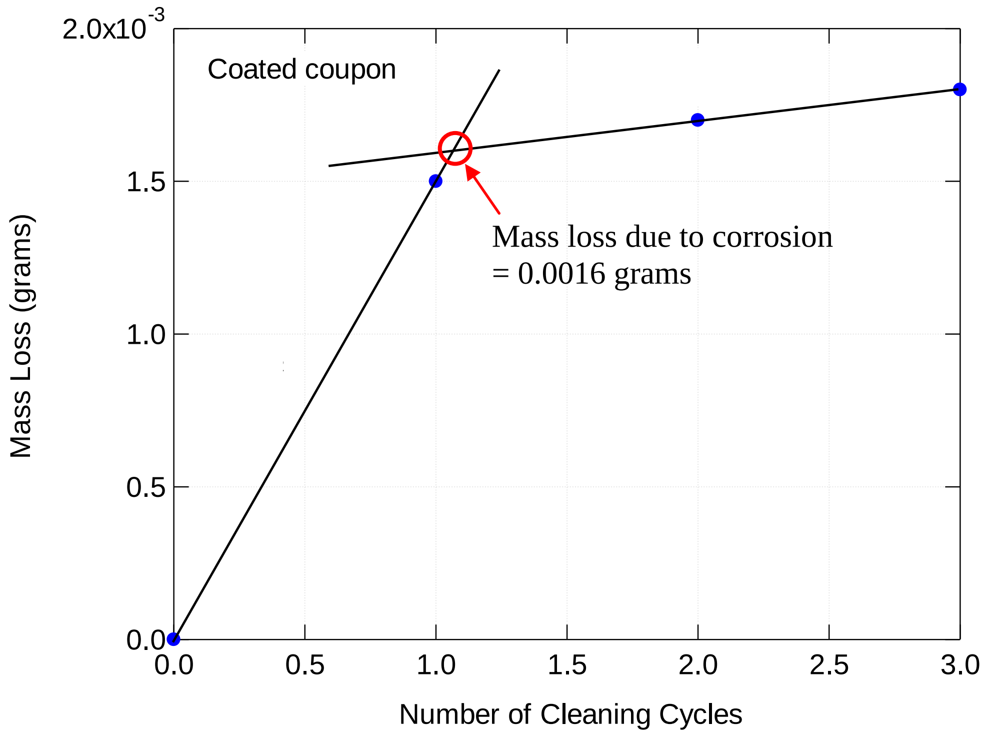


(a) Coated Duplex 2205 Stainless Steel Plate, After Cleaning 10X

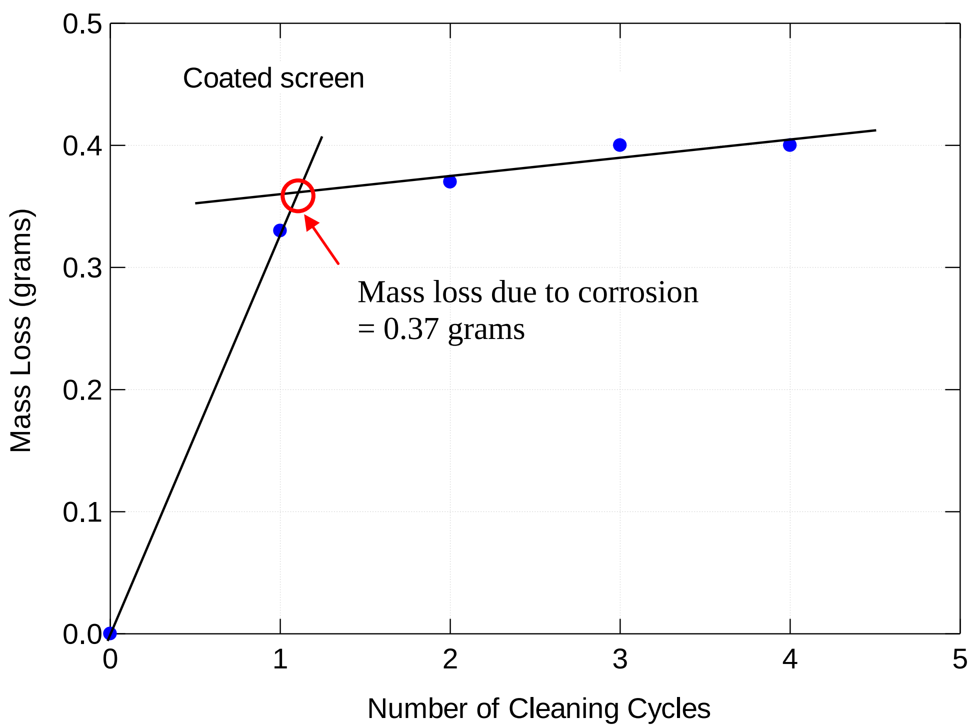


(b) Coated Duplex 2205 Stainless Steel Plate, After Cleaning 50X

Figure 33 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating plate after a 12 month corrosion test, after cleaning.

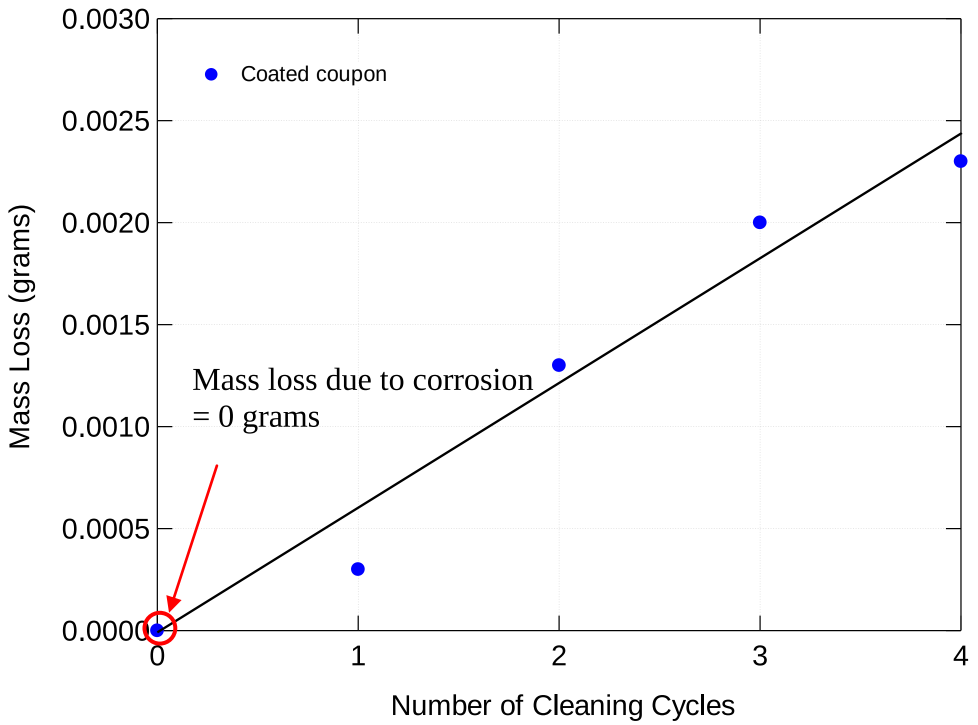


(a)

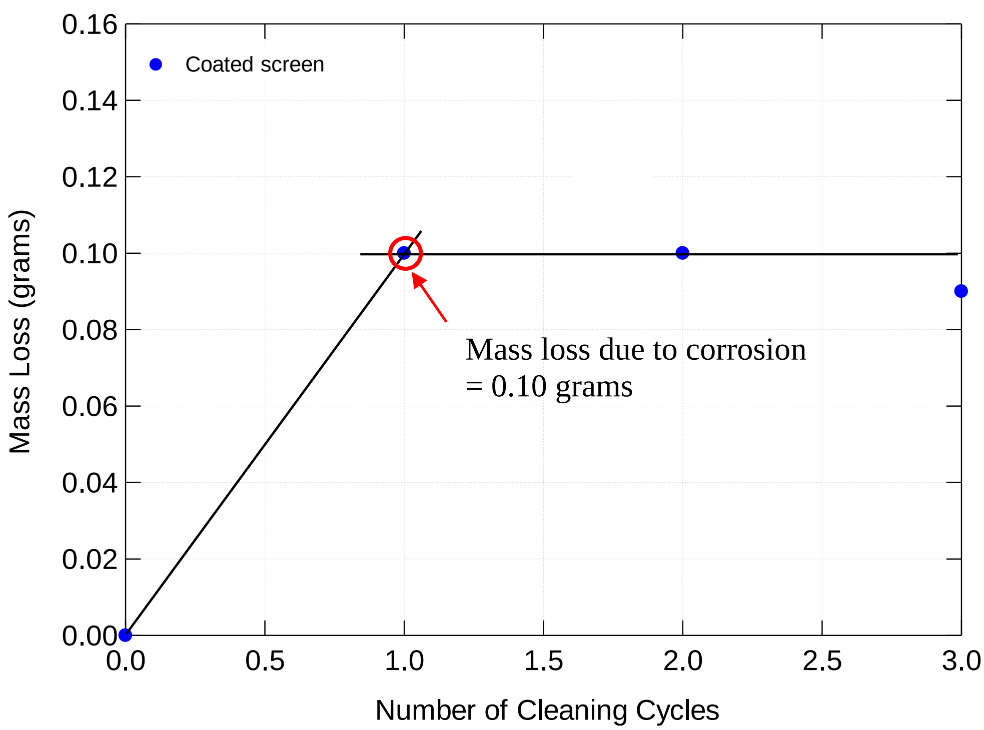


(b)

Figure 34 Mass loss of the duplex 2205 stainless steel with anti-biofouling coating (a) coupon 1 and (b) screen 1 during cleaning.

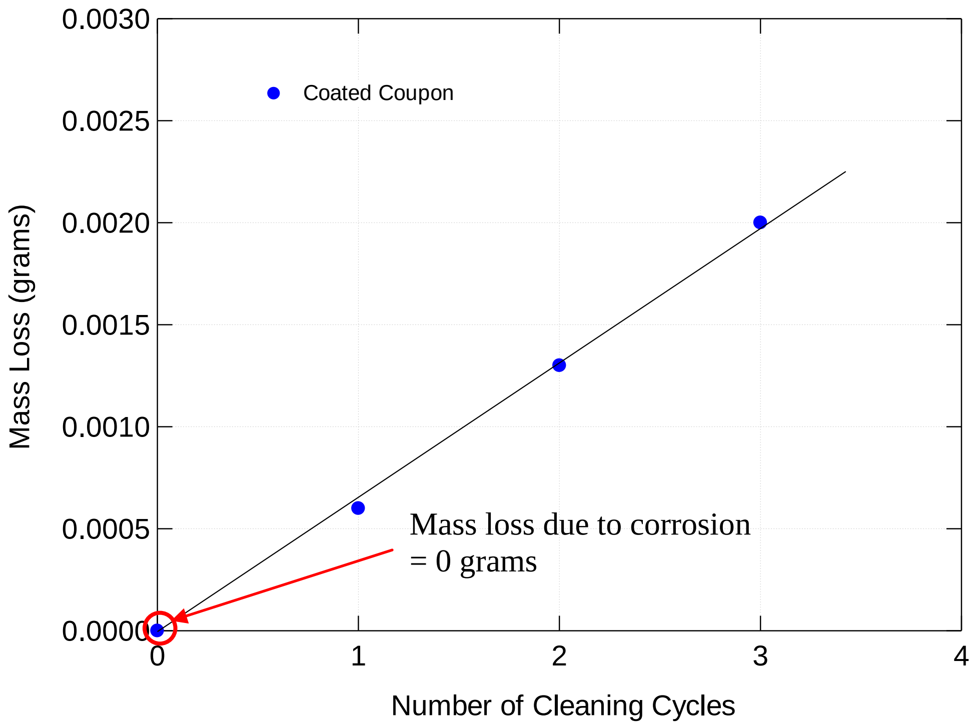


(a)

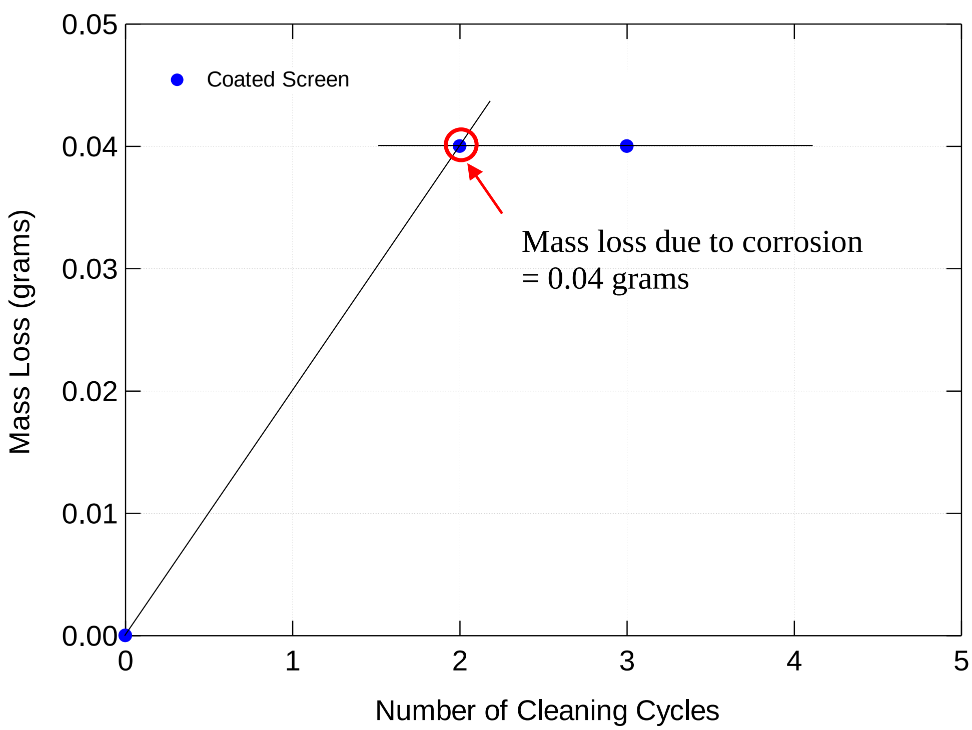


(b)

Figure 35 Mass loss of the duplex 2205 stainless steel with anti-biofouling coating (a) coupon 2 and (b) screen 2 during cleaning.

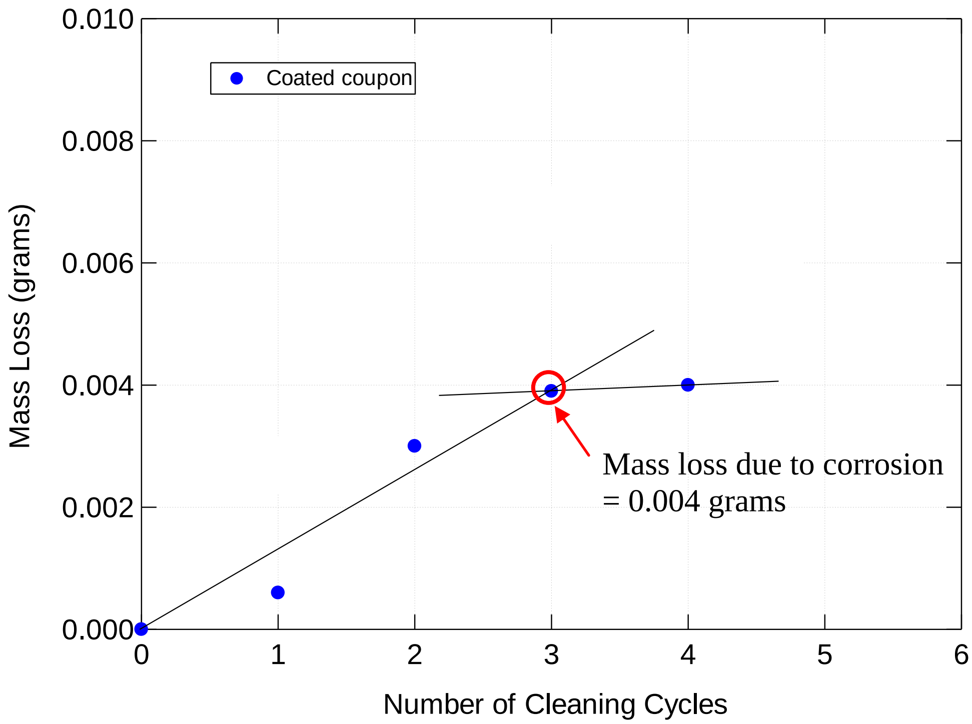


(a)

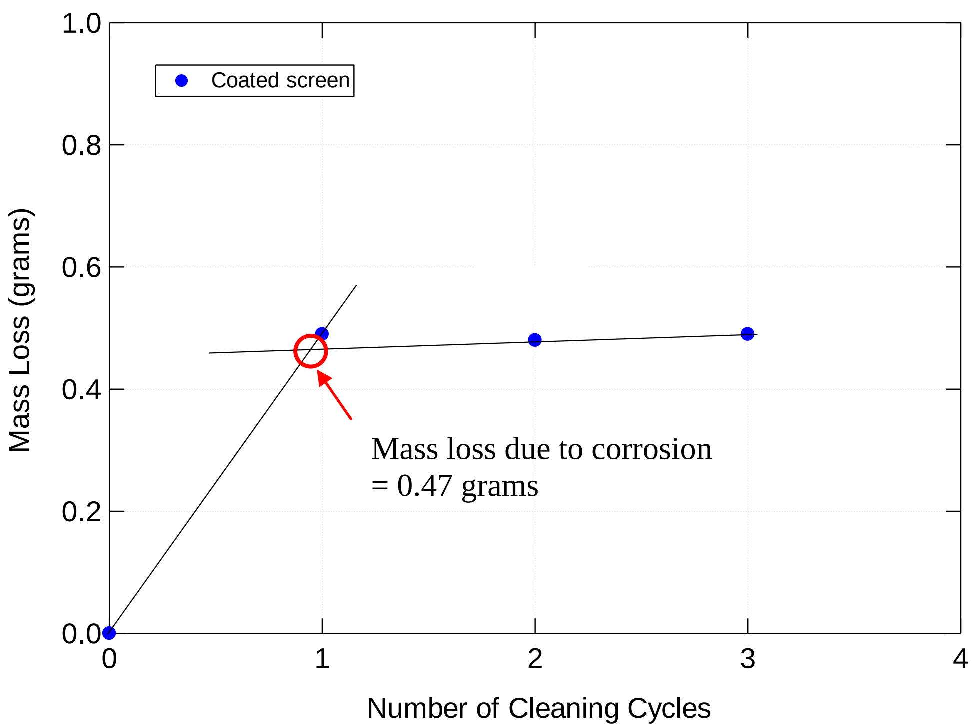


(b)

Figure 36 Mass loss of the duplex 2205 stainless steel with anti-biofouling coating (a) coupon 3 and (b) screen 3 during cleaning.

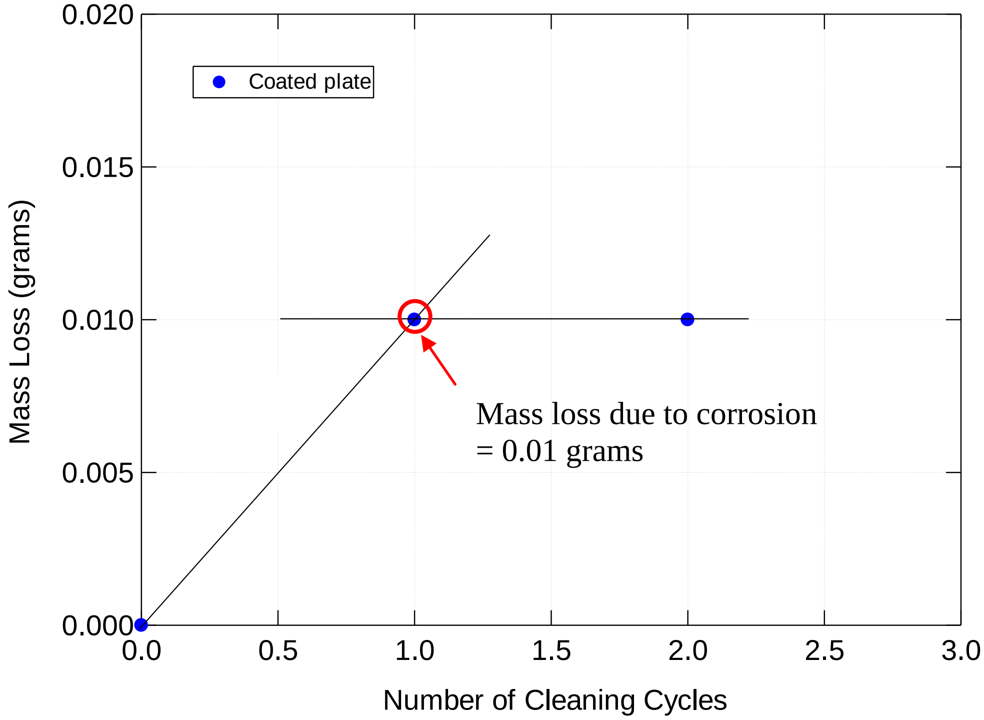


(a)



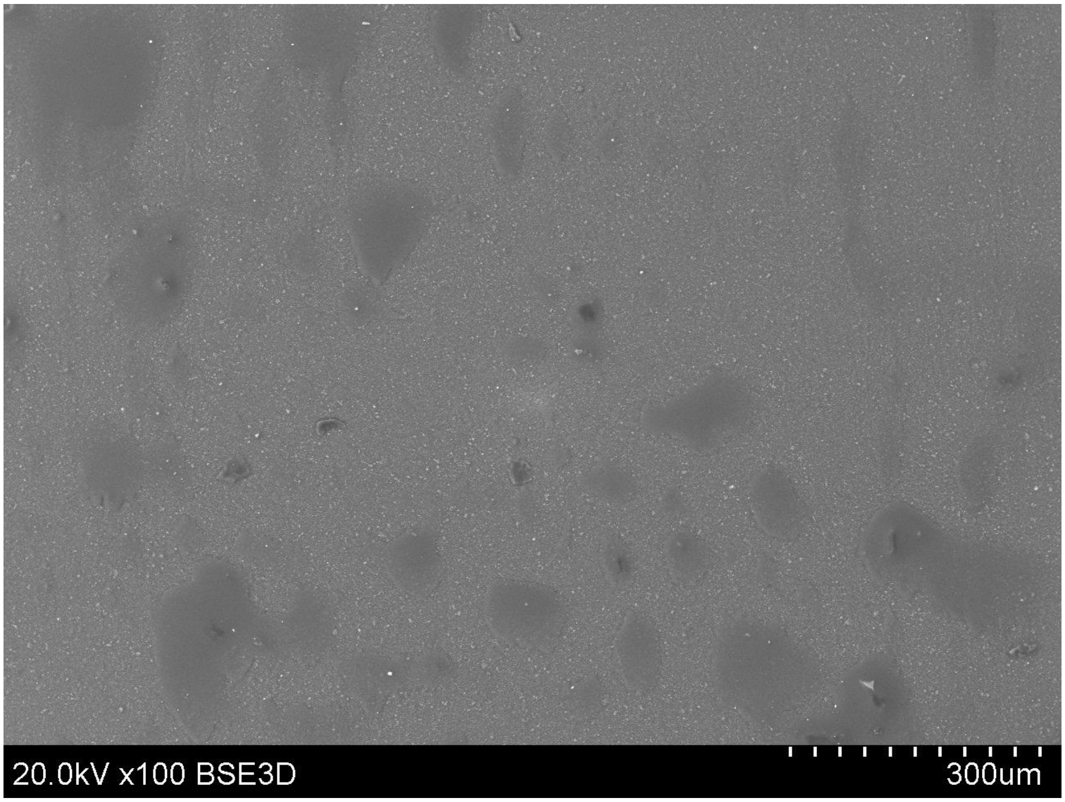
(b)

Figure 37 Mass loss of the duplex 2205 stainless steel with anti-biofouling coating (a) coupon 4 and (b) screen 4 during cleaning.

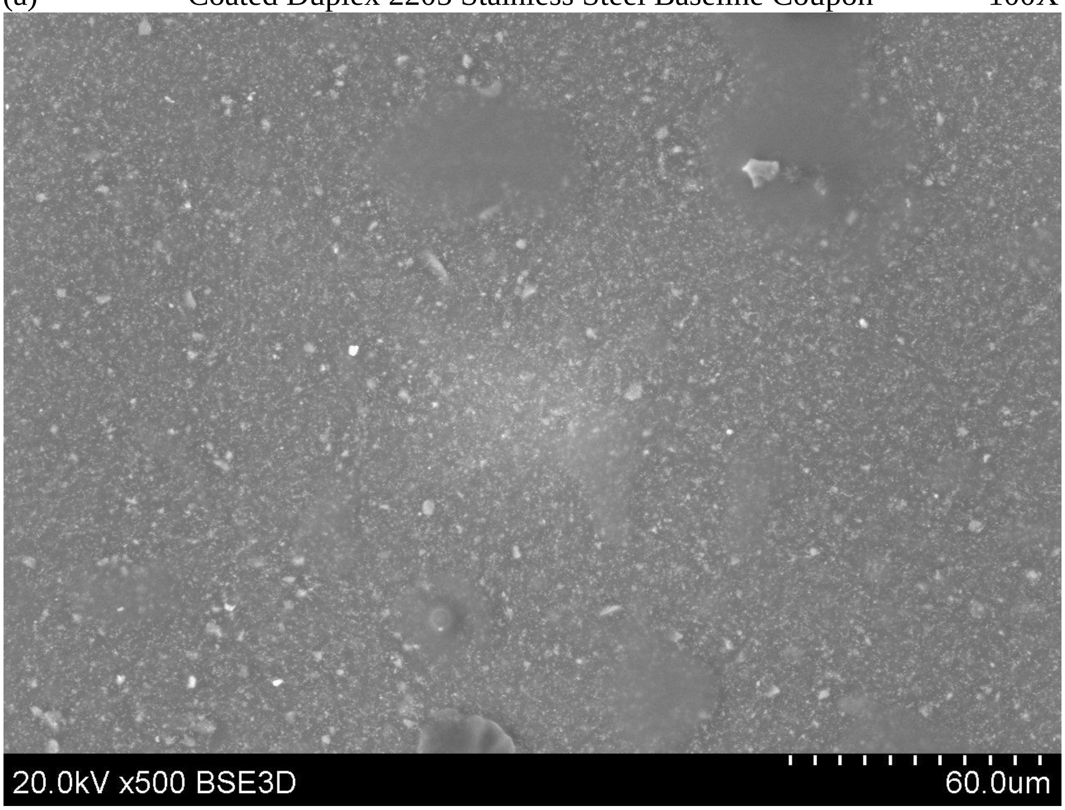


(b)

Figure 38 Mass loss of the duplex 2205 stainless steel with anti-biofouling coating plate during cleaning.

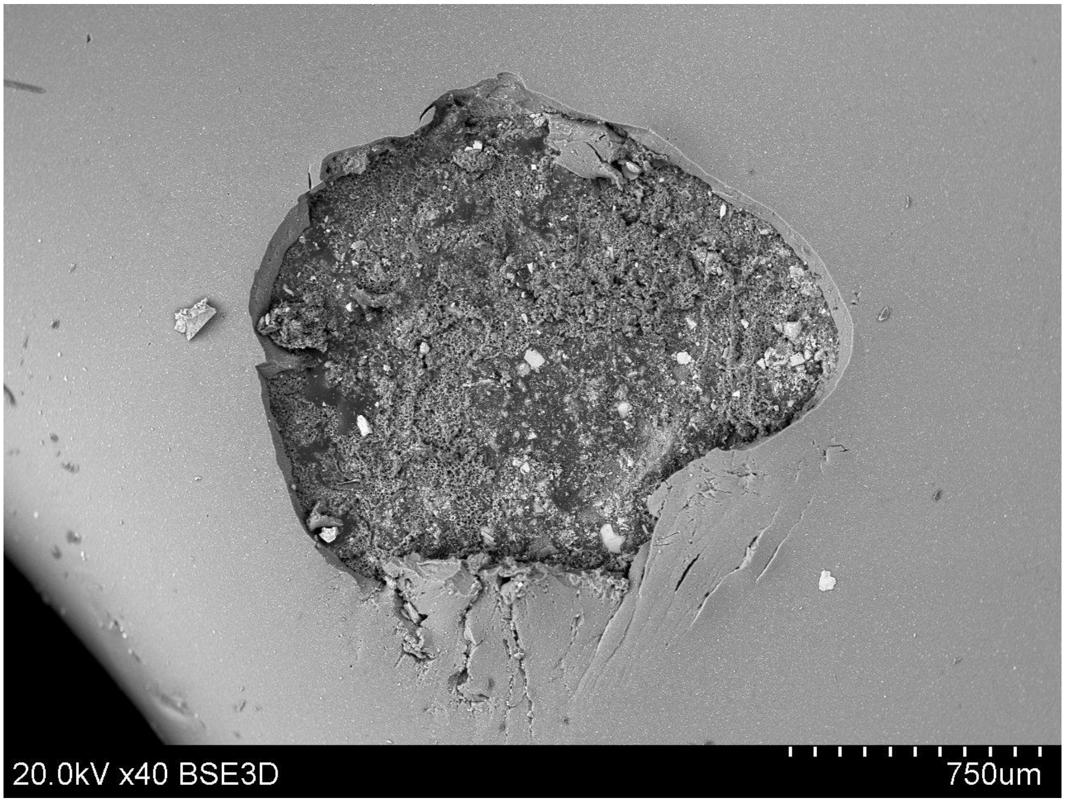


(a) Coated Duplex 2205 Stainless Steel Baseline Coupon 100X

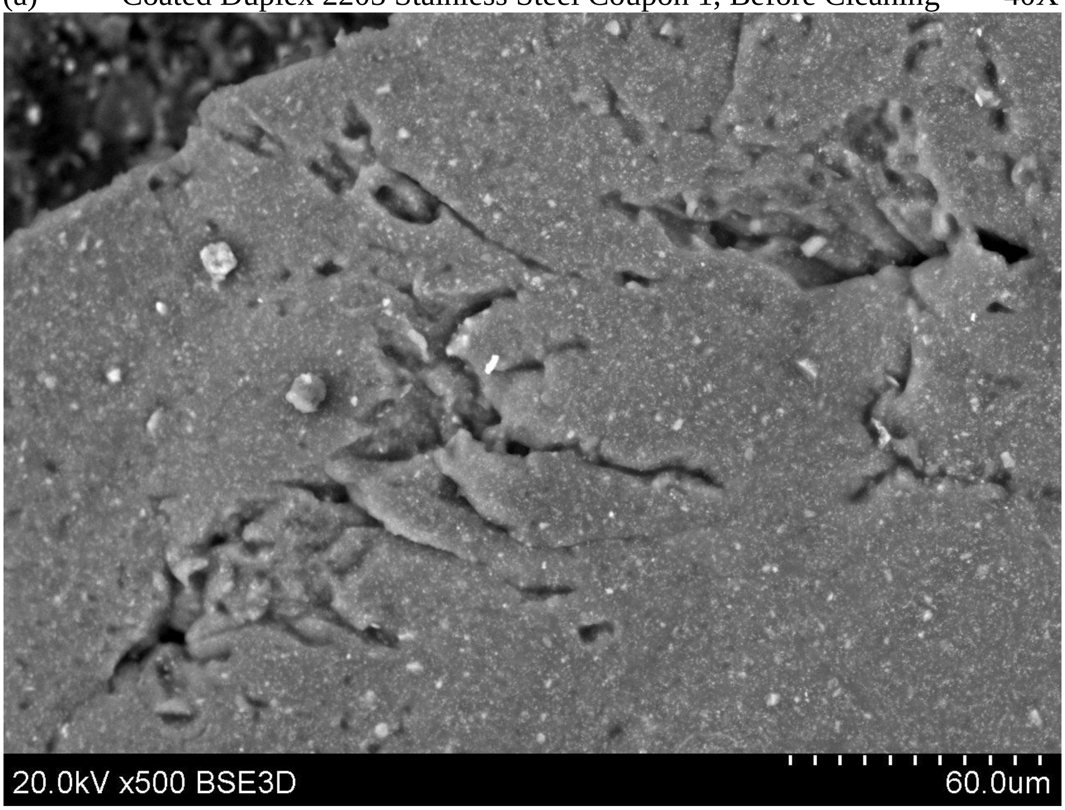


(b) Coated Duplex 2205 Stainless Steel Baseline Coupon 500X

Figure 39 Scanning electron micrographs of the duplex 2205 stainless steel with anti-biofouling coating baseline coupon.

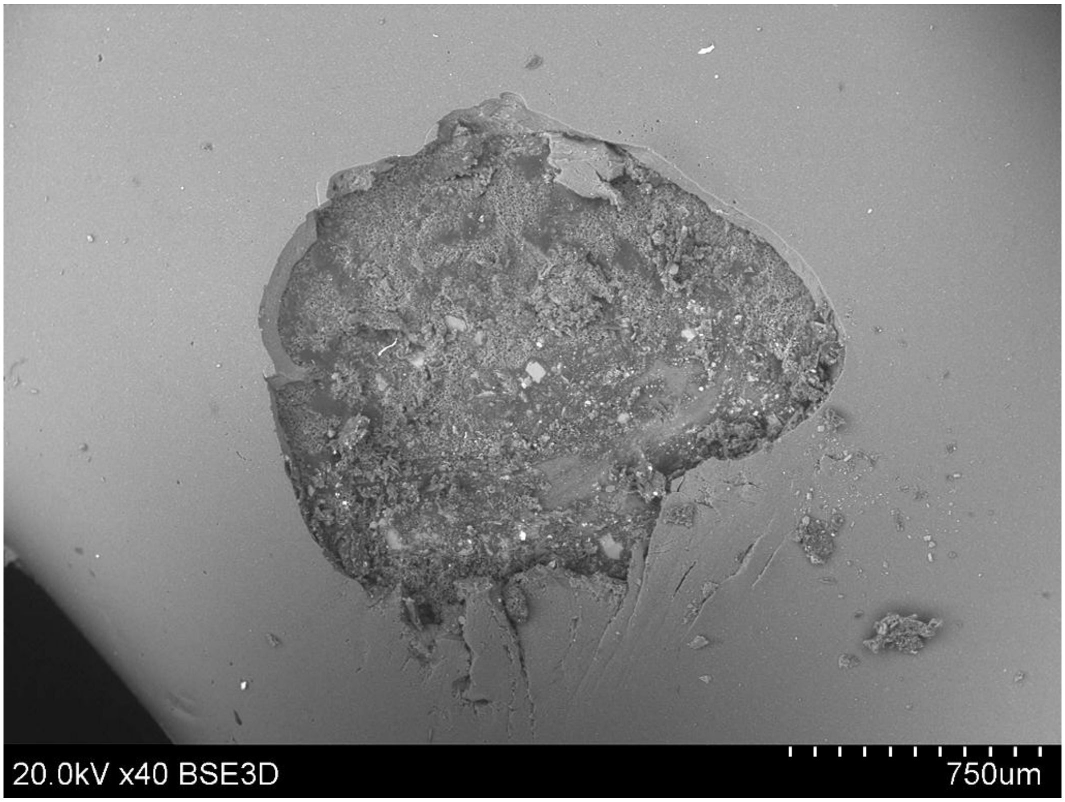


(a) Coated Duplex 2205 Stainless Steel Coupon 1, Before Cleaning 40X

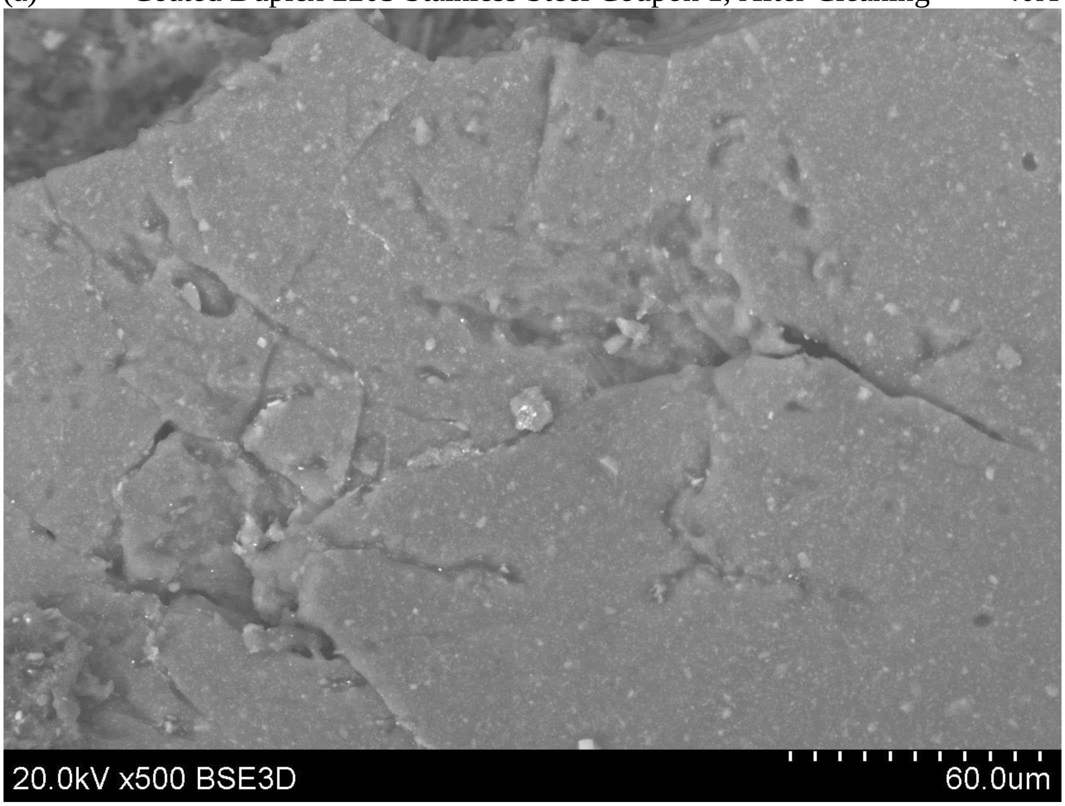


(b) Coated Duplex 2205 Stainless Steel Coupon 1, Before Cleaning 500X

Figure 40 Scanning electron micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 1 after a 3 month corrosion test, before cleaning.

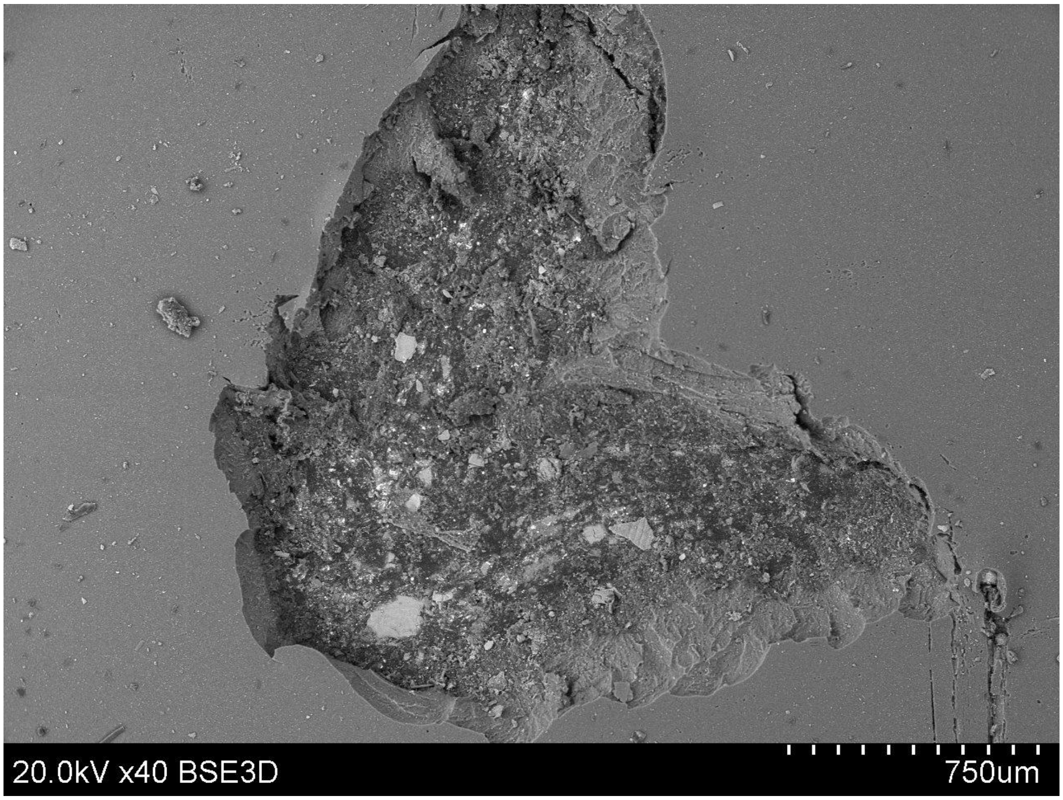


(a) Coated Duplex 2205 Stainless Steel Coupon 1, After Cleaning 40X

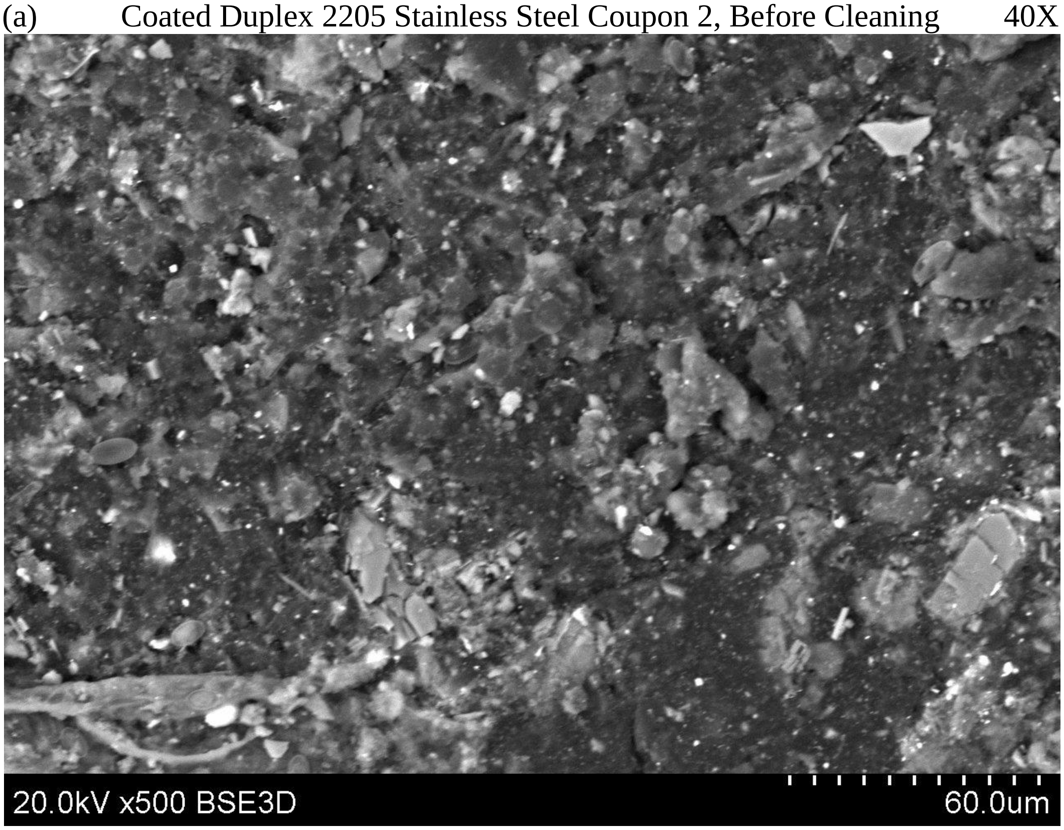


(b) Coated Duplex 2205 Stainless Steel Coupon 1, After Cleaning 500X

Figure 41 Scanning electron micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 1 after a 3 month corrosion test, after cleaning.

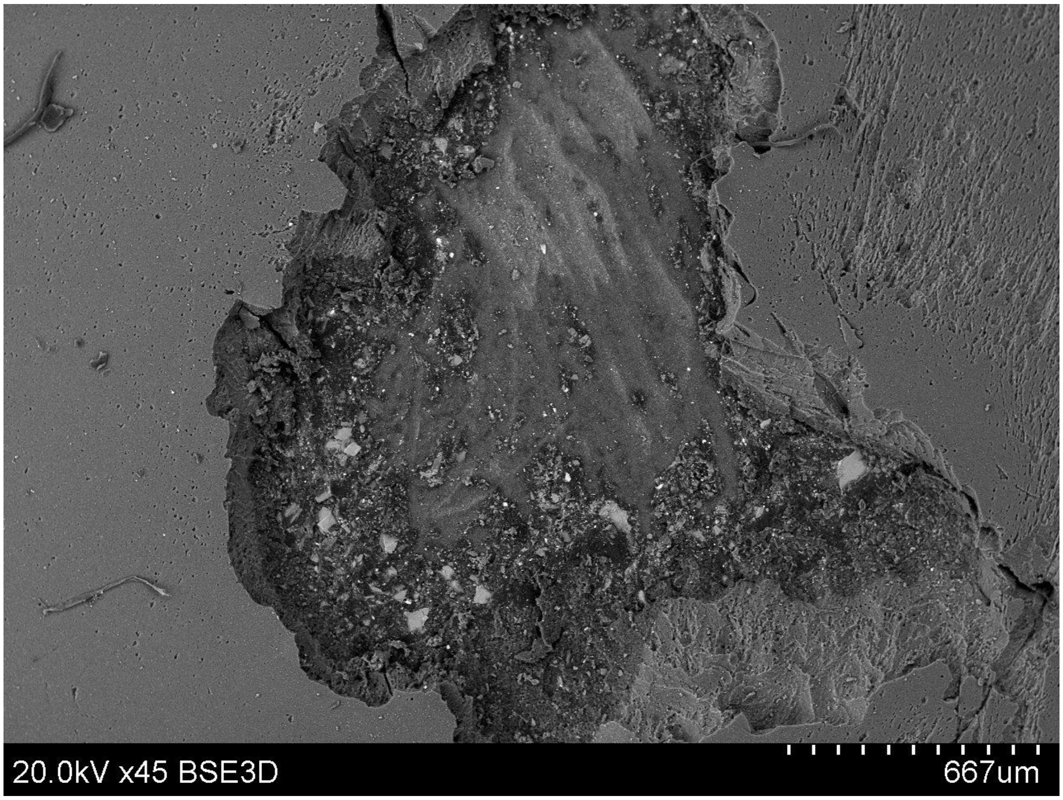


(a) Coated Duplex 2205 Stainless Steel Coupon 2, Before Cleaning 40X

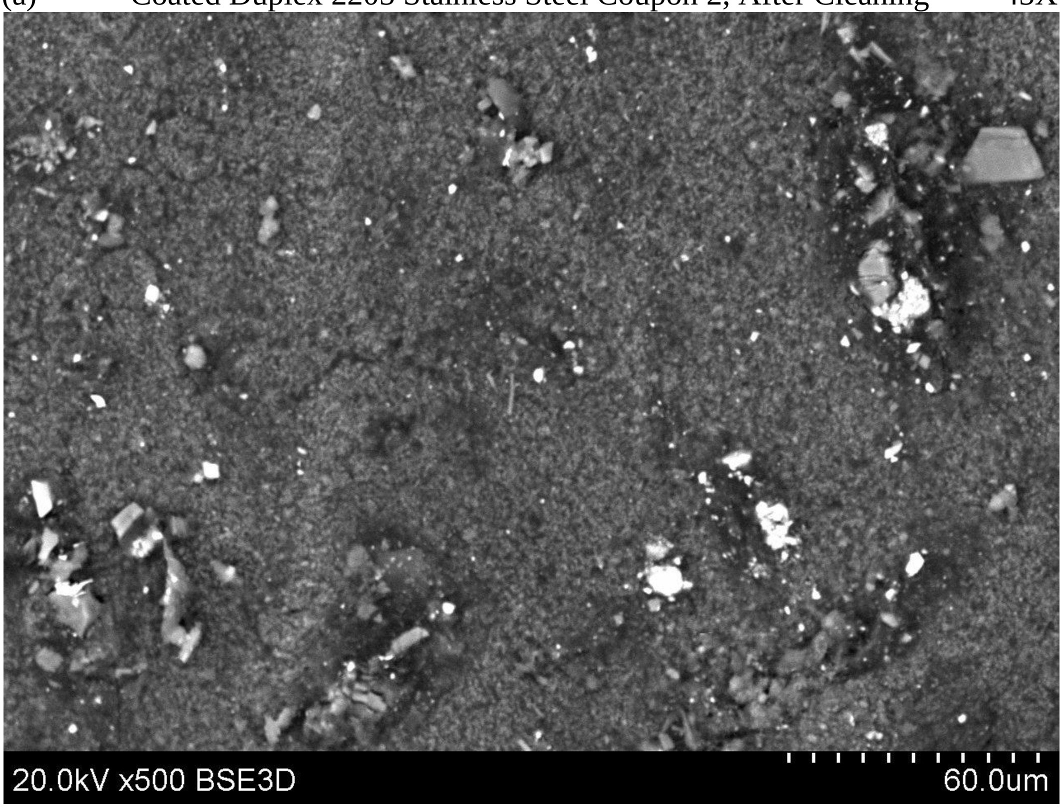


(b) Coated Duplex 2205 Stainless Steel Coupon 2, Before Cleaning 500X

Figure 42 Scanning electron micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 2 after a 6 month corrosion test, before cleaning.

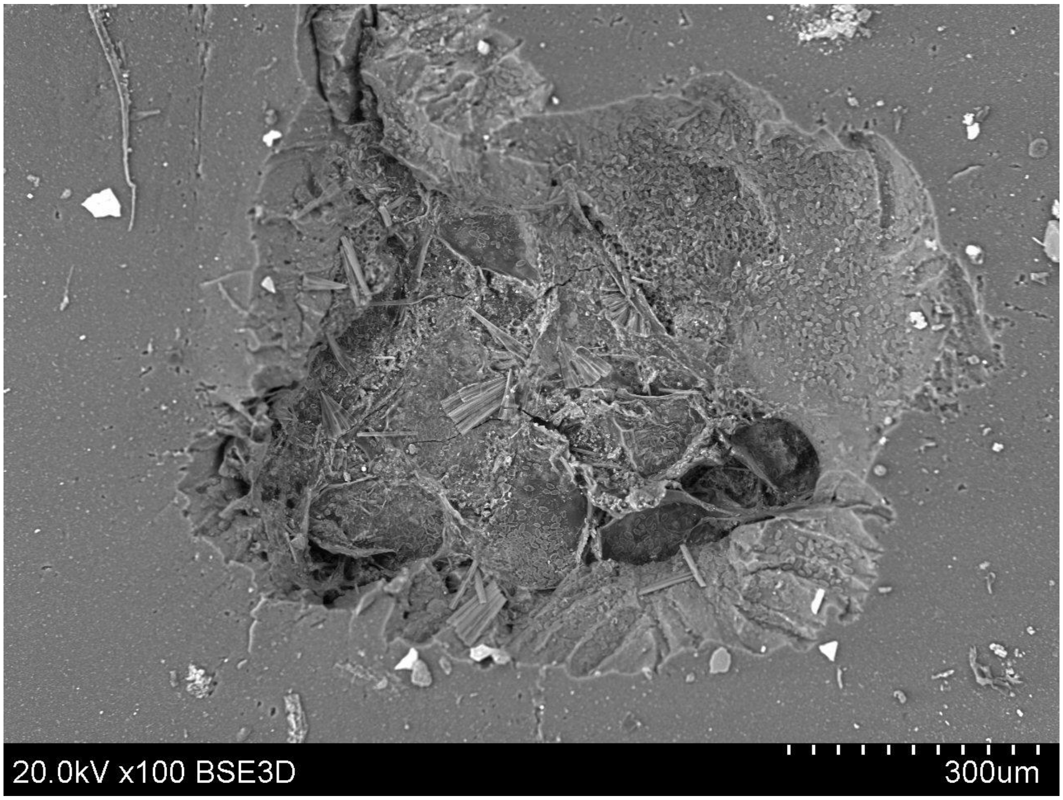


(a) Coated Duplex 2205 Stainless Steel Coupon 2, After Cleaning 45X

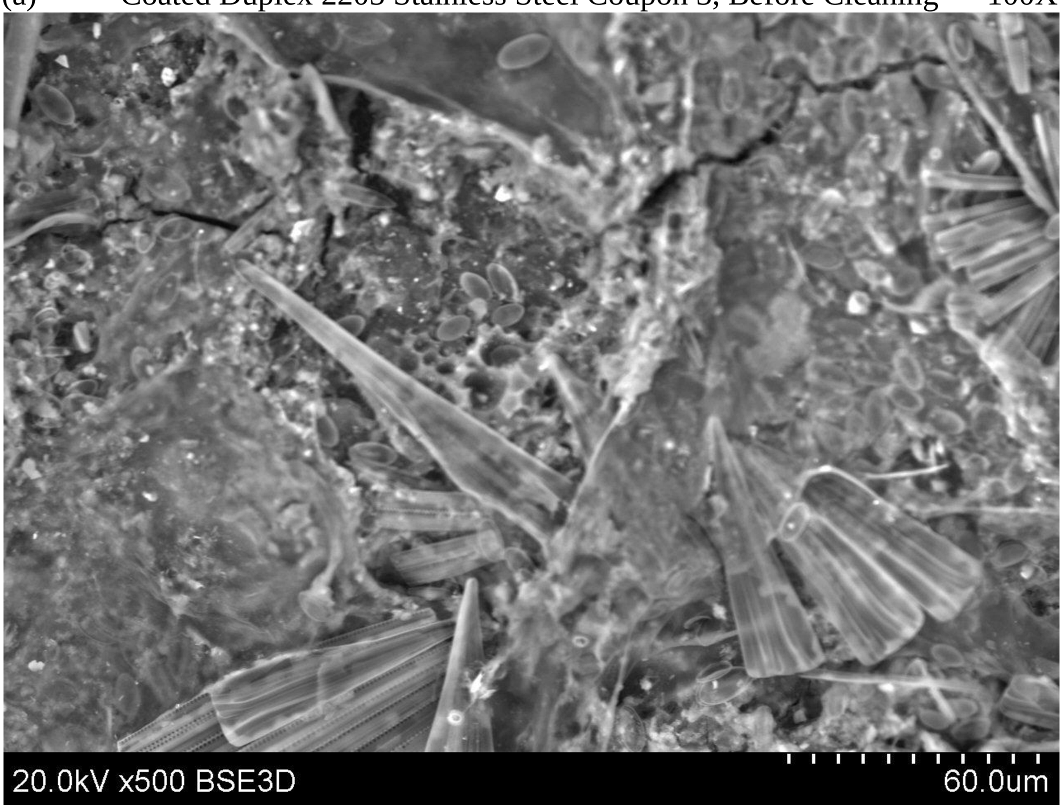


(b) Coated Duplex 2205 Stainless Steel Coupon 2, After Cleaning 500X

Figure 43 Scanning electron micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 2 after a 6 month corrosion test, after cleaning.

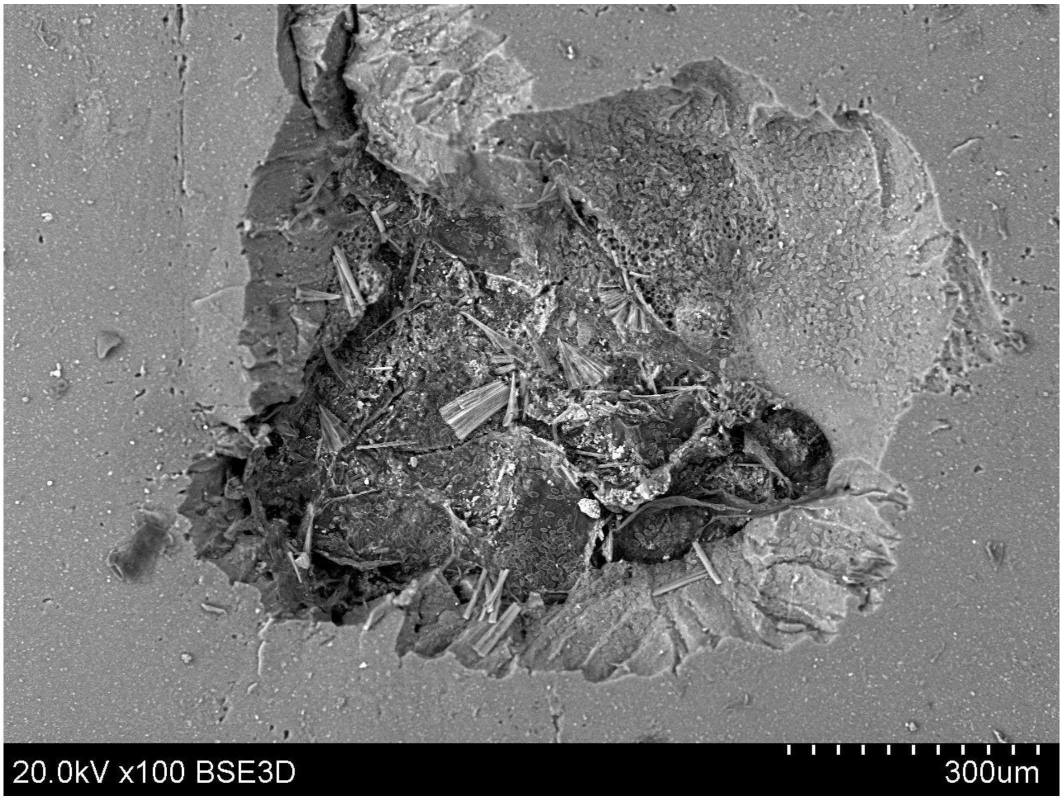


(a) Coated Duplex 2205 Stainless Steel Coupon 3, Before Cleaning 100X

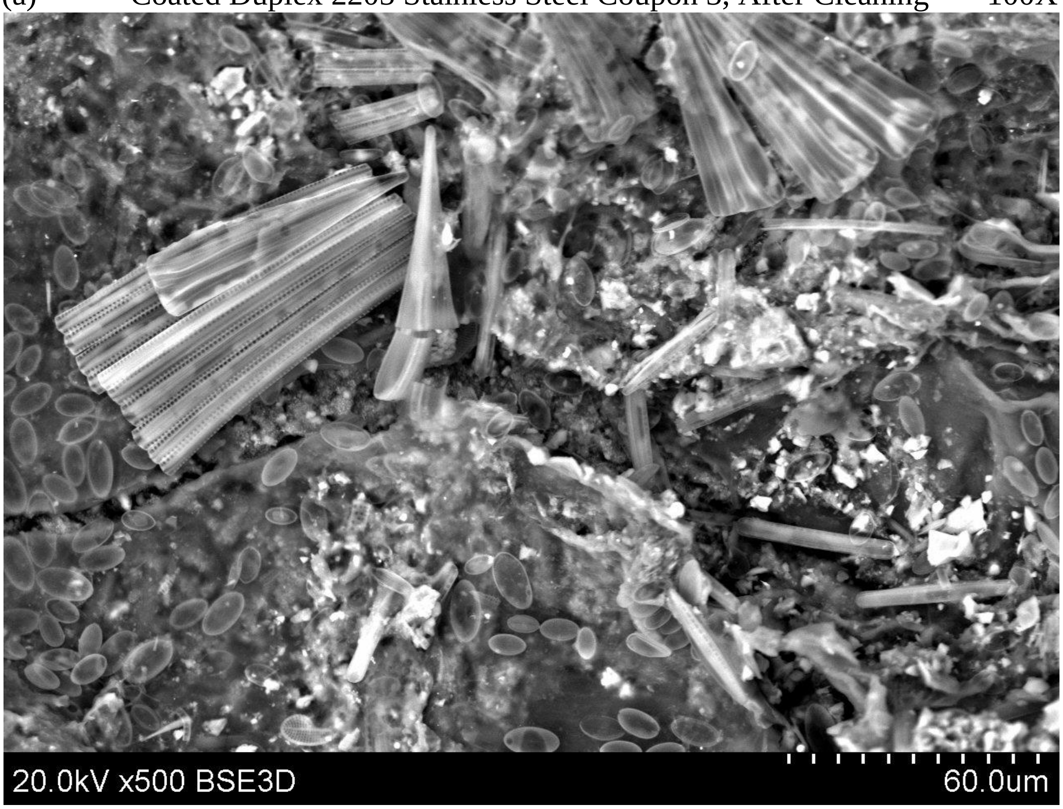


(b) Coated Duplex 2205 Stainless Steel Coupon 3, Before Cleaning 500X

Figure 44 Scanning electron micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 3 after a 10 month corrosion test, before cleaning.

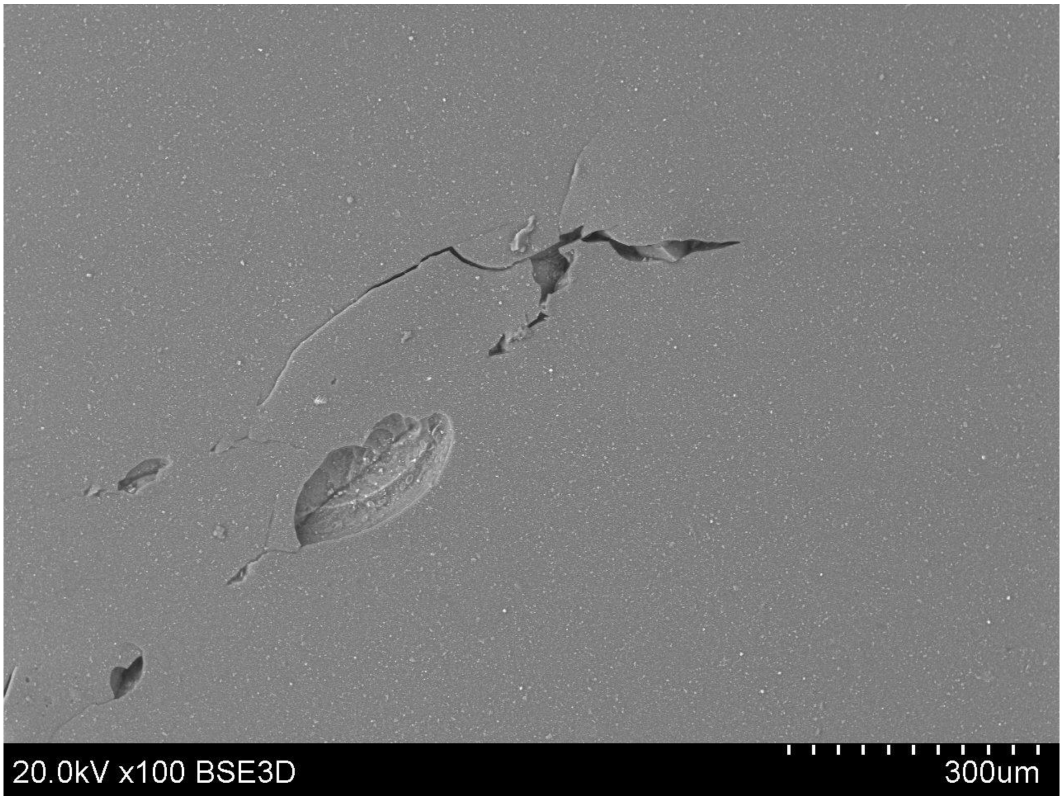


(a) Coated Duplex 2205 Stainless Steel Coupon 3, After Cleaning 100X

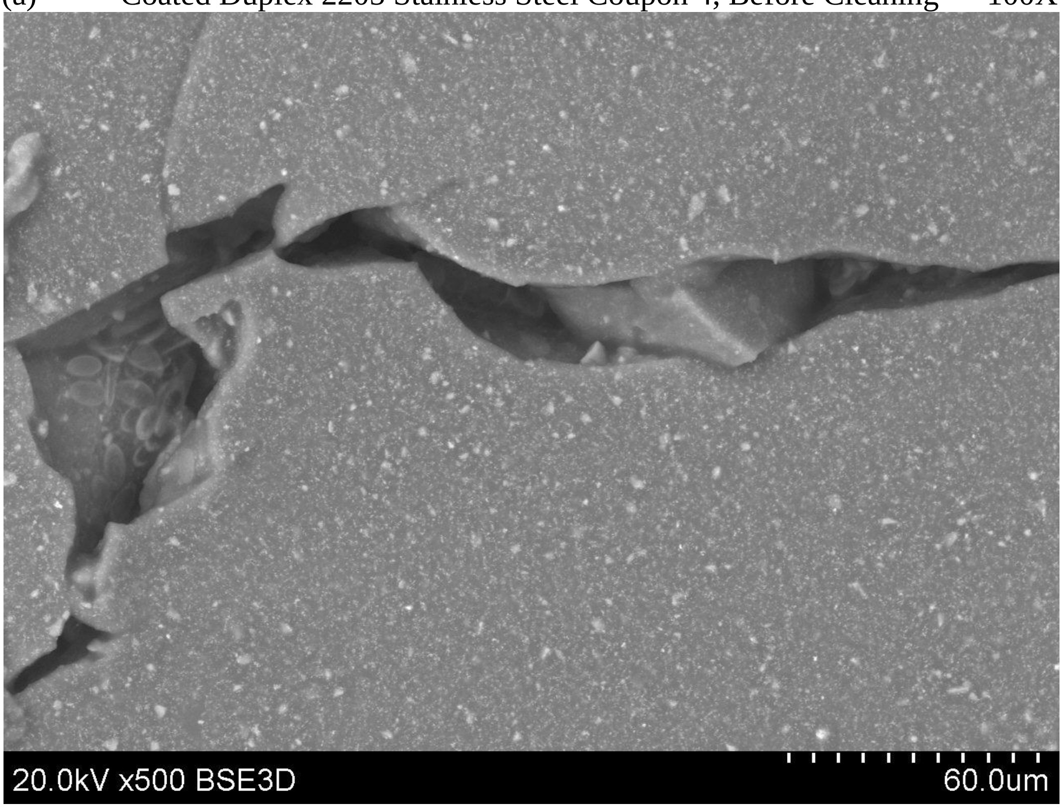


(b) Coated Duplex 2205 Stainless Steel Coupon 3, After Cleaning 500X

Figure 45 Scanning electron micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 3 after a 10 month corrosion test, after cleaning.

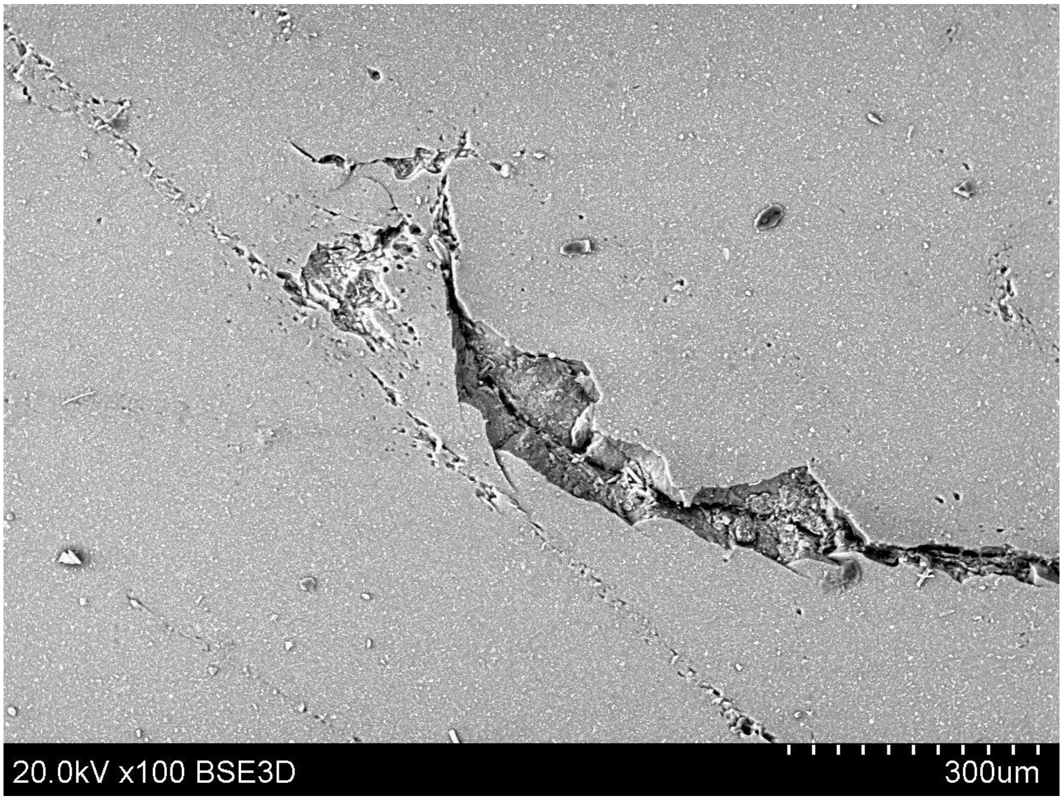


(a) Coated Duplex 2205 Stainless Steel Coupon 4, Before Cleaning 100X

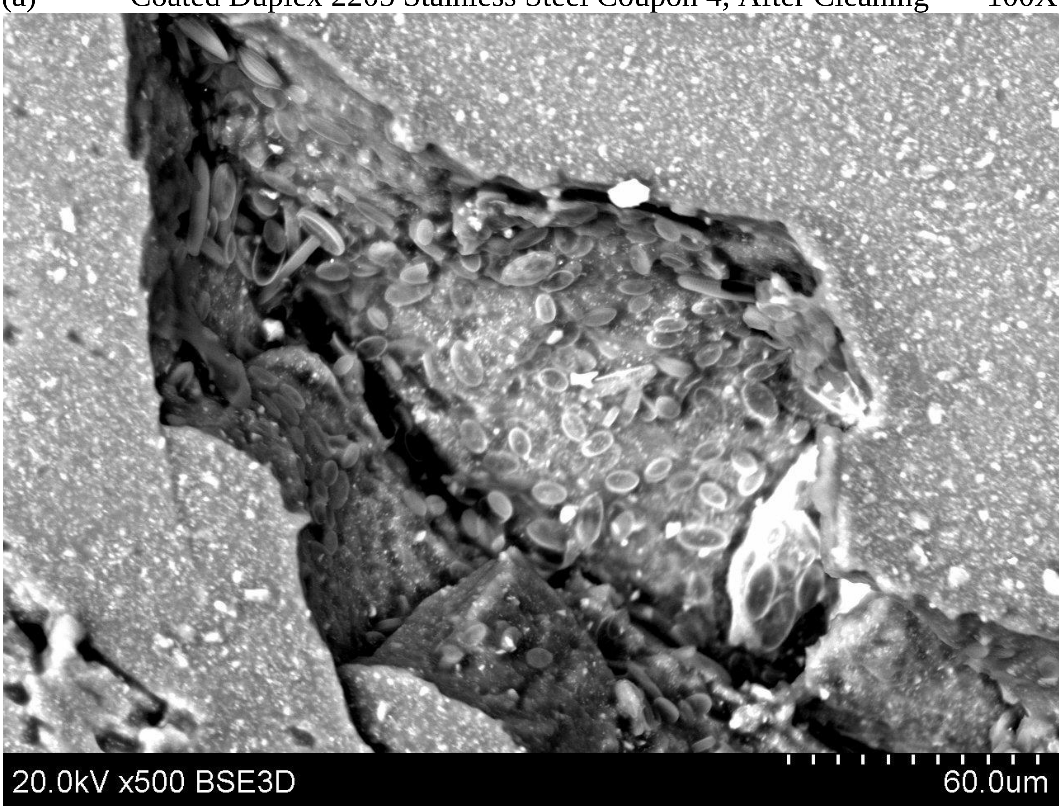


(b) Coated Duplex 2205 Stainless Steel Coupon 4, Before Cleaning 500X

Figure 46 Scanning electron micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 4 after a 12 month corrosion test, before cleaning.

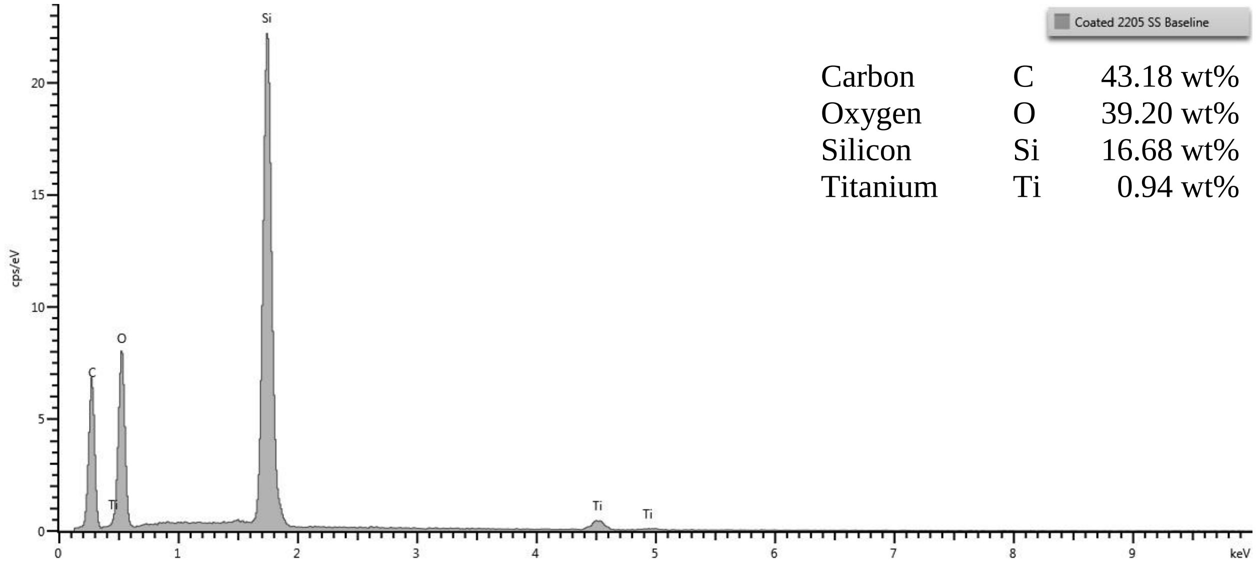


(a) Coated Duplex 2205 Stainless Steel Coupon 4, After Cleaning 100X



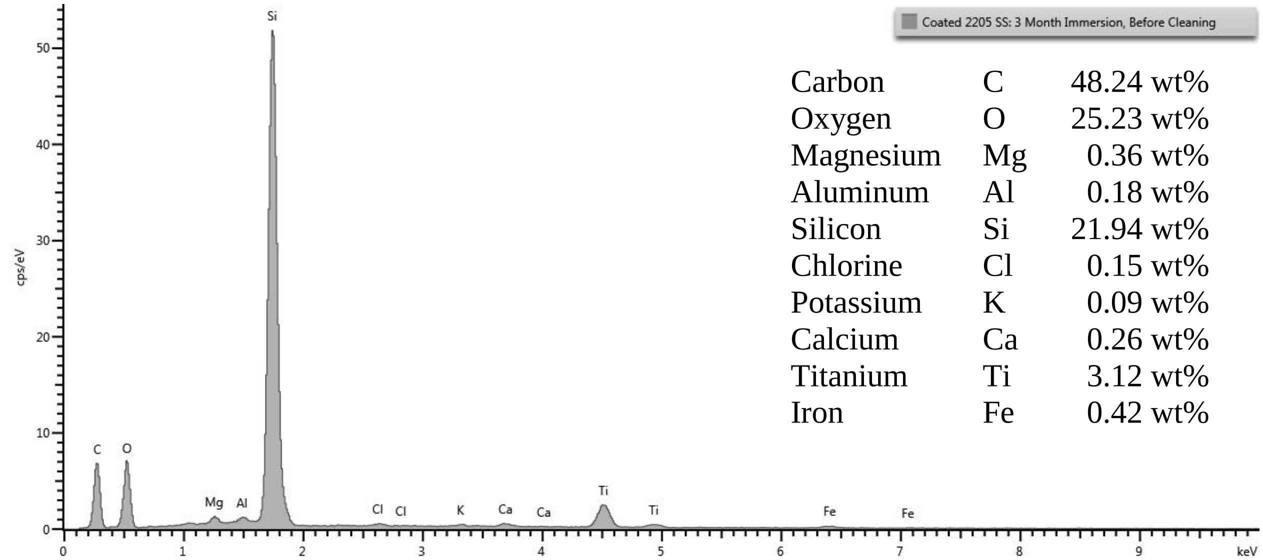
(b) Coated Duplex 2205 Stainless Steel Coupon 4, After Cleaning 500X

Figure 47 Scanning electron micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 4 after a 12 month corrosion test, after cleaning.

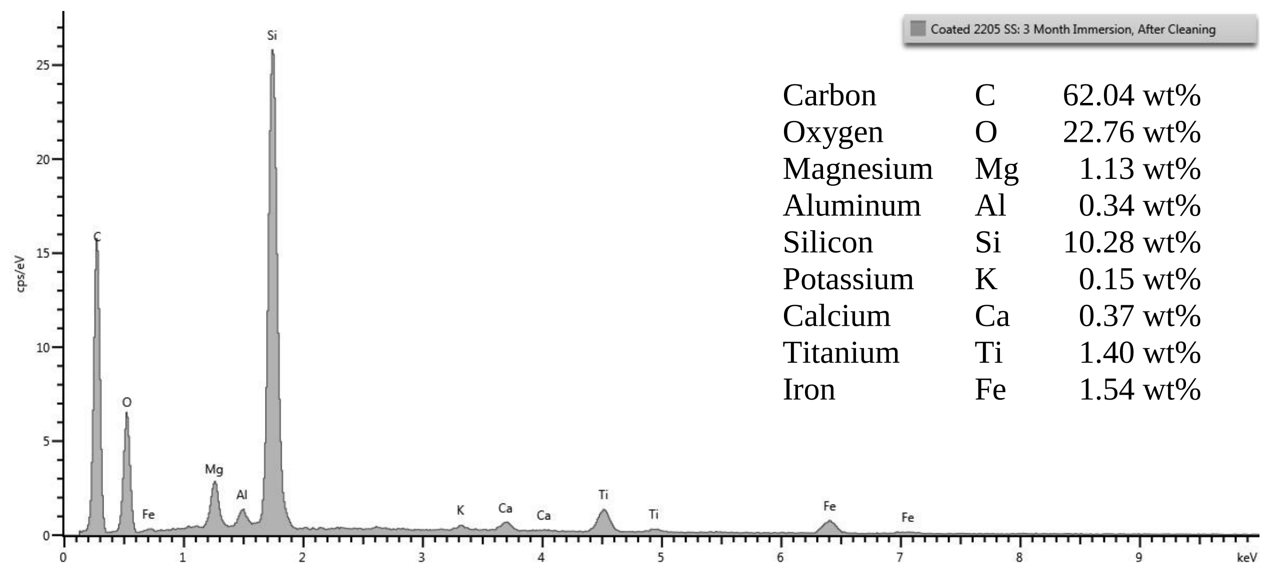


(a) Coated Duplex 2205 Stainless Steel Baseline Coupon

Figure 48 Energy dispersive x-ray spectra of the duplex 2205 stainless steel with anti-biofouling coating baseline coupon.

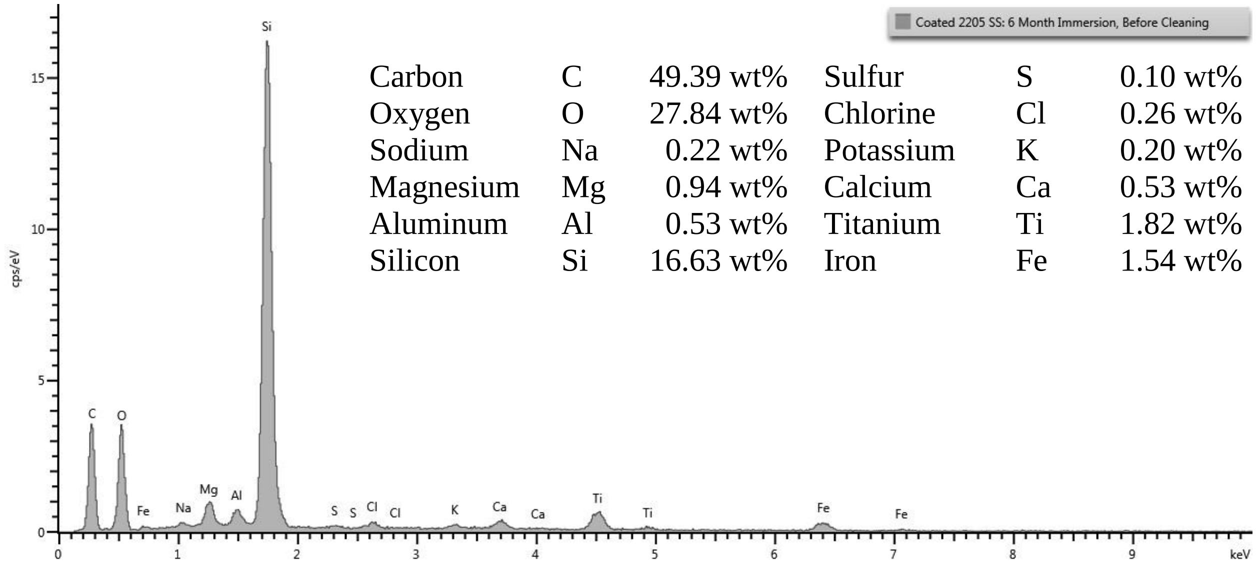


(a) Coated Duplex 2205 Stainless Steel Coupon 1, Before Cleaning

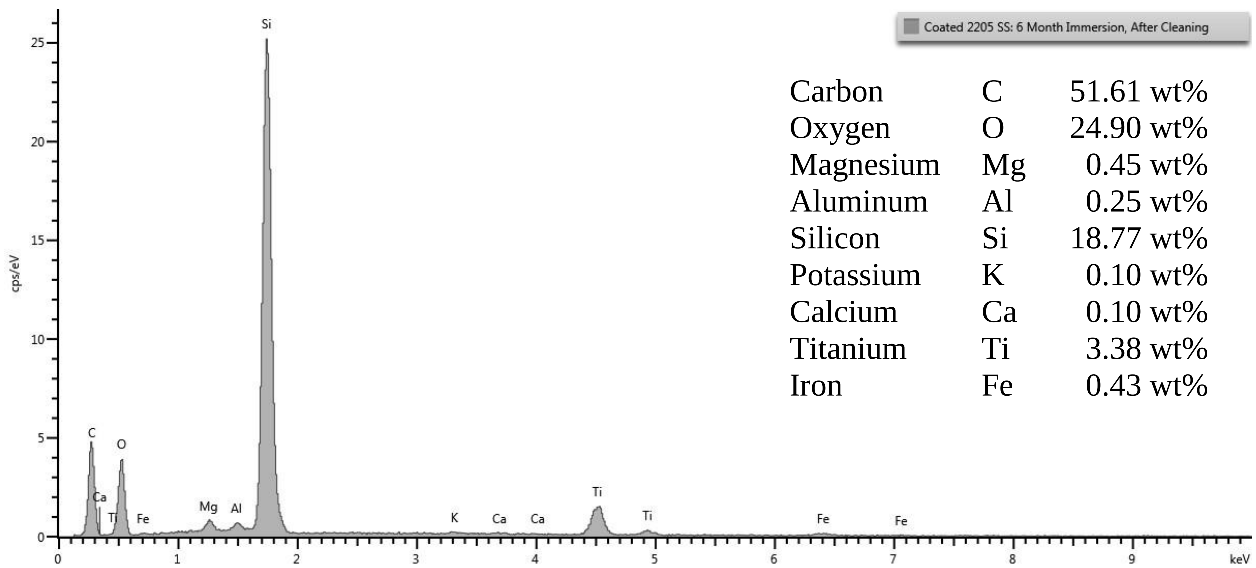


(b) Coated Duplex 2205 Stainless Steel Coupon 1, After Cleaning

Figure 49 Energy dispersive x-ray spectra of duplex 2205 stainless steel with anti-biofouling coating coupon 1 after a 3 month corrosion test (a) before cleaning and (b) after cleaning.

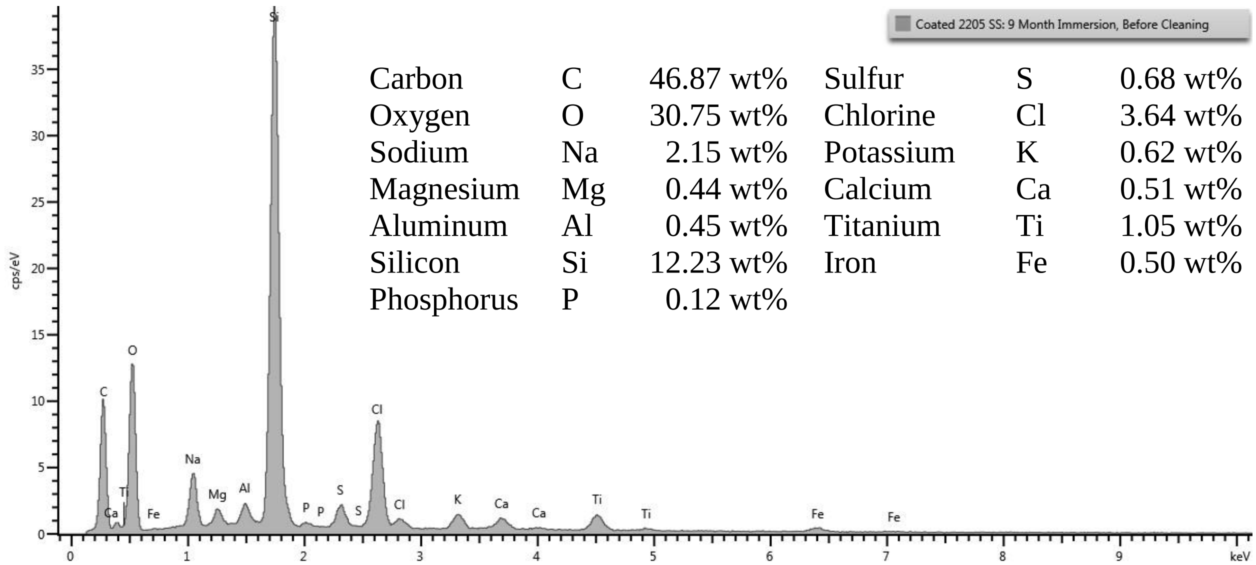


(a) Coated Duplex 2205 Stainless Steel Coupon 2, Before Cleaning

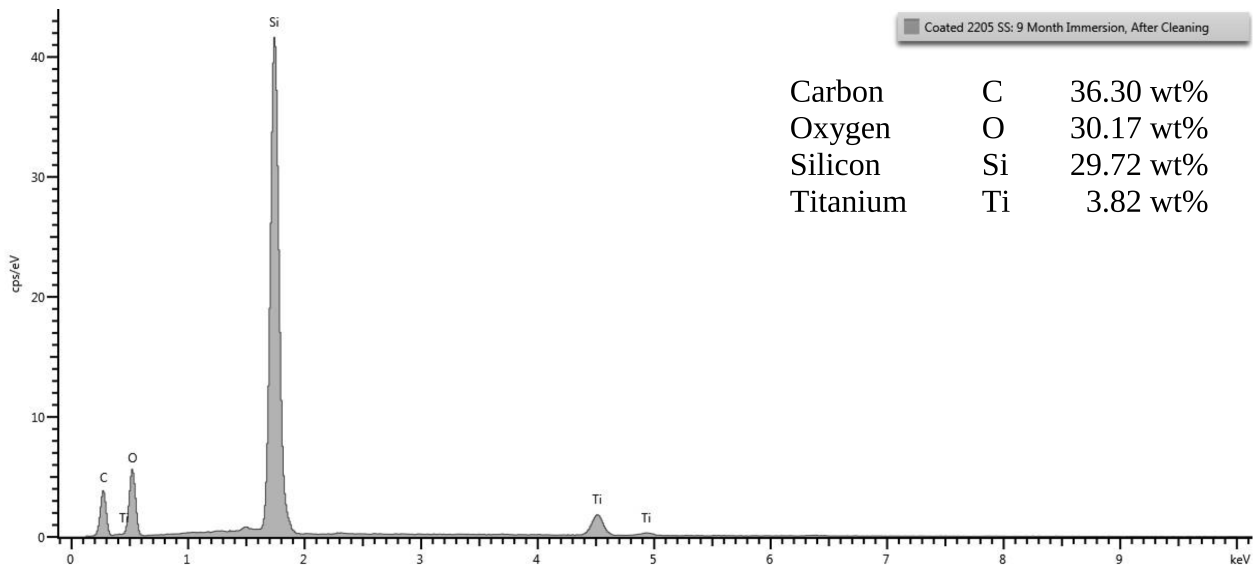


(b) Coated Duplex 2205 Stainless Steel Coupon 2, After Cleaning

Figure 50 Energy dispersive x-ray spectra of duplex 2205 stainless steel with anti-biofouling coating coupon 2 after a 6 month corrosion test (a) before cleaning and (b) after cleaning.

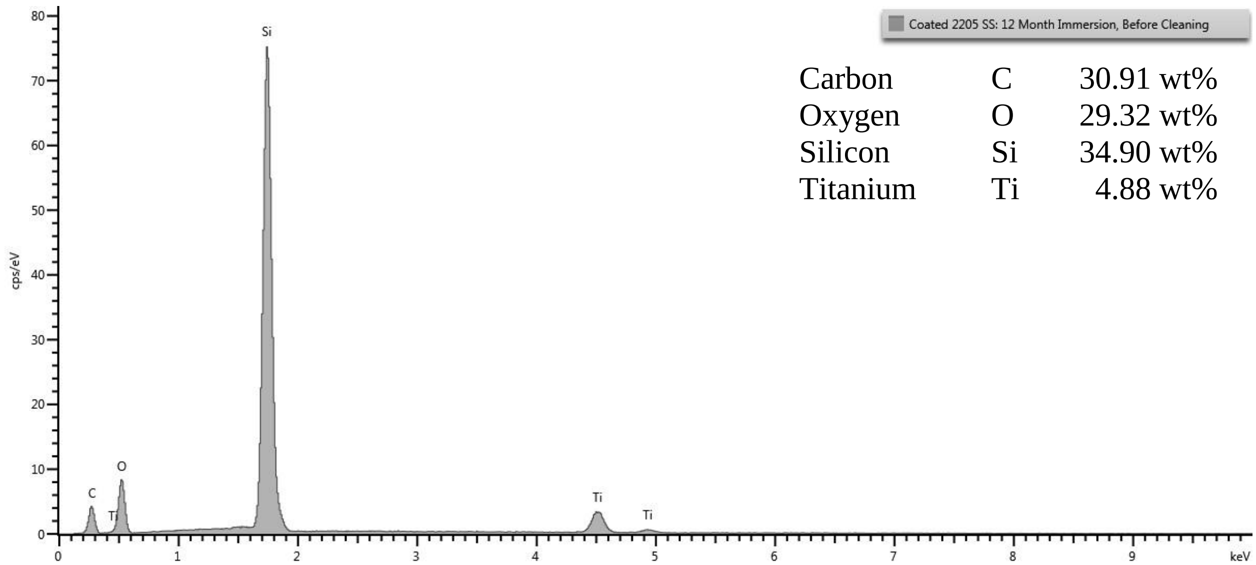


(a) Coated Duplex 2205 Stainless Steel Coupon 3, Before Cleaning

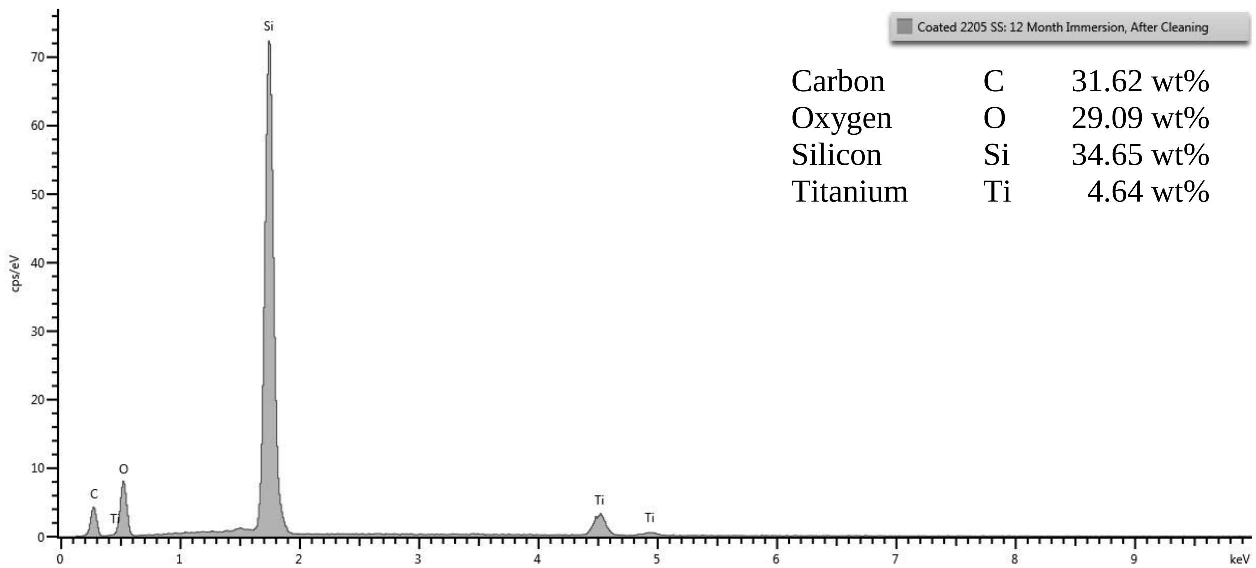


(b) Coated Duplex 2205 Stainless Steel Coupon 3, After Cleaning

Figure 51 Energy dispersive x-ray spectra of duplex 2205 stainless steel with anti-biofouling coating coupon 3 after a 10 month corrosion test (a) before cleaning and (b) after cleaning.

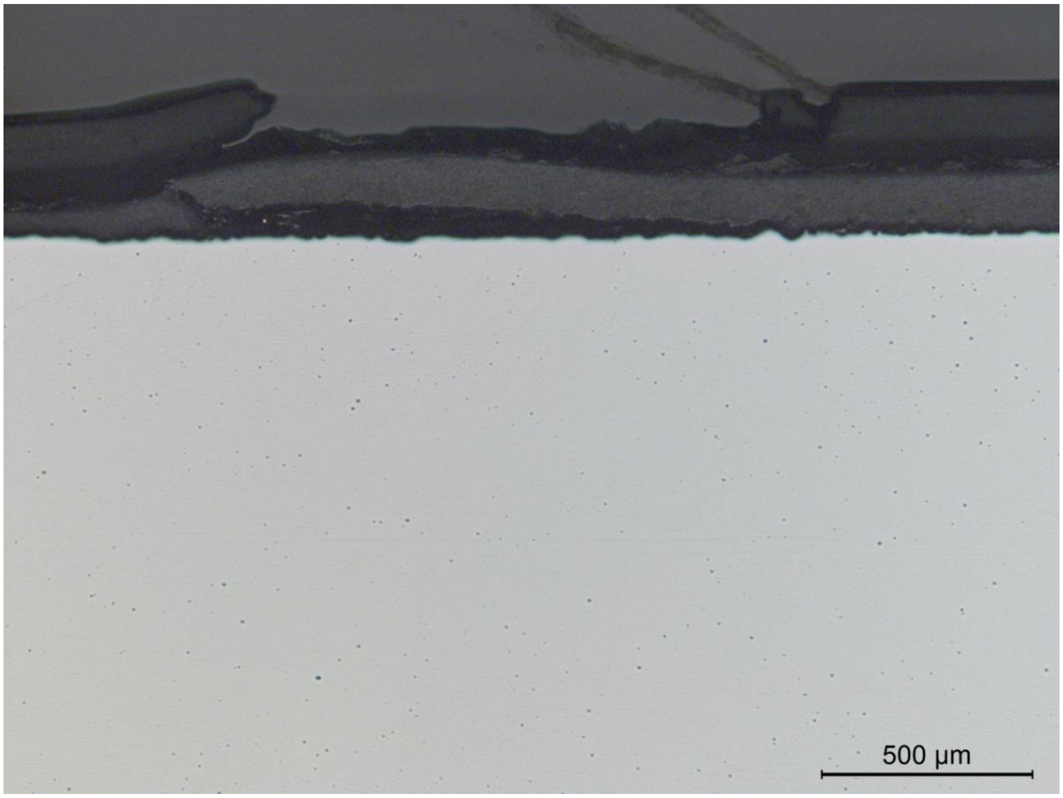


(a) Coated Duplex 2205 Stainless Steel Coupon 4, Before Cleaning

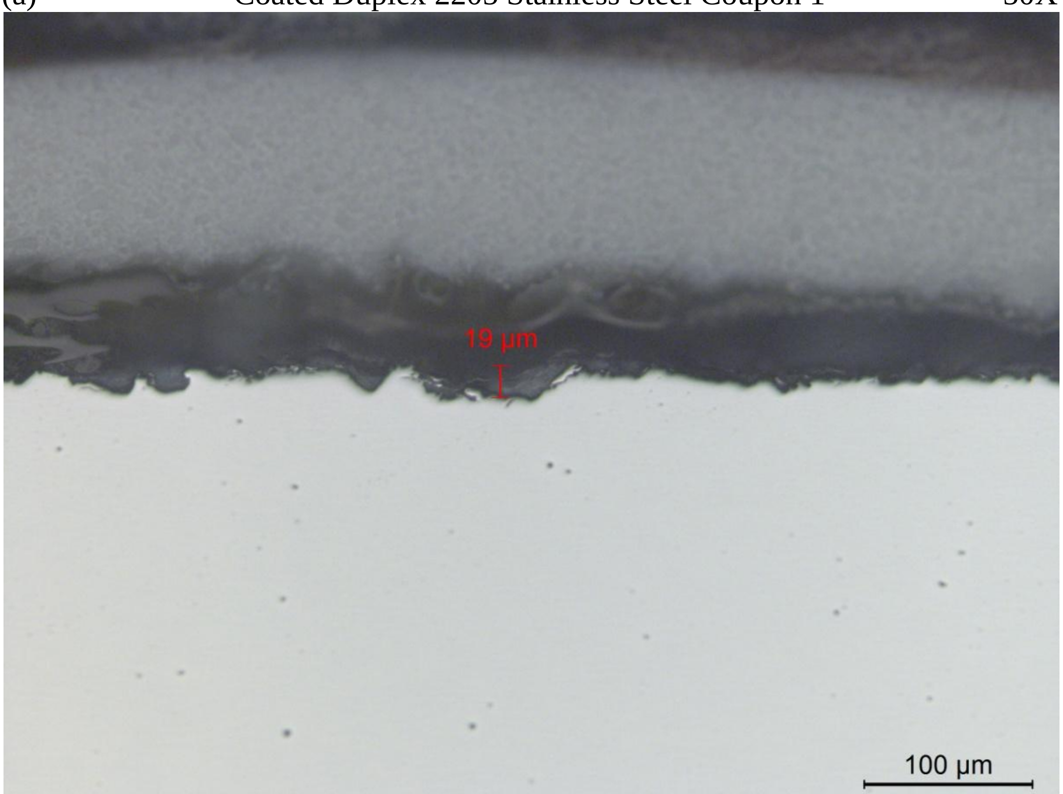


(b) Coated Duplex 2205 Stainless Steel Coupon 4, After Cleaning

Figure 52 Energy dispersive x-ray spectra of duplex 2205 stainless steel with anti-biofouling coating coupon 4 after a 12 month corrosion test (a) before cleaning and (b) after cleaning.



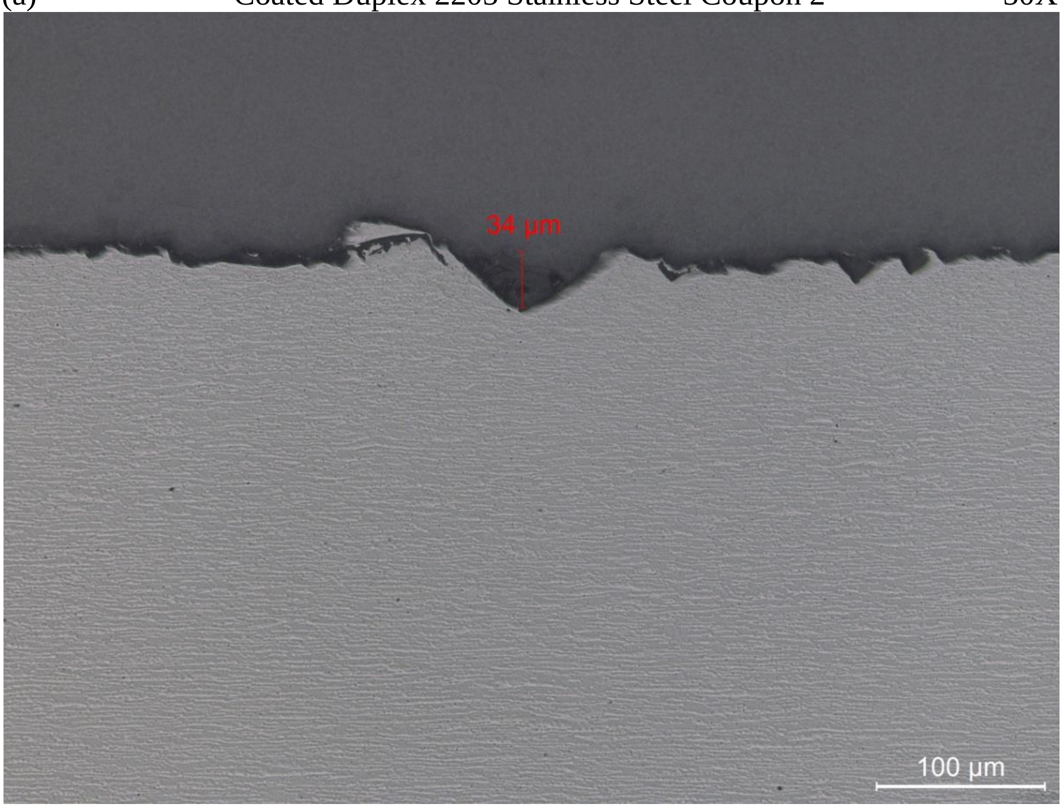
(a) Coated Duplex 2205 Stainless Steel Coupon 1 50X



(b) Coated Duplex 2205 Stainless Steel Coupon 1 200X

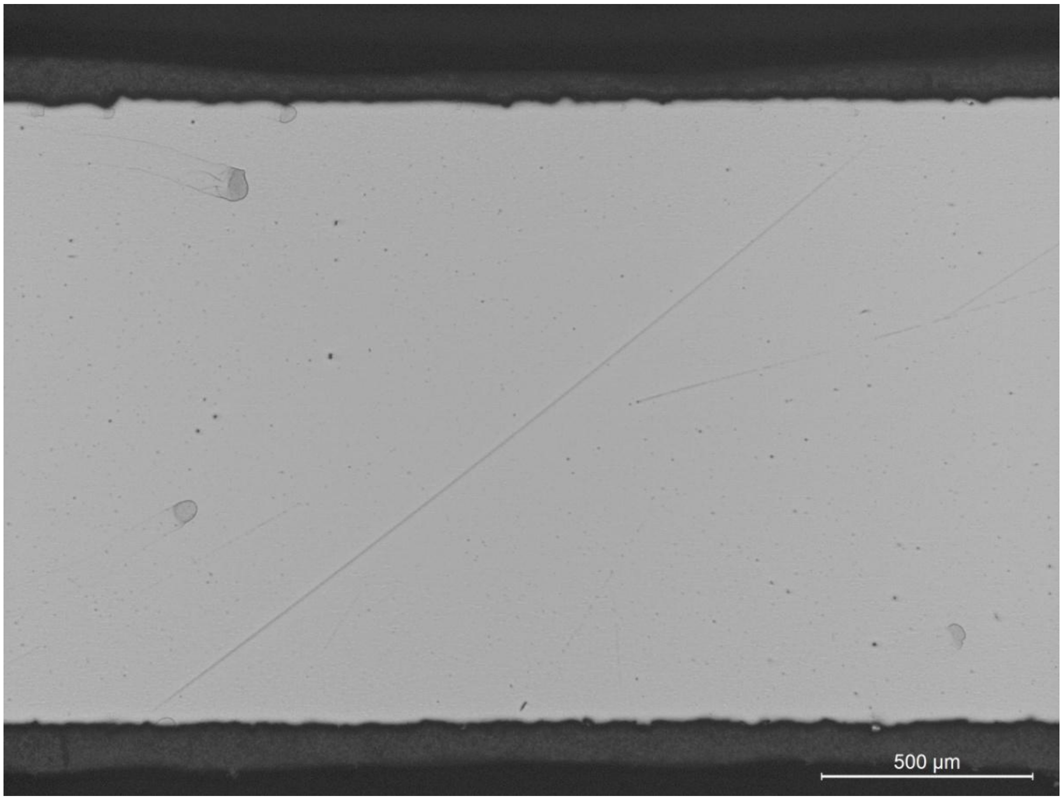
Figure 53 Optical micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 1.

(a) Coated Duplex 2205 Stainless Steel Coupon 2 50X

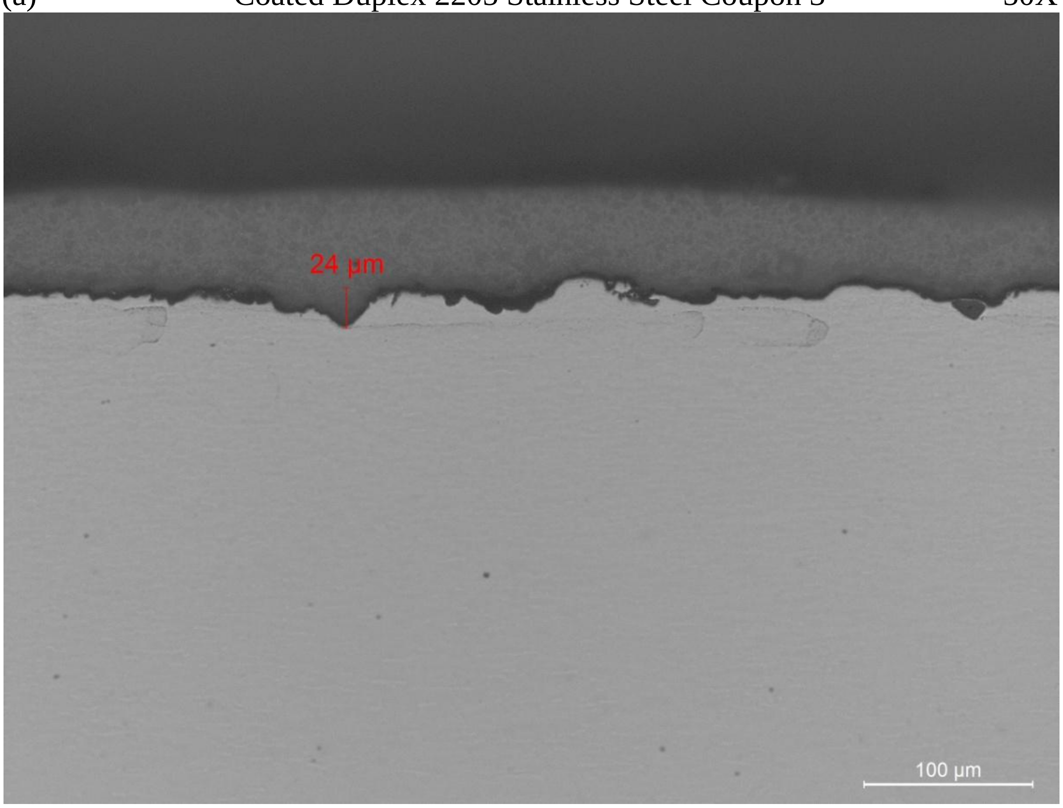


(b) Coated Duplex 2205 Stainless Steel Coupon 2 200X

Figure 54 Optical micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 2.

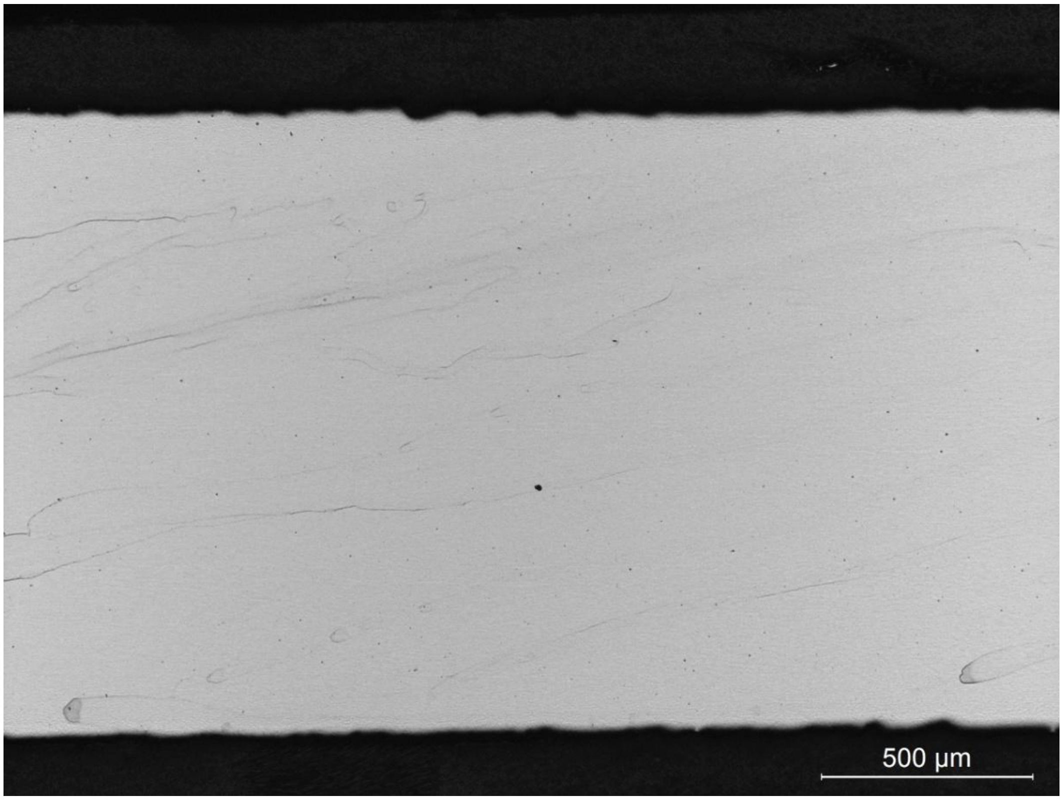


(a) Coated Duplex 2205 Stainless Steel Coupon 3 50X

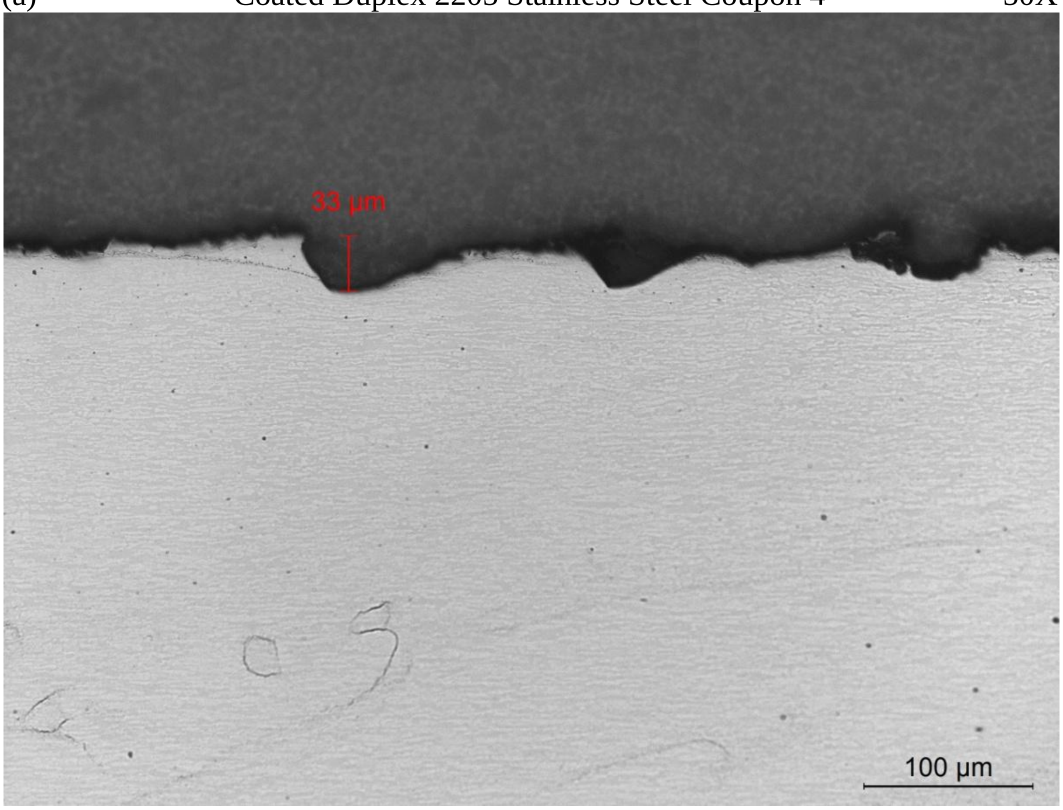


(b) Coated Duplex 2205 Stainless Steel Coupon 3 200X

Figure 55 Optical micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 3.



(a) Coated Duplex 2205 Stainless Steel Coupon 4 50X



(b) Coated Duplex 2205 Stainless Steel Coupon 4 200X

Figure 56 Optical micrographs of duplex 2205 stainless steel with anti-biofouling coating coupon 4.

Report No. 5005.0361D **July 17, 2015**

CORROSION EVALUATION OF CDA 715 COUPONS AND SCREENS

Customer Authorization: Verbal

Report To: V & A Engineering
Attn: Manuel Najar
155 Grand Avenue, Suite 700
Oakland, CA 94612

1.0 INTRODUCTION

Five coupons, five wedge wire screens, and one plate made from CDA 715, a 70-Copper, 30-Nickel alloy, were submitted by V&A Engineering for corrosion evaluation. The coupons were 1-inch by 3-inches by ¼-inch thick. The wedge wire screens were 4-inches by 4-inches by 1/4-inch tall with 2 mm spacing. The plate was 4-inches by 4-inches by 1/8-inch thick.

Four coupons, four screens, and one plate were to be placed in seawater for a period up to one year. After every 3 month interval, one coupon and one screen were to be removed from the test system and examined for corrosion. After 12 months, the plate was removed from the test system and examined for corrosion. The purpose of this evaluation was to document the samples in the baseline as-received condition, then again after 3, 6, 10, and 12 months of water exposure, record any loss in mass, examine for any pitting corrosion, and estimate the corrosion rate.

The samples were evaluated by the following laboratory procedures:

1) Visual examination and weighing
2) Cleaning per ASTM G1[1]
3) Scanning electron microscopy and energy dispersive x-ray spectroscopy
4) Metallography

The results of the evaluation showed minimal mass loss and corrosion for the coupon and screen after 3, 6, 10, and 12 months of corrosion testing. The coupons, after 3, 6, 10, and 12 months of corrosion testing, had a corrosion rate of 0.021, 0.016, 0.010, and 0.012 millimeters per year, respectively. The screens, after 3, 6, 10, and 12 months of corrosion testing, had a corrosion rate of 0.022, 0.022, 0.016, and 0.018 millimeters per year, respectively. The plate, after 12 months of corrosion testing, had a corrosion rate of 0.008 millimeters per year. Both the coupons and screens lost more material over time, but had a decreasing corrosion rate over the duration of the corrosion test.

[1] G1: Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

2.0 EVALUATION[2]

2.1 Visual Examination

The sample identifications for the coupons and wedge wire screens and their corresponding immersion times are shown in Table 1. The coupons had identification numbers stamped on the front face by V&A Engineering. A number of notches, corresponding to the sample number, were sawed at the edge of each screen for identification after the corrosion test. The weights of the samples were recorded. Coupons 1 – 4 and screens 1 – 5 were sent back to V&A for corrosion testing. Coupon 5 was the baseline sample and documented by photography, optical stereoscopy and scanning electron microscopy for comparison to the tested samples. Screen 5 was documented as a baseline by photography and optical stereoscopy, and then sent to V&A for testing.

Photographs of the baseline coupon are shown in Figure 1. Photographs of coupons 1 – 4, after 3, 6, 10, and 12 months of corrosion testing, are shown in Figures 2 – 5. A photograph of the baseline screen is shown in Figure 6. Photographs of screens 1 – 4, after 3, 6, 10, and 12 months of corrosion testing, are shown in Figures 7 – 10. A photograph of the baseline plate is shown in Figure 11 and a photograph of the plate after 12 months of corrosion testing is shown in Figure 12.

2.2 Cleaning

The coupon and screen were cleaned with solution C.2.1 per ASTM G1.[3] One cleaning cycle was approximately 1 minute. After each cleaning cycle, the samples were rinsed in water, dried, and weighed. The cleaning and weighing cycle was completed five times for the coupon and four times for the screen. The weights of the samples as-received, after corrosion testing but before cleaning, and after each cleaning cycle are presented in Table 2.

Optical macrographs of the baseline coupon, screen, and plate are shown in Figures 13, 22, and 31, respectively. Representative optical macrographs of coupons 1 – 4 after 3, 6, 10, and 12 months of corrosion testing, before and after cleaning, are shown in Figures 14 – 21. Representative optical macrographs of screens 1 – 4 after 3, 6, 10, and 12 months of corrosion testing, before and after cleaning, are shown in Figures 23 – 30. Representative optical macrographs of the plate after 12 months of corrosion testing, before and after cleaning, are shown in Figures 32 – 33.

The mass loss versus the number of cleaning cycles was plotted, shown in Figures 34 – 38. The equations for best fit lines AB and BC, calculated using IGOR Pro, are listed in Table 3. Point B, indicated by the red circle in each plot, corresponds to the mass loss due to corrosion during the cleaning process for each sample. This mass loss was subtracted from the weight of the sample before cleaning and from the weight of the sample as-received to determine the total mass loss from corrosion. The corrosion rate of each sample was determined by the formula specified in Section 8.1 of ASTM G1:

[2] The magnifications of the optical and scanning electron micrographs in this report are approximate and should not be used as a basis for dimensional analyses unless otherwise indicated.
[3] 500 mL hydrochloric acid + 500 ml reagent water.

$$Corrosion\ Rate = \frac{K\ x\ W}{A\ x\ T\ x\ D}$$

where K = 8.76 x 10^4, T = time of exposure in hours, A = area in cm^2, W = mass loss in grams, and D = density in g/cm^3. The total mass loss from corrosion and the calculated corrosion rate of each sample is shown in Table 4.

2.3 Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy

The baseline coupon and coupons 1 – 4 were examined with a scanning electron microscope. Representative scanning electron micrographs of the baseline coupon are shown in Figure 39. Representative scanning electron micrographs of coupons 1 – 4, before and after cleaning, are shown in Figures 40 – 47. Energy dispersive x-ray spectra of the baseline coupon and coupons 1 – 4, before and after cleaning, are shown in Figures 48 – 52.

2.4 Metallography

A cross section was taken from the coupon and prepared for a metallographic examination. Optical micrographs of the surfaces for coupons 1 – 4 are shown in Figures 53 – 56. Small pits were observed in all coupons, the deepest of which measured 52 μm.

3.0 DISCUSSION

The coupon and screen showed minimal mass loss and pitting overall after 3, 6, 10, and 12 months of corrosion testing. The coupons had more material loss over time, but had a decreasing corrosion rate over the duration of the corrosion test. The screens had more material loss over time, but had a slightly decreasing corrosion rate over the duration of the corrosion test.

4.0 CONCLUSIONS[4]

The following conclusions are based upon the submitted samples and the evidence gathered:

1. The coupons, after 3, 6, 10, and 12 months of corrosion testing, had a mass loss of 0.248 grams, 0.386 grams, 0.387 grams and 0.566 grams, respectively. The coupons had more mass loss over the duration of the corrosion test.

2. The coupons, after 3, 6, 10, and 12 months of corrosion testing, had a corrosion rate of 0.021 mm / year, 0.016 mm / year, 0.010 mm / year, and 0.012 mm / year, respectively. The coupons had a decreasing corrosion rate over the duration of the corrosion test.

3. The screens, after 3, 6, 10, and 12 months of corrosion testing, had a mass loss of 2.04 grams, 4.05 grams, 4.94 grams, and 6.79 grams, respectively. The screens had more mass loss over the duration of the corrosion test.

4. The screens, after 3, 6, 10, and 12 months of corrosion testing, had a corrosion rate of 0.022 mm / year, 0.022 mm / year, 0.016 mm / year, and 0.018 mm / year, respectively. The screens had a decreasing corrosion rate over the duration of the corrosion test.

5. The plate, after 12 months of corrosion testing, had a mass loss of 1.67 grams and a corrosion rate of 0.008 mm / year.

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[4] The conclusions in this report are based upon the available information and evidence provided by the client and gathered by Anamet, within the scope of work authorized by the client, and they are hereby presented by Anamet to a reasonable degree of engineering and scientific certainty. Anamet reserves the right to amend or supplement its conclusions or opinions presented in this report should additional data or information become available, or further work be approved by the client.

Table 1
Sample Identifications

Description		V&A Engineering Identification (As-Received)	Anamet Identification (in report)	Notes
Alloy	Part			
CDA 715 (Cu 70 – Ni 30)	**Flat Plate** 4-inch x 4-inch x 1/8-inch	CDA 715 1	Plate	None
	Coupon 1-inch x 3-inch x 1/8-inch with autogenous weld bead	CDA 715W 1	Coupon 1	3 Month Immersion
		CDA 715W 2	Coupon 2	6 Month Immersion
		CDA 715W 3	Coupon 3	10 Month Immersion
		CDA 715W 4	Coupon 4	12 Month Immersion
		CDA 715W 5	Coupon 5	Baseline Sample (no exposure)
	Wedge Wire Screen 4-inch x 4-inch x 1-inch with 2 mm spacing	None	Screen 1	3 Month Immersion
		None	Screen 2	6 Month Immersion
		None	Screen 3	10 Month Immersion
		None	Screen 4	12 Month Immersion
		None	Screen 5	12 Month Immersion

Table 2
Sample Weights

Sample	Baseline Measurement	Measurements after 3 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 1	23.3284	23.1538	23.0863	32.0802	23.0795	23.0782	23.0770
Screen 1	210.45	209.34	208.52	208.42	208.41	208.41	-

Sample	Baseline Measurement	Measurements after 6 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 2	24.8463	24.5762	24.4601	24.4578	24.4571	24.4530	24.4519
Screen 2	211.63	208.66	207.58	207.57	207.57	207.53	-

Sample	Baseline Measurement	Measurements after 10 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 3	24.1830	23.9022	23.7974	23.7958	23.7920	23.7909	23.7907
Screen 3	212.46	209.33	207.55	207.48	207.40	207.38	207.32

Sample	Baseline Measurement	Measurements after 12 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 4	24.4801	24.1759	23.9143	23.9138	23.9135	23.9134	-
Screen 4	211.37	207.04	204.60	204.50	204.41	204.37	-
Plate	328.28	327.12	326.61	326.60	326.59	-	-

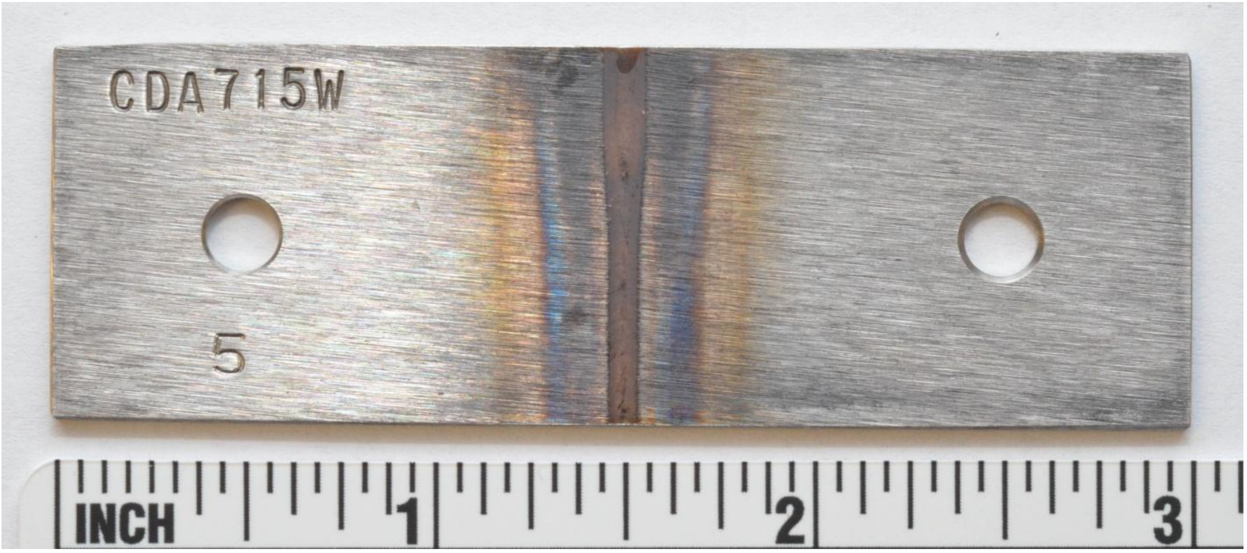
Table 3
Equations of Lines AB and BC for Corrosion Testing Samples

Sample	Line AB	Line BC	Point B (Approximate Mass Loss from Corrosion During Cleaning)
Coupon 1	y = 0.068x	y = 0.001x + 0.072	0.073 grams
Coupon 2	y = 0.116x	y = 0.002x + 0.114	0.116 grams
Coupon 3	y = 0.105x	y = 0.002x + 0.104	0.106 grams
Coupon 4	y = 0.262x	y = 0.262	0.262 grams
Screen 1	y = 0.83x	y = 0.01x + 0.92	0.93 grams
Screen 2	y = 1.08x	y = 0.02x + 1.06	1.08 grams
Screen 3	y = 1.78x	y = 0.05x + 1.76	1.81 grams
Screen 4	y = 2.44x	y = 0.08x + 2.38	2.46 grams
Plate	y = 0.51x	y = 0.01x + 0.50	0.51 grams

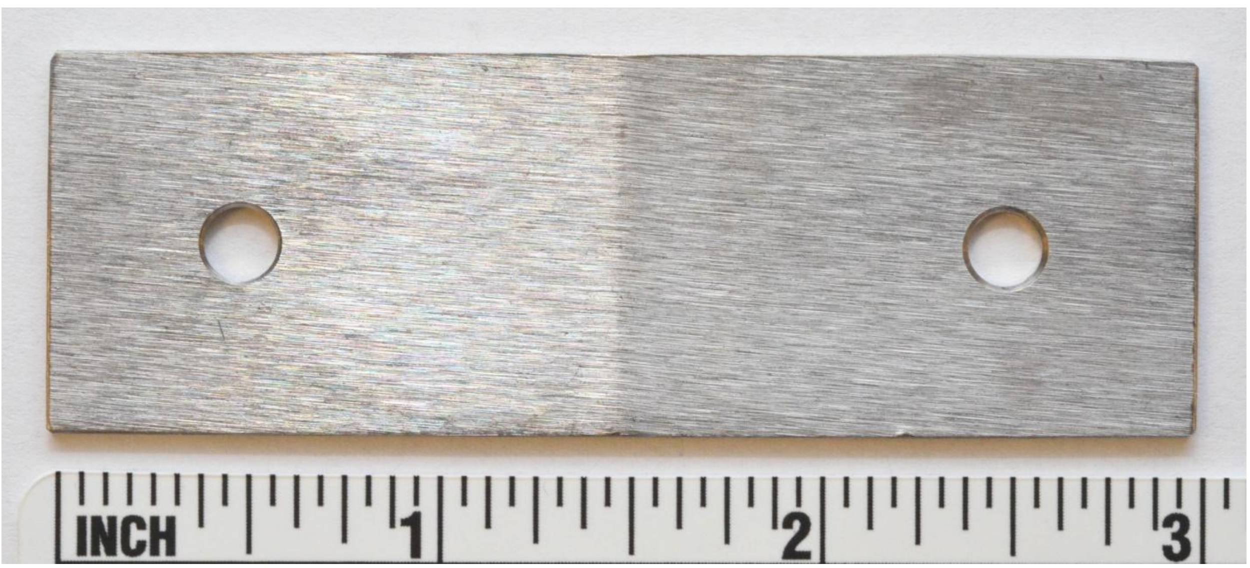
Table 4
Total Mass Loss from Corrosion and Corrosion Rates

Sample	Total Mass Loss from Corrosion*	Corrosion Rate
Coupon 1	0.248 grams	0.021 mm / year
Coupon 2	0.386 grams	0.016 mm / year
Coupon 3	0.387 grams	0.010 mm / year
Coupon 4	0.566 grams	0.012 mm / year
Screen 1	2.04 grams	0.022 mm / year
Screen 2	4.05 grams	0.022 mm / year
Screen 3	4.94 grams	0.016 mm / year
Screen 4	6.79 grams	0.018 mm / year
Plate	1.67 grams	0.008 mm / year

* Weight As-Received – (Weight Before Cleaning – Mass Loss from Corrosion During Cleaning)

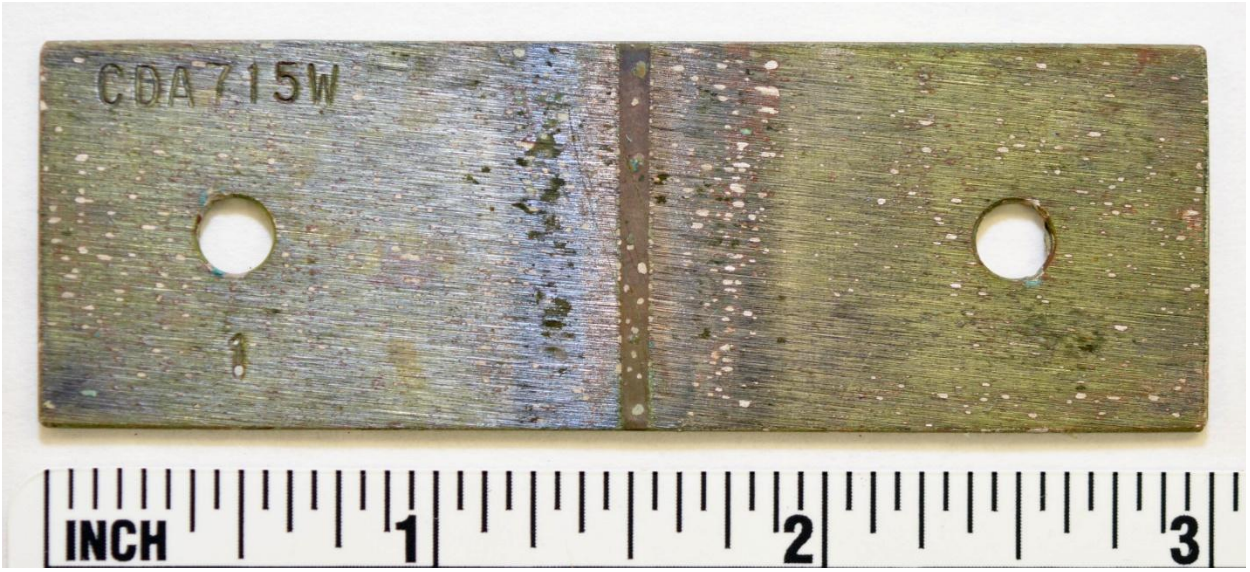


(a) CDA 715 Baseline Coupon, Front Side

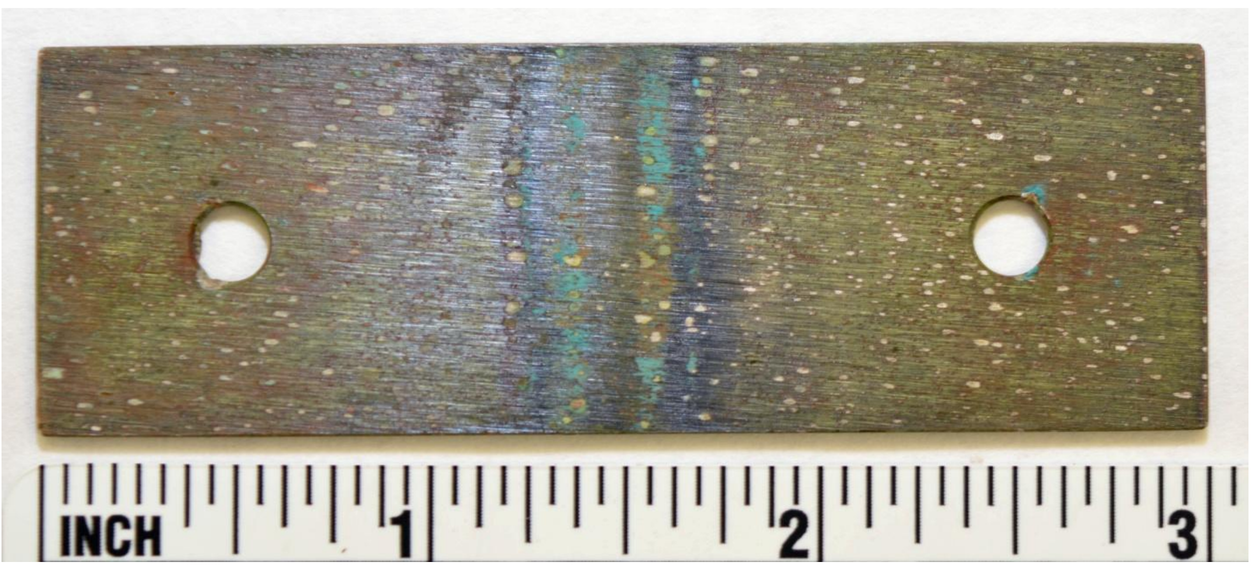


(b) CDA 715 Baseline Coupon, Back Side

Figure 1 Photographs of the CDA 715 baseline coupon (a) front and (b) back side.

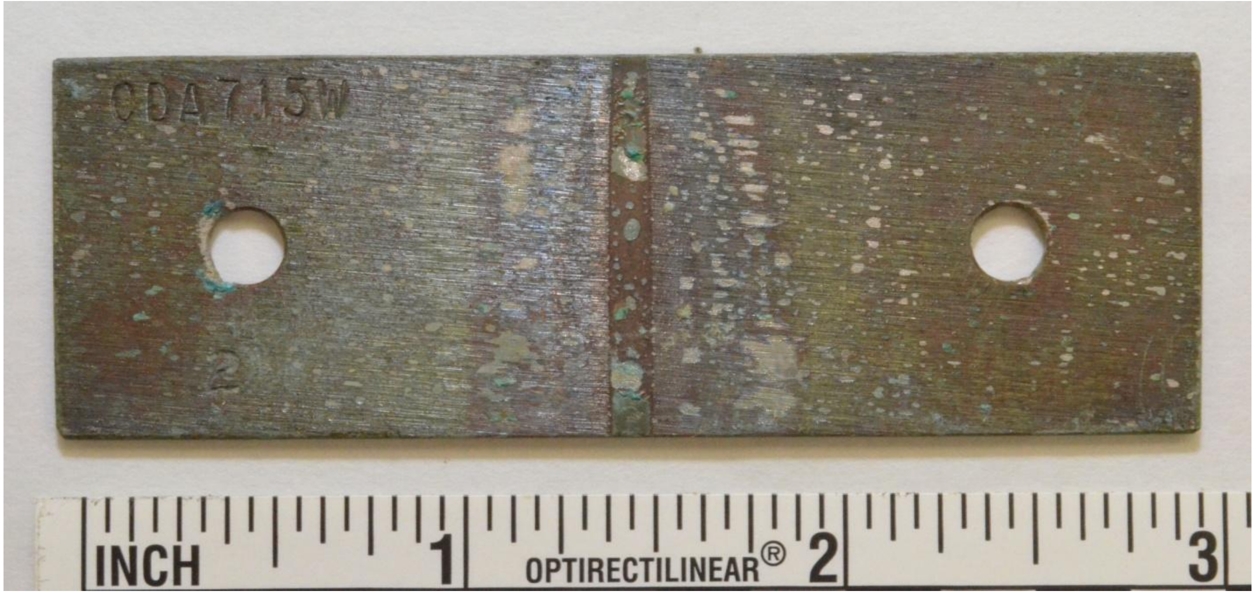


(a) CDA 715 Coupon 1, Front Side

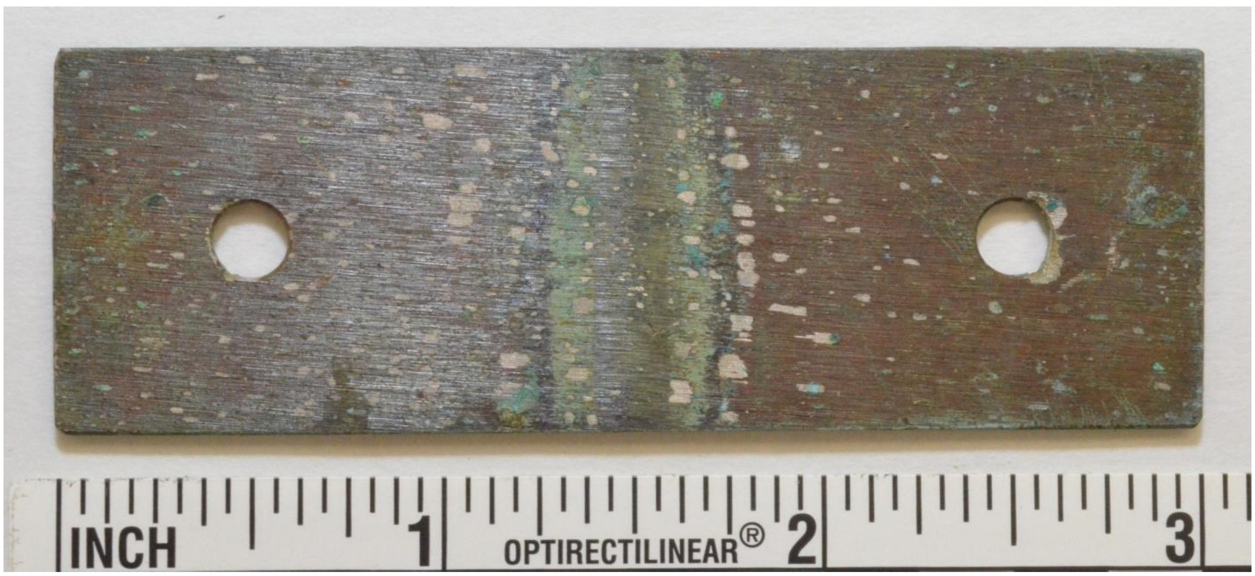


(b) CDA 715 Coupon 1, Back Side

Figure 2 Photographs of CDA 715 coupon 1 (a) front and (b) back side after a 3 month corrosion test.

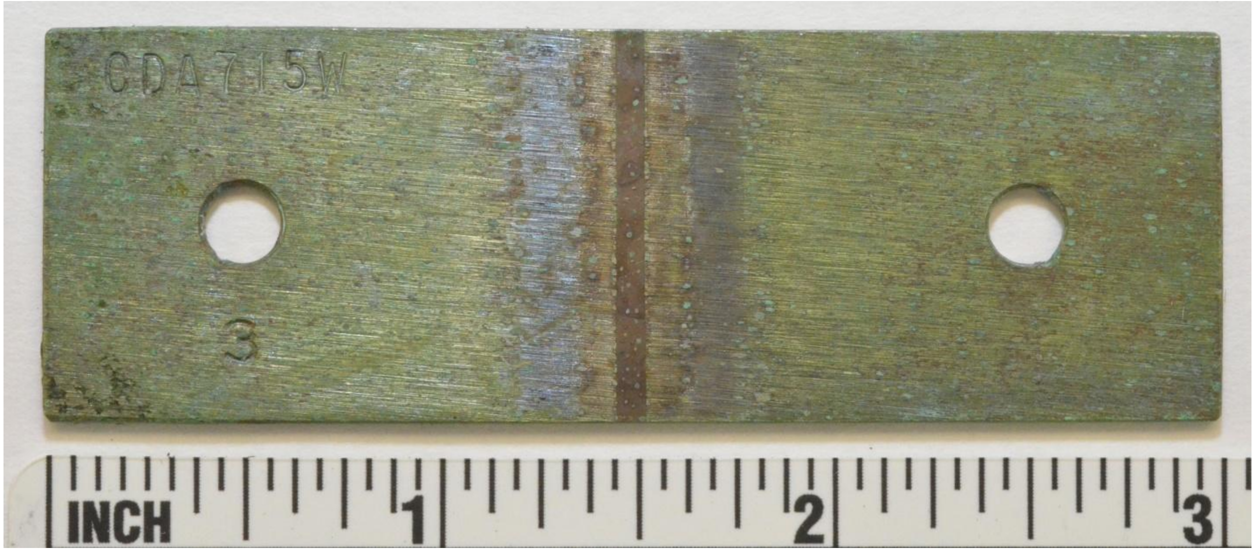


(a) CDA 715 Coupon 2, Front Side

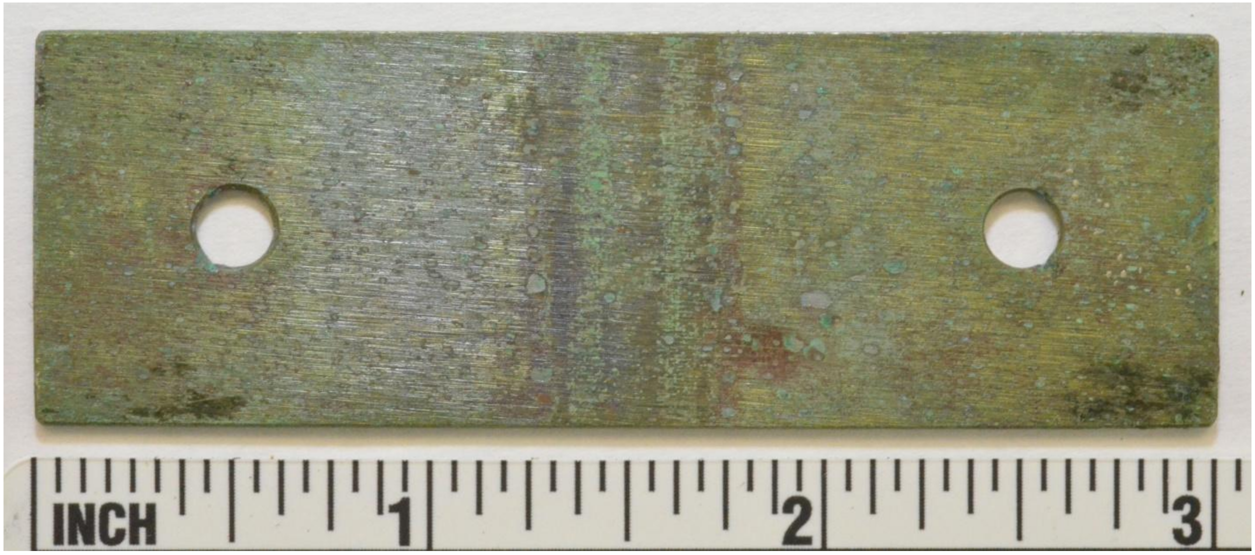


(b) CDA 715 Coupon 2, Back Side

Figure 3 Photographs of CDA 715 coupon 2 (a) front and (b) back side after a 6 month corrosion test.

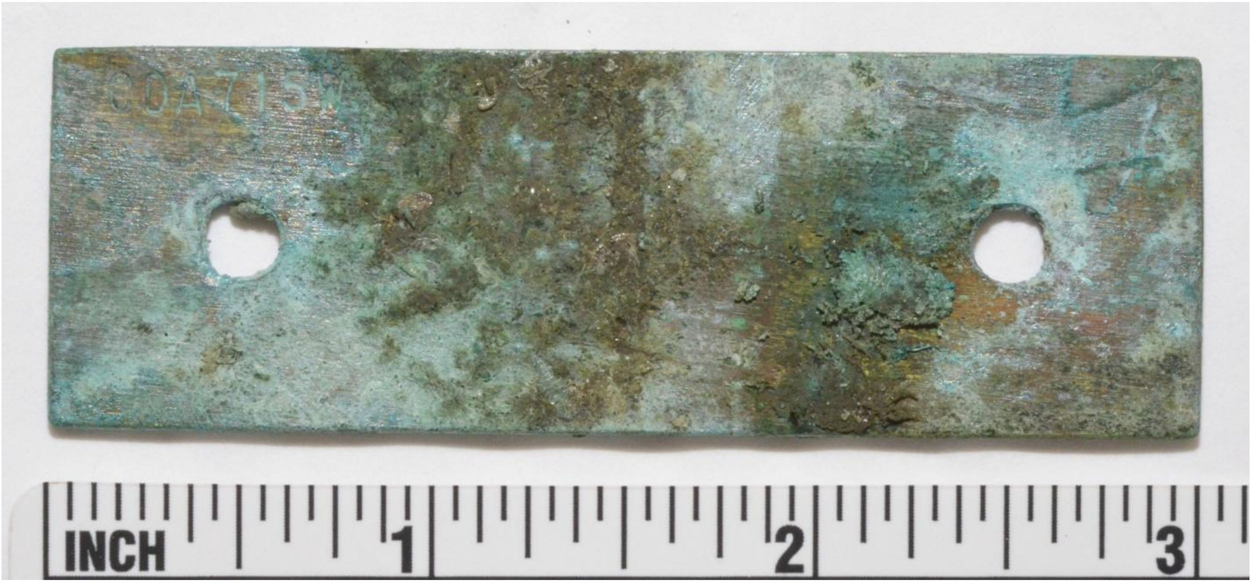


(a) CDA 715 Coupon 3, Front Side

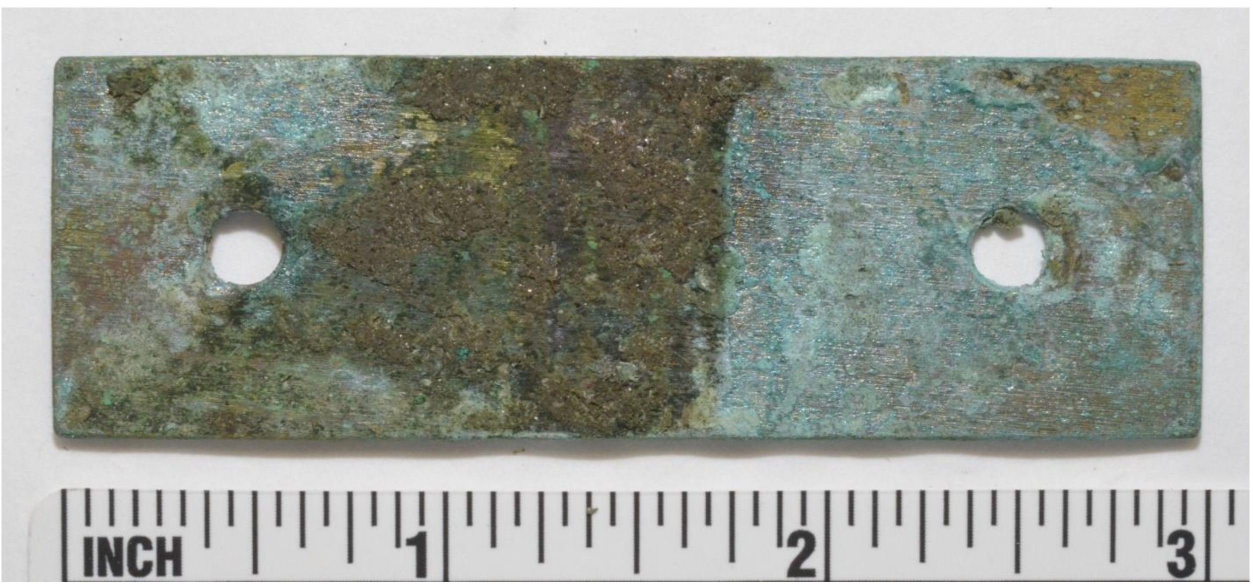


(b) CDA 715 Coupon 3, Back Side

Figure 4 Photographs of CDA 715 coupon 3 (a) front and (b) back side after a 10 month corrosion test.

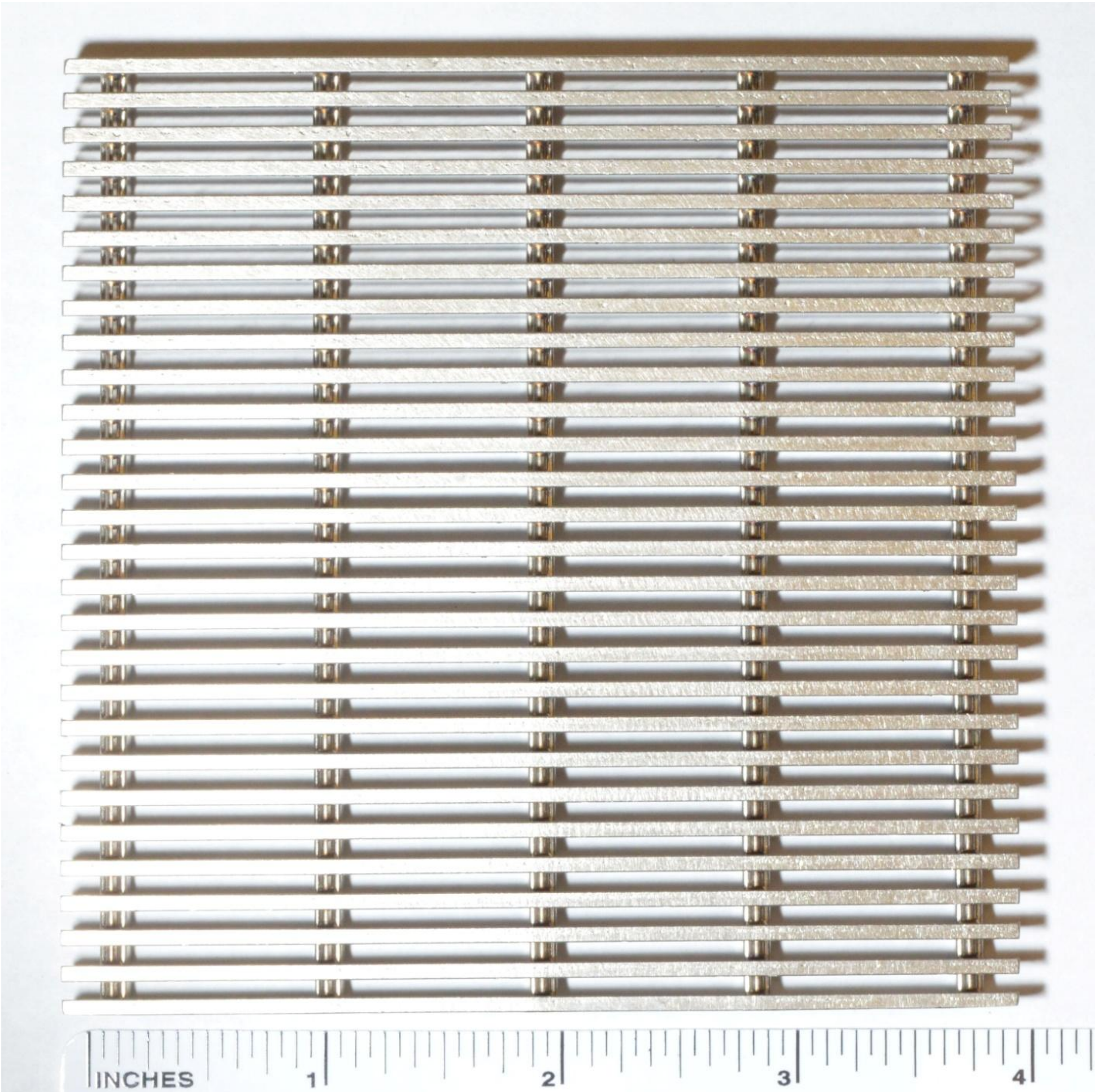


(a) CDA 715 Coupon 4, Front Side



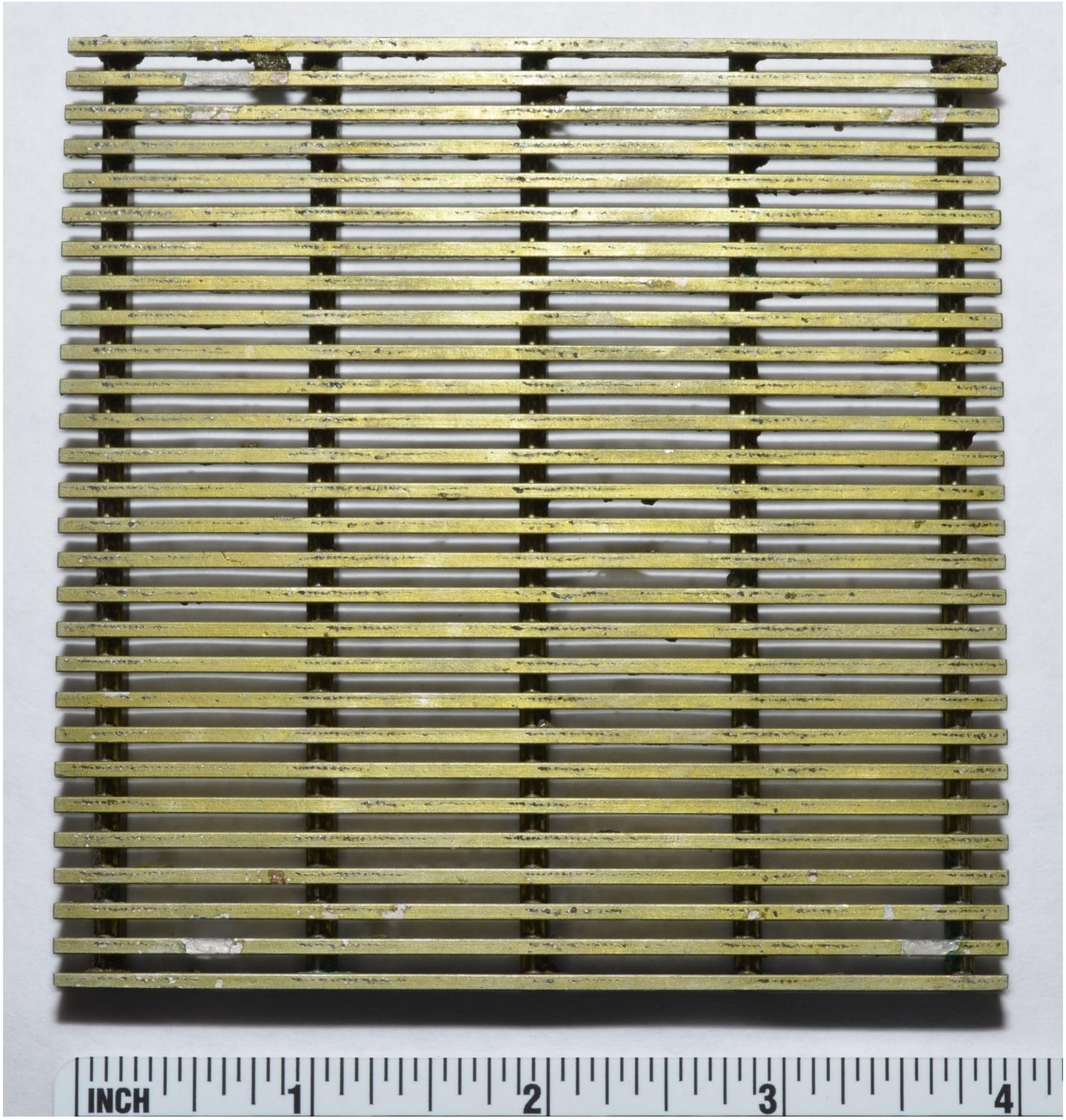
(b) CDA 715 Coupon 4, Back Side

Figure 5 Photographs of CDA 715 coupon 4 (a) front and (b) back side after a 12 month corrosion test.



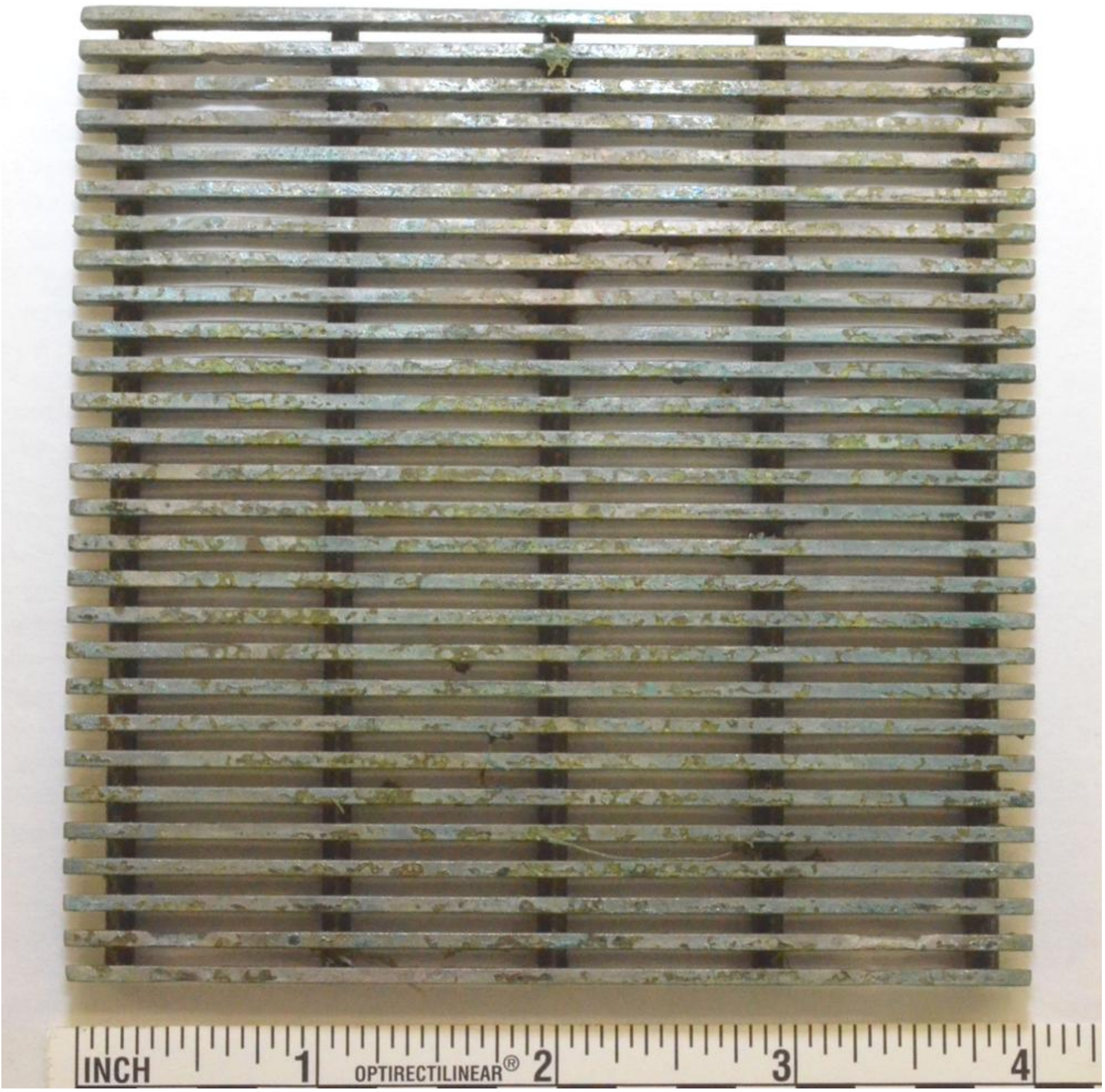
(a) CDA 715 Baseline Screen

Figure 6 Photograph of the CDA 715 baseline screen.



(a) CDA 715 Screen 1

Figure 7 Photograph of CDA 715 screen 1 after a 3 month corrosion test.

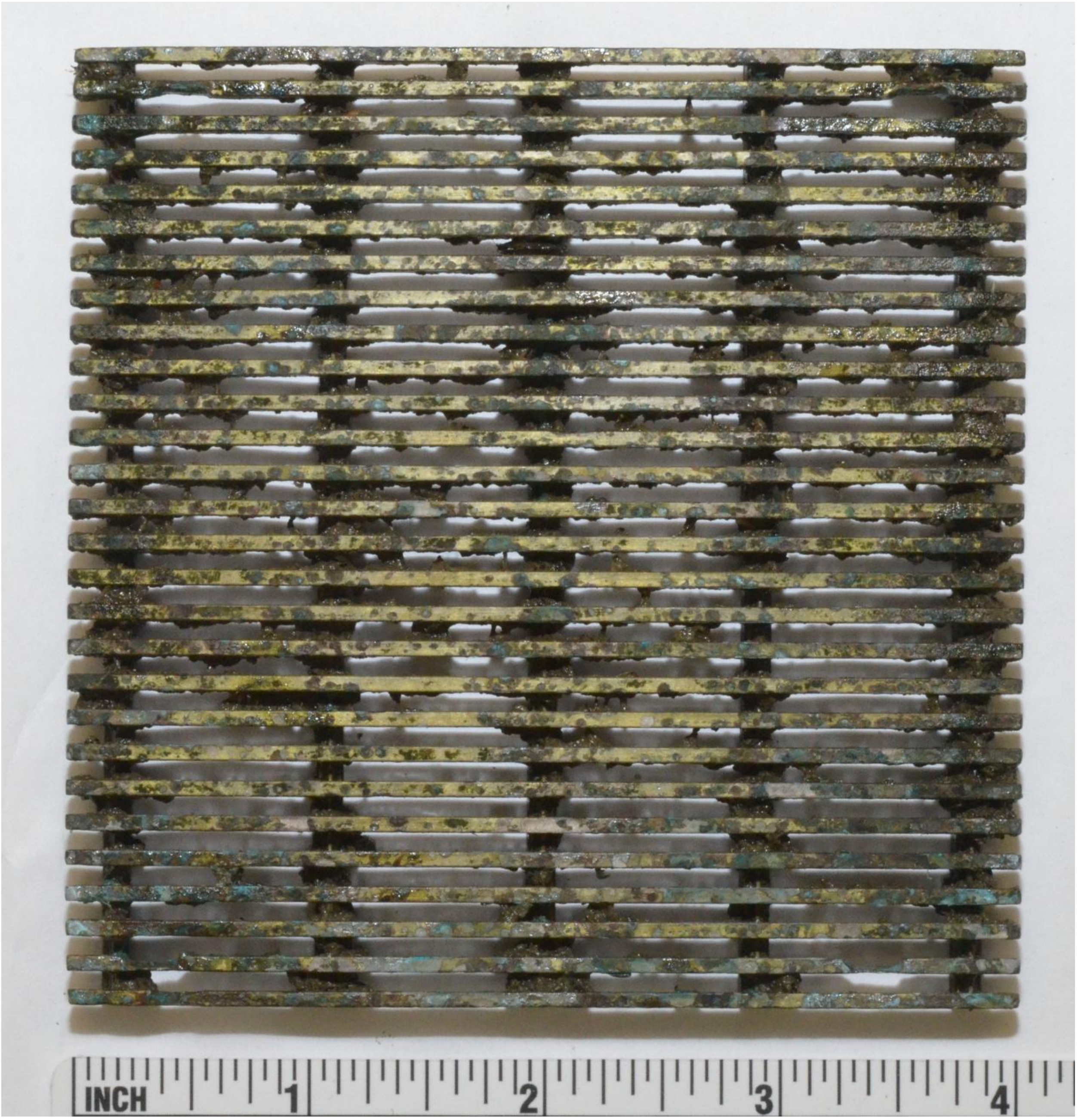


(a) CDA 715 Screen 2

Figure 8 Photograph of CDA 715 screen 2 after a 6 month corrosion test.

(a) CDA 715 Screen 3

Figure 9 Photograph of CDA 715 screen 3 after a 10 month corrosion test.

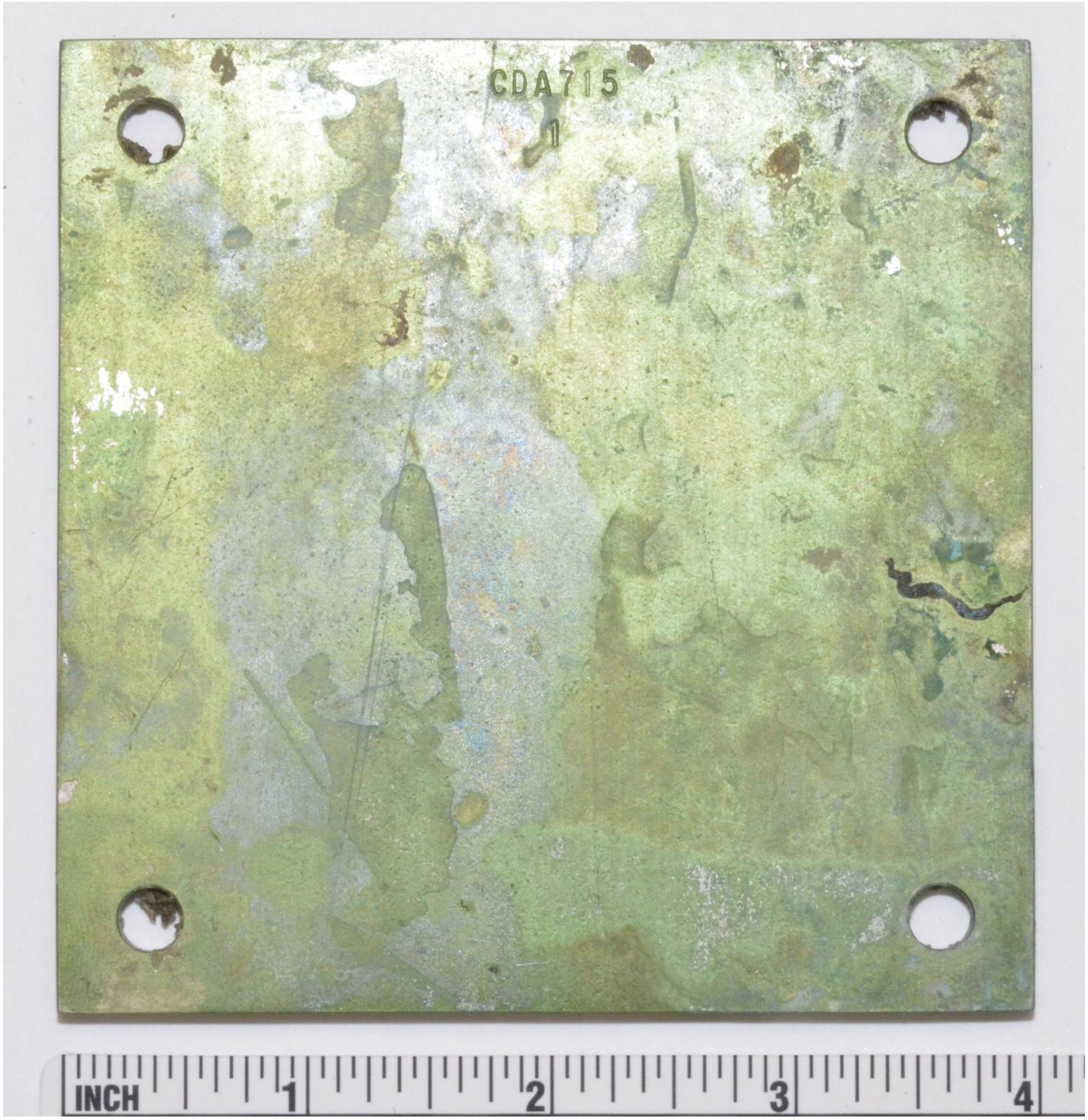


(a) CDA 715 Screen 4

Figure 10 Photograph of CDA 715 screen 4 after a 12 month corrosion test.

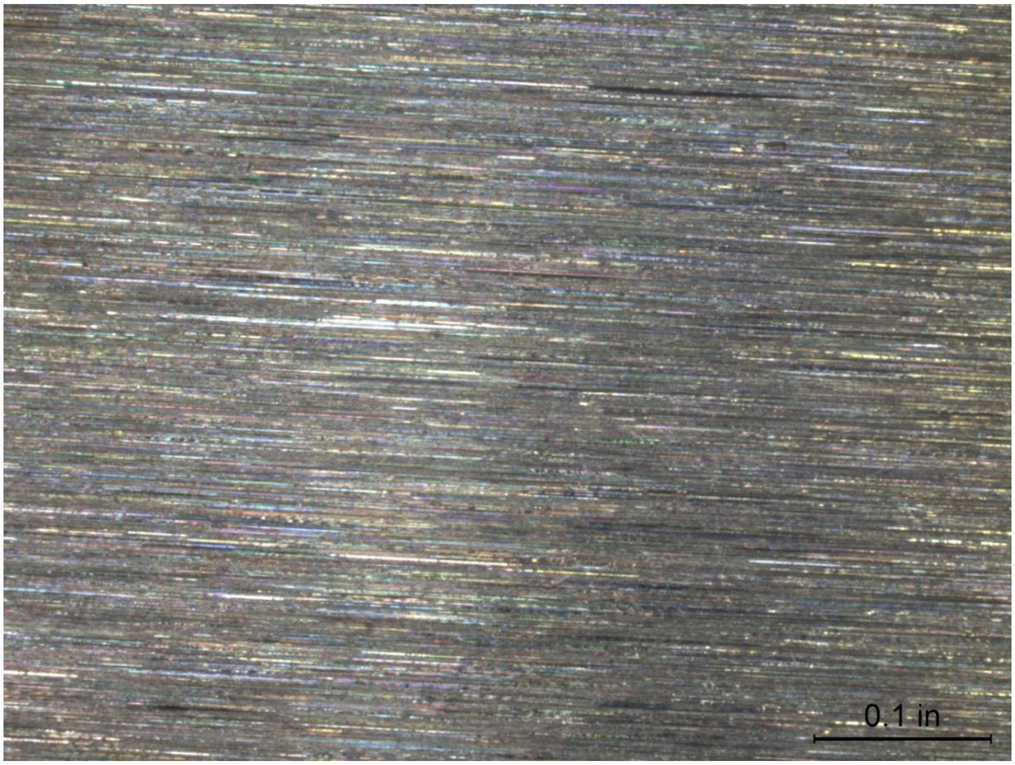
(a) CDA 715 Baseline Plate

Figure 11 Photograph of the CDA 715 baseline plate.

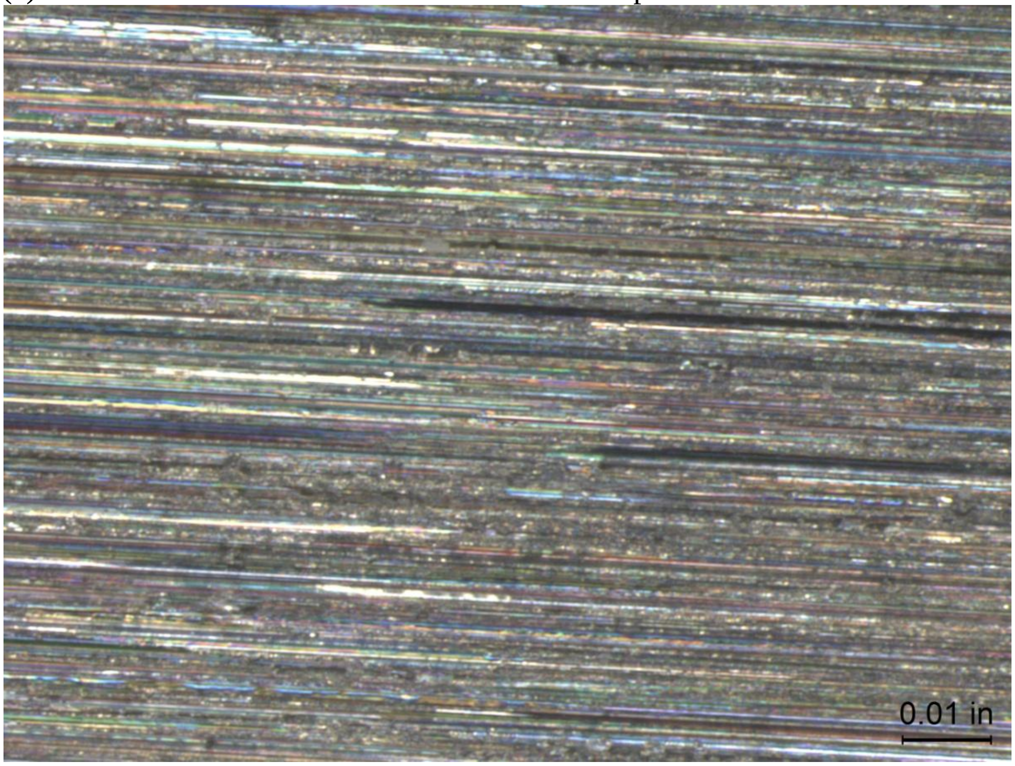


(a) CDA 715 Plate

Figure 12 Photograph of CDA 715 plate after a 12 month corrosion test.



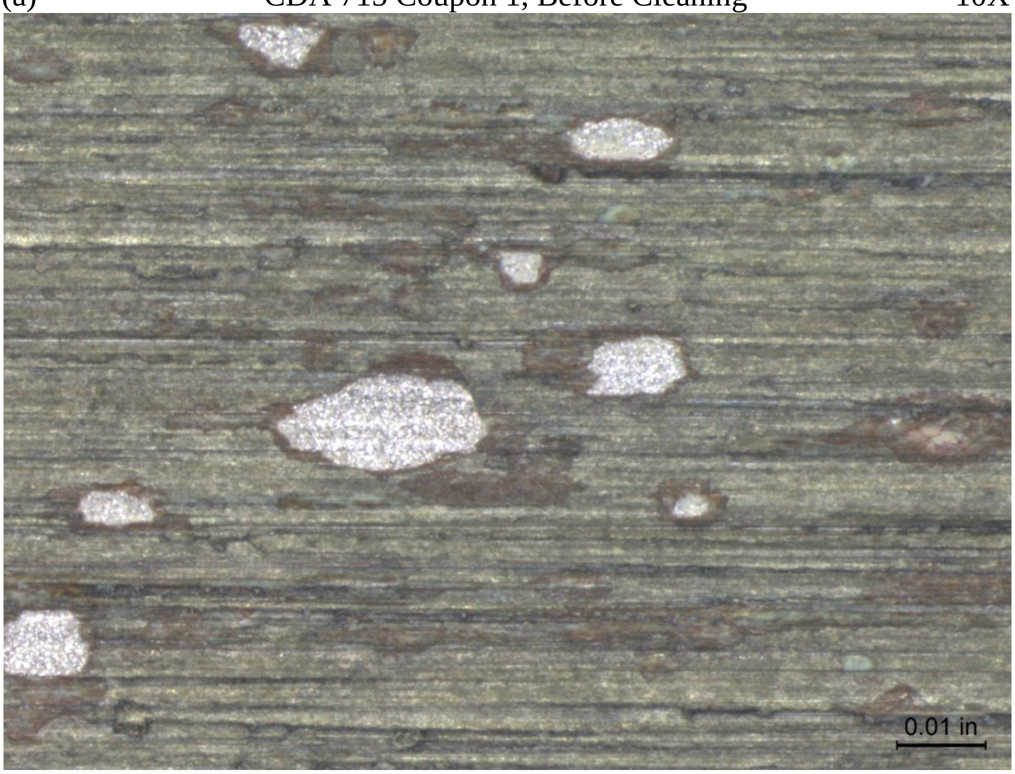
(a) CDA 715 Baseline Coupon 10X



(b) CDA 715 Baseline Coupon 50X

Figure 13 Optical macrographs of the CDA 715 baseline coupon.

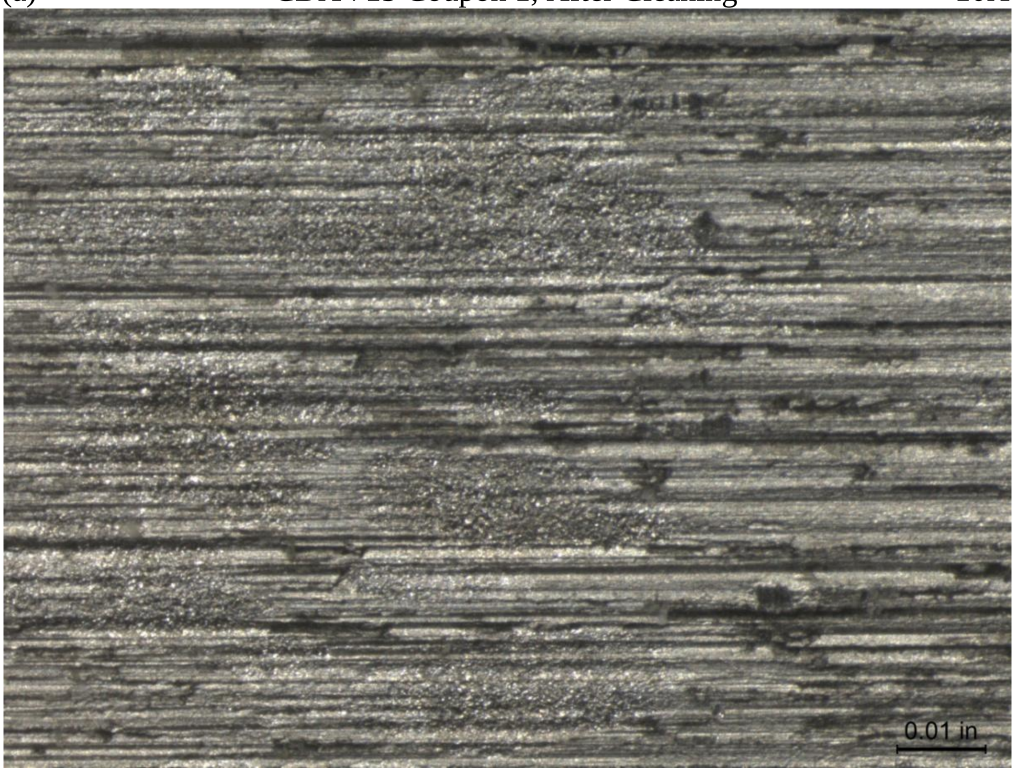
(a) CDA 715 Coupon 1, Before Cleaning 10X



(b) CDA 715 Coupon 1, Before Cleaning 50X

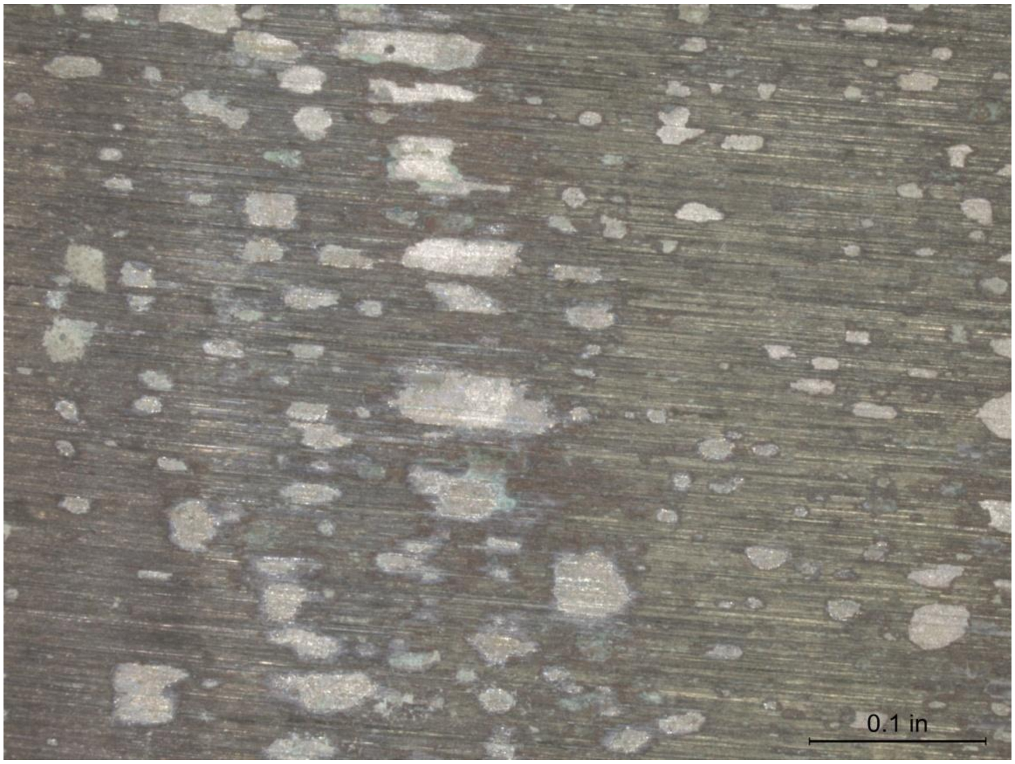
Figure 14 Optical macrographs of CDA 715 coupon 1 after a 3 month corrosion test, before cleaning.

(a) CDA 715 Coupon 1, After Cleaning 10X

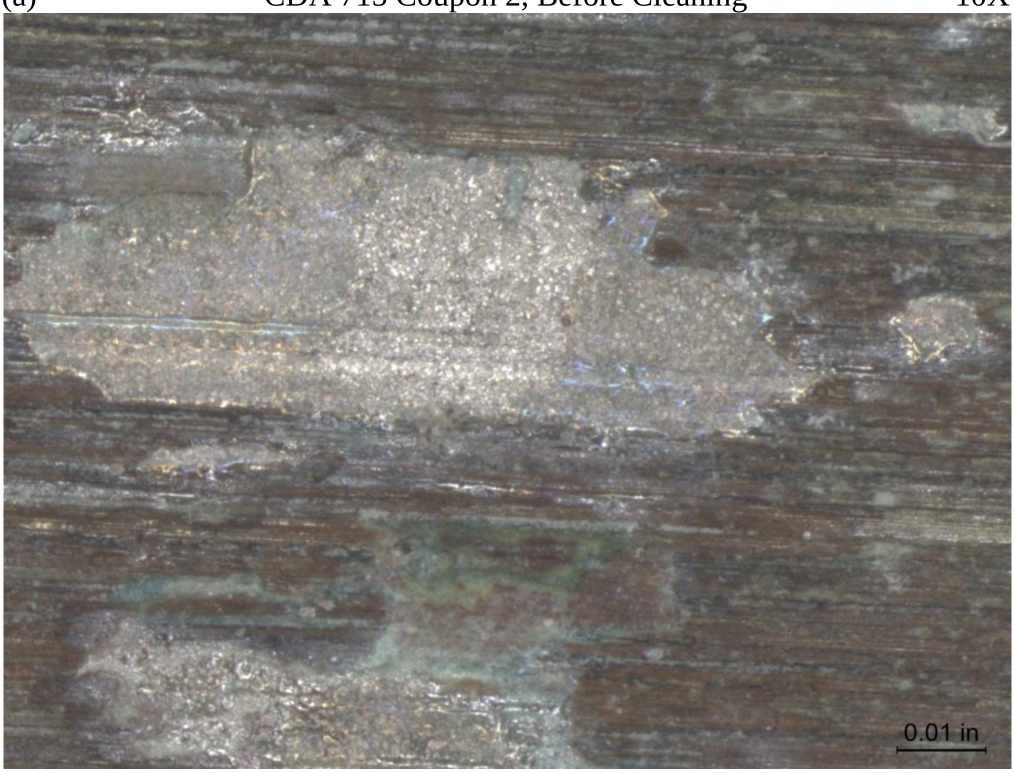


(b) CDA 715 Coupon 1, After Cleaning 50X

Figure 15 Optical macrographs of CDA 715 coupon 1 after a 3 month corrosion test, after cleaning.



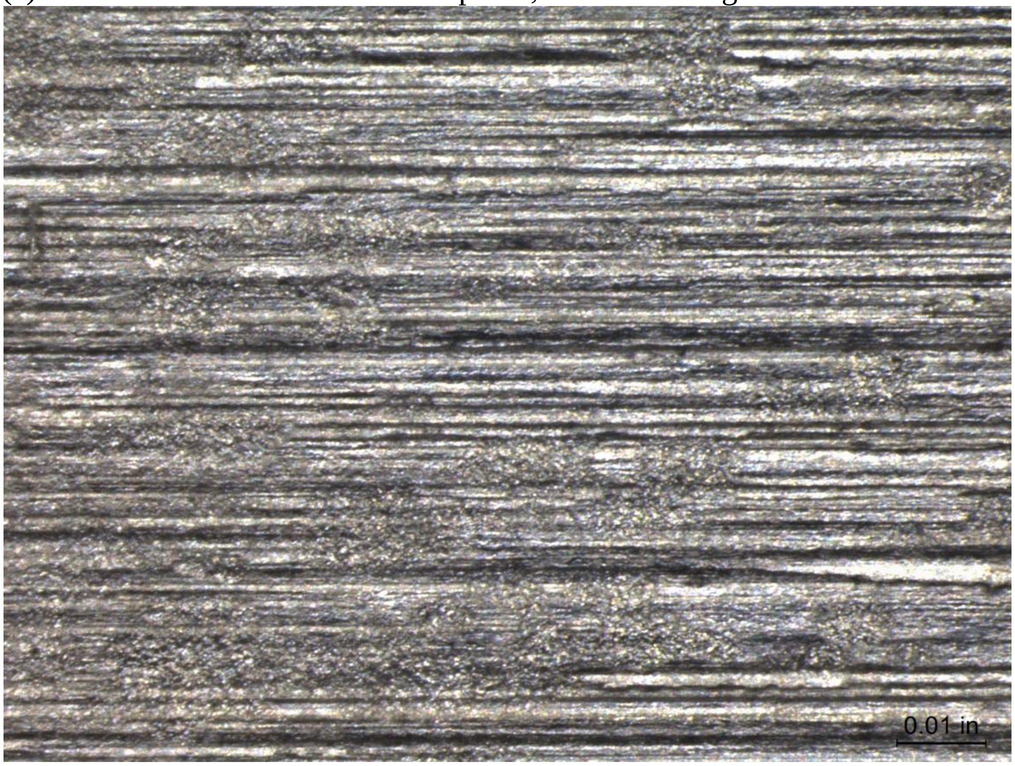
(a) CDA 715 Coupon 2, Before Cleaning 10X



(b) CDA 715 Coupon 2, Before Cleaning 50X

Figure 16 Optical macrographs of CDA 715 coupon 2 after a 6 month corrosion test, before cleaning.

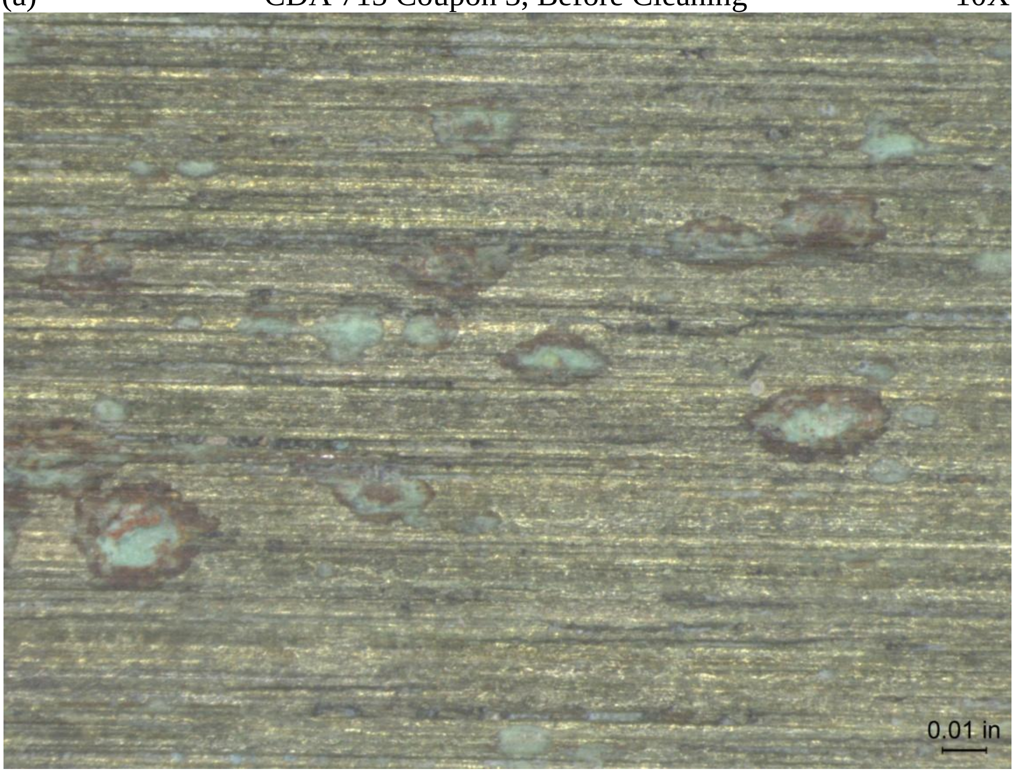
(a) CDA 715 Coupon 2, After Cleaning 10X



(b) CDA 715 Coupon 2, After Cleaning 50X

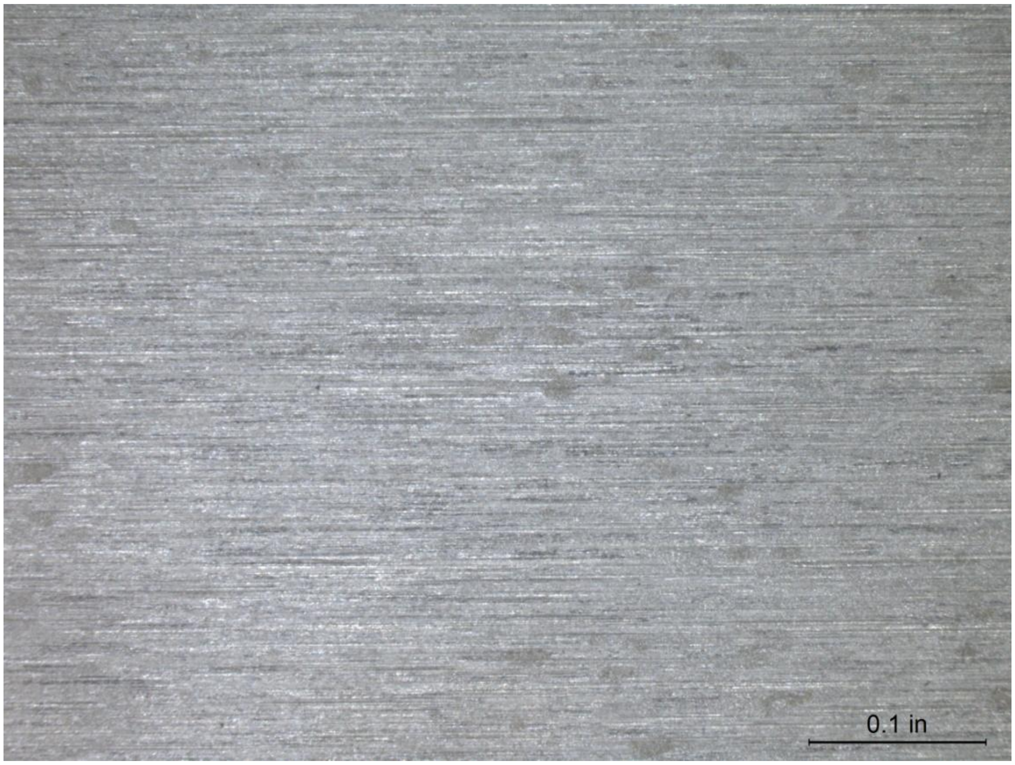
Figure 17 Optical macrographs of CDA 715 coupon 2 after a 6 month corrosion test, after cleaning.

(a) CDA 715 Coupon 3, Before Cleaning 10X

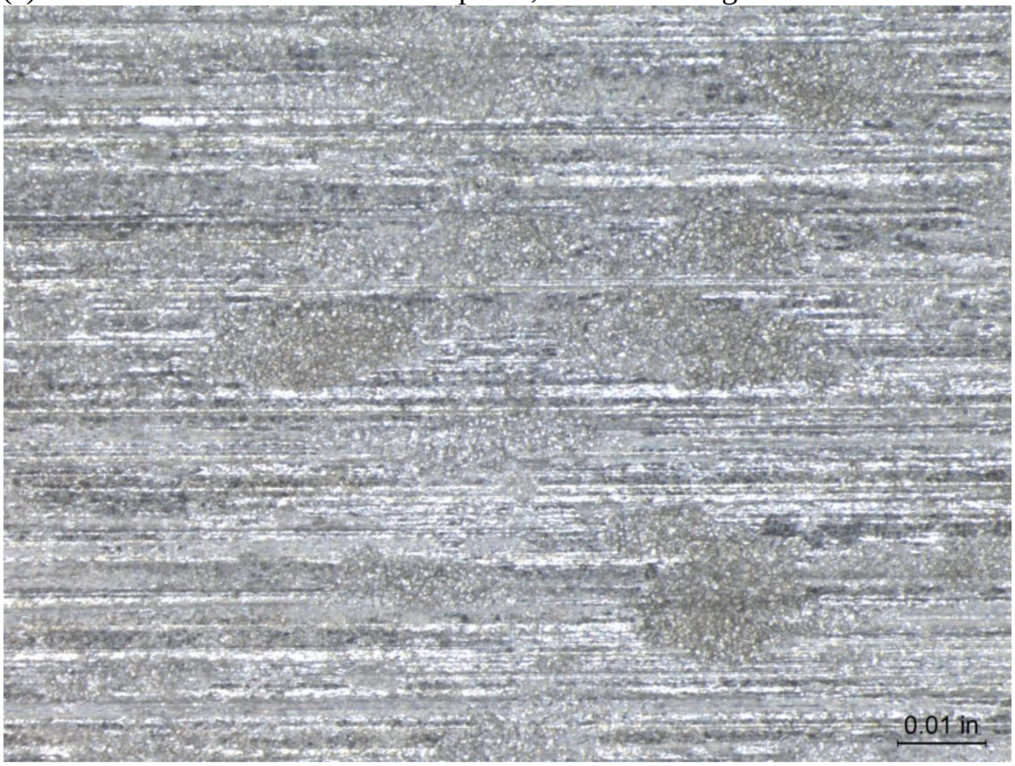


(b) CDA 715 Coupon 3, Before Cleaning 50X

Figure 18 Optical macrographs of CDA 715 coupon 3 after a 10 month corrosion test, before cleaning.



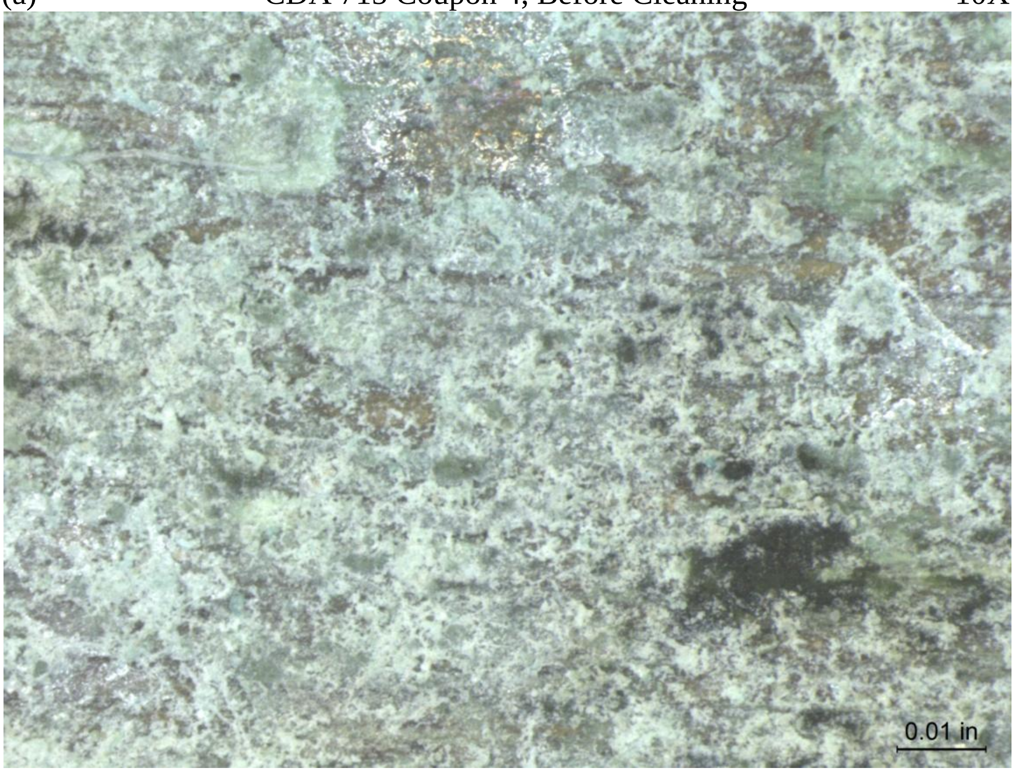
(a) CDA 715 Coupon 3, After Cleaning 10X



(b) CDA 715 Coupon 3, After Cleaning 50X

Figure 19 Optical macrographs of CDA 715 coupon 3 after a 10 month corrosion test, after cleaning.

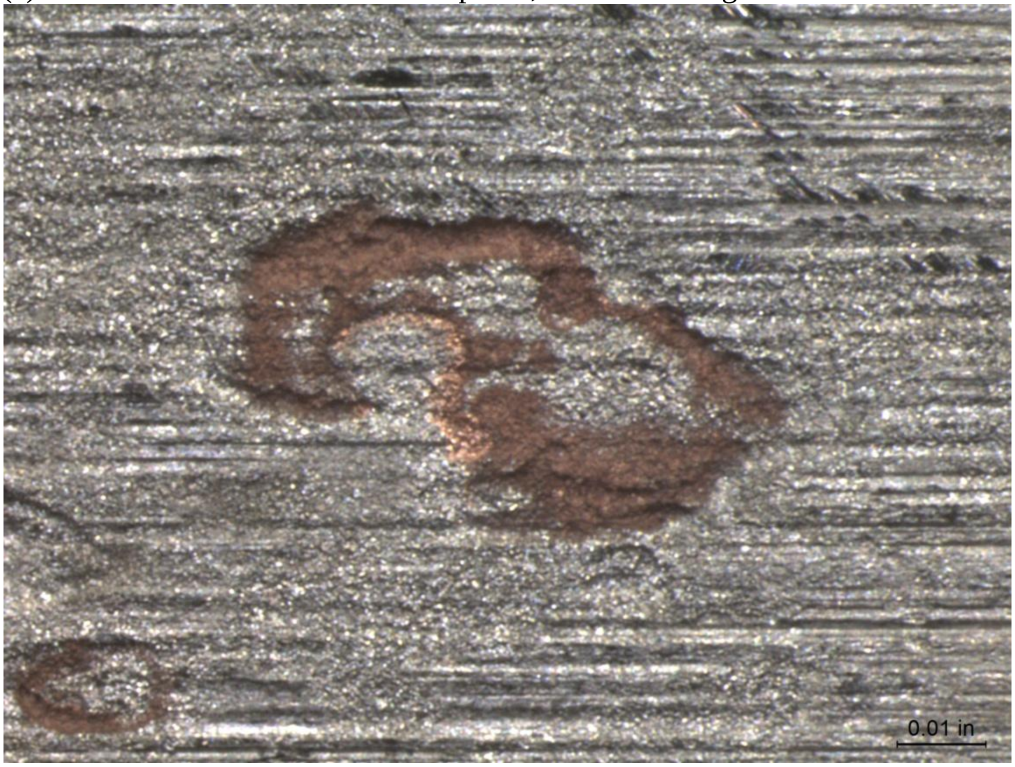
(a) CDA 715 Coupon 4, Before Cleaning 10X



(b) CDA 715 Coupon 4, Before Cleaning 50X

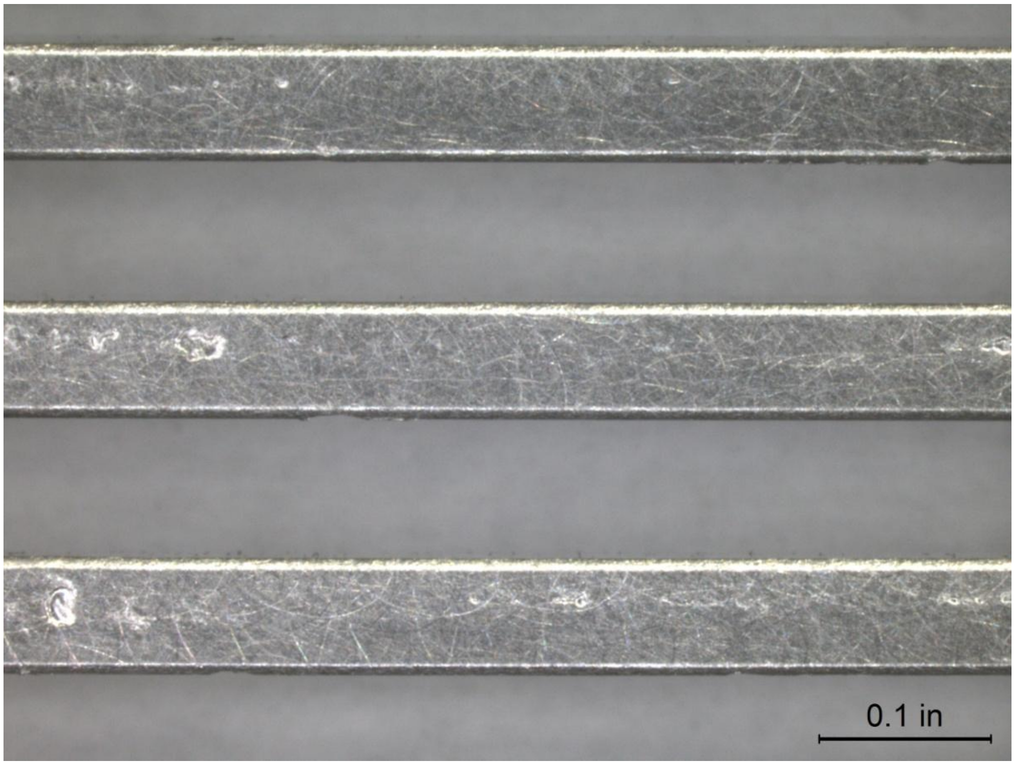
Figure 20 Optical macrographs of CDA 715 coupon 4 after a 12 month corrosion test, before cleaning.

(a) CDA 715 Coupon 4, After Cleaning 10X

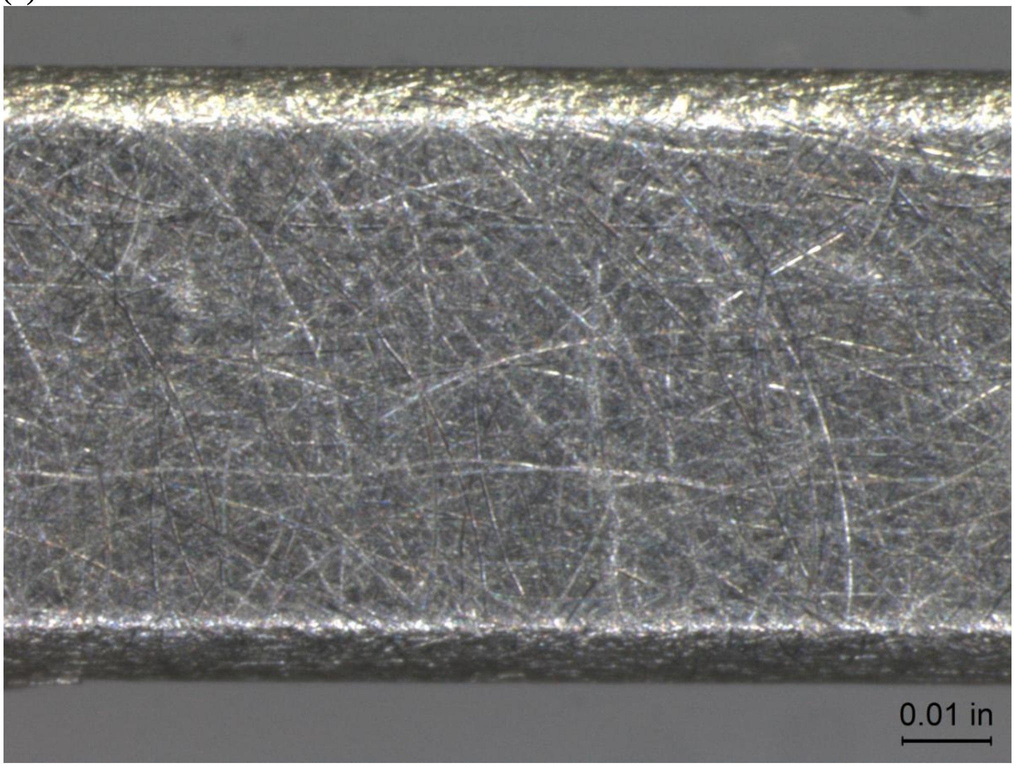


(b) CDA 715 Coupon 4, After Cleaning 50X

Figure 21 Optical macrographs of CDA 715 coupon 4 after a 12 month corrosion test, after cleaning.

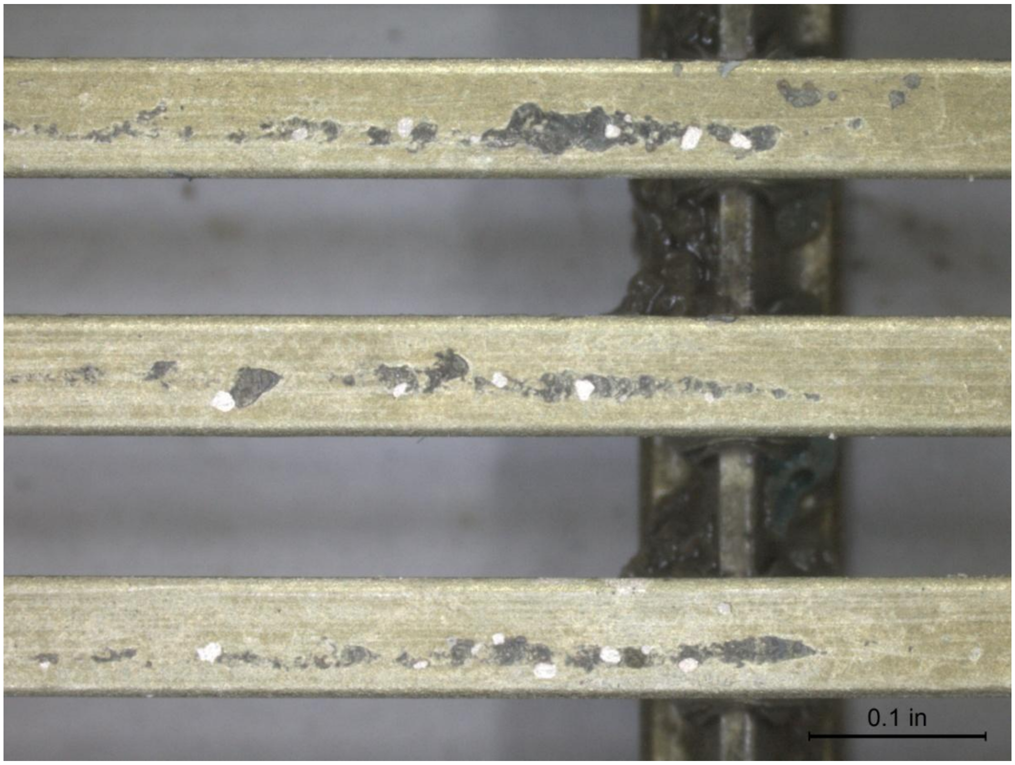


(a) CDA 715 Baseline Screen 10X

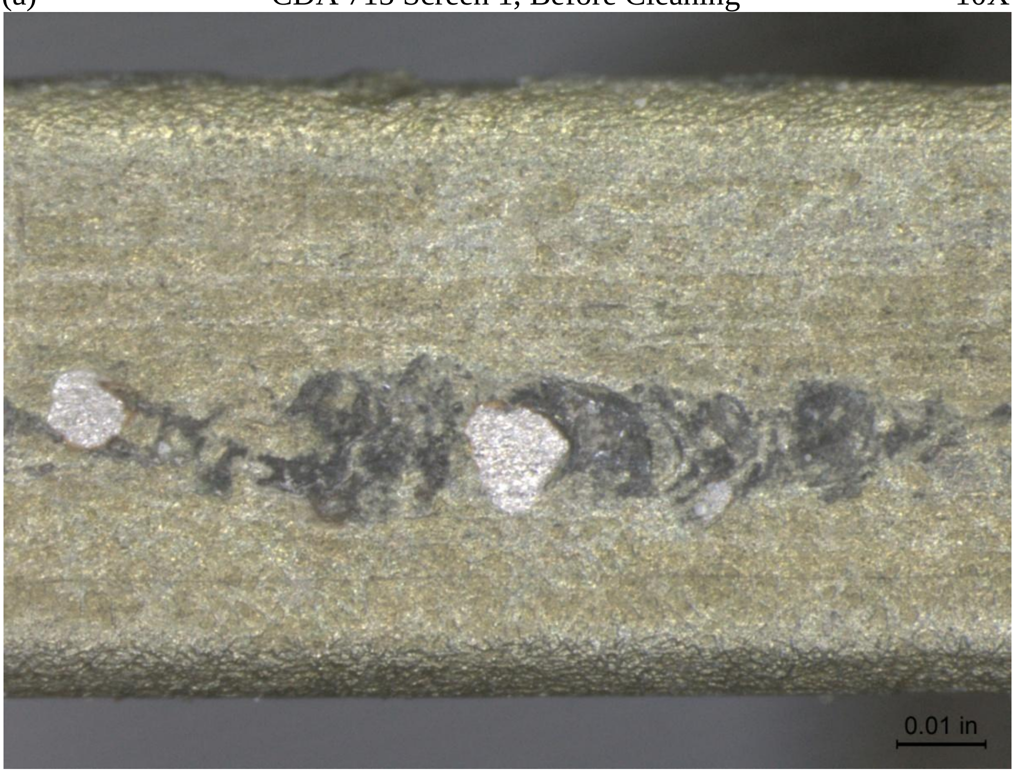


(b) CDA 715 Baseline Screen 50X

Figure 22 Optical macrographs of the CDA 715 baseline screen.

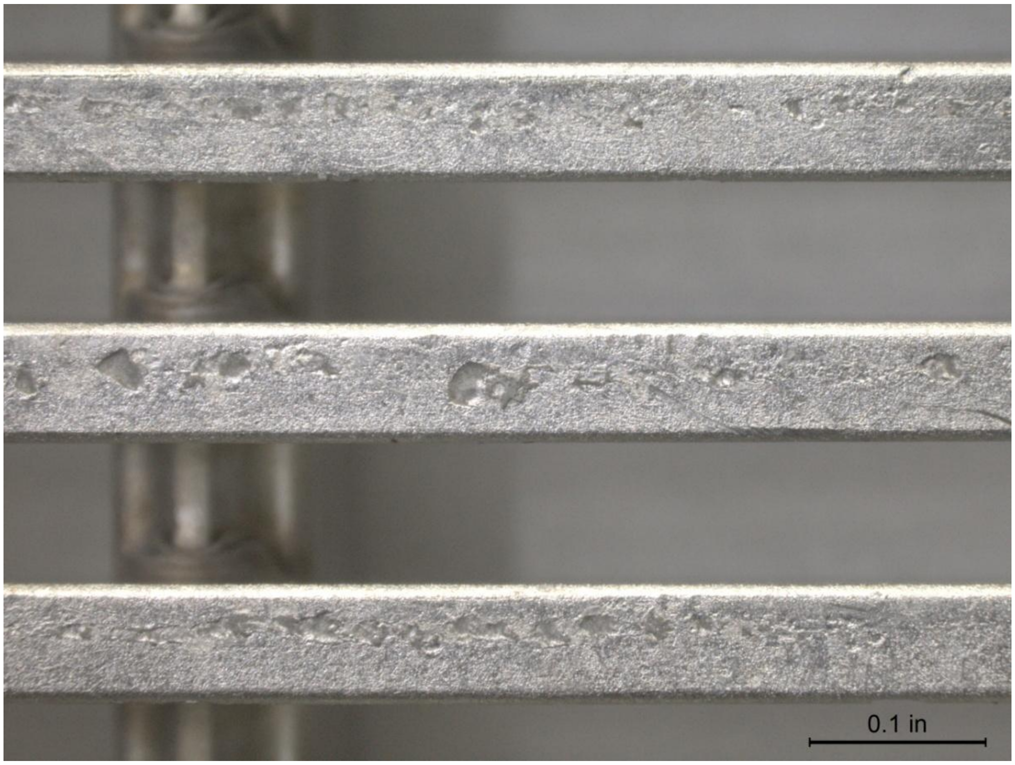


(a) CDA 715 Screen 1, Before Cleaning 10X

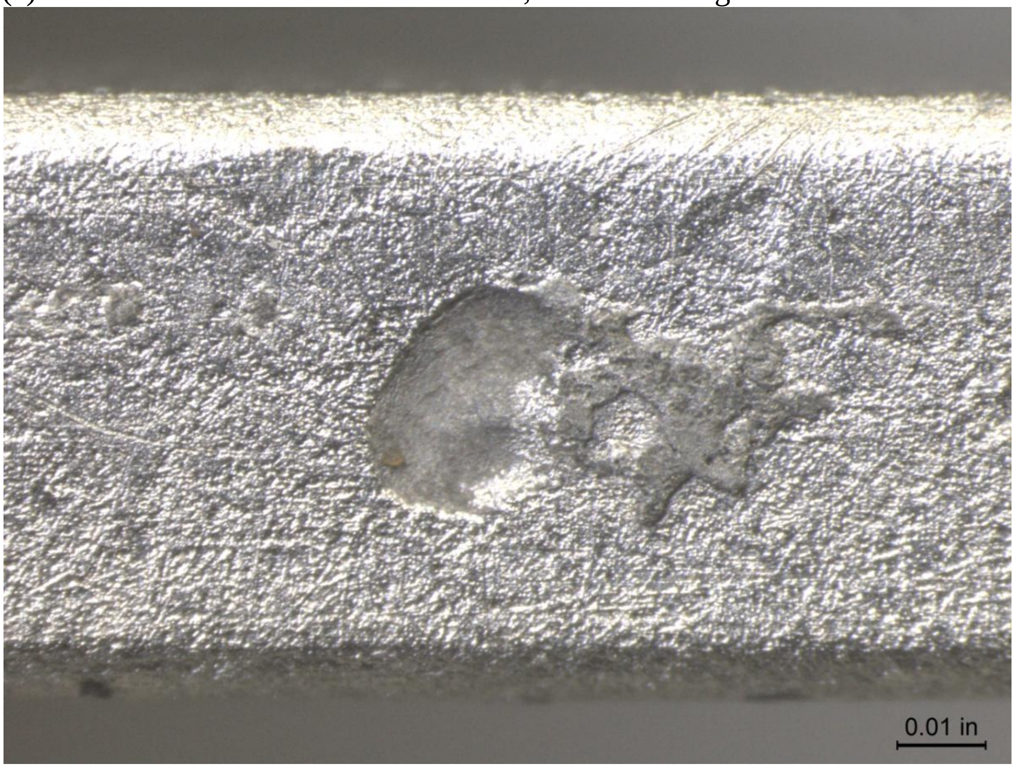


(b) CDA 715 Screen 1, Before Cleaning 50X

Figure 23 Optical macrographs of CDA 715 screen 1 after a 3 month corrosion test, before cleaning.

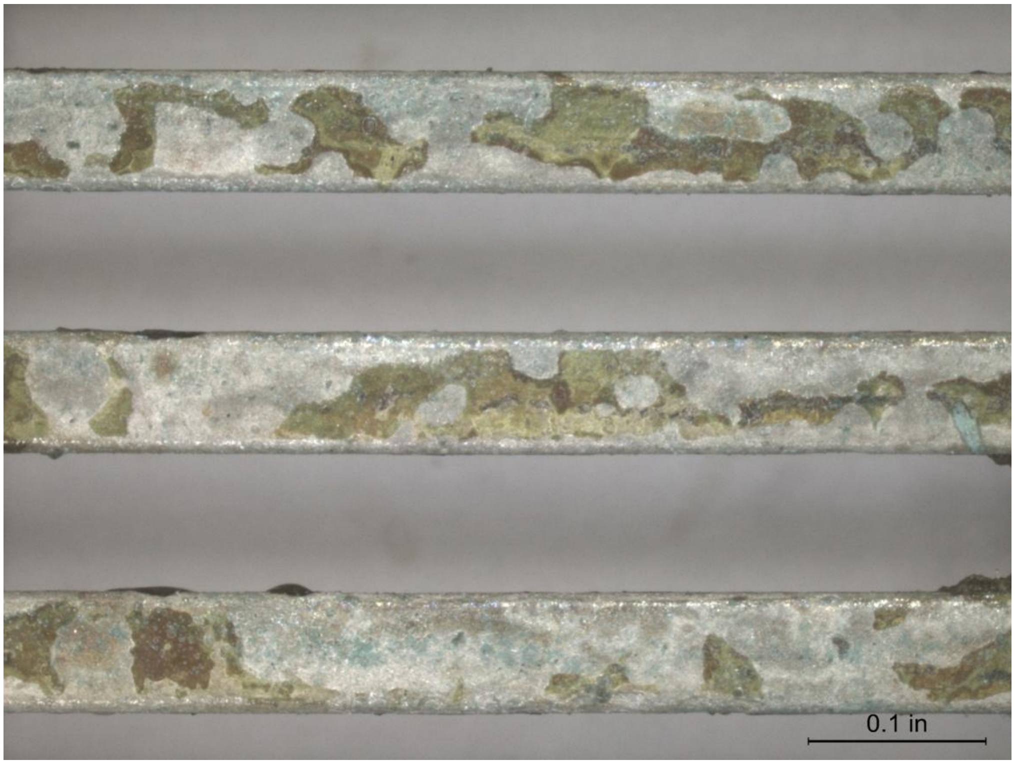


(a) CDA 715 Screen 1, After Cleaning 10X



(b) CDA 715 Screen 1, After Cleaning 50X

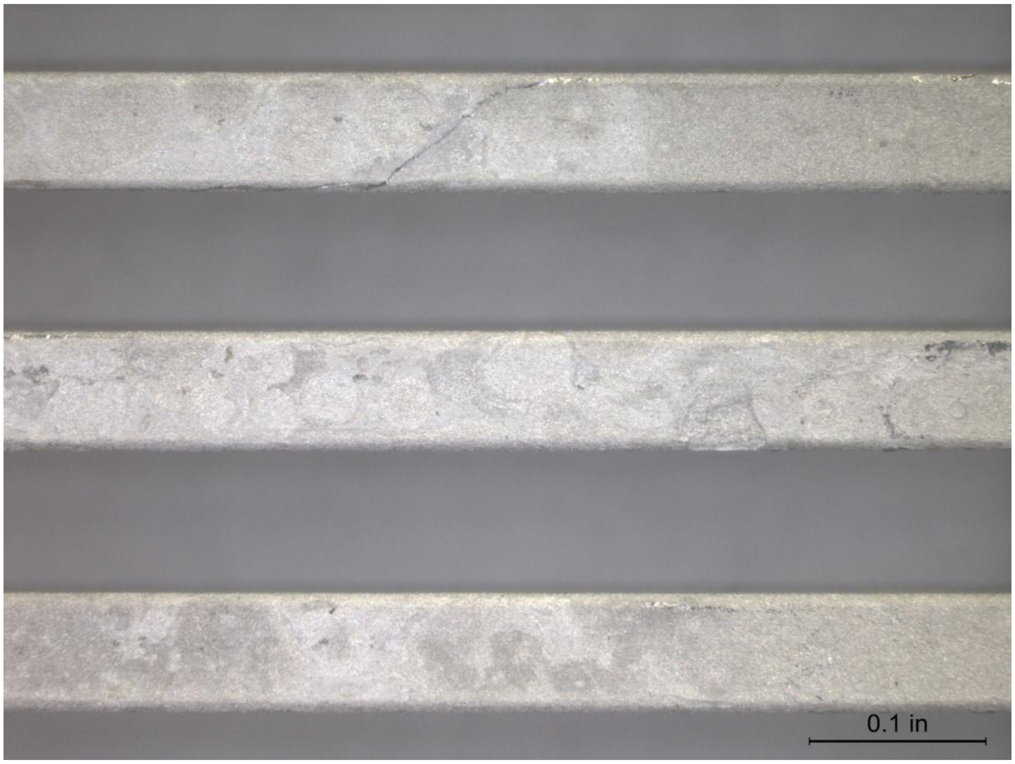
Figure 24 Optical macrographs of CDA 715 screen 1 after a 3 month corrosion test, after cleaning.



(a) CDA 715 Screen 2, Before Cleaning 10X

(b) CDA 715 Screen 2, Before Cleaning 50X

Figure 25 Optical macrographs of CDA 715 screen 2 after a 6 month corrosion test, before cleaning.



(a) CDA 715 Screen 2, After Cleaning 10X

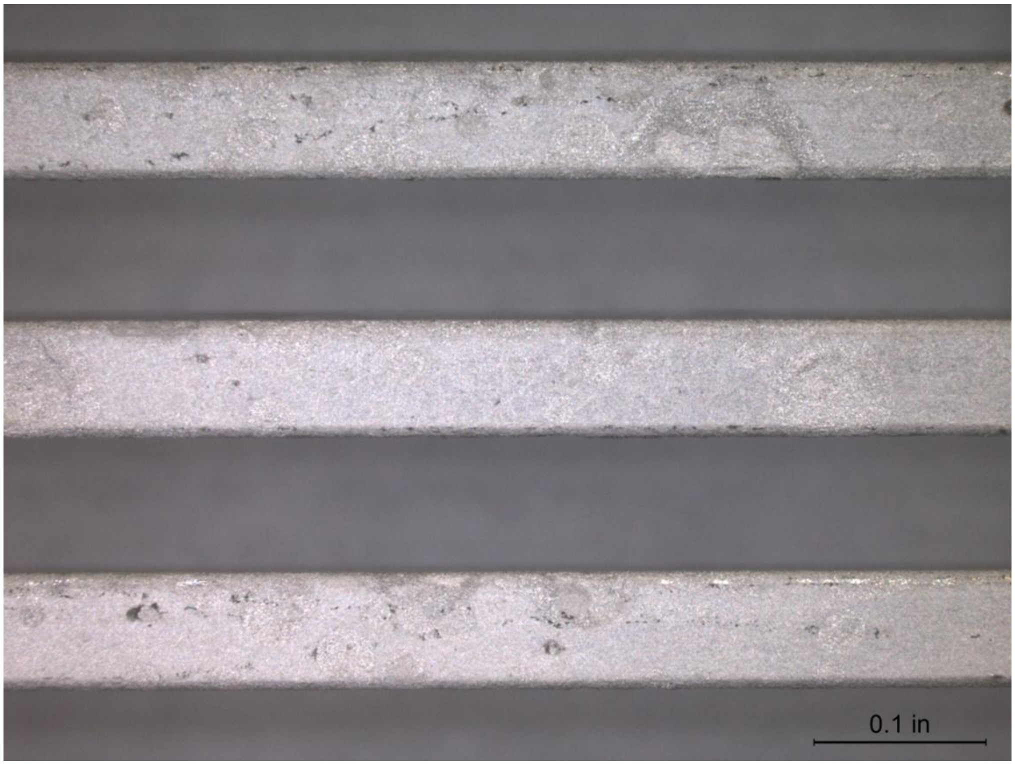
(b) CDA 715 Screen 2, After Cleaning 50X

Figure 26 Optical macrographs of CDA 715 screen 2 after a 6 month corrosion test, after cleaning.

(a) CDA 715 Screen 3, Before Cleaning 10X

(b) CDA 715 Screen 3, Before Cleaning 50X

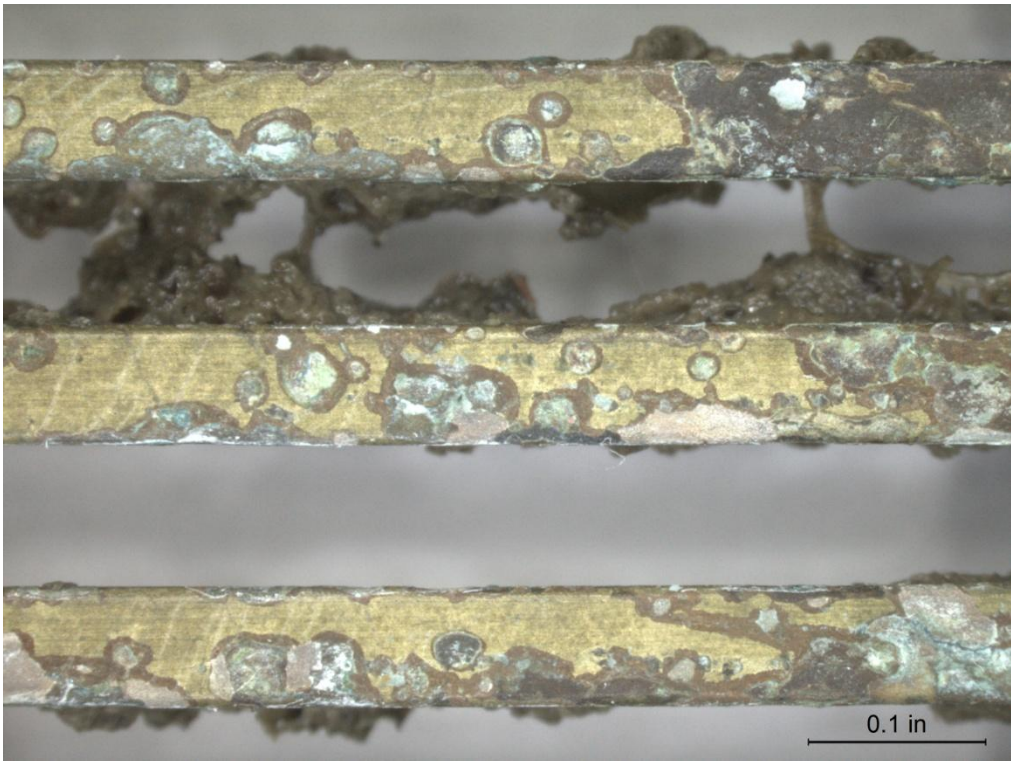
Figure 27 Optical macrographs of CDA 715 screen 3 after a 10 month corrosion test, before cleaning.



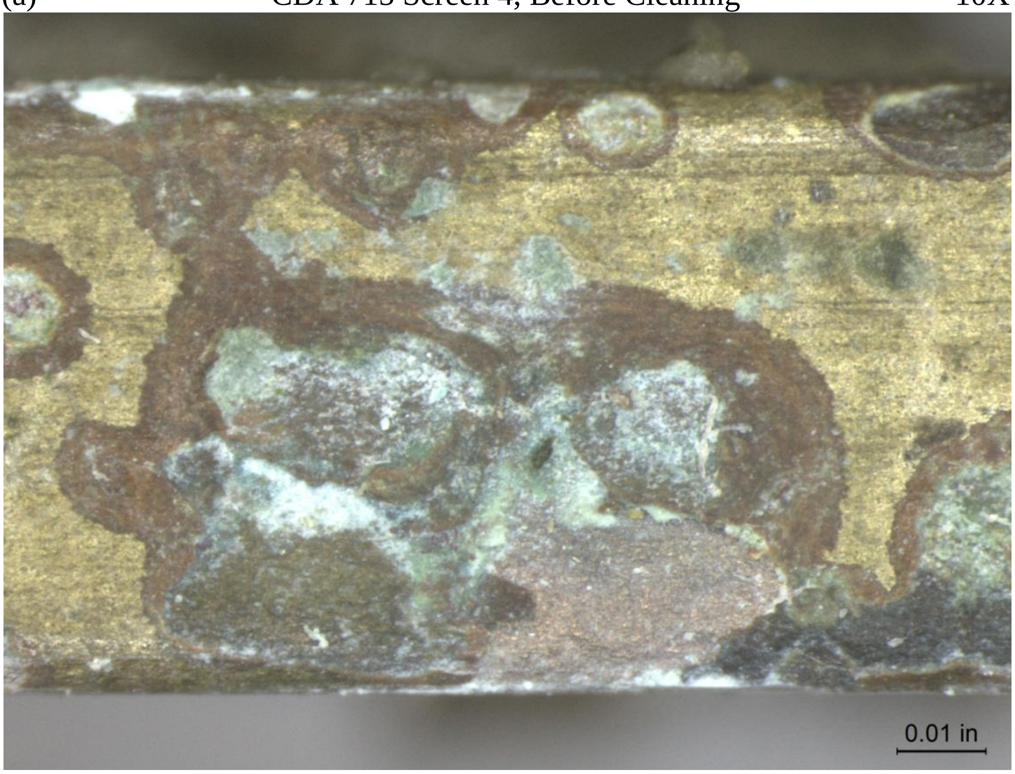
(a) CDA 715 Screen 3, After Cleaning 10X

(b) CDA 715 Screen 3, After Cleaning 50X

Figure 28 Optical macrographs of CDA 715 screen 3 after a 10 month corrosion test, after cleaning.

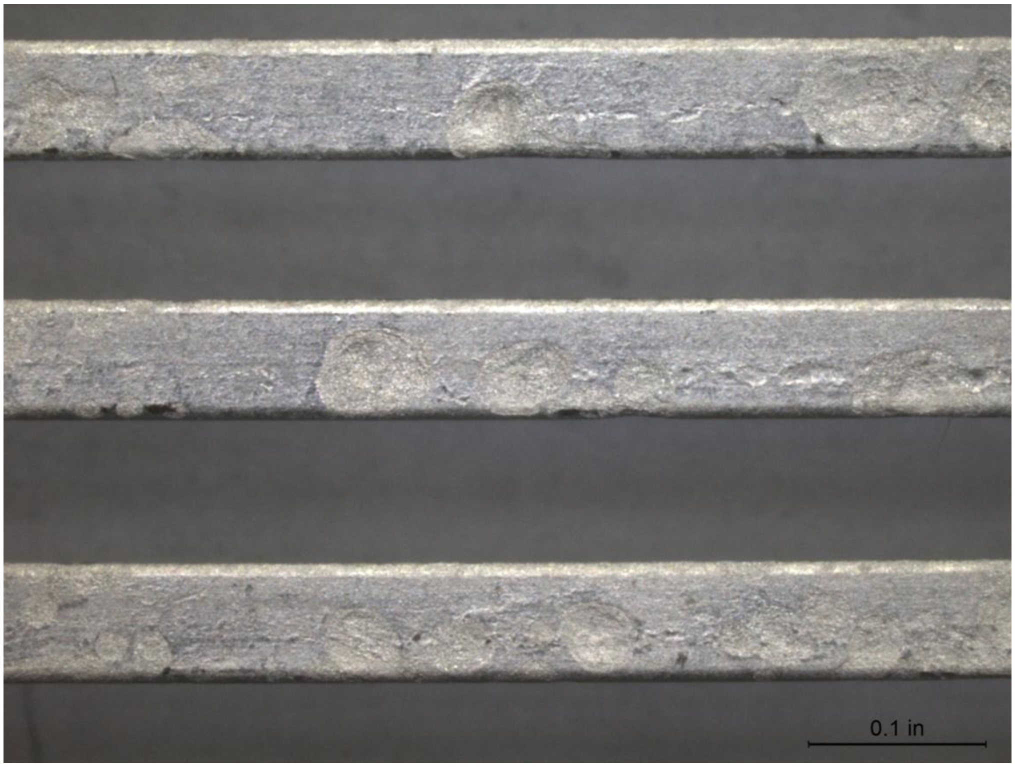


(a) CDA 715 Screen 4, Before Cleaning 10X



(b) CDA 715 Screen 4, Before Cleaning 50X

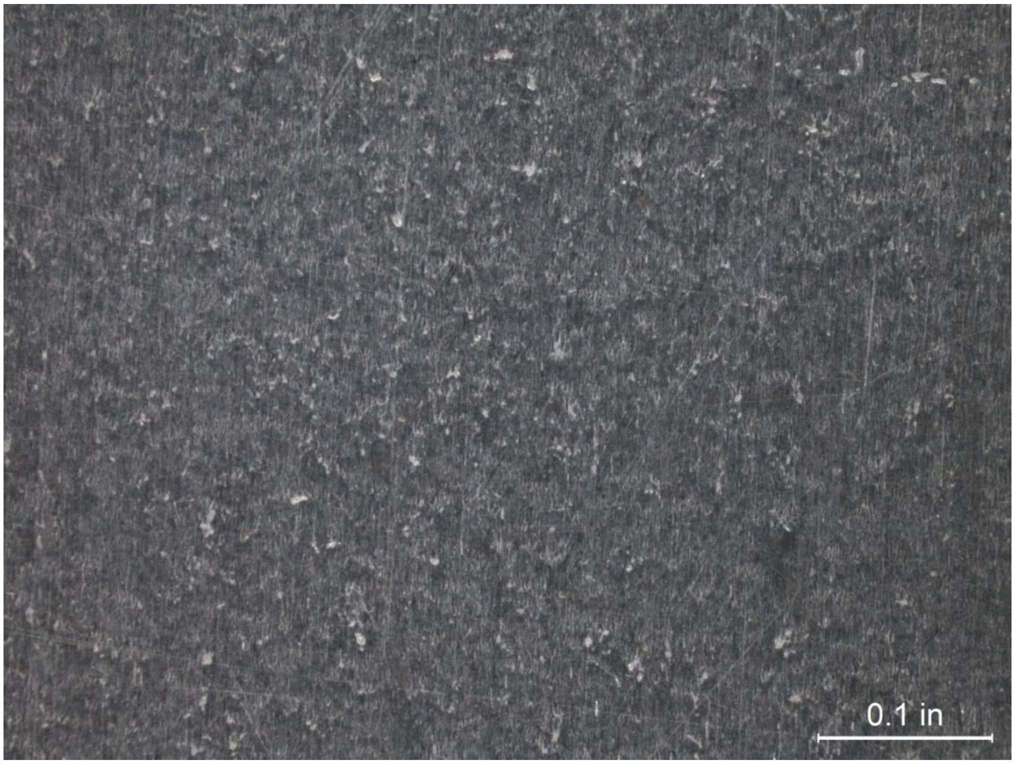
Figure 29 Optical macrographs of CDA 715 screen 4 after a 12 month corrosion test, before cleaning.



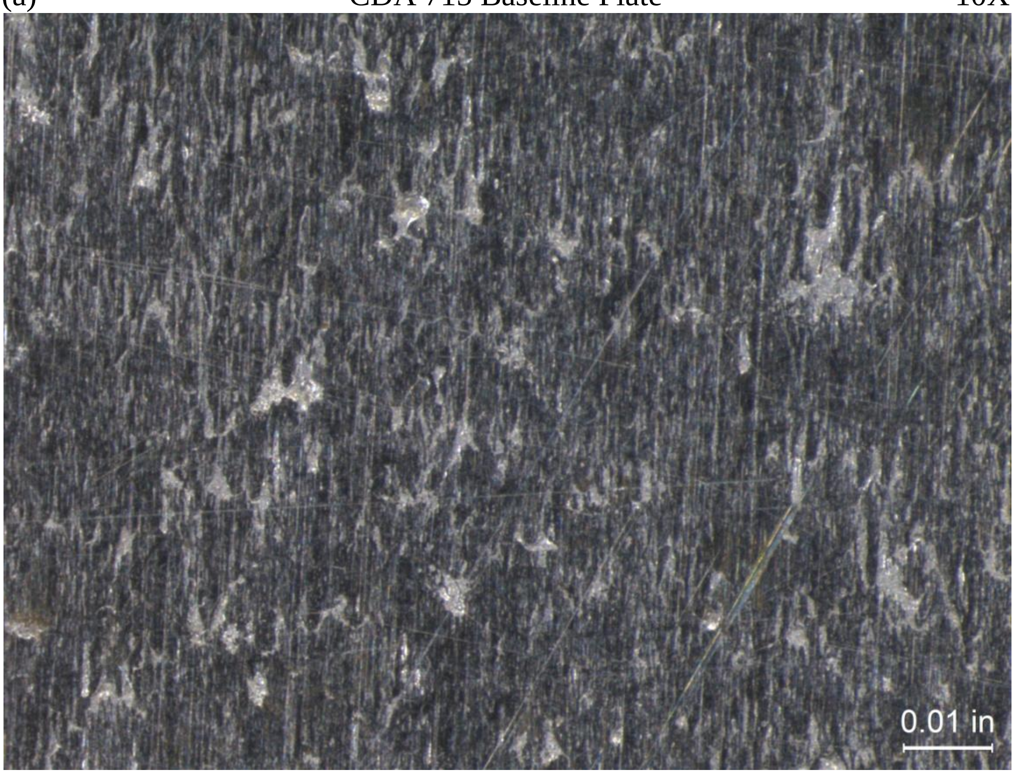
(a) CDA 715 Plate 4, After Cleaning 10X

(b) CDA 715 Screen 4, After Cleaning 50X

Figure 30 Optical macrographs of CDA 715 screen 4 after a 12 month corrosion test, after cleaning.

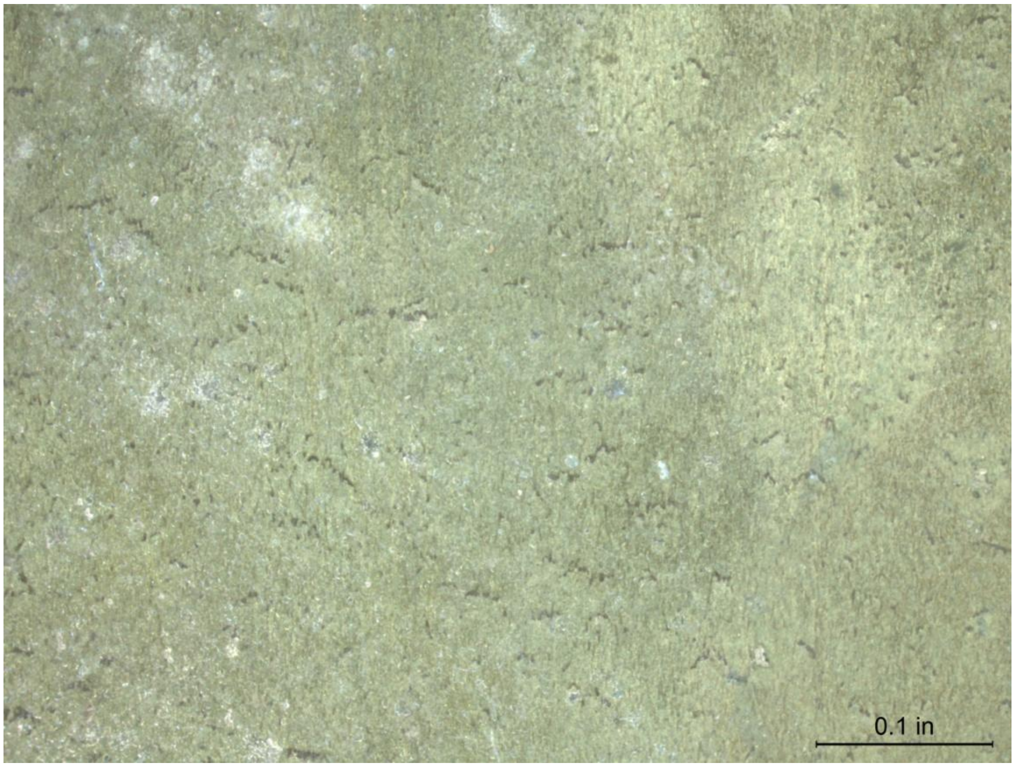


(a) CDA 715 Baseline Plate 10X

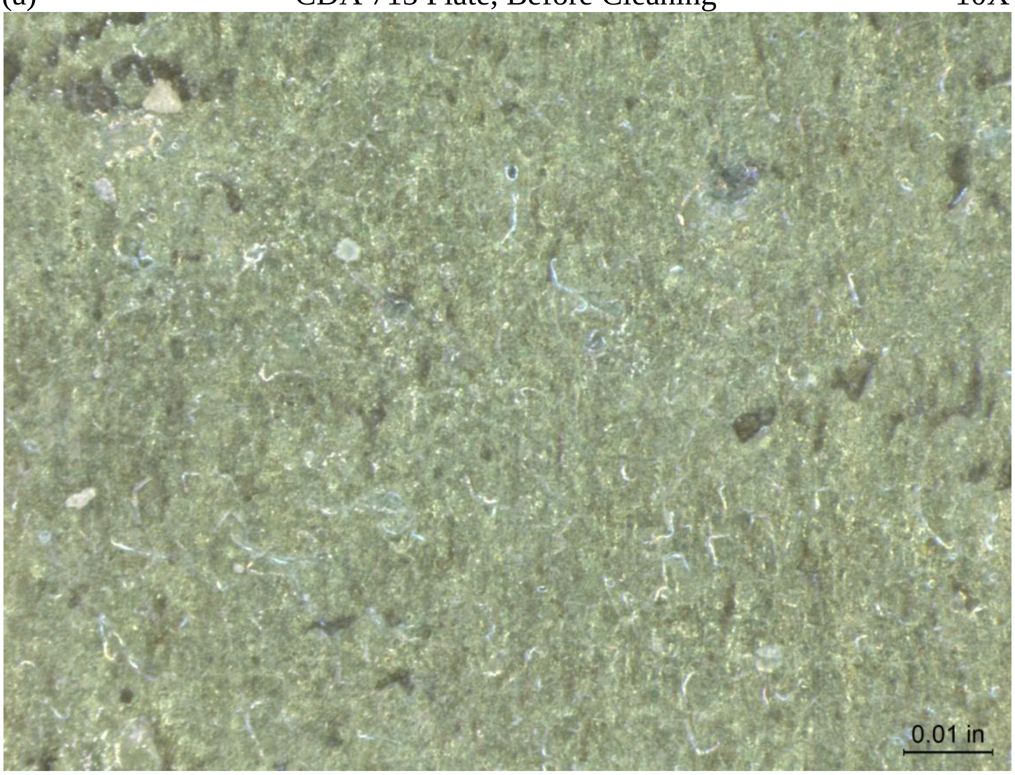


(b) CDA 715 Baseline Plate 50X

Figure 31 Optical macrographs of the CDA 715 baseline plate.

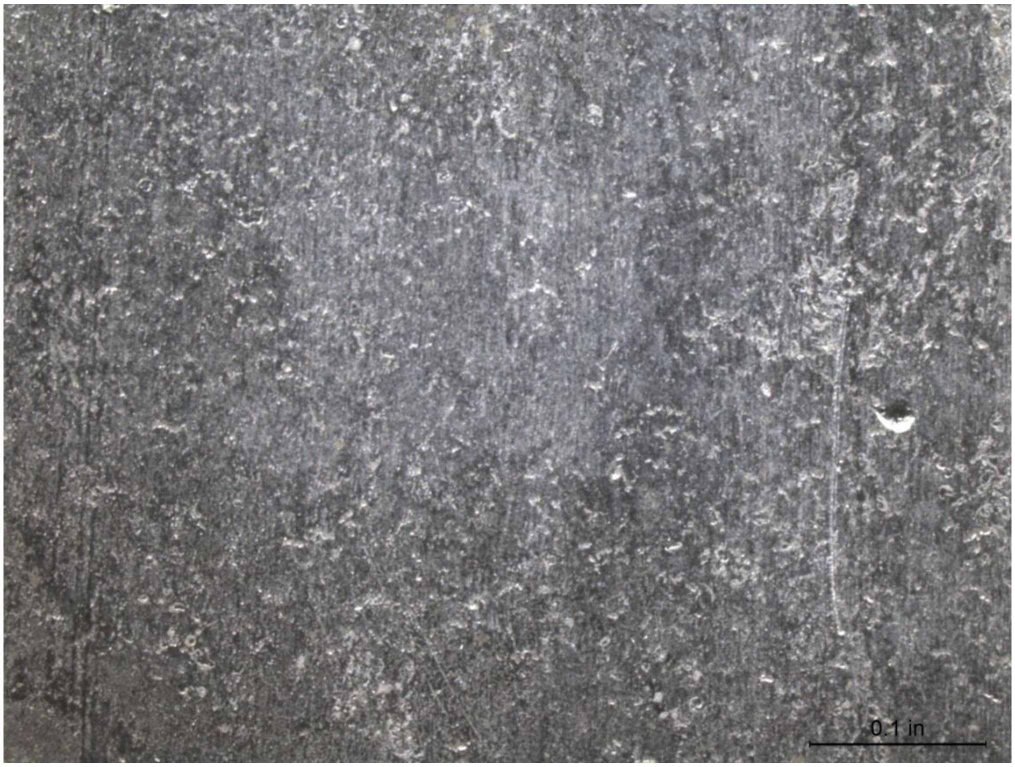


(a) CDA 715 Plate, Before Cleaning 10X

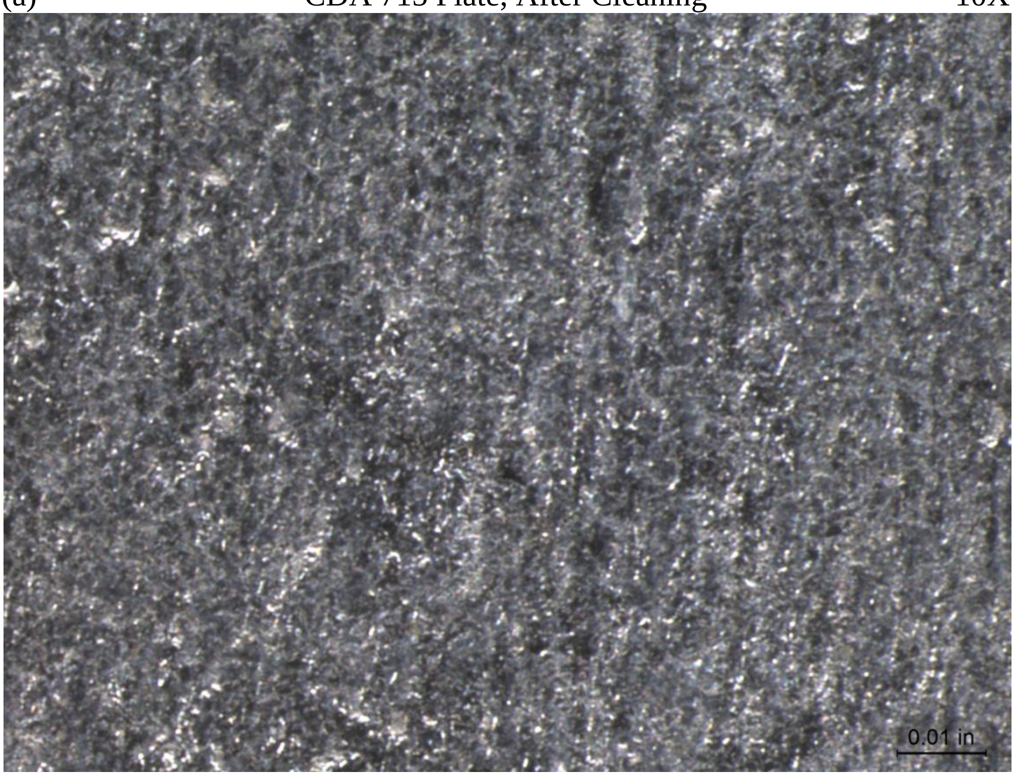


(b) CDA 715 Plate, Before Cleaning 50X

Figure 32 Optical macrographs of CDA 715 plate after a 12 month corrosion test, before cleaning.

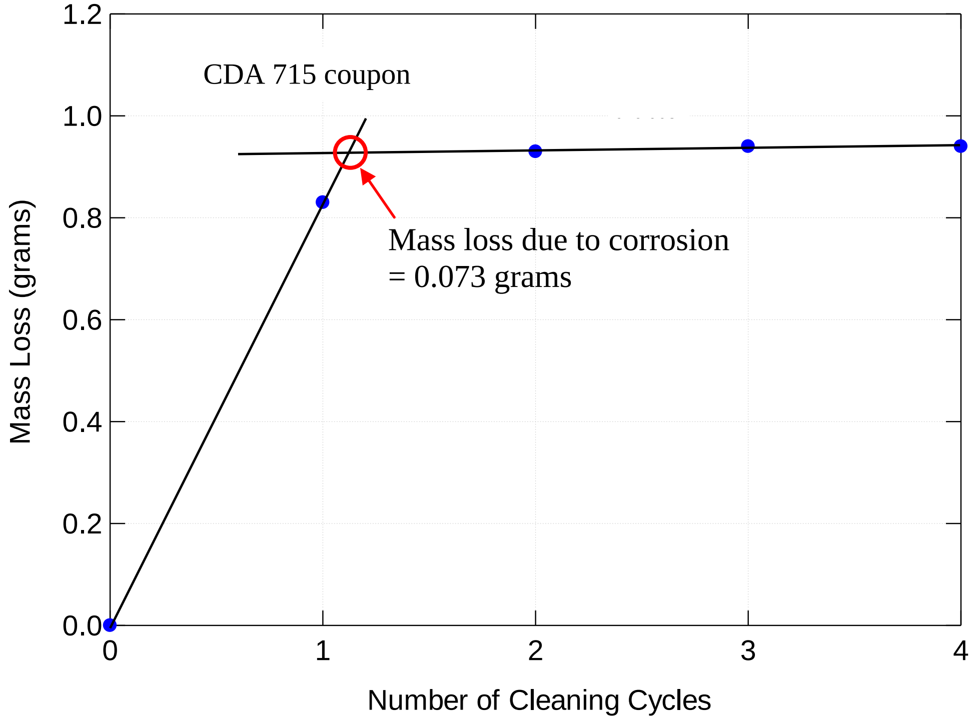


(a) CDA 715 Plate, After Cleaning 10X

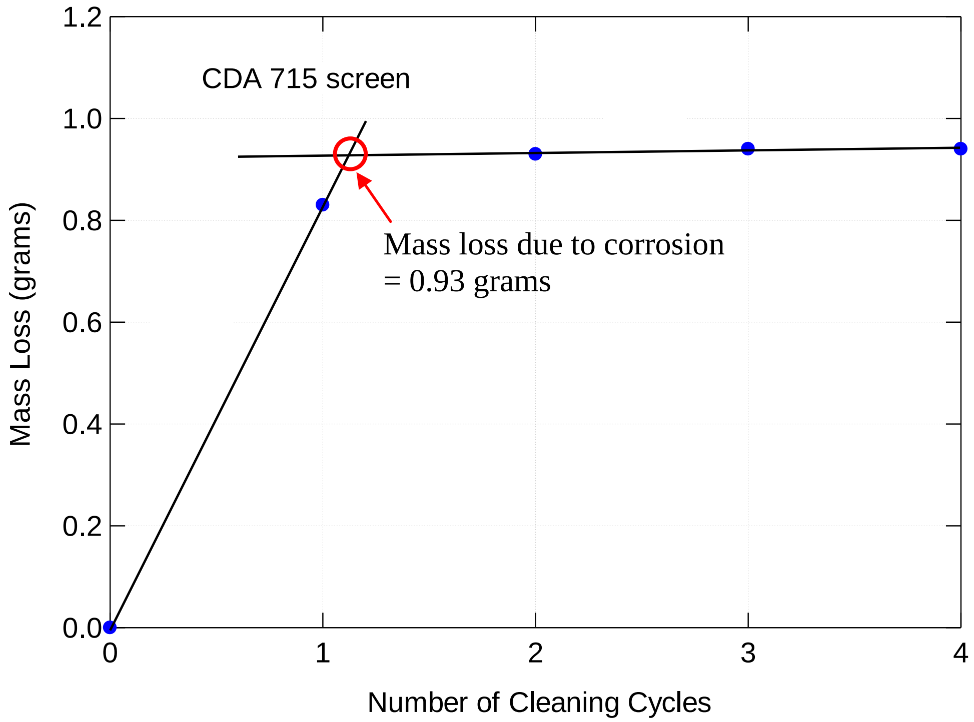


(b) CDA 715 Plate, After Cleaning 50X

Figure 33 Optical macrographs of CDA 715 plate after a 12 month corrosion test, after cleaning.

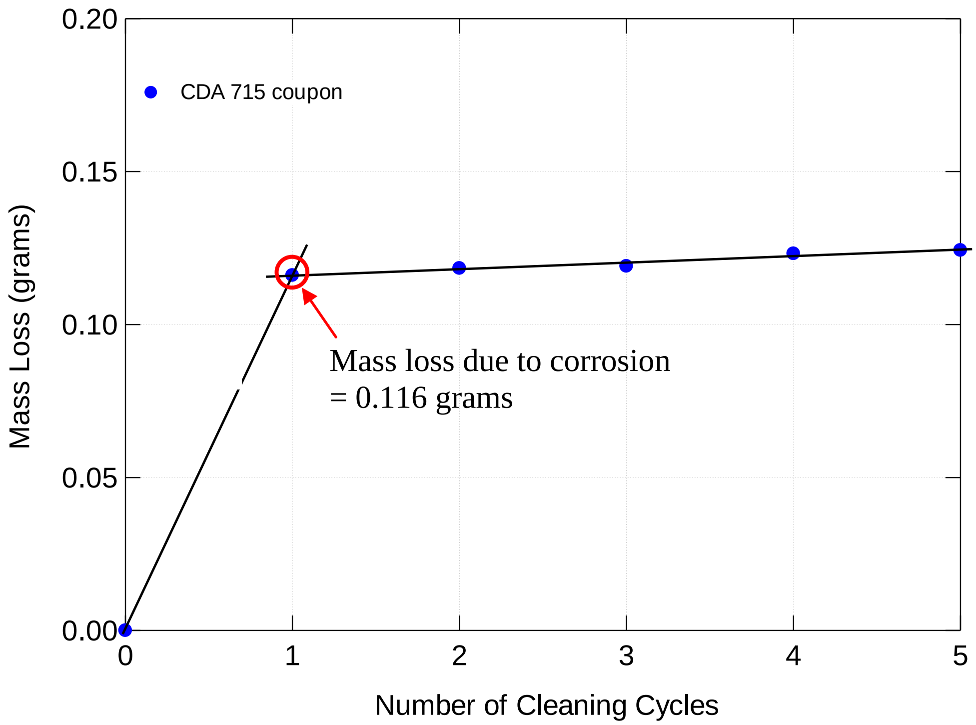


(a)

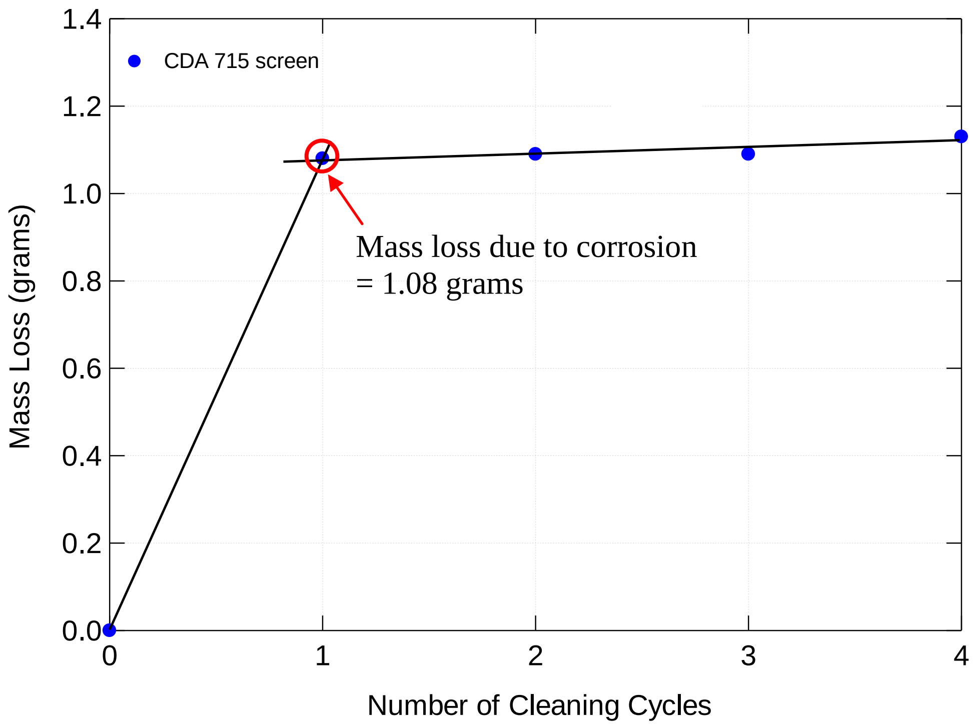


(b)

Figure 34 Mass loss of CDA 715 (a) coupon 1 and (b) screen 1 during cleaning.

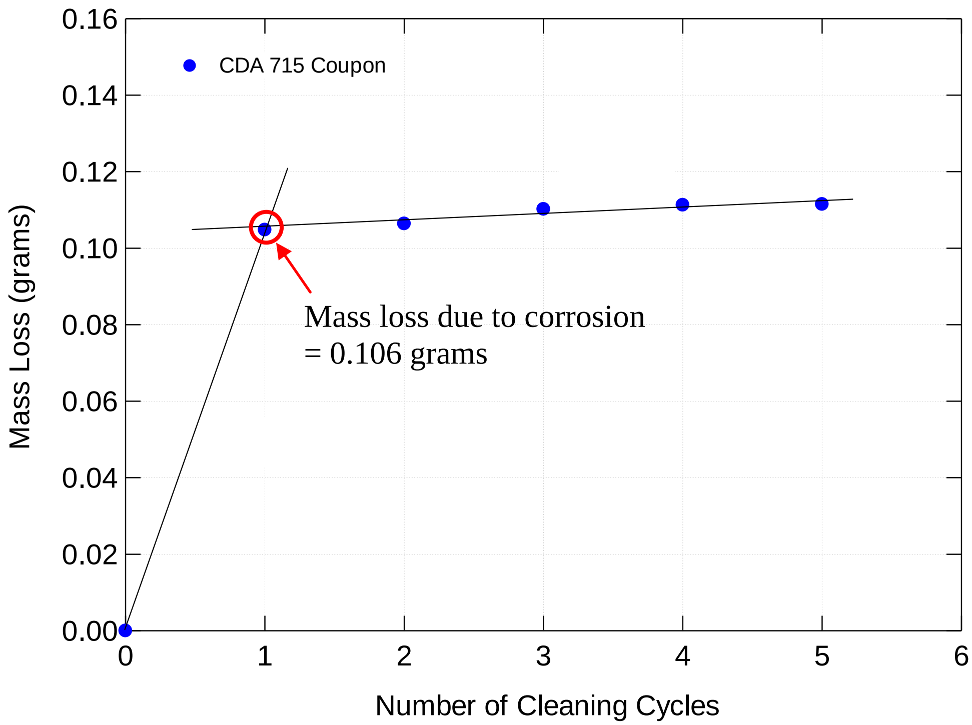


(a)

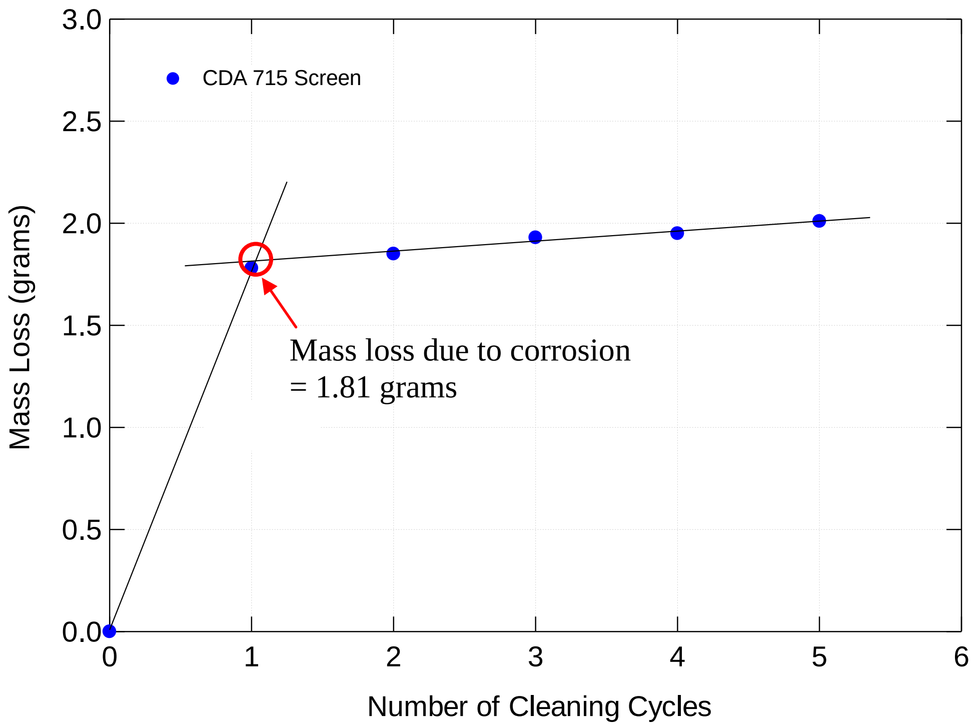


(b)

Figure 35 Mass loss of CDA 715 (a) coupon 2 and (b) screen 2 during cleaning.

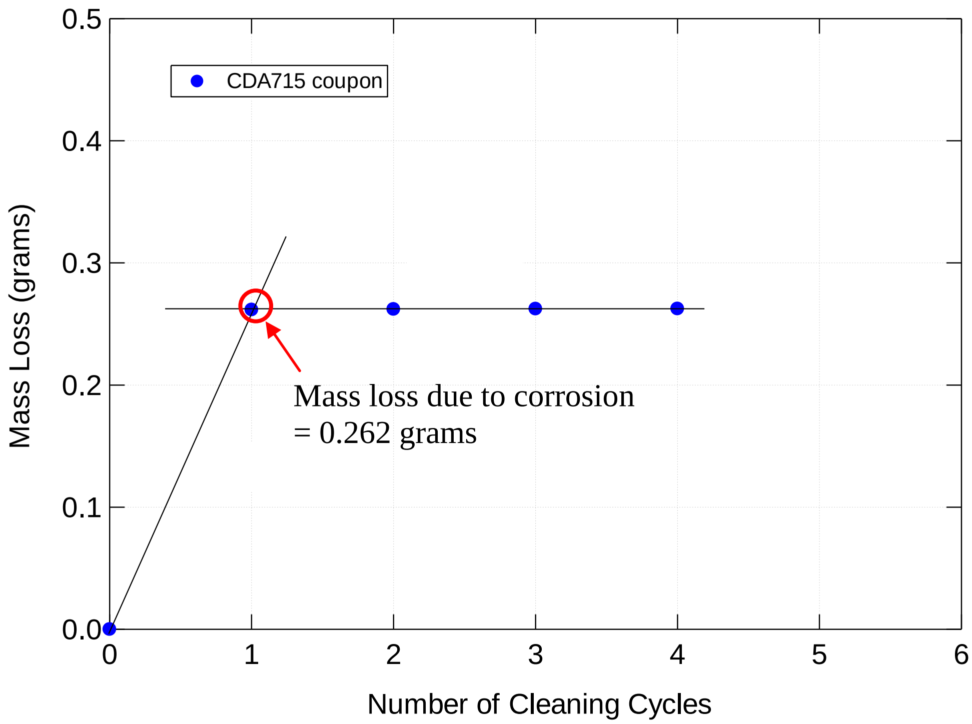


(a)

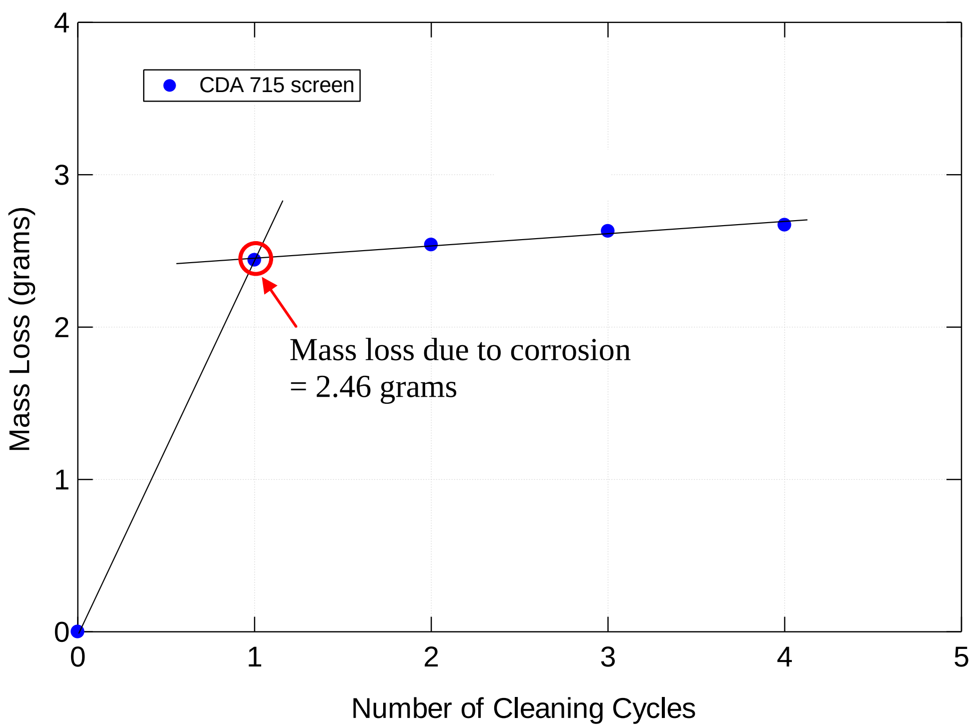


(b)

Figure 36 Mass loss of CDA 715 (a) coupon 3 and (b) screen 3 during cleaning.

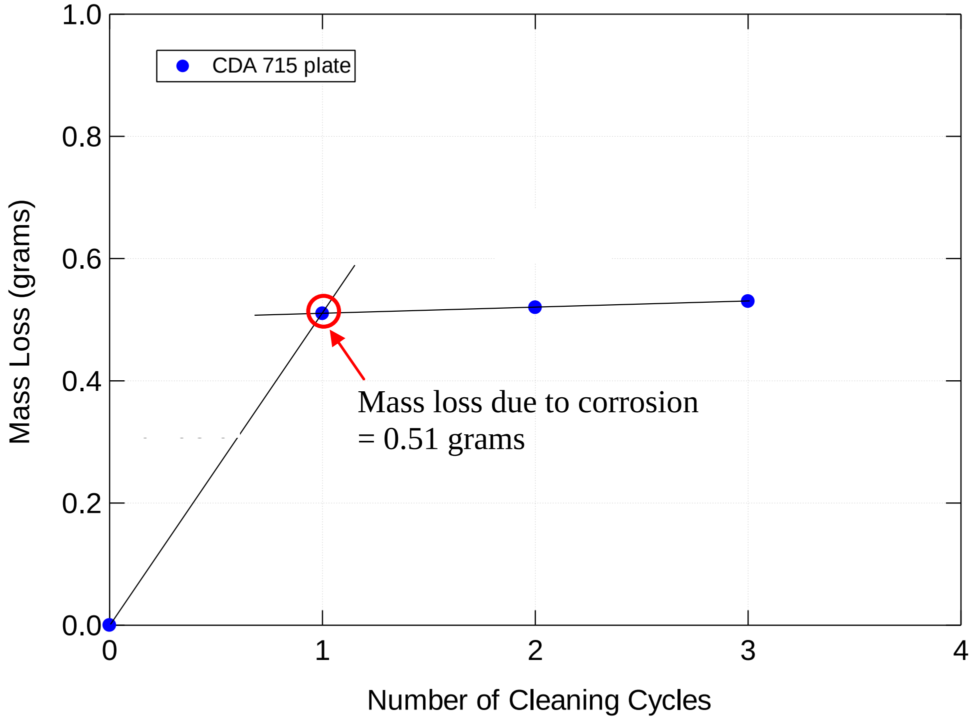


(a)



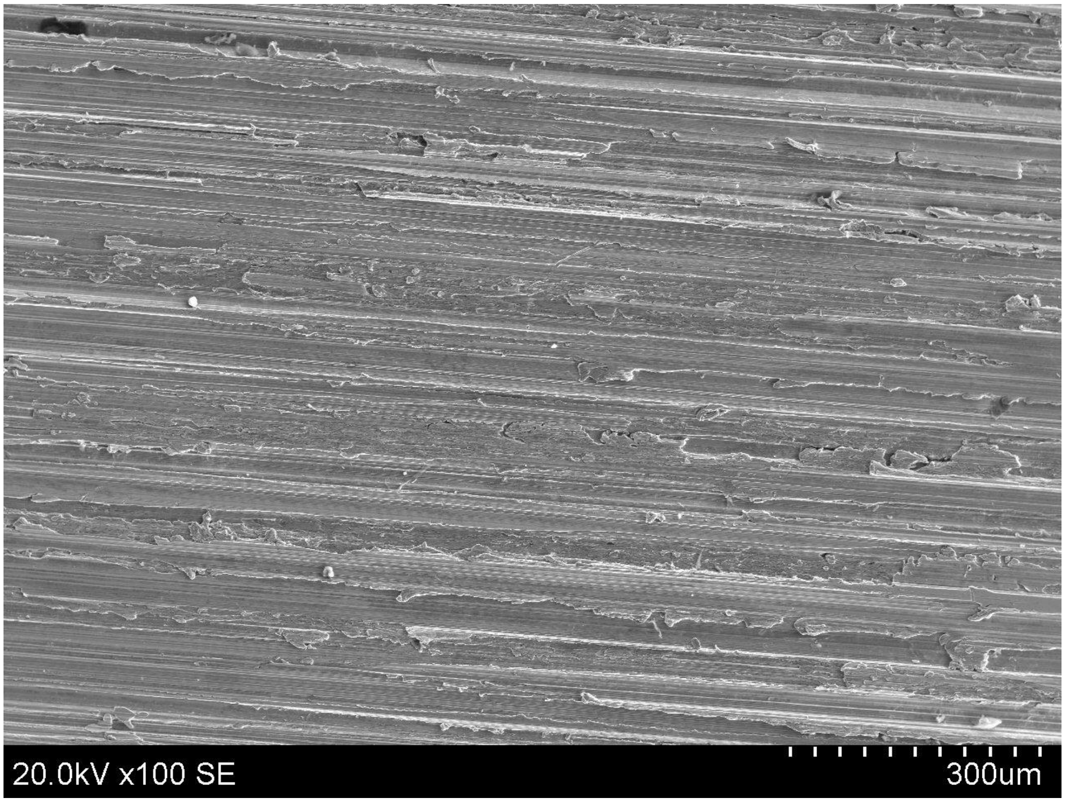
(b)

Figure 37 Mass loss of CDA 715 (a) coupon 4 and (b) screen 4 during cleaning.

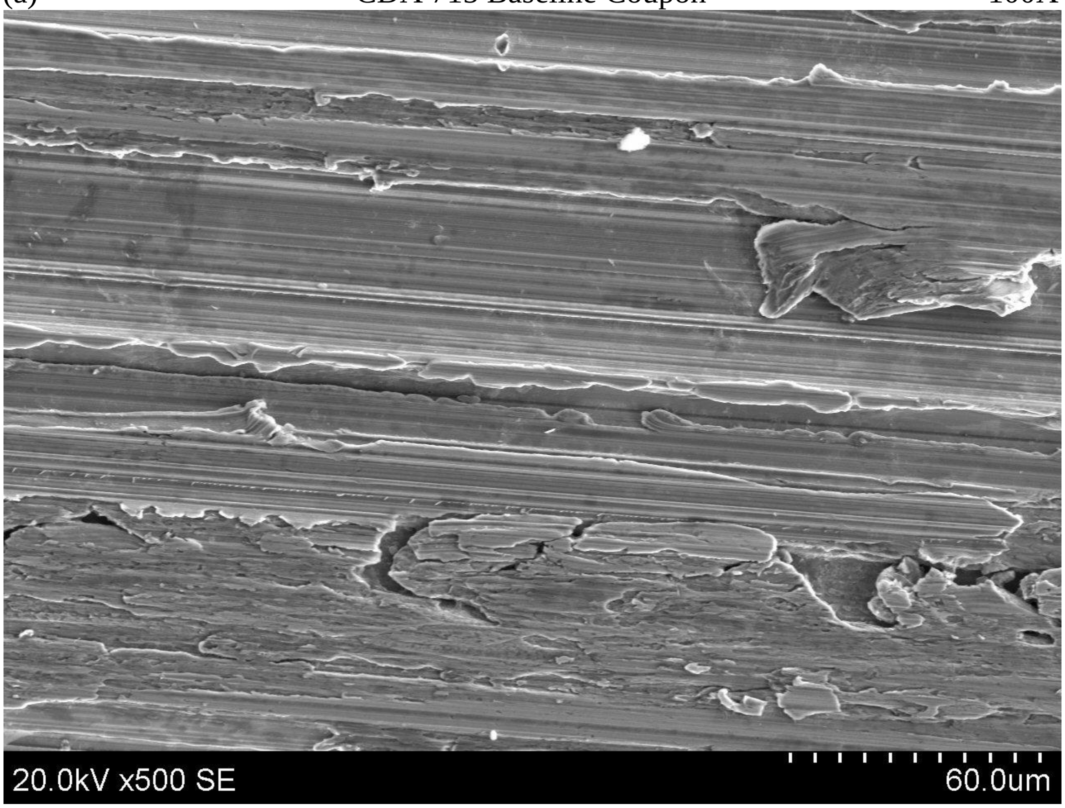


(b)

Figure 38 Mass loss of CDA 715 plate during cleaning.

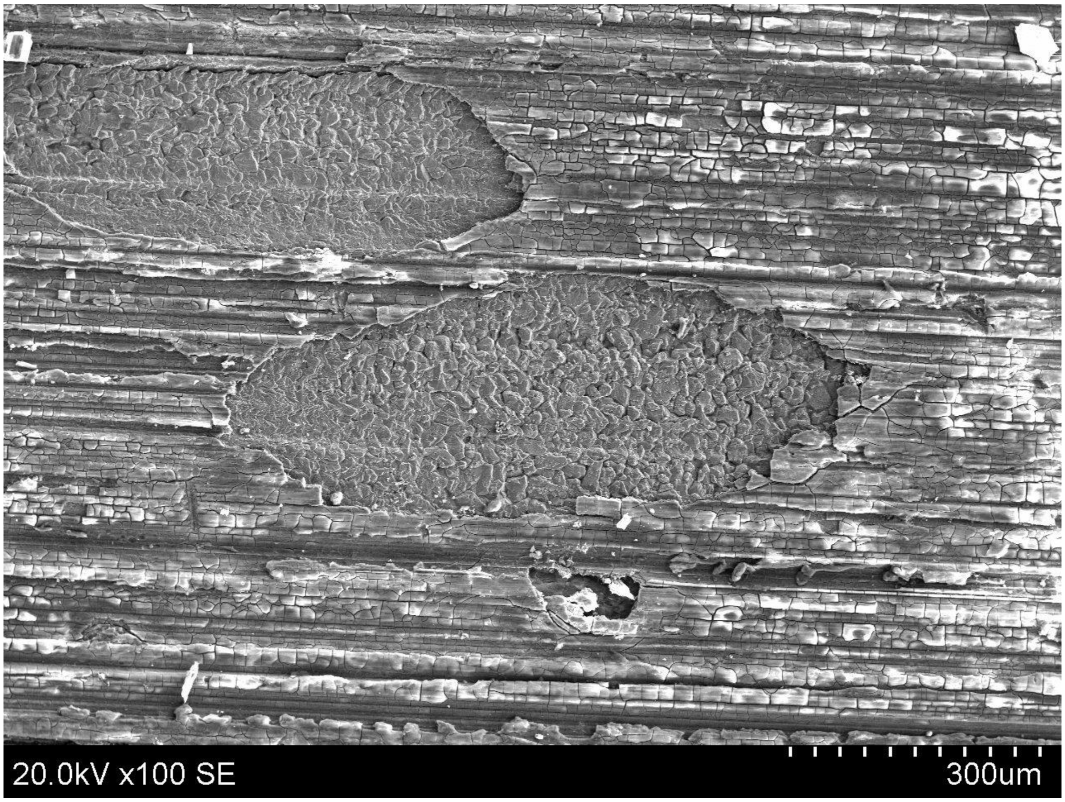


(a) CDA 715 Baseline Coupon 100X

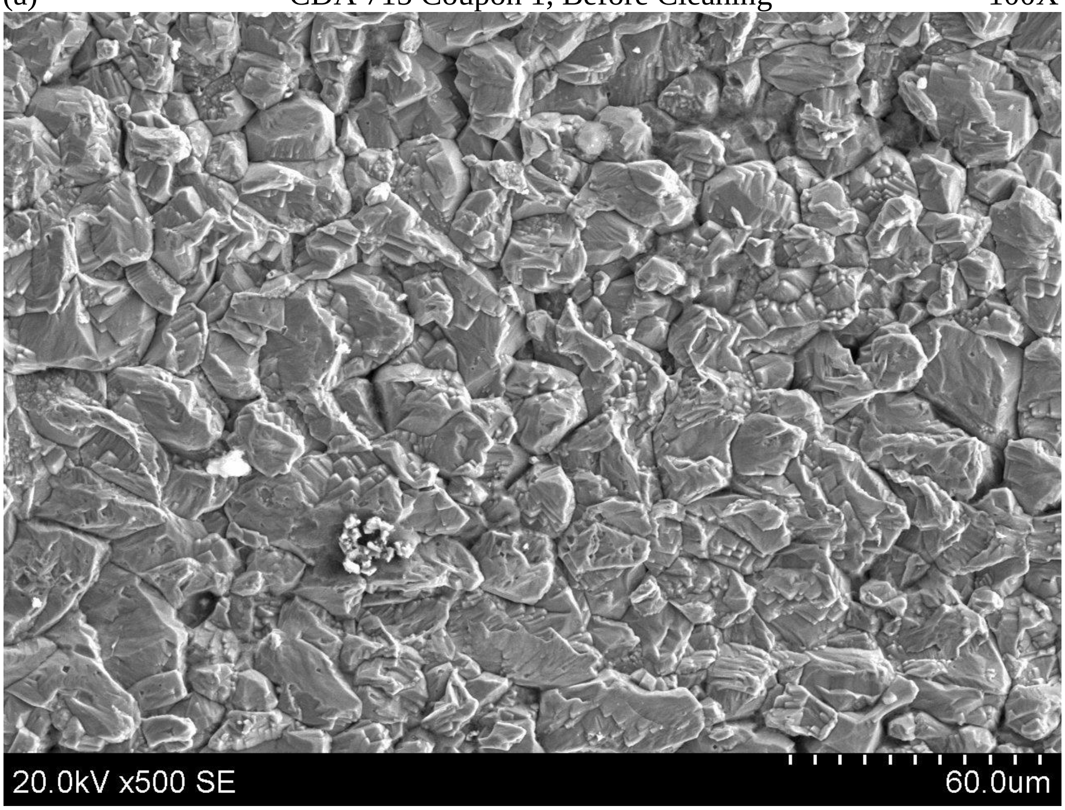


(b) CDA 715 Baseline Coupon 500X

Figure 39 Scanning electron micrographs of the CDA 715 baseline coupon.

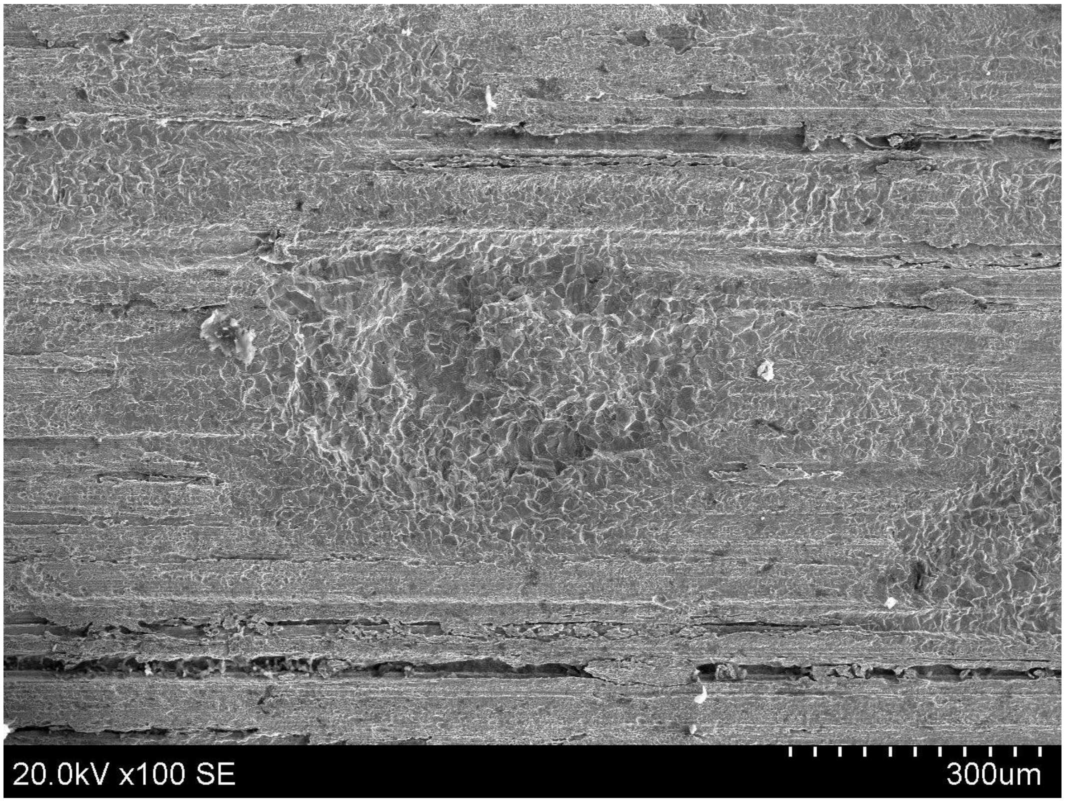


(a) CDA 715 Coupon 1, Before Cleaning 100X

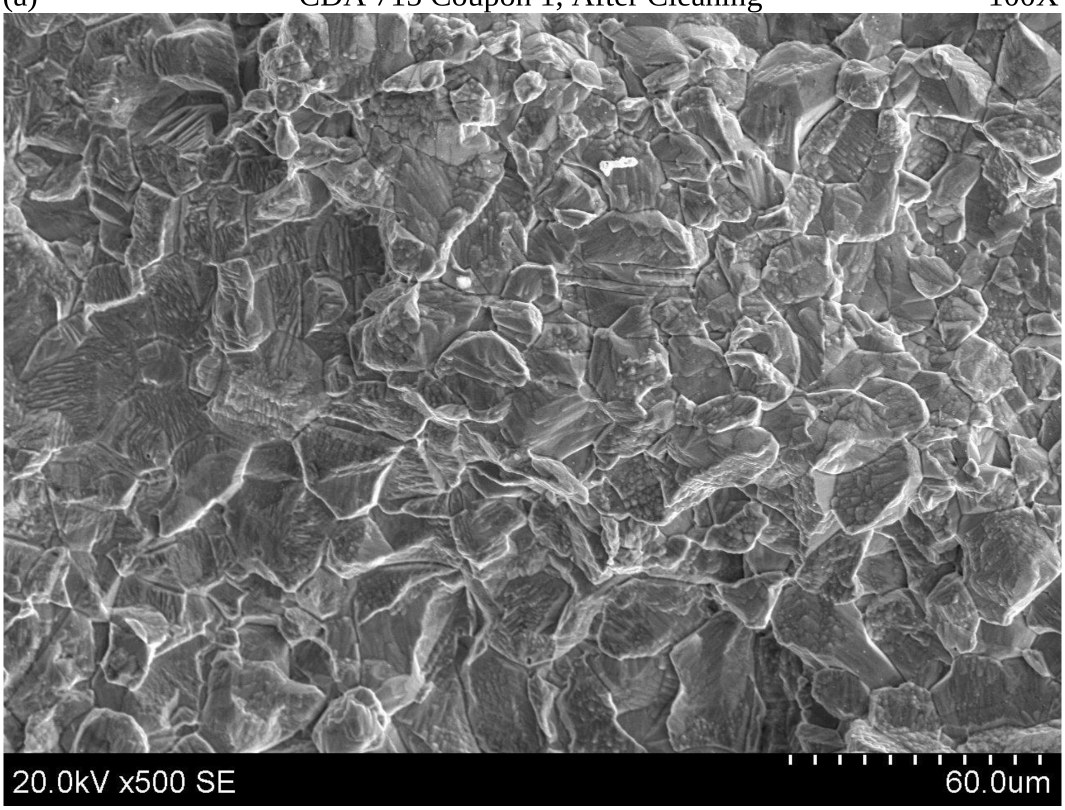


(b) CDA 715 Coupon 1, Before Cleaning 500X

Figure 40 Scanning electron micrographs of CDA 715 coupon 1 after a 3 month immersion test, before cleaning.



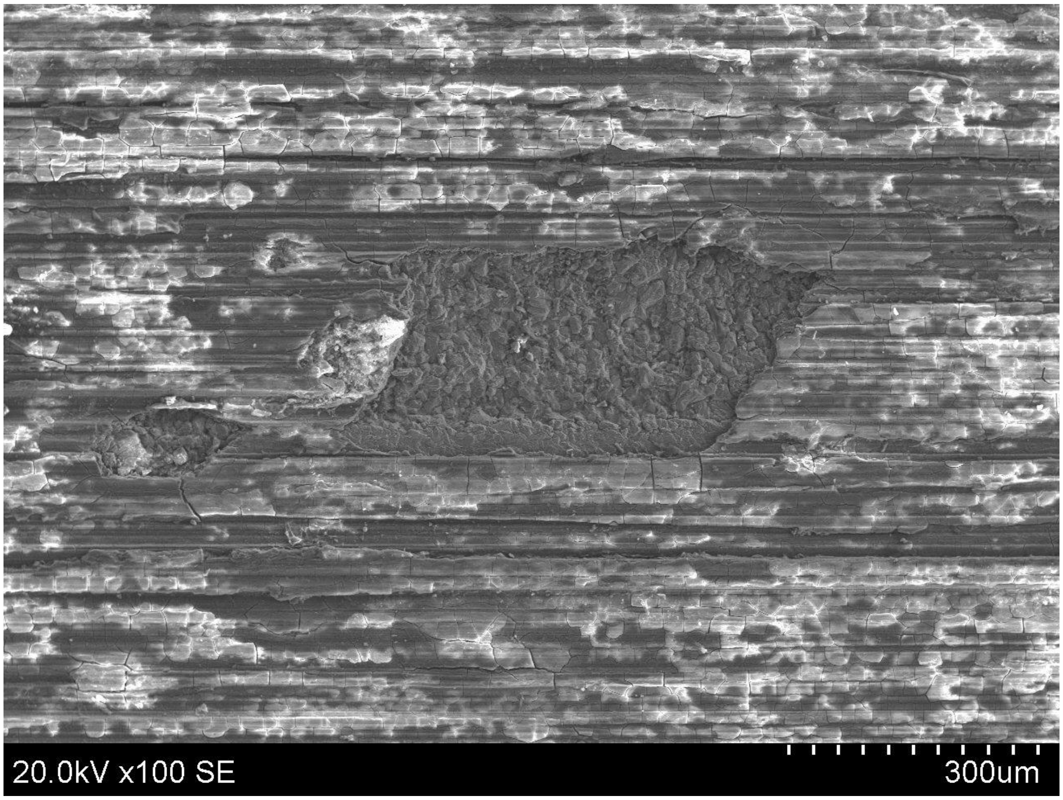
(a) CDA 715 Coupon 1, After Cleaning 100X



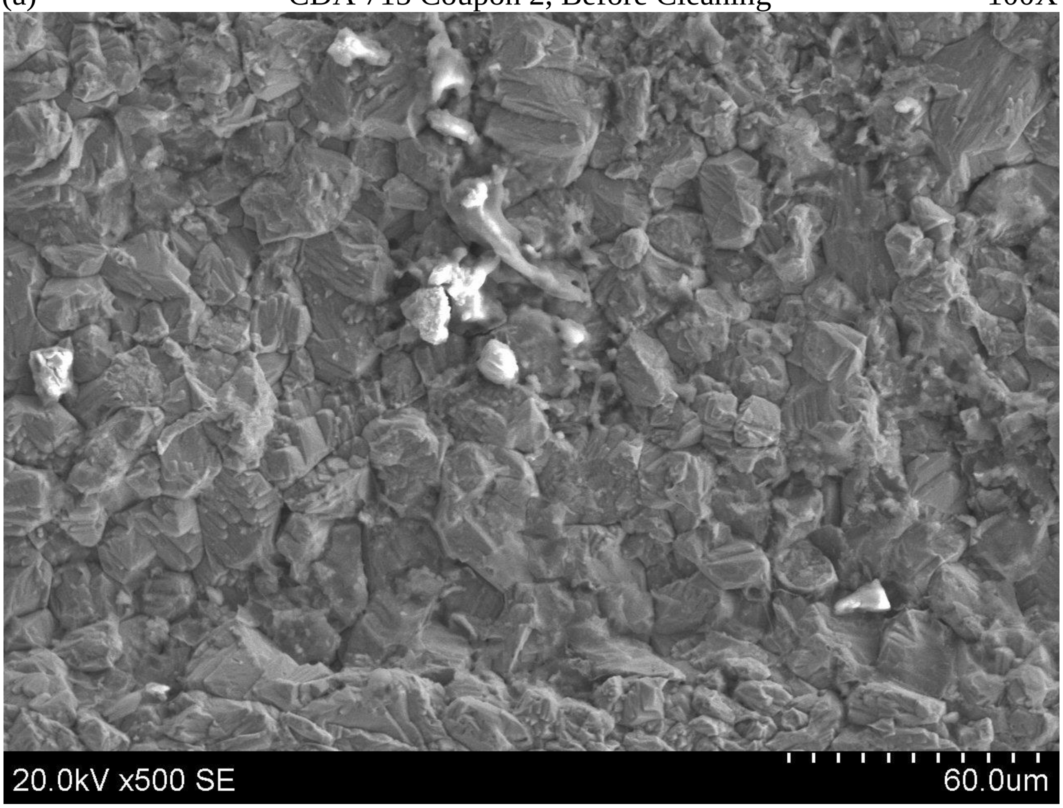
(b) CDA 715 Coupon 1, After Cleaning 500X

Figure 41 Scanning electron micrographs of CDA 715 coupon 1 after a 3 month immersion test, after cleaning

.

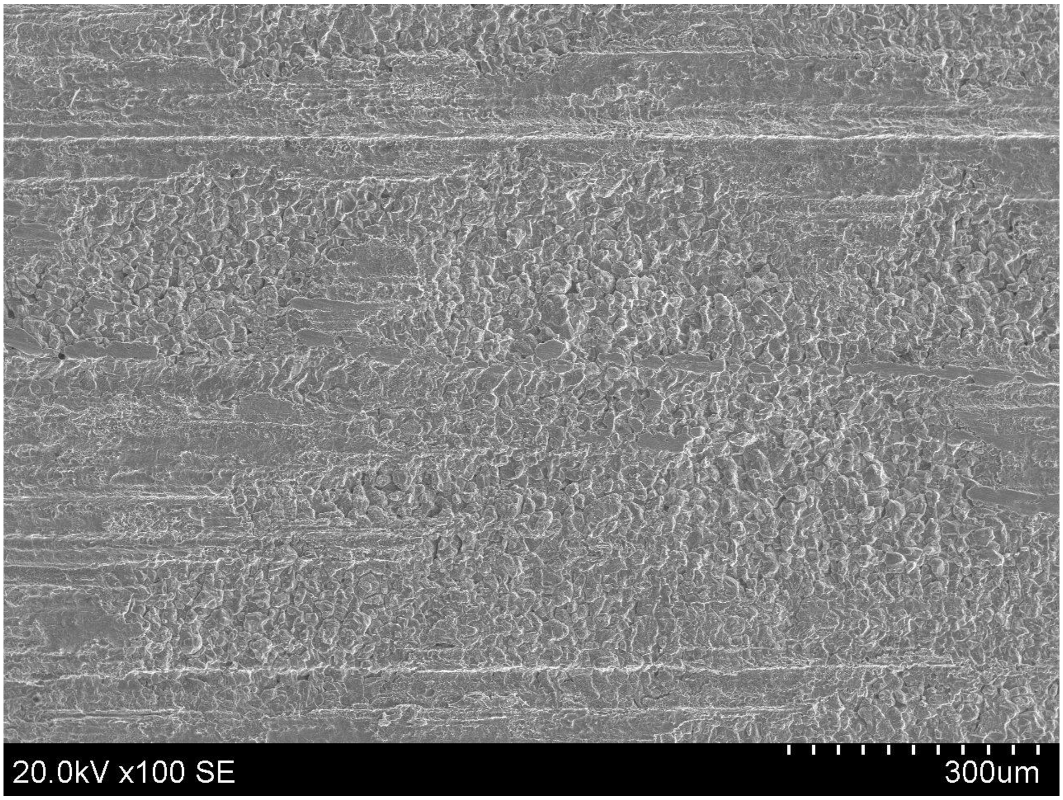


(a) CDA 715 Coupon 2, Before Cleaning 100X

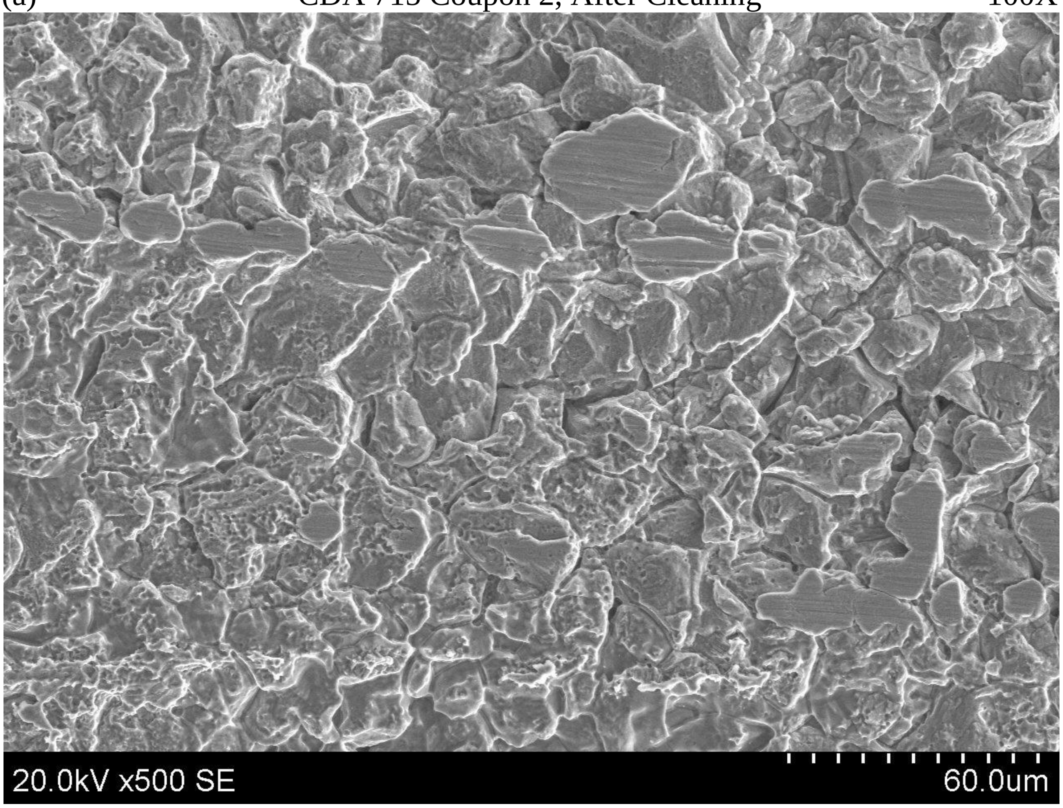


(b) CDA 715 Coupon 2, Before Cleaning 500X

Figure 42 Scanning electron micrographs of CDA 715 coupon 2 after a 6 month immersion test, before cleaning.

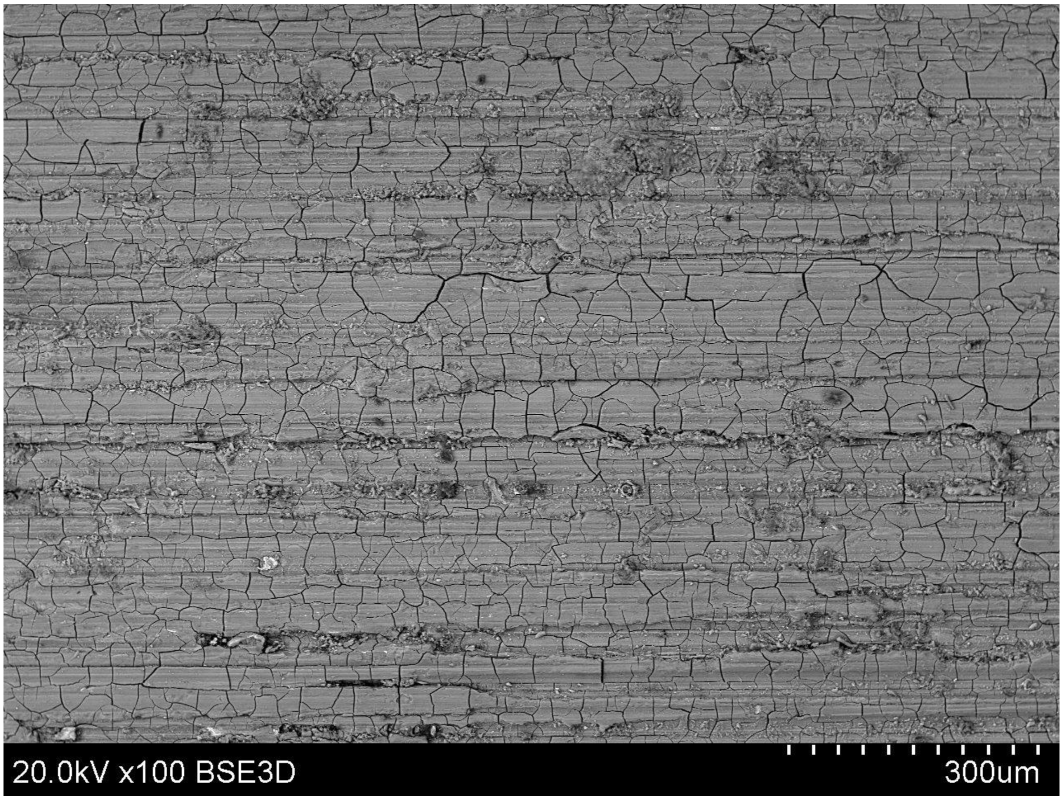


(a) CDA 715 Coupon 2, After Cleaning 100X

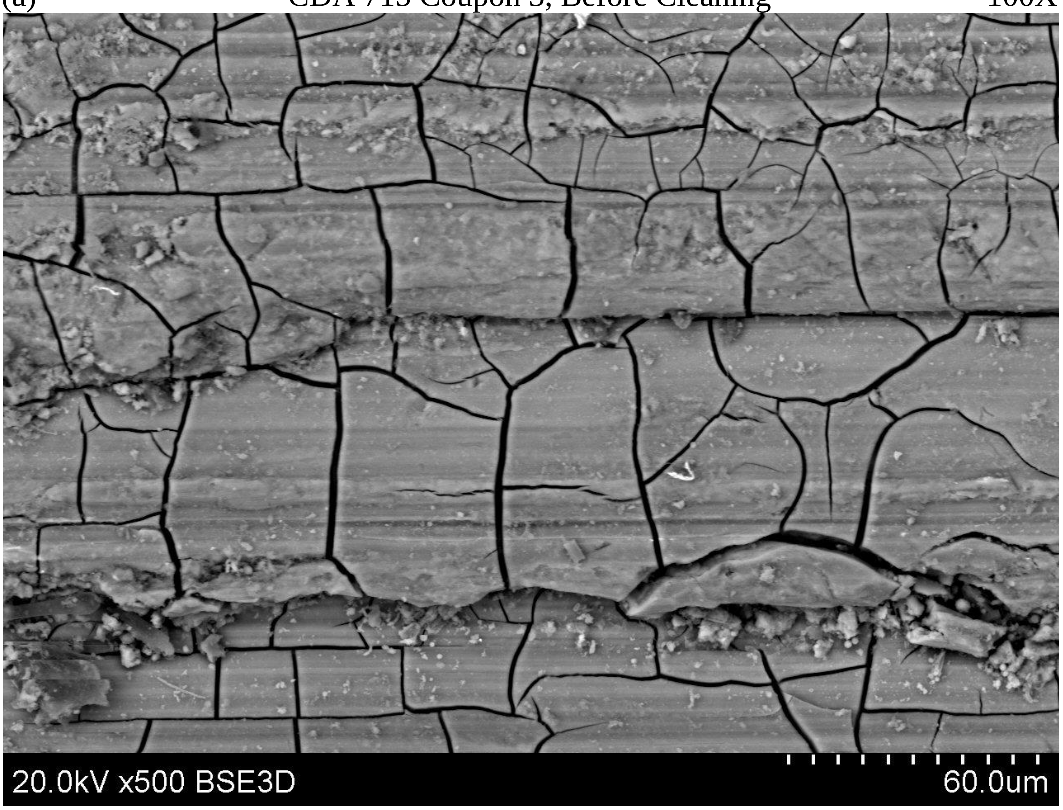


(b) CDA 715 Coupon 2, After Cleaning 500X

Figure 43 Scanning electron micrographs of CDA 715 coupon 2 after a 6 month immersion test, after cleaning.

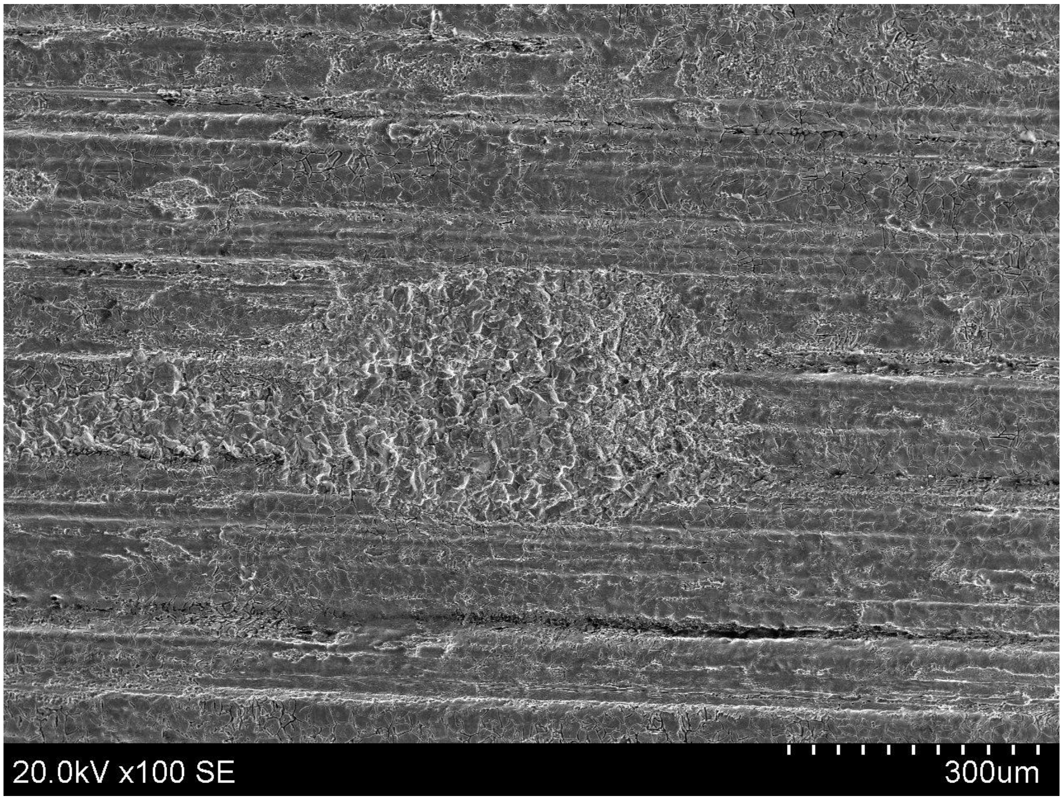


(a) CDA 715 Coupon 3, Before Cleaning 100X

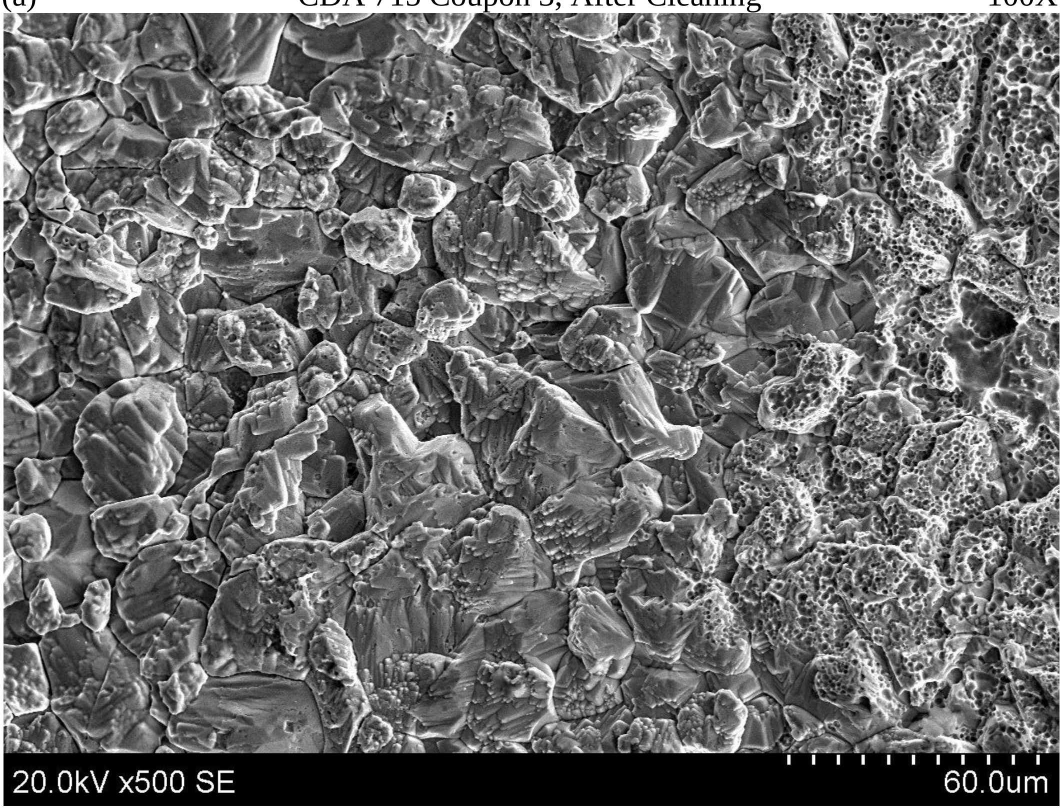


(b) CDA 715 Coupon 3, Before Cleaning 500X

Figure 44 Scanning electron micrographs of CDA 715 coupon 3 after a 10 month immersion test, before cleaning.

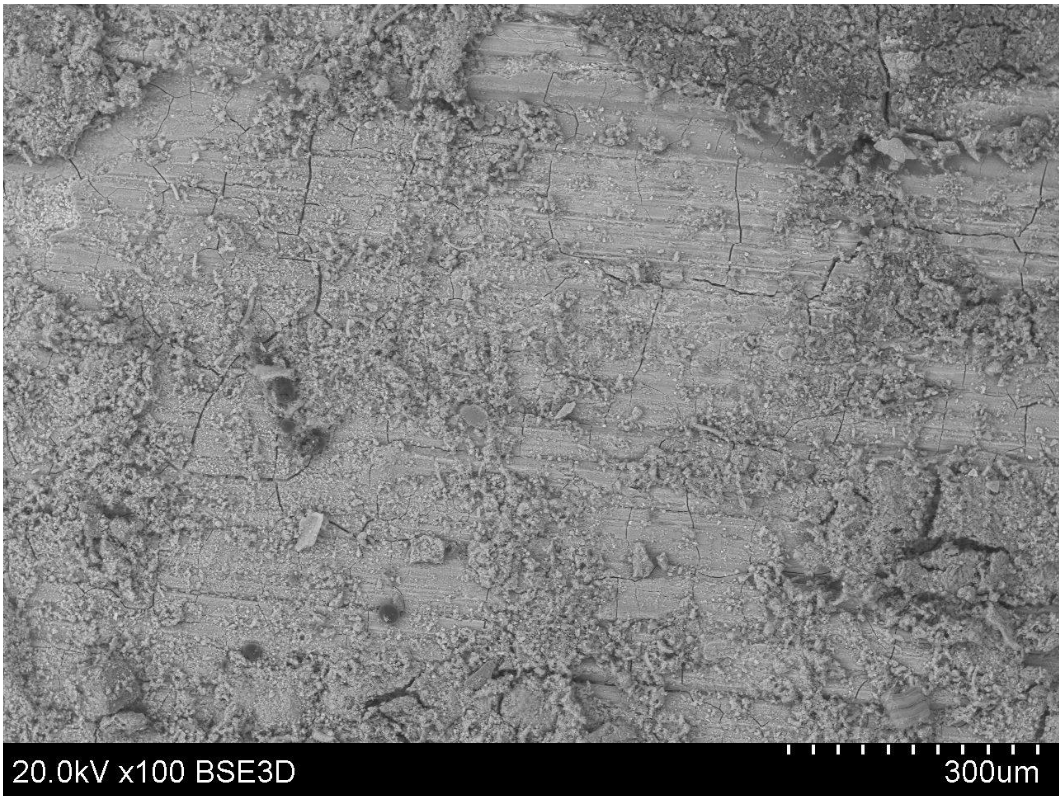


(a) CDA 715 Coupon 3, After Cleaning 100X

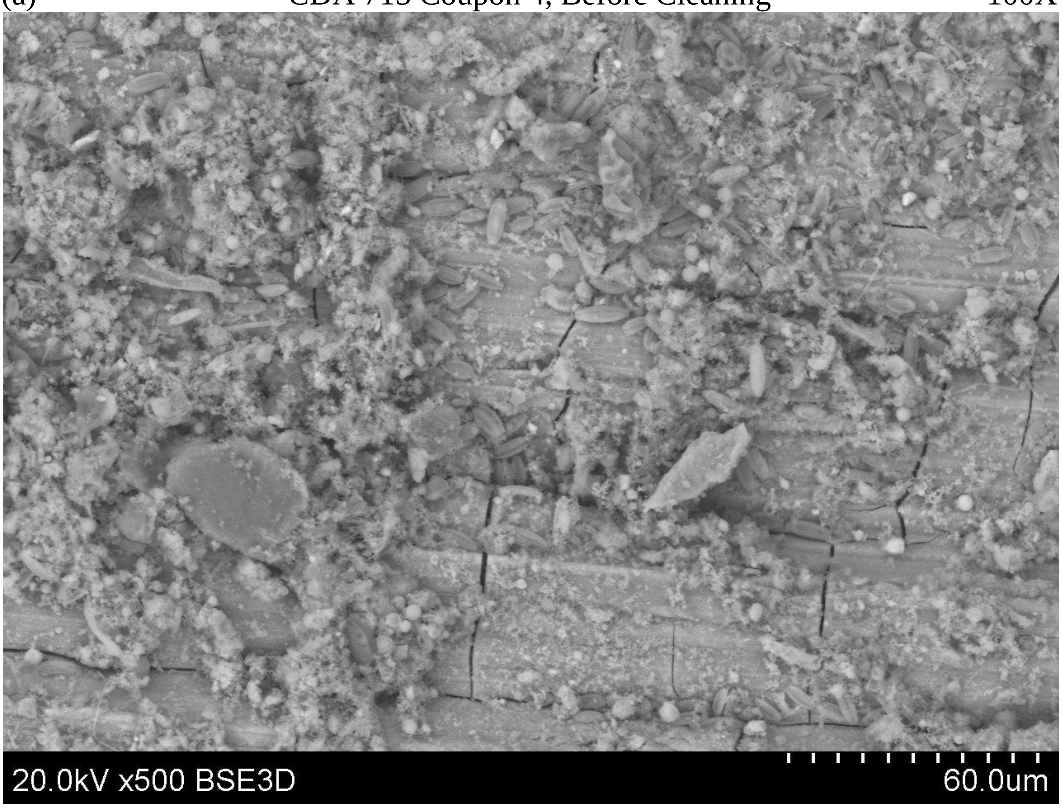


(b) CDA 715 Coupon 3, After Cleaning 500X

Figure 45 Scanning electron micrographs of CDA 715 coupon 3 after a 10 month immersion test, after cleaning.

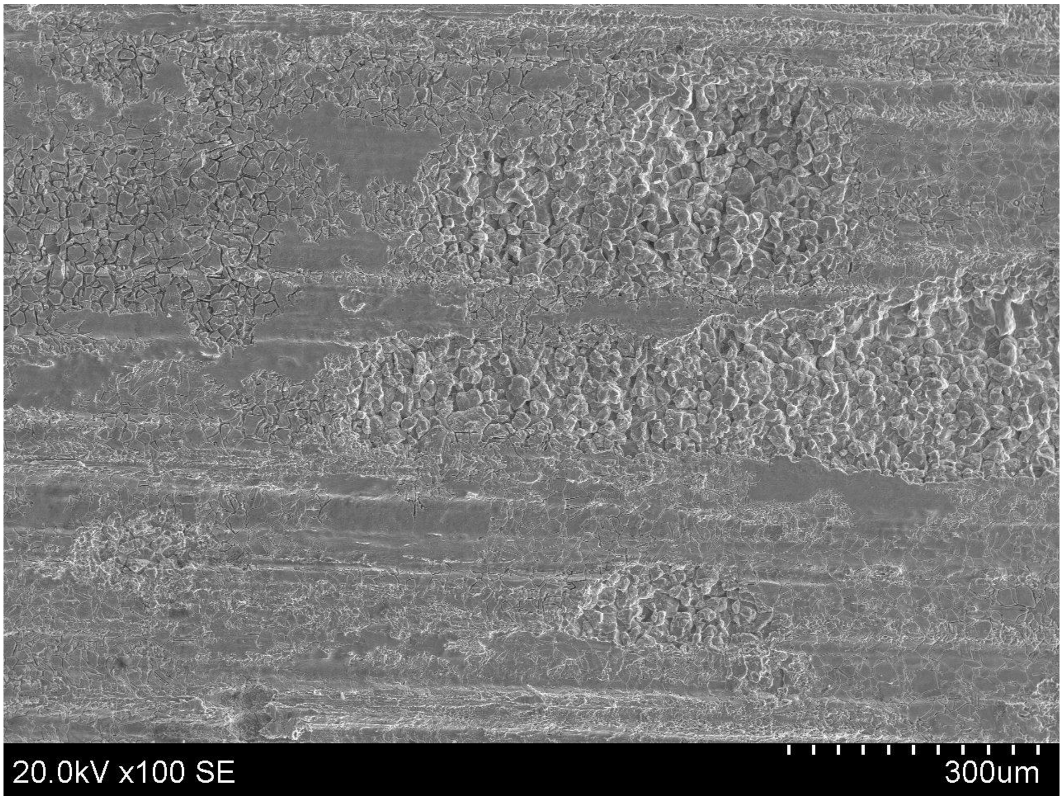


(a) CDA 715 Coupon 4, Before Cleaning 100X

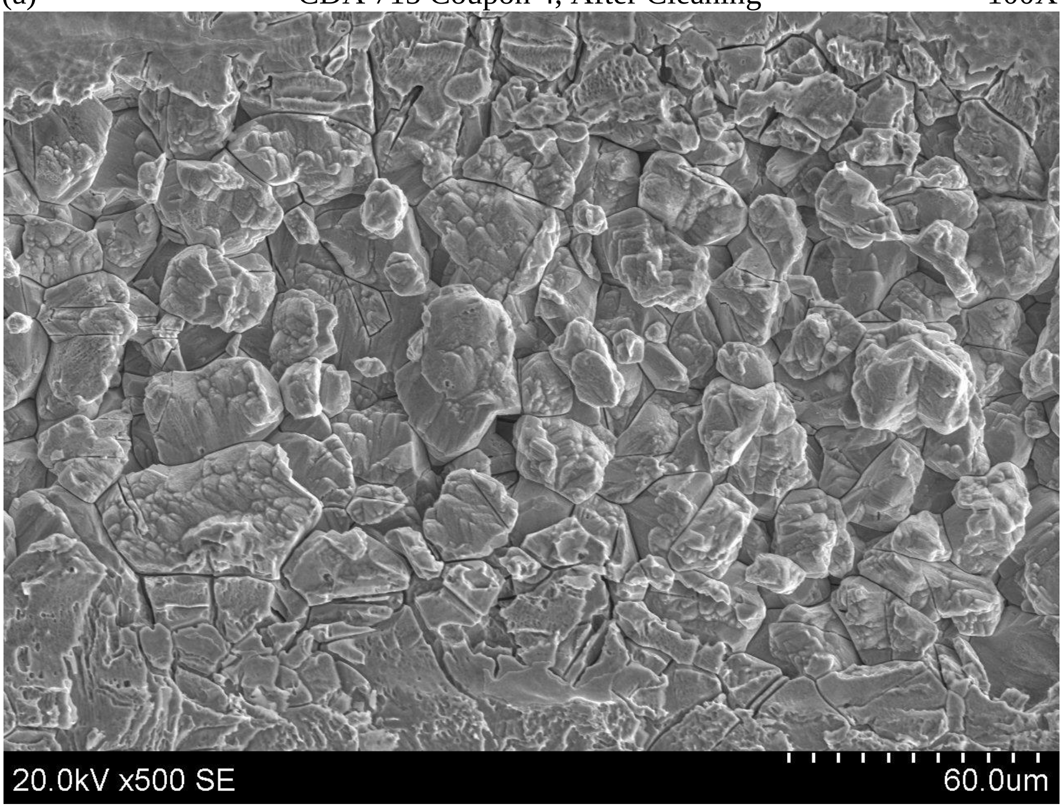


(b) CDA 715 Coupon 4, Before Cleaning 500X

Figure 46 Scanning electron micrographs of CDA 715 coupon 4 after a 12 month immersion test, before cleaning.

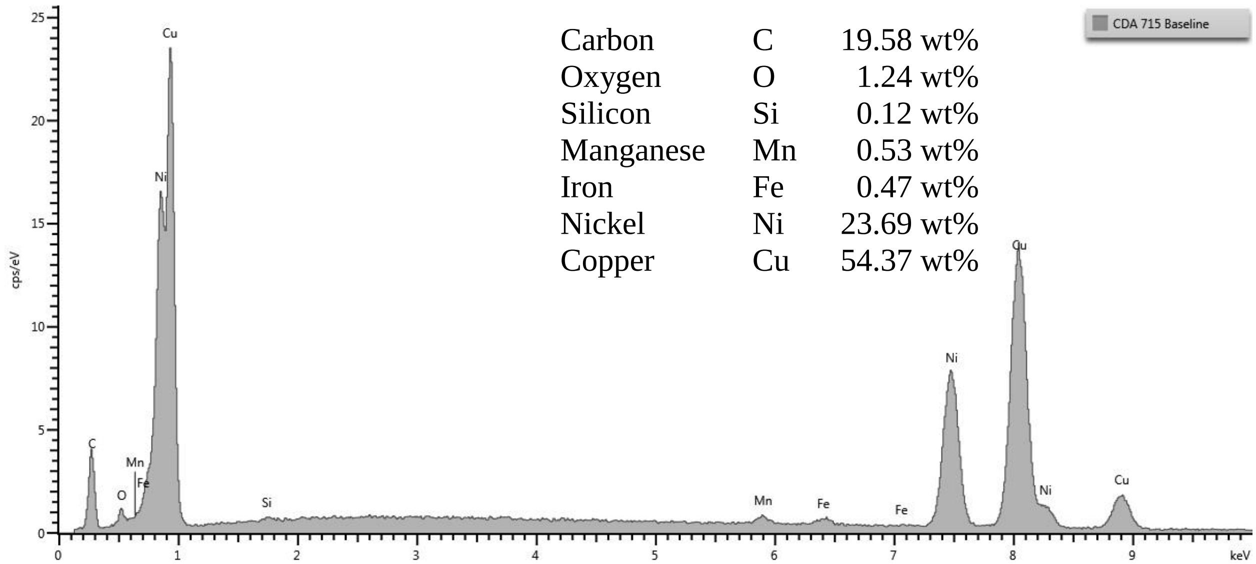


(a) CDA 715 Coupon 4, After Cleaning 100X



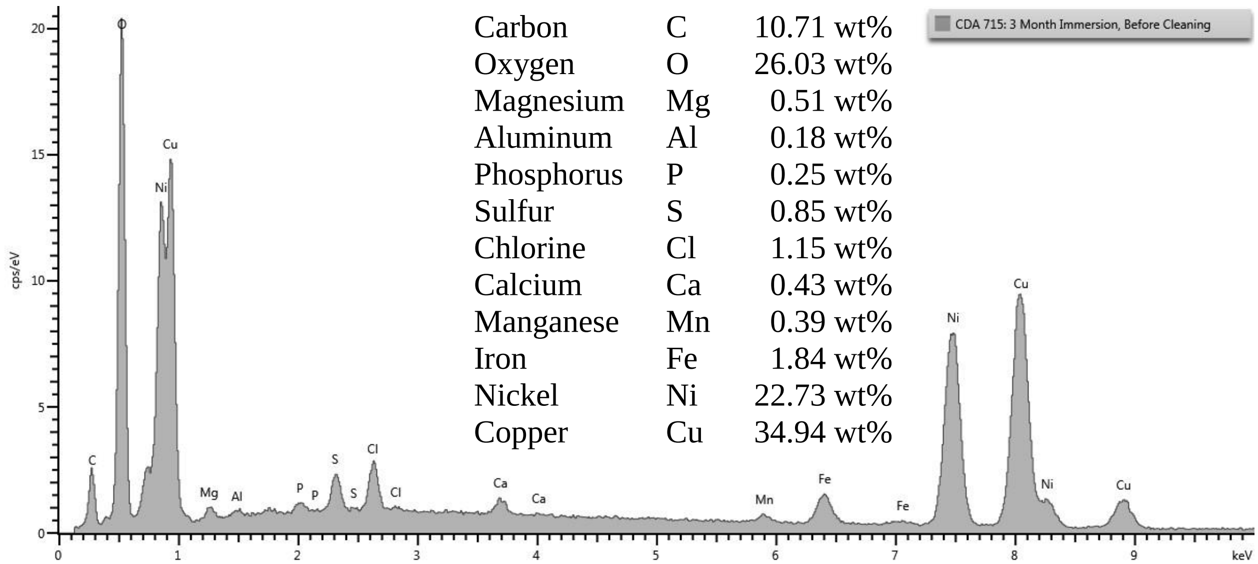
(b) CDA 715 Coupon 4, After Cleaning 500X

Figure 47 Scanning electron micrographs of CDA 715 coupon 4 after a 12 month immersion test, after cleaning.

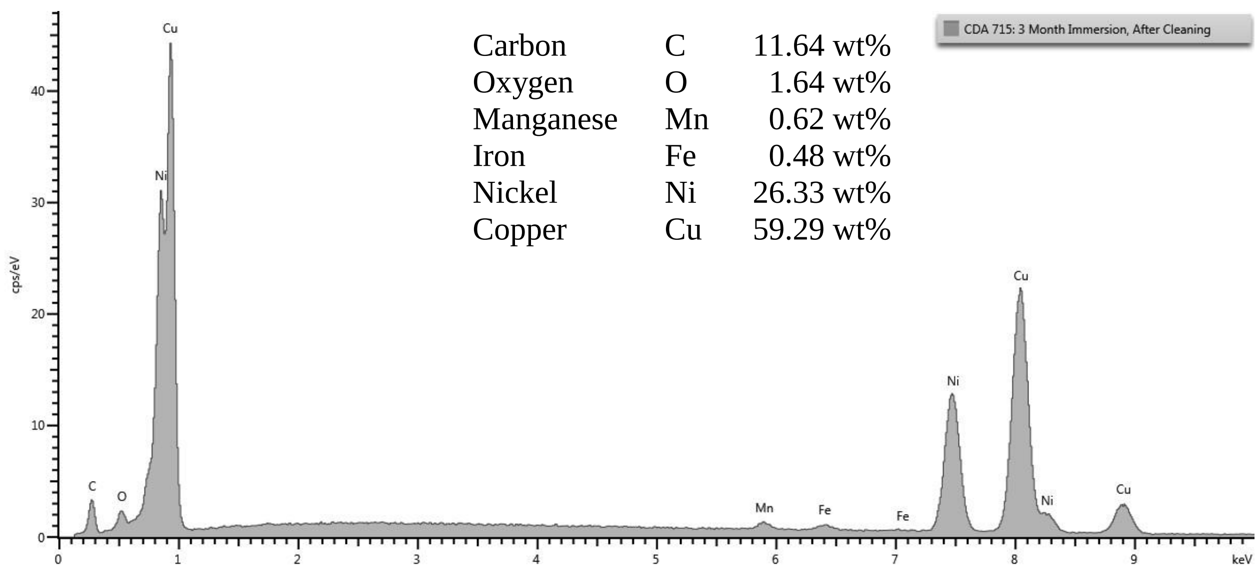


(a) CDA 715 Baseline Coupon

Figure 48 Energy dispersive x-ray spectra of the CDA 715 baseline coupon.

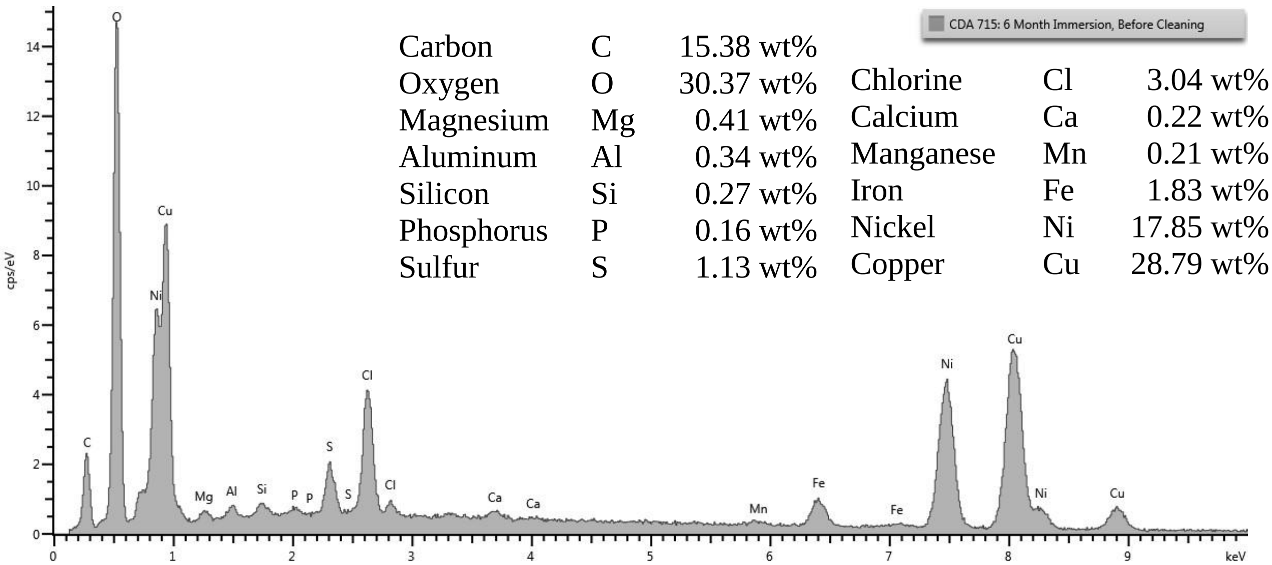


(a) CDA 715 Coupon 1, Before Cleaning

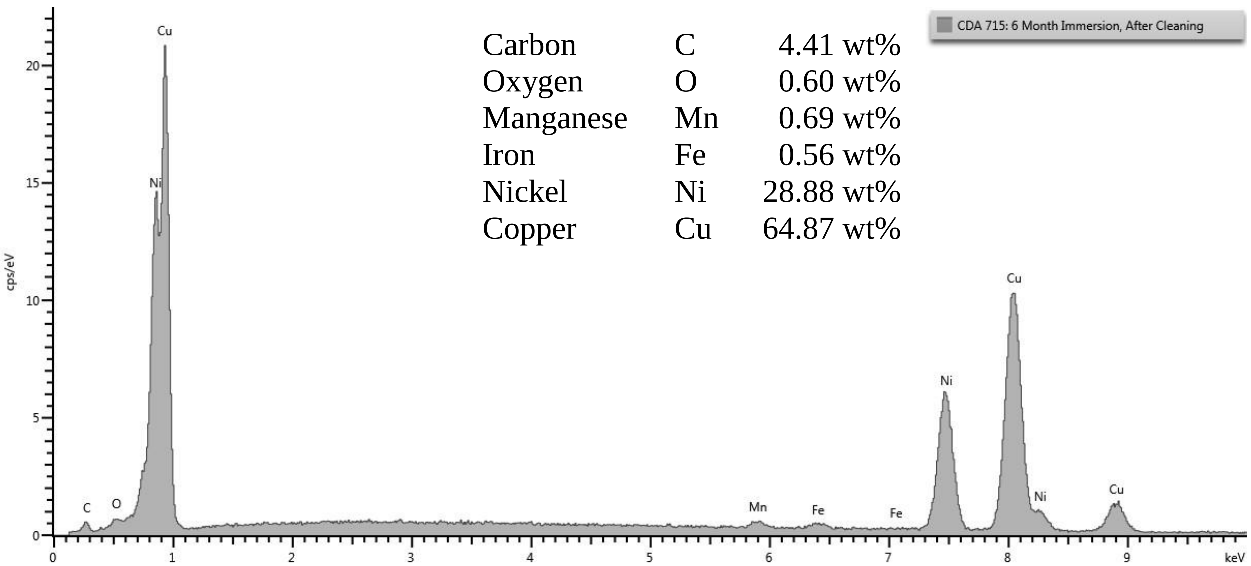


(b) CDA 715 Coupon 1, After Cleaning

Figure 49 Energy dispersive x-ray spectra of CDA 715 coupon 1 after a 3 month corrosion test (a) before cleaning and (b) after cleaning.

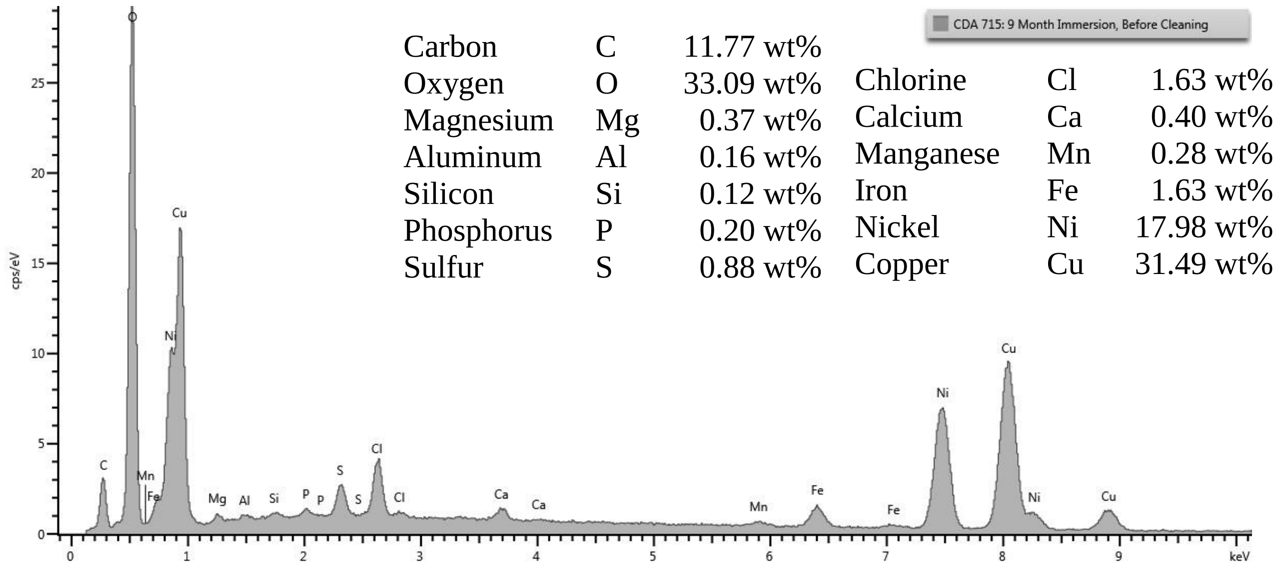


(a) CDA 715 Coupon 2, Before Cleaning

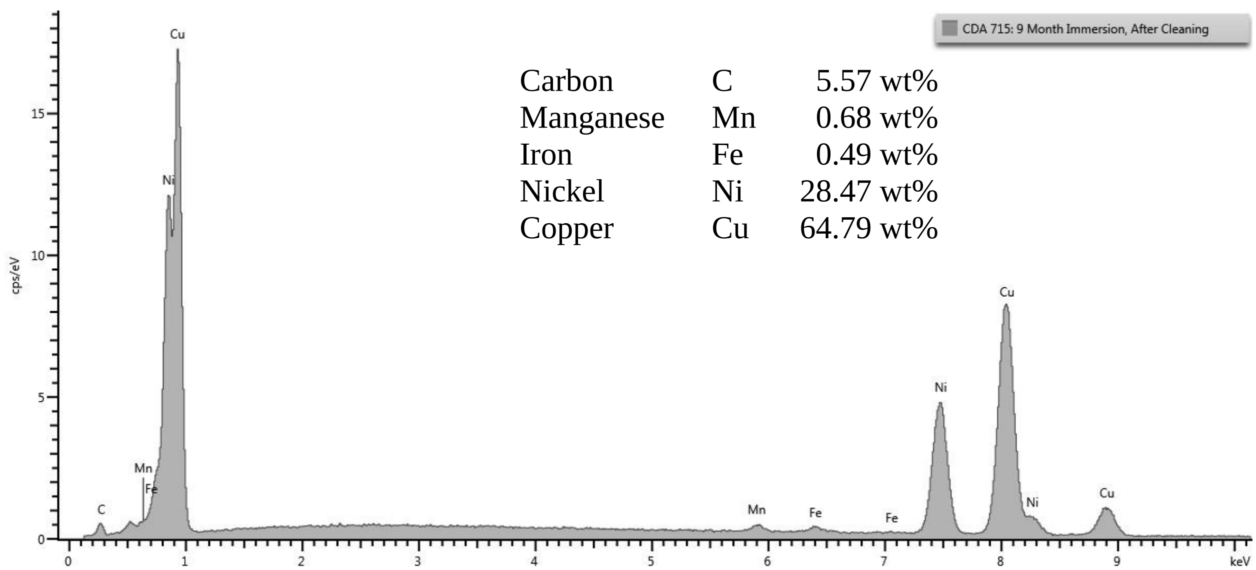


(b) CDA 715 Coupon 2, After Cleaning

Figure 50 Energy dispersive x-ray spectra of CDA 715 coupon 2 after a 6 month corrosion test (a) before cleaning and (b) after cleaning.

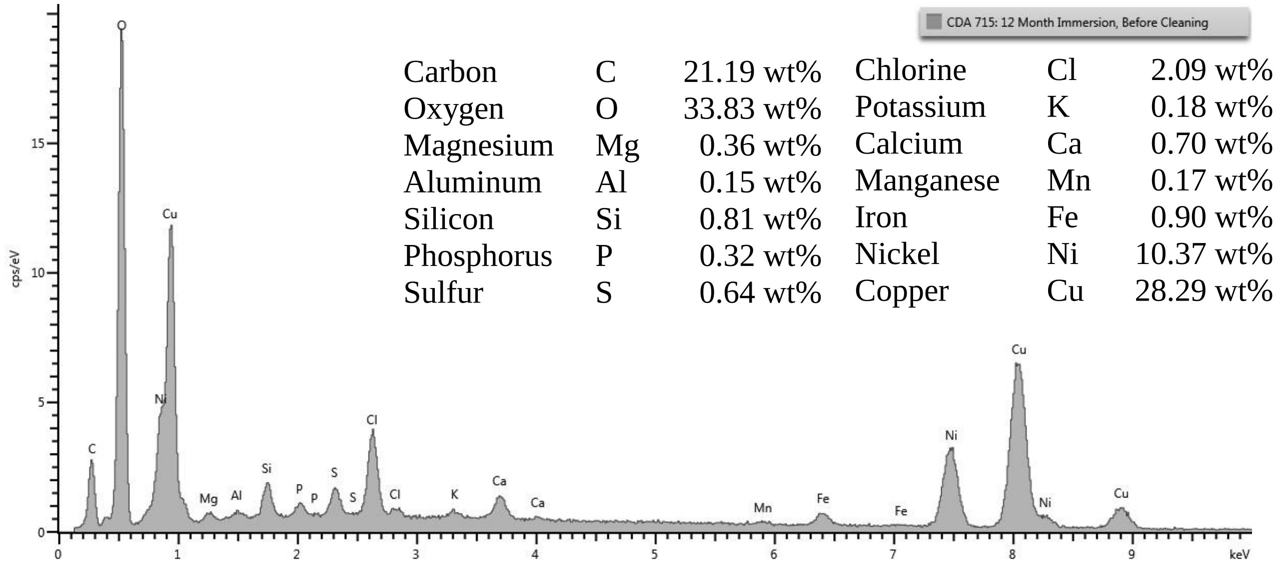


(a) CDA 715 Coupon 3, Before Cleaning

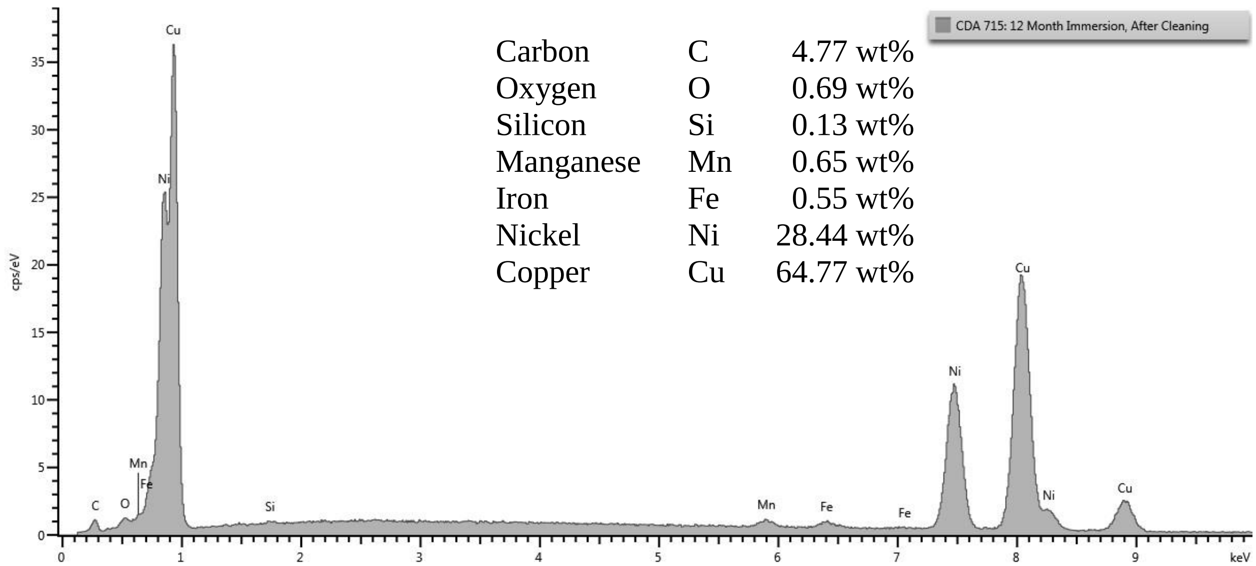


(b) CDA 715 Coupon 3, After Cleaning

Figure 51 Energy dispersive x-ray spectra of CDA 715 coupon 3 after a 10 month corrosion test (a) before cleaning and (b) after cleaning.

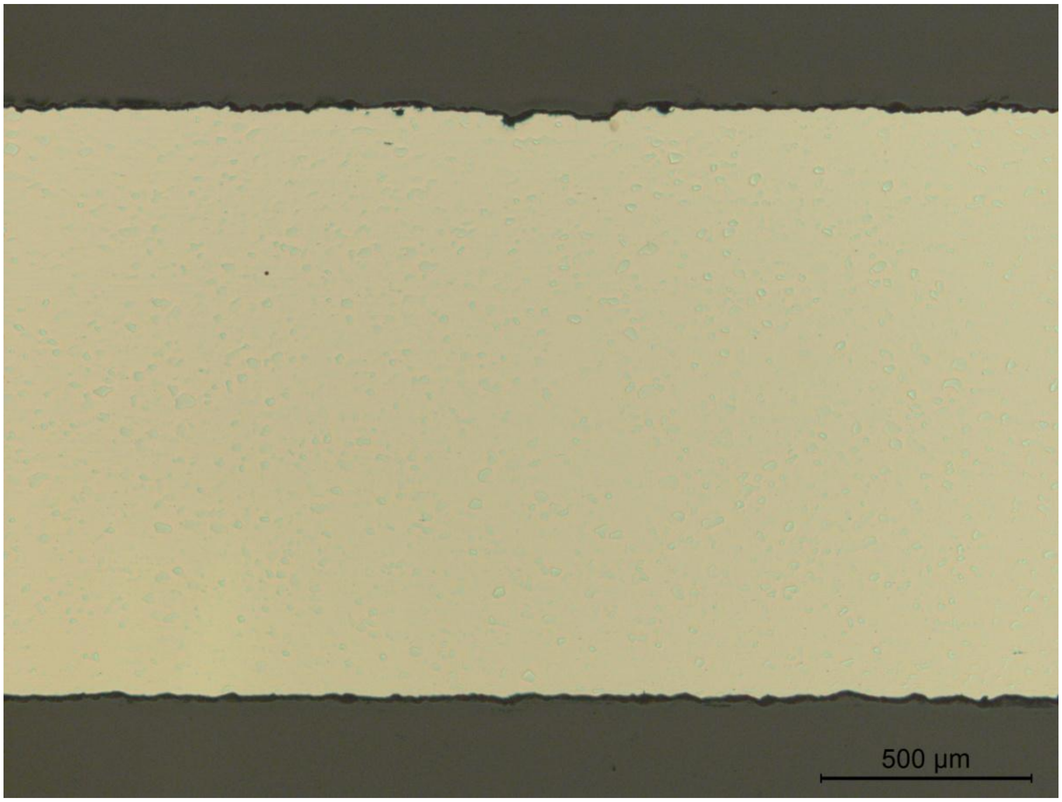


(a) CDA 715 Coupon 4, Before Cleaning

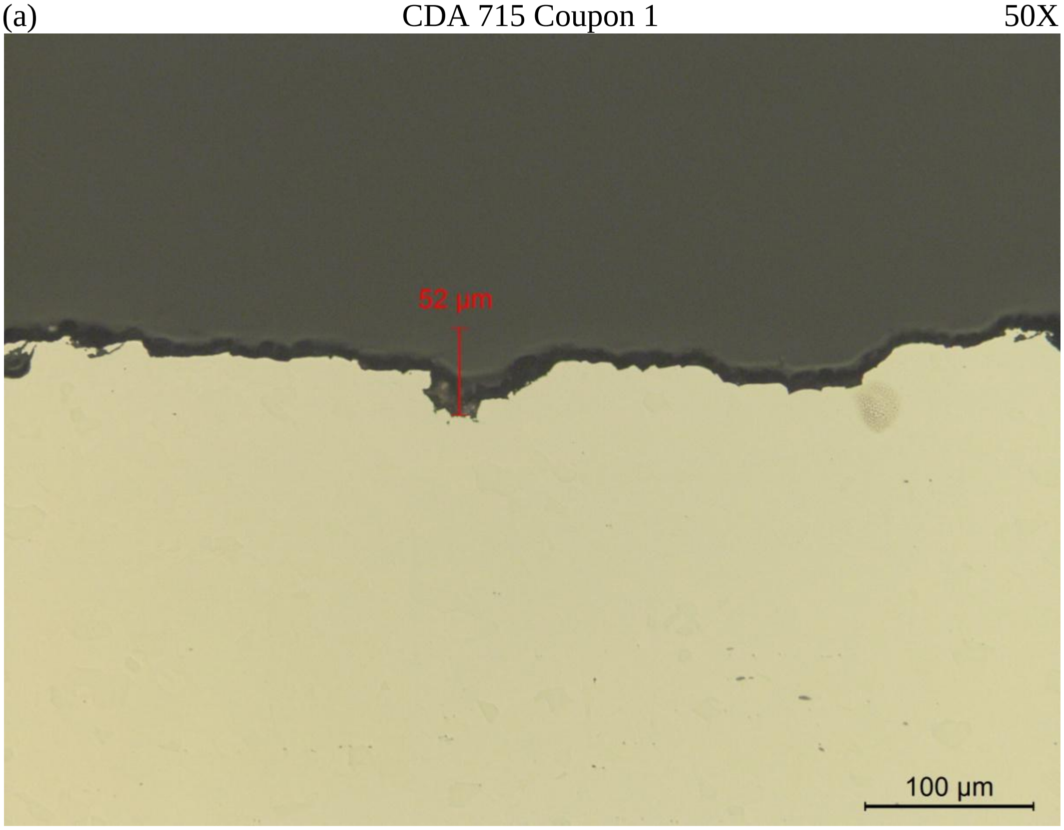


(b) CDA 715 Coupon 4, After Cleaning

Figure 52 Energy dispersive x-ray spectra of CDA 715 coupon 4 after a 12 month corrosion test (a) before cleaning and (b) after cleaning.



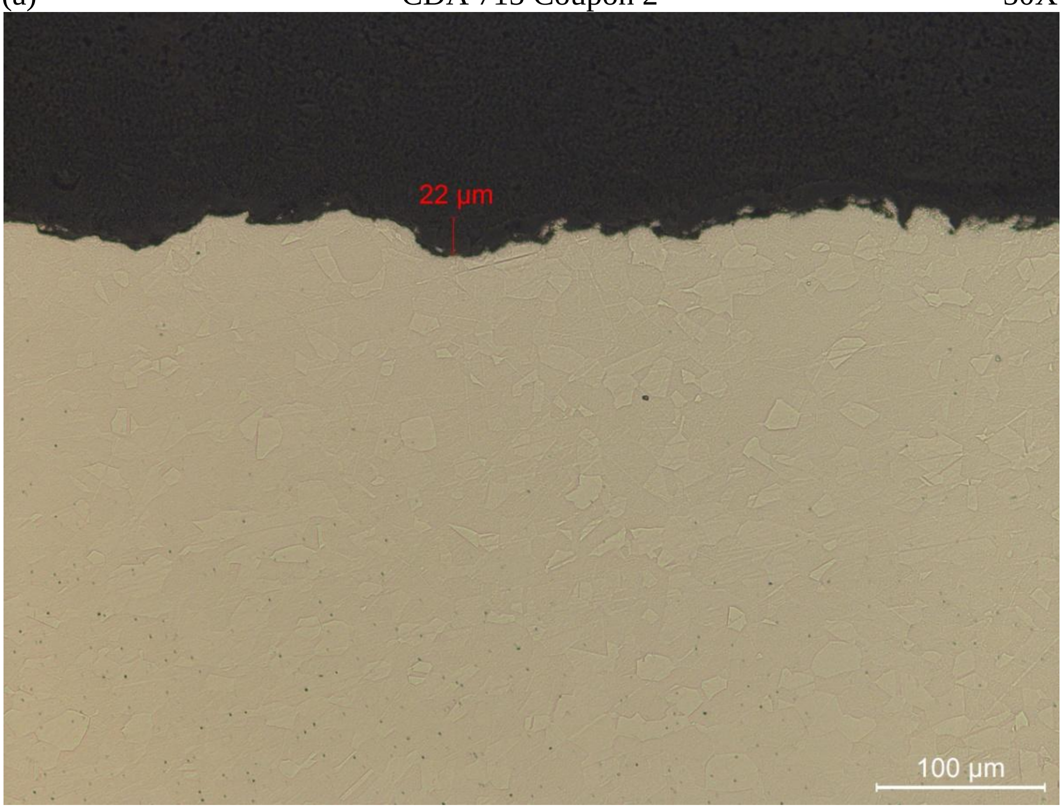
(a) CDA 715 Coupon 1 50X



(b) CDA 715 Coupon 1 200X

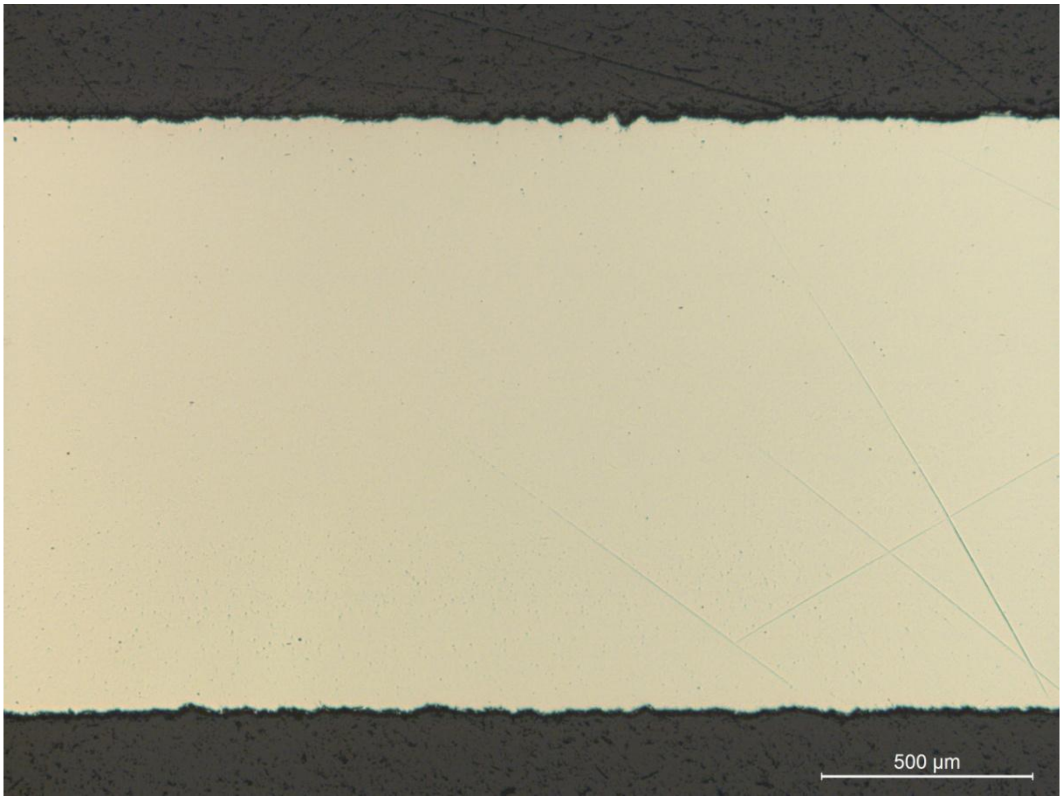
Figure 53 Optical micrographs of CDA 715 coupon 1.

(a) CDA 715 Coupon 2 50X

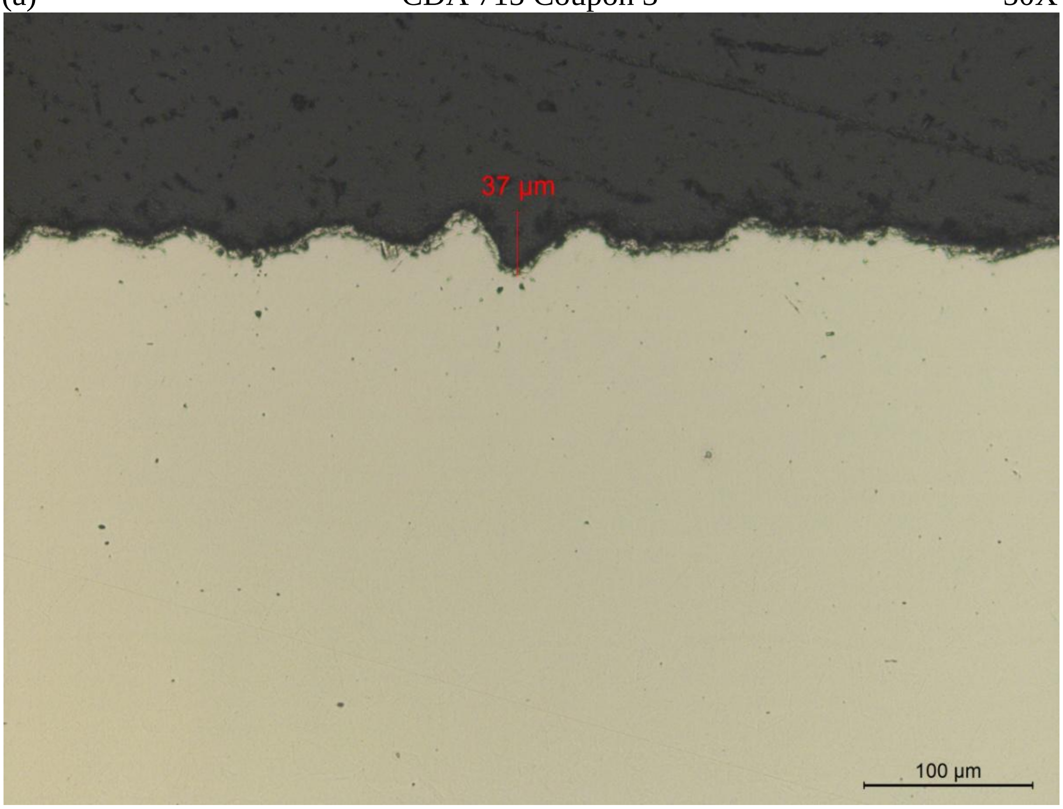


(b) CDA 715 Coupon 2 200X

Figure 54 Optical micrographs of CDA 715 coupon 2.

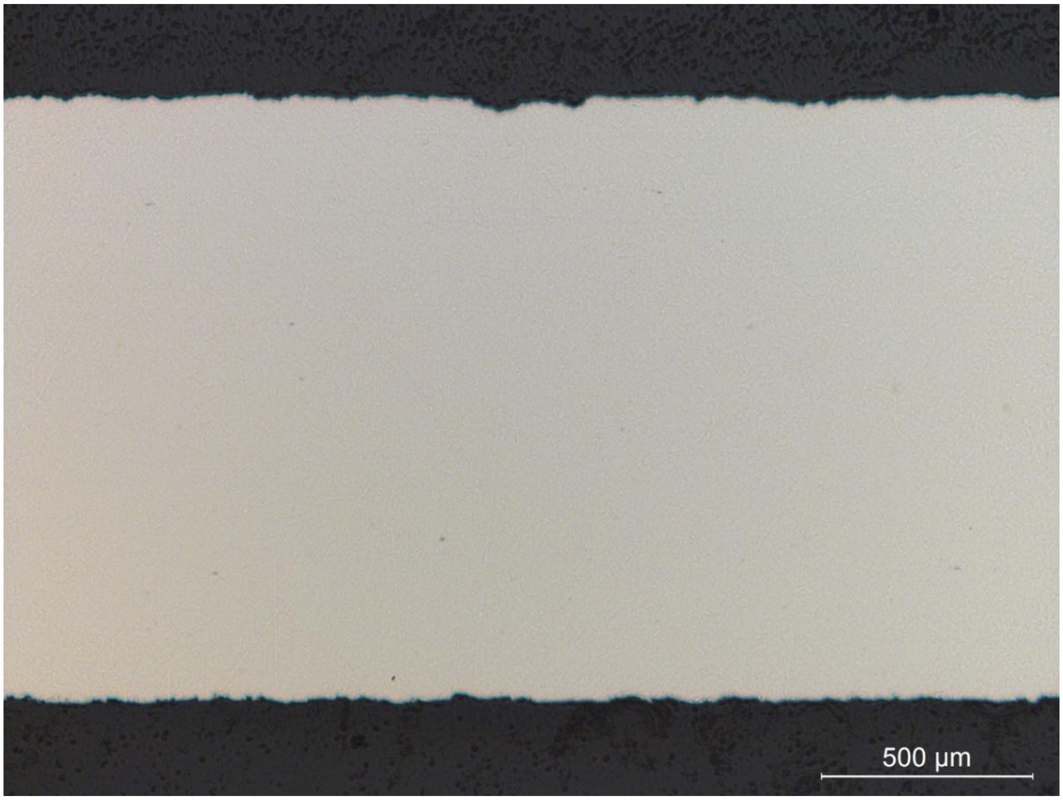


(a) CDA 715 Coupon 3 50X

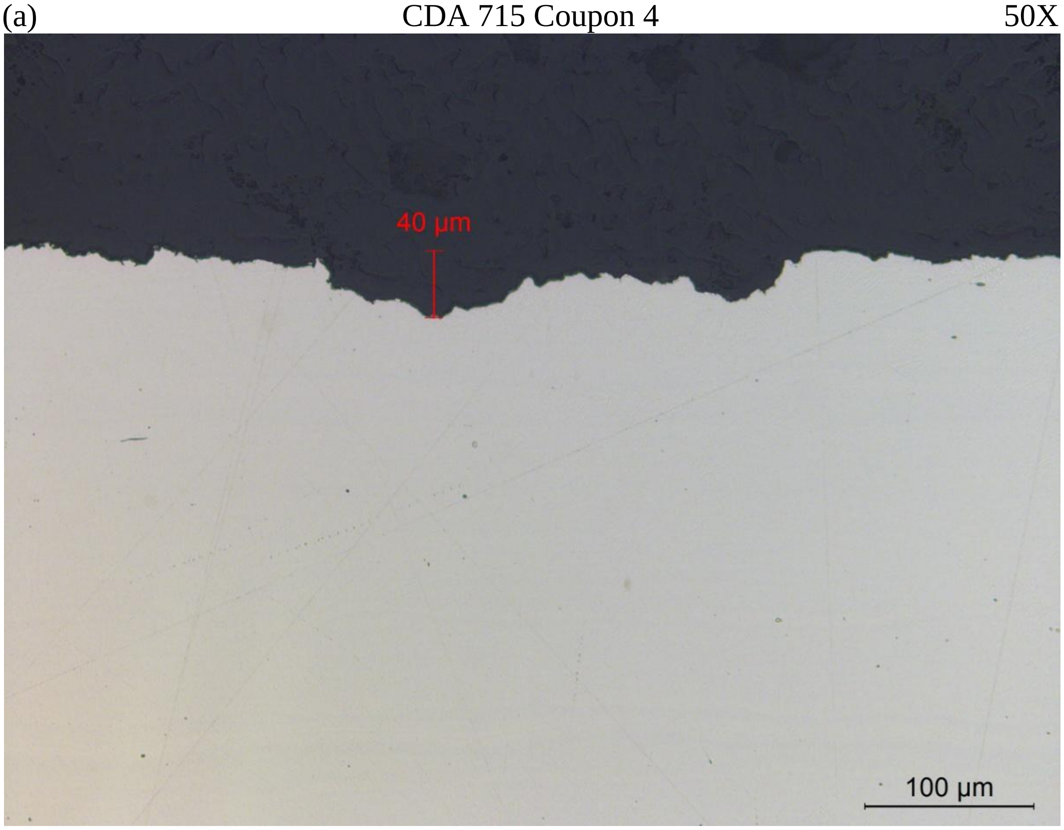


(b) CDA 715 Coupon 3 200X

Figure 55 Optical micrographs of CDA 715 coupon 3.



(a) CDA 715 Coupon 4 50X



(b) CDA 715 Coupon 4 200X

Figure 56 Optical micrographs of CDA 715 coupon 4.

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Report No. 5005.0361C **July 17, 2015**

CORROSION EVALUATION OF CDA 706 COUPONS AND SCREENS

Customer Authorization: Verbal

Report To: V & A Engineering
Attn: Manuel Najar
155 Grand Avenue, Suite 700
Oakland, CA 94612

1.0 INTRODUCTION

Five coupons, five wedge wire screens, and one plate made from CDA 706, a 90-Copper, 10-Nickel alloy, were submitted by V&A Engineering for corrosion evaluation. The coupons were 1-inch by 3-inches by ¼-inch thick. The wedge wire screens were 4-inches by 4-inches by 1-inch tall with 4 mm spacing. The plate was 4-inches by 4-inches by 1/8-inch thick.

Four coupons, four screens, and one plate were to be placed in seawater for a period up to one year. After every 3 month interval, one coupon and one screen were to be removed from the test system and examined for corrosion. After 12 months, the plate was removed from the test system and examined for corrosion. The purpose of this evaluation was to document the samples in the baseline as-received condition, then again after 3, 6, 10, and 12 months of water exposure, record any loss in mass, examine for any pitting corrosion, and estimate the corrosion rate.

The samples were evaluated by the following laboratory procedures:

1) Visual examination and weighing
2) Cleaning per ASTM G1[1]
3) Scanning electron microscopy and energy dispersive x-ray spectroscopy
4) Metallography

The results of the evaluation showed minimal mass loss and corrosion for the coupon and screen after 3, 6, 10, and 12 months of corrosion testing. The coupons, after 3, 6, 10, and 12 months of corrosion testing, had a corrosion rate of 0.022, 0.023, 0.018, and 0.017 millimeters per year. The screens, after 3, 6, 10, and 12 months of corrosion testing, had a corrosion rate of 0.129, 0.067, 0.047, and 0.044 millimeters per year, respectively. The plate, after 12 months of corrosion testing, had a corrosion rate of 0.029 millimeters per year. Both the coupons and screens lost more material over time, but had a decreasing corrosion rate over the duration of the corrosion test.

[1] G1: Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

2.0 EVALUATION[2]

2.1 Visual Examination

The sample identifications for the coupons and wedge wire screens and their corresponding immersion times are shown in Table 1. The coupons had identification numbers stamped on the front face by V&A Engineering. A number of notches, corresponding to the sample number, were sawed at the edge of each screen for identification after the corrosion test. The weights of the samples were recorded. Coupons 1 – 4 and screens 1 – 5 were sent back to V&A for corrosion testing. Coupon 5 was the baseline sample and documented by photography, optical stereoscopy and scanning electron microscopy for comparison to the tested samples. Screen 5 was documented as a baseline by photography and optical stereoscopy, and then sent to V&A for testing.

Photographs of the baseline coupon are shown in Figure 1. Photographs of coupons 1 – 4, after 3, 6, 10, and 12 months of corrosion testing, are shown in Figures 2 – 5. A photograph of the baseline screen is shown in Figure 6. Photographs of screens 1 – 4, after 3, 6, 10, and 12 months of corrosion testing, are shown in Figures 7 – 10. A photograph of the baseline plate is shown in Figure 11 and a photograph of the plate after 12 months of corrosion testing is shown in Figure 12.

2.2 Cleaning

The coupon and screen were cleaned with solution C.2.1 per ASTM G1.[3] One cleaning cycle was approximately 1 minute. After each cleaning cycle, the samples were rinsed in water, dried, and weighed. The cleaning and weighing cycle was completed five times for the coupon and screen. The weights of the samples as-received, after corrosion testing but before cleaning, and after each cleaning cycle are presented in Table 2.

Optical macrographs of the baseline coupon, screen, and plate are shown in Figures 13, 22, and 31, respectively. Representative optical macrographs of coupons 1 – 4 after 3, 6, 10, and 12 months of corrosion testing, before and after cleaning, are shown in Figures 14 – 21. Representative optical macrographs of screens 1 – 4 after 3, 6, 10, and 12 months of corrosion testing, before and after cleaning, are shown in Figures 23 – 30. Representative optical macrographs of the plate after 12 months of corrosion testing, before and after cleaning, are shown in Figures 32 – 33.

The mass loss versus the number of cleaning cycles was plotted, shown in Figures 34 – 38. The equations for best fit lines AB and BC, calculated using IGOR Pro, are listed in Table 3. Point B, indicated by the red circle in each plot, corresponds to the mass loss due to corrosion during the cleaning process for each sample. This mass loss was subtracted from the weight of the sample before cleaning and from the weight of the sample as-received to determine the total mass loss from corrosion. The corrosion rate of each sample was determined by the formula specified in Section 8.1 of ASTM G1:

[2] The magnifications of the optical and scanning electron micrographs in this report are approximate and should not be used as a basis for dimensional analyses unless otherwise indicated.
[3] 500 mL hydrochloric acid + 500 ml reagent water.

$$Corrosion\ Rate = \frac{K\ x\ W}{A\ x\ T\ x\ D}$$

where K = 8.76 x 10^4, T = time of exposure in hours, A = area in cm^2, W = mass loss in grams, and D = density in g/cm^3. The total mass loss from corrosion and the calculated corrosion rate of each sample is shown in Table 4.

2.3 Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy

The baseline coupon and coupons 1 – 4 were examined with a scanning electron microscope. Representative scanning electron micrographs of the baseline coupon are shown in Figure 39. Representative scanning electron micrographs of coupons 1 – 4, before and after cleaning, are shown in Figures 40 – 47. Energy dispersive x-ray spectra of the baseline coupon and coupons 1 – 4, before and after cleaning, are shown in Figures 48 – 52.

2.4 Metallography

Cross sections were taken from the coupon and prepared for a metallographic examination. Optical micrographs of the surfaces for coupons 1 – 4 are shown in Figures 53 – 56. Some wide, shallow pits were observed in coupon 1, the deepest of which measured 80 µm. Small, shallow pits, the deepest of which measured 22 µm, were observed in coupon 2. Small, narrow pits, the deepest of which measured 34 µm, were observed in coupon 3. A wide, deep pit was observed in coupon 4, measuring 291 µm deep and 2.3 mm wide.

3.0 DISCUSSION

The coupon and screen showed minimal mass loss and pitting overall after 3, 6, 10, and 12 months of corrosion testing. The coupons had more material loss over time, but maintained a consistent corrosion rate over the duration of the corrosion test. The screens had more material loss over time, but had a decreasing corrosion rate over the duration of the corrosion test.

4.0 CONCLUSIONS[4]

The following conclusions are based upon the submitted samples and the evidence gathered:

1. The coupons, after 3, 6, 10, and 12 months of corrosion testing, had a mass loss of 0.256 grams, 0.550 grams, 0.726 grams and 0.783 grams, respectively. The coupons had more mass loss over the duration of the corrosion test.

2. The coupons, after 3, 6, 10, and 12 months of corrosion testing, had a corrosion rate of 0.022 mm / year, 0.023 mm / year, 0.018 mm / year, and 0.017 mm / year, respectively. The coupons had a decreasing corrosion rate over the duration of the corrosion test.

3. The screens, after 3, 6, 10, and 12 months of corrosion testing, had a mass loss of 14.48 grams, 15.24 grams, 17.96 grams, and 20.05 grams, respectively. The screens had more mass loss over the duration of the corrosion test.

4. The screens, after 3, 6, 10, and 12 months of corrosion testing, had a corrosion rate of 0.129 mm / year, 0.067 mm / year, 0.047 mm / year, and 0.044 mm / year, respectively. The screens had a decreasing corrosion rate over the duration of the corrosion test.

5. The plate, after 12 months of corrosion testing, had a mass loss of 5.71 grams and a corrosion rate of 0.029 mm / year.

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[4] The conclusions in this report are based upon the available information and evidence provided by the client and gathered by Anamet, within the scope of work authorized by the client, and they are hereby presented by Anamet to a reasonable degree of engineering and scientific certainty. Anamet reserves the right to amend or supplement its conclusions or opinions presented in this report should additional data or information become available, or further work be approved by the client.

Table 1
Sample Identifications

Description		V&A Engineering Identification (As-Received)	Anamet Identification (in report)	Notes
Alloy	Part			
CDA 706 (Cu 90 – Ni 10)	**Flat Plate** 4-inch x 4-inch x 1/8-inch	CDA 706 1	Plate	None
	Coupon 1-inch x 3-inch x 1/8-inch with autogenous weld bead	CDA 706W 1	Coupon 1	3 Month Immersion
		CDA 706W 2	Coupon 2	6 Month Immersion
		CDA 706W 3	Coupon 3	10 Month Immersion
		CDA 706W 4	Coupon 4	12 Month Immersion
		CDA 706W 5	Coupon 5	Baseline Sample (no exposure)
	Wedge Wire Screen 4-inch x 4-inch x 1-inch with 2 mm spacing	None	Screen 1	3 Month Immersion
		None	Screen 2	6 Month Immersion
		None	Screen 3	10 Month Immersion
		None	Screen 4	12 Month Immersion
		None	Screen 5	12 Month Immersion

Table 2
Sample Weights

Sample	Baseline Measurement	Measurements after 3 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 1	25.8560	25.6429	25.6003	25.5972	25.5954	25.5930	25.5915
Screen 1	310.59	301.27	298.54	296.15	295.97	295.80	295.78

Sample	Baseline Measurement	Measurements after 6 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 2	25.9215	25.4409	25.3721	25.3689	25.3689	25.3650	25.3630
Screen 2	310.45	300.16	295.21	295.17	295.13	295.11	-

Sample	Baseline Measurement	Measurements after 10 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 3	25.5983	25.0228	24.8784	24.8715	24.8693	24.8678	24.8672
Screen 3	309.69	296.62	292.59	291.65	291.58	291.57	291.38

Sample	Baseline Measurement	Measurements after 12 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 4	25.6262	25.1559	24.8427	24.8424	24.8421	24.8418	24.8417
Screen 4	310.13	294.17	289.92	289.04	288.96	288.94	-
Plate	298.48	294.20	292.81	292.76	292.75	292.74	-

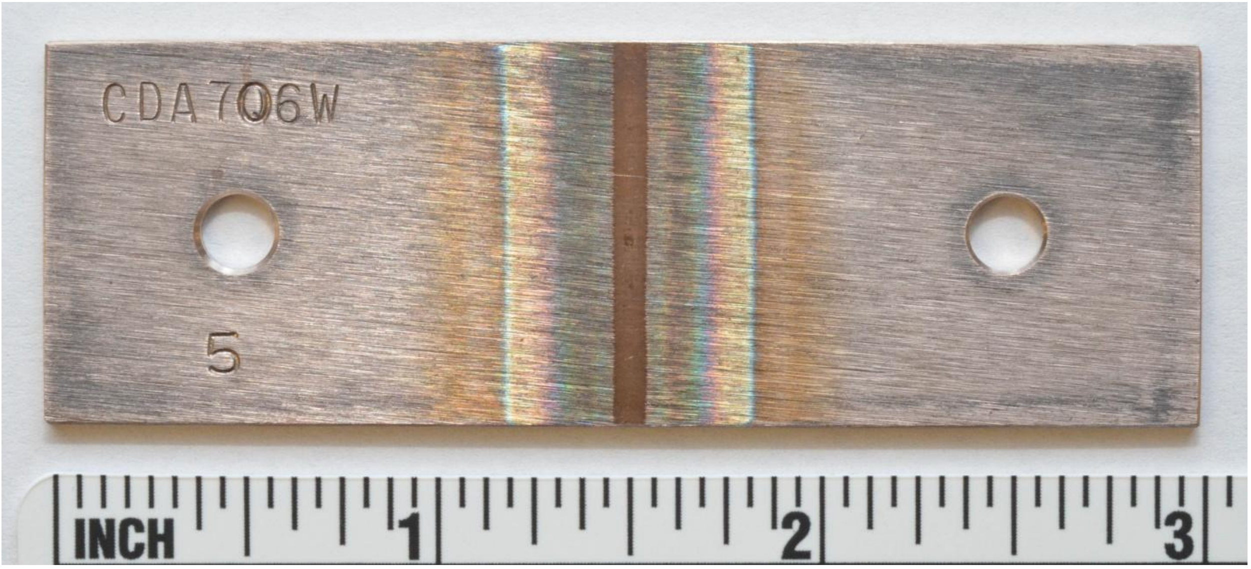
Table 3
Equations of Lines AB and BC for Corrosion Testing Samples

Sample	Line AB	Line BC	Point B (Approximate Mass Loss from Corrosion)
Coupon 1	y = 0.043x	y = 0.002x + 0.041	0.043 grams
Coupon 2	y = 0.061x	y = 0.002x + 0.067	0.069 grams
Coupon 3	y = 0.144x	y = 0.001x + 0.149	0.150 grams
Coupon 4	y = 0.313x	y = 0.313	0.313 grams
Screen 1	y = 2.59x	y = 0.13x + 4.90	5.16 grams
Screen 2	y = 4.95x	y = 0.03x + 4.92	4.95 grams
Screen 3	y = 4.03x	y = 0.08x + 4.79	4.89 grams
Screen 4	y = 4.25x	y = 0.05x + 4.04	4.09 grams
Plate	y = 1.39x	y = 0.01x + 1.42	1.43 grams

Table 4
Total Mass Loss from Corrosion and Corrosion Rate

Sample	Total Mass Loss from Corrosion*	Corrosion Rate
Coupon 1	0.256 grams	0.022 mm / year
Coupon 2	0.550 grams	0.023 mm / year
Coupon 3	0.726 grams	0.018 mm / year
Coupon 4	0.783 grams	0.017 mm / year
Screen 1	14.48 grams	0.129 mm / year
Screen 2	15.24 grams	0.067 mm / year
Screen 3	17.95 grams	0.047 mm / year
Screen 4	20.05 grams	0.044 mm / year
Plate	5.71 grams	0.029 mm / year

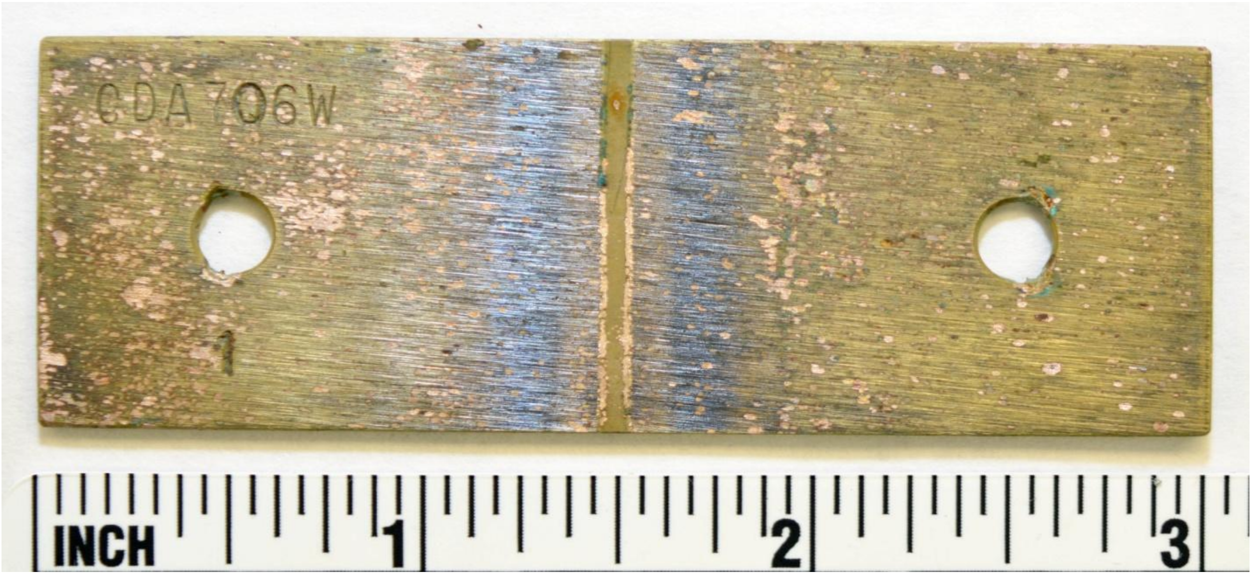
* Weight As-Received – (Weight Before Cleaning – Mass Loss from Corrosion During Cleaning)



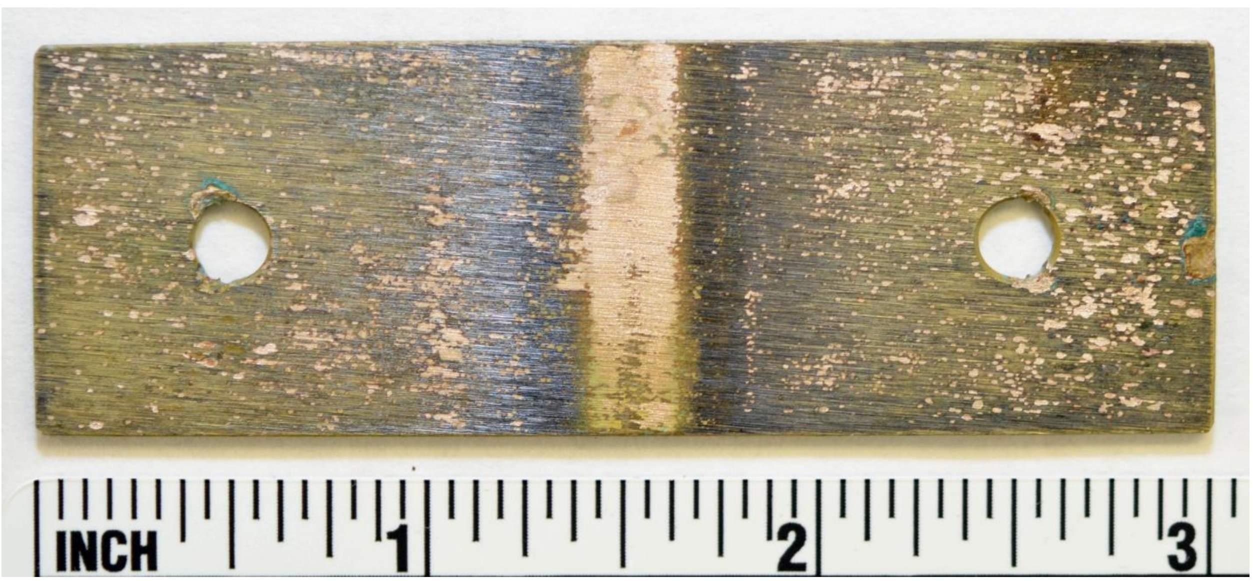
(a) CDA 706 Baseline Coupon, Front Side

(b) CDA 706 Baseline Coupon, Back Side

Figure 1 Photographs of the CDA 706 baseline coupon (a) front and (b) back side.

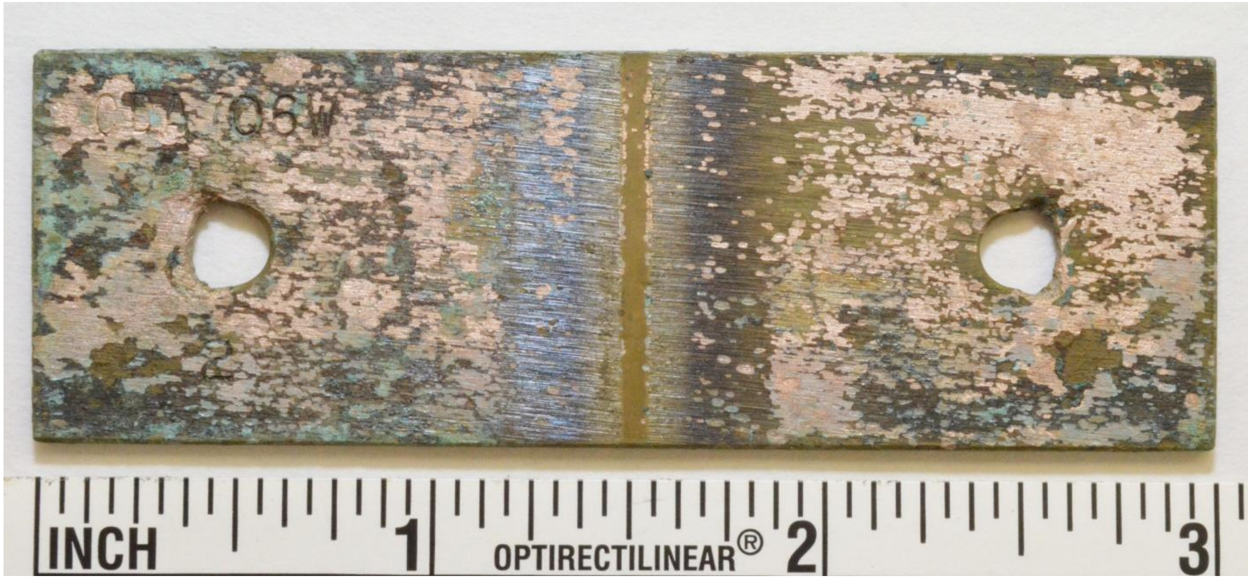


(a) CDA 706 Coupon 1, Front Side

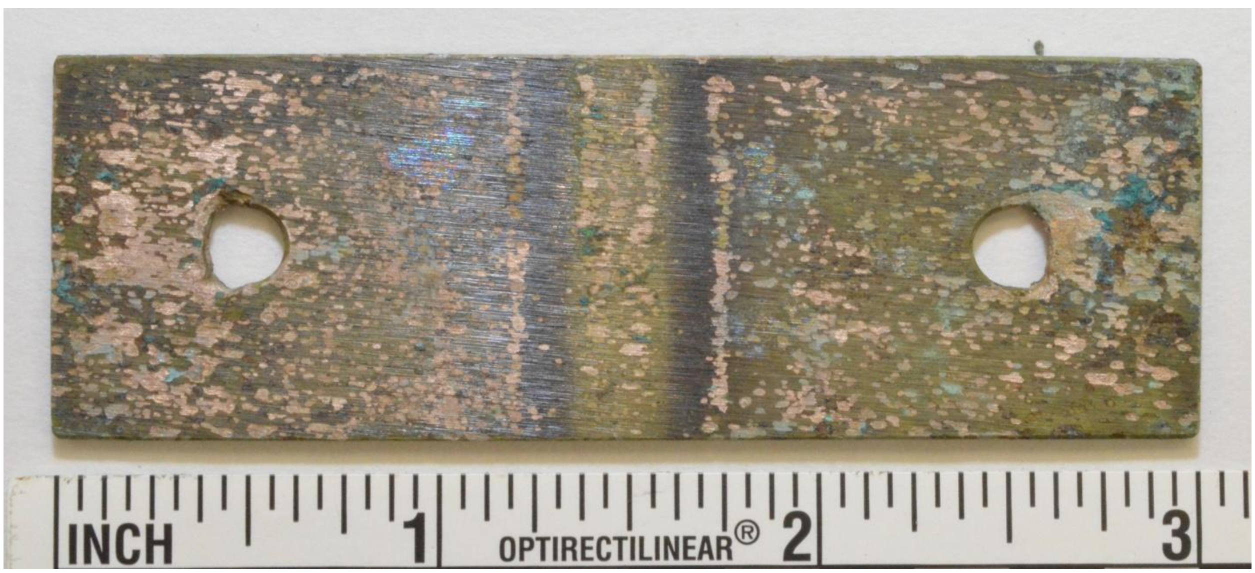


(b) CDA 706 Coupon 1, Back Side

Figure 2 Photographs of CDA 706 coupon 1 (a) front and (b) back side after a 3 month corrosion test.

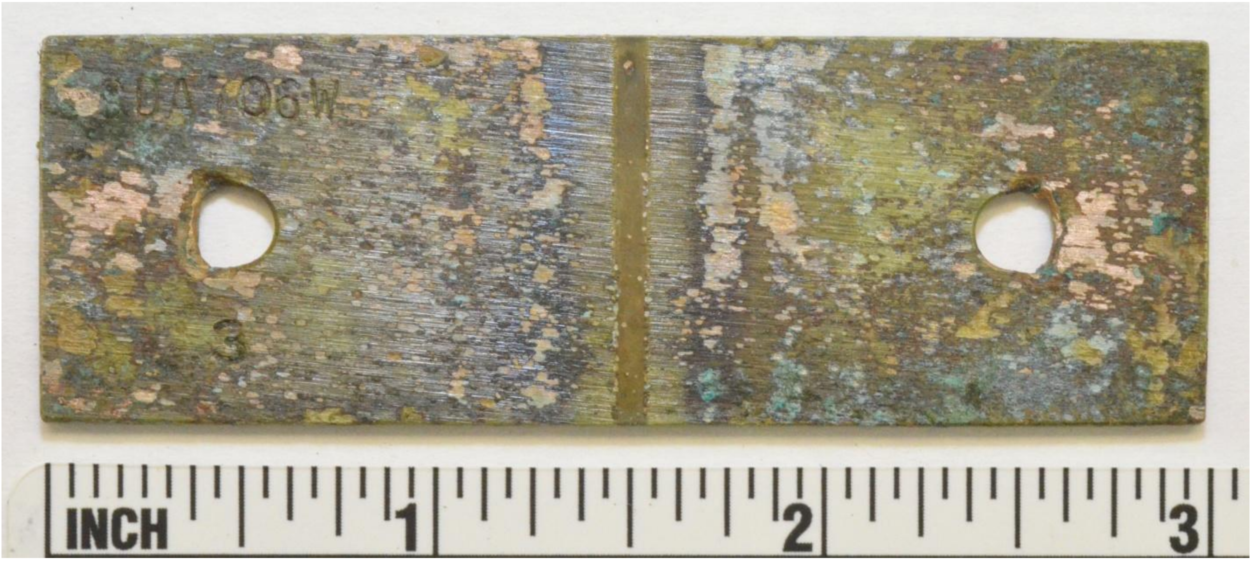


(a) CDA 706 Coupon 2, Front Side

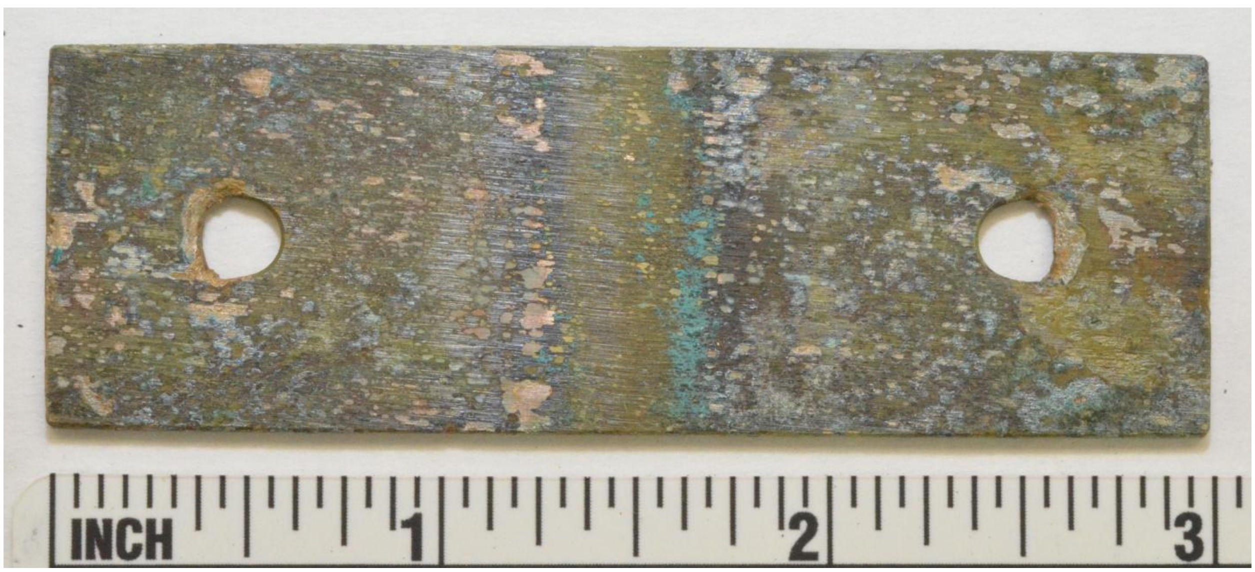


(b) CDA 706 Coupon 2, Back Side

Figure 3 Photographs of CDA 706 coupon 2 (a) front and (b) back side after a 6 month corrosion test.

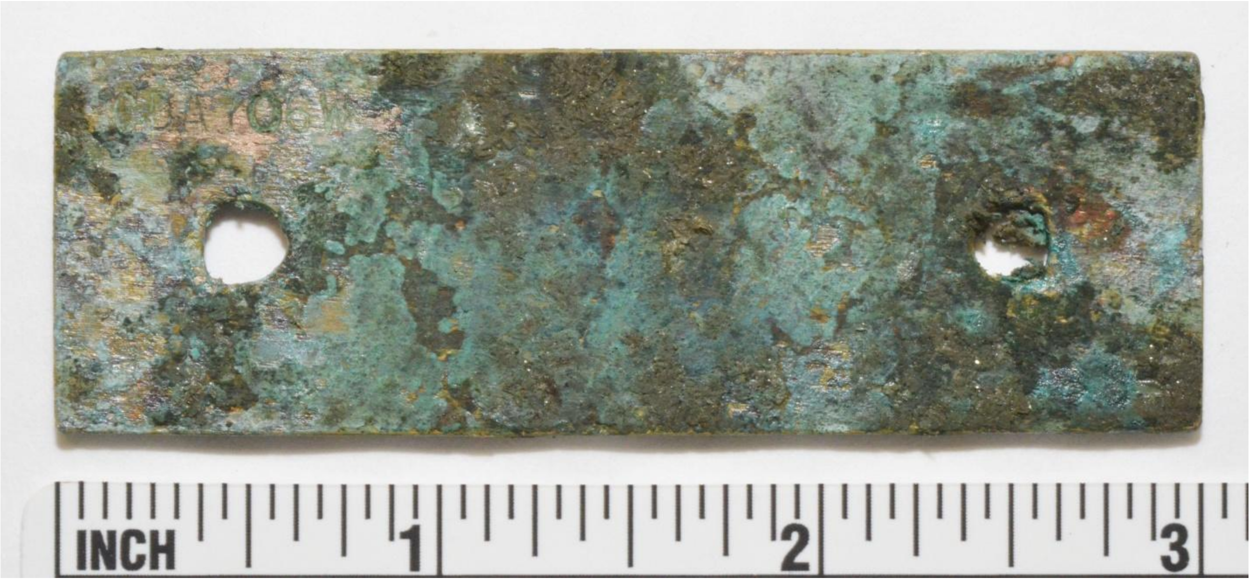


(a) CDA 706 Coupon 3, Front Side

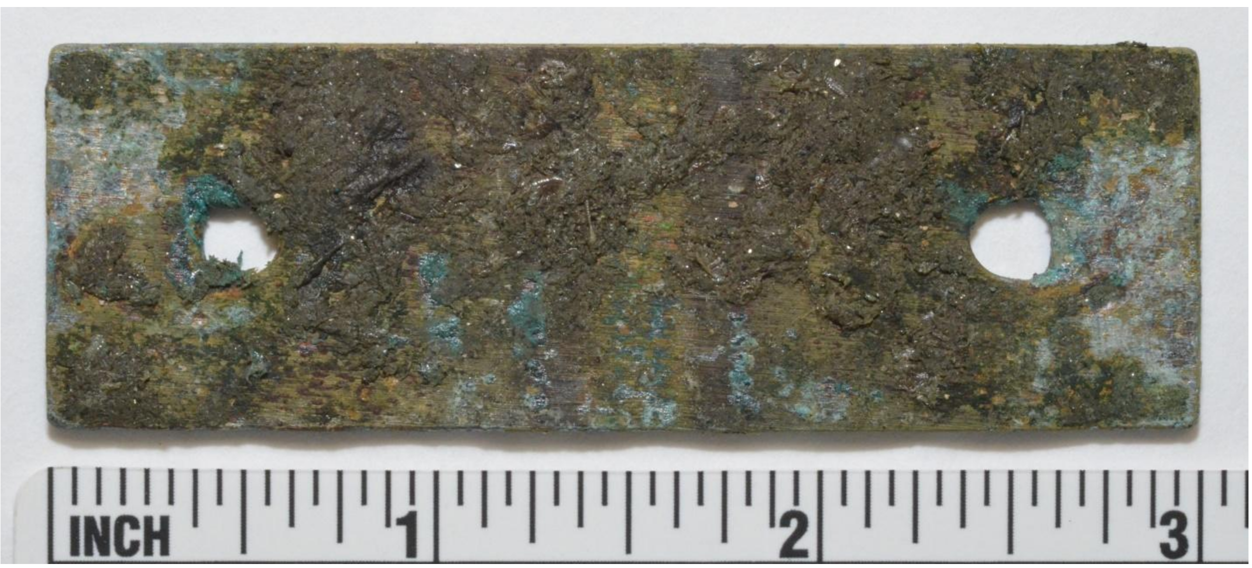


(b) CDA 706 Coupon 3, Back Side

Figure 4 Photographs of CDA 706 coupon 3 (a) front and (b) back side after a 10 month corrosion test.

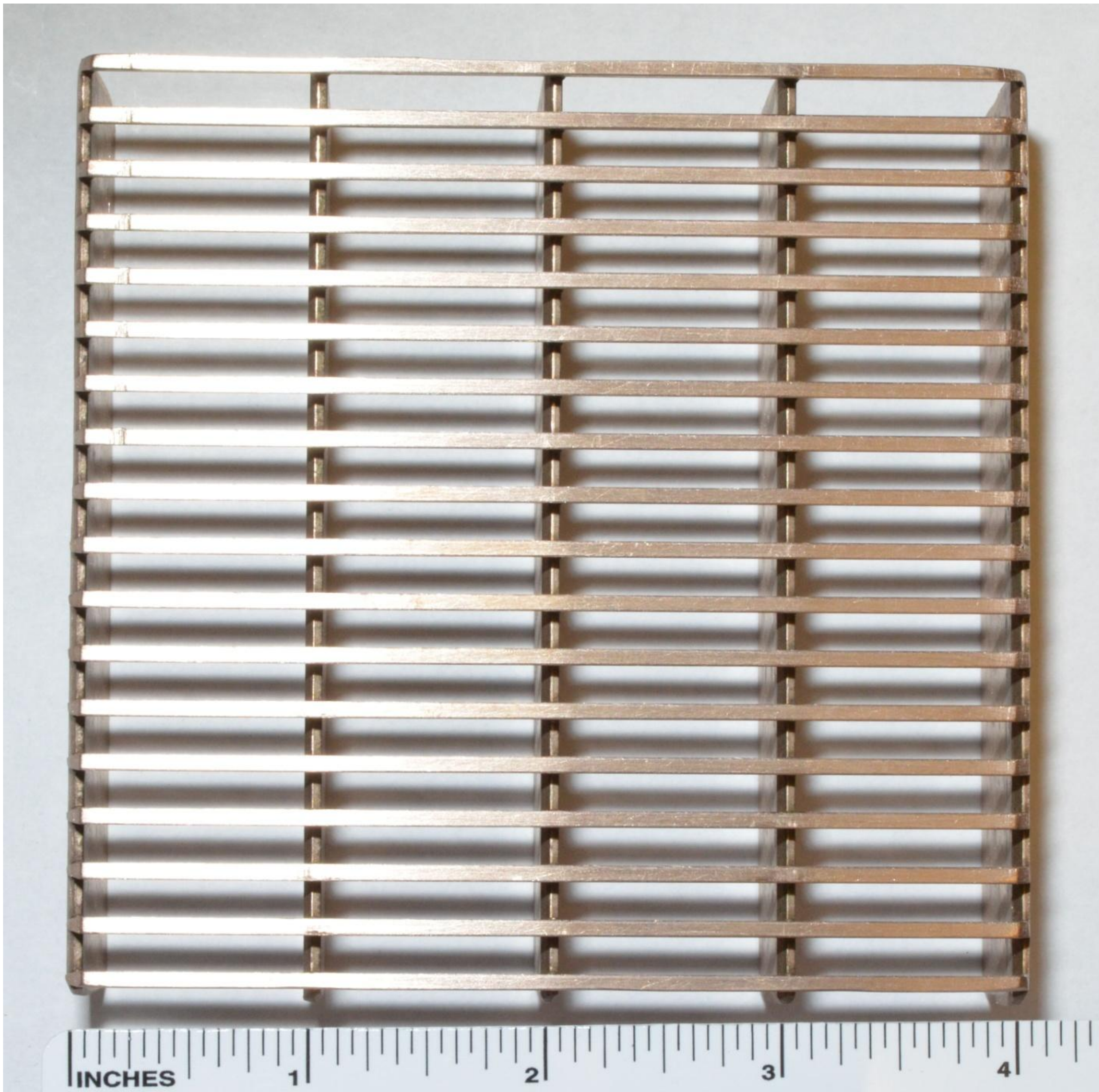


(a) CDA 706 Coupon 4, Front Side



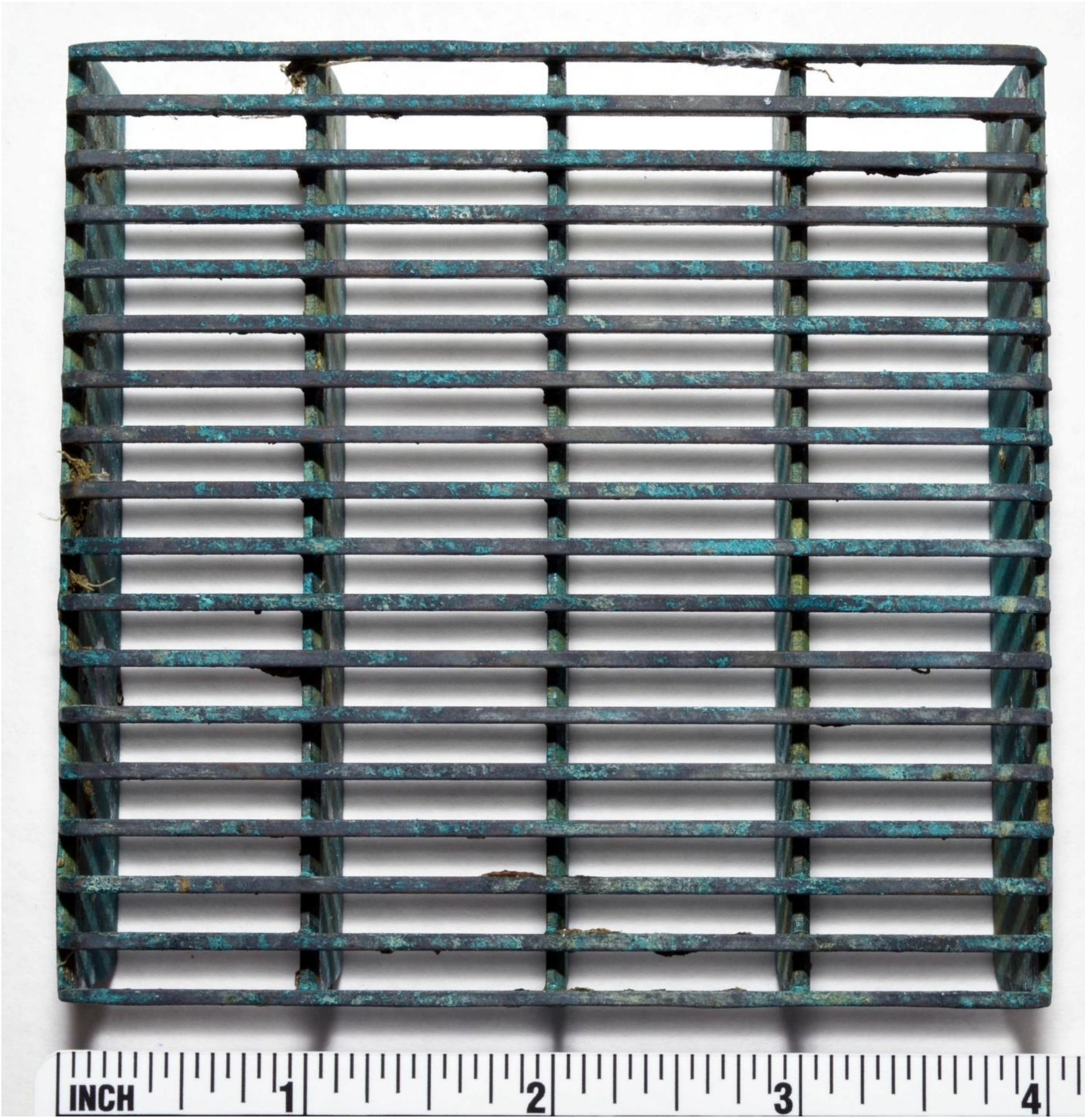
(b) CDA 706 Coupon 4, Back Side

Figure 5 Photographs of CDA 706 coupon 4 (a) front and (b) back side after a 12 month corrosion test.



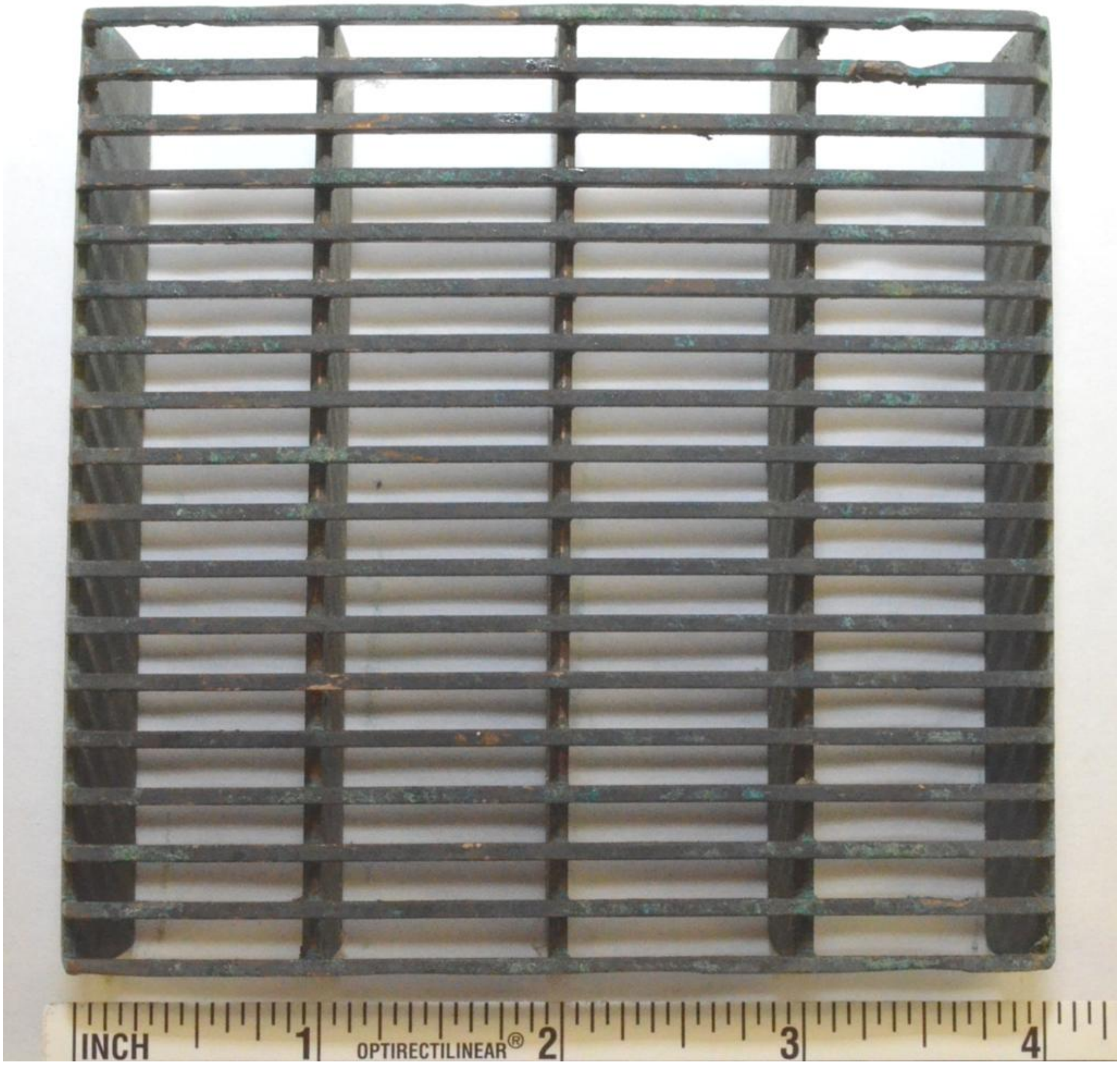
(a) CDA 706 Baseline Screen

Figure 6 Photograph of the CDA 706 baseline screen.



(a) CDA 706 Screen 1

Figure 7 Photograph of CDA 706 screen 1 after a 3 month corrosion test.



(a) CDA 706 Screen 2

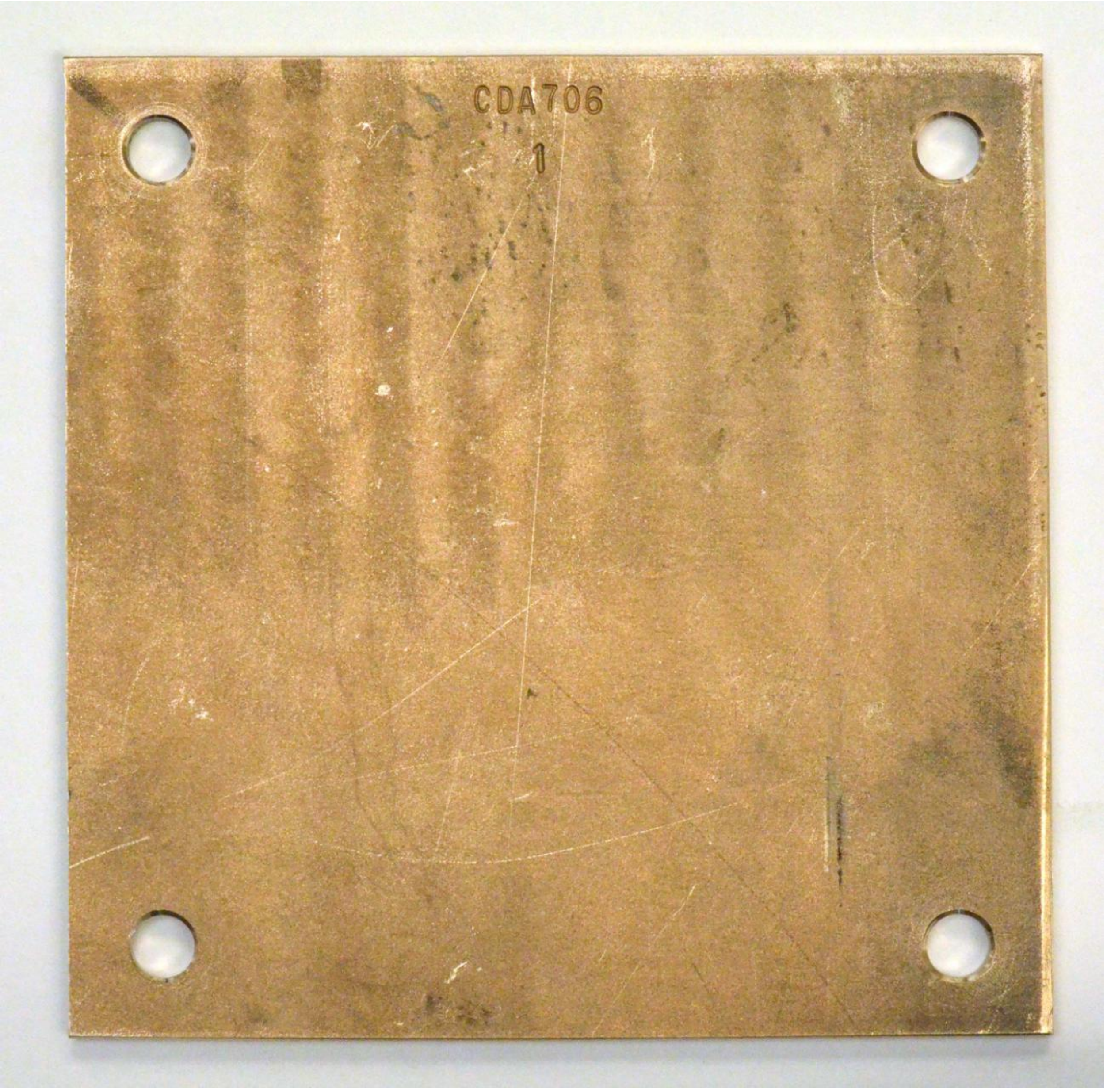
Figure 8 Photograph of CDA 706 screen 2 after a 6 month corrosion test.

(a) CDA 706 Screen 3

Figure 9 Photograph of CDA 706 screen 3 after a 10 month corrosion test.

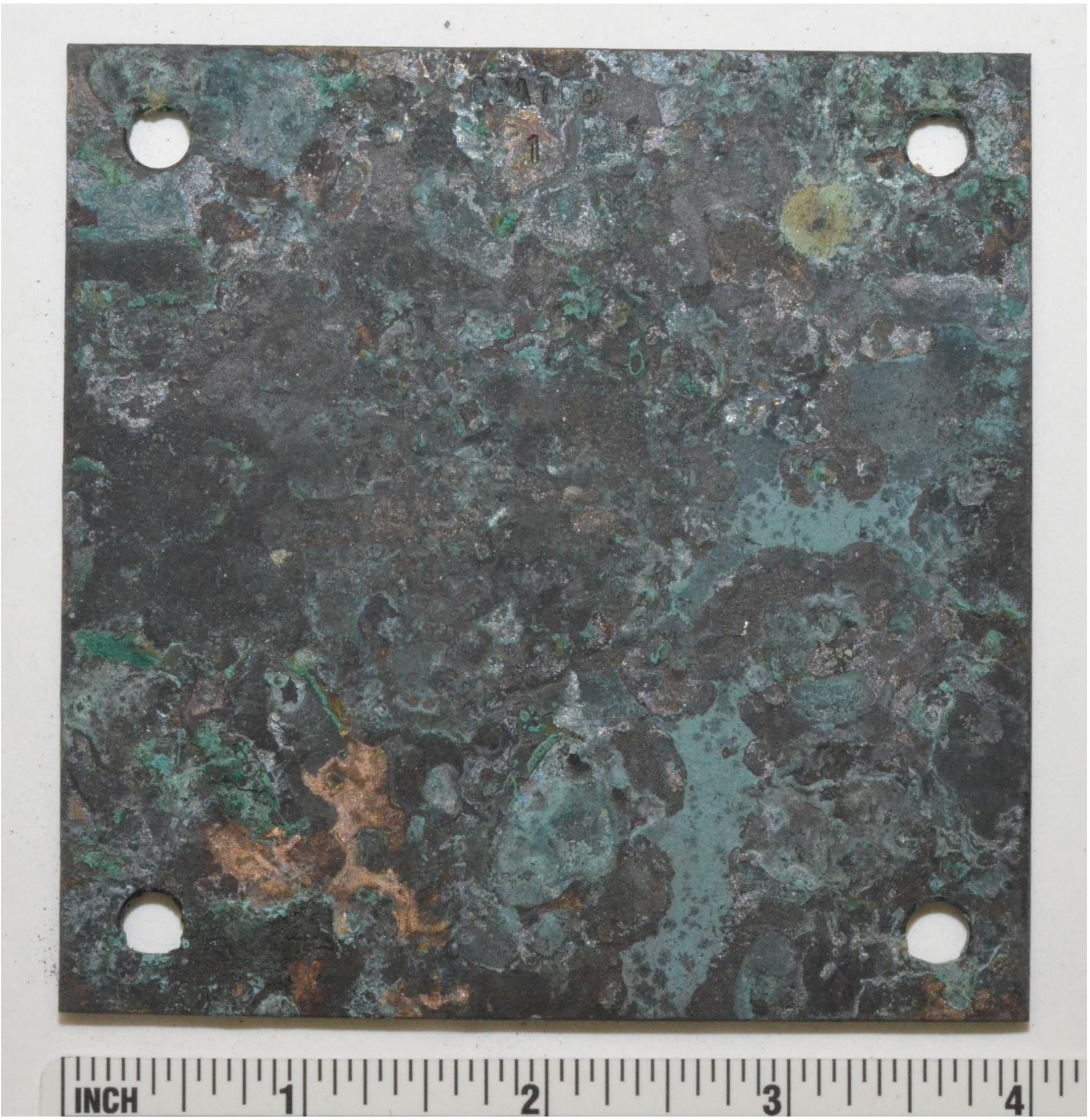
(a) CDA 706 Screen 4

Figure 10 Photograph of CDA 706 screen 4 after a 12 month corrosion test.



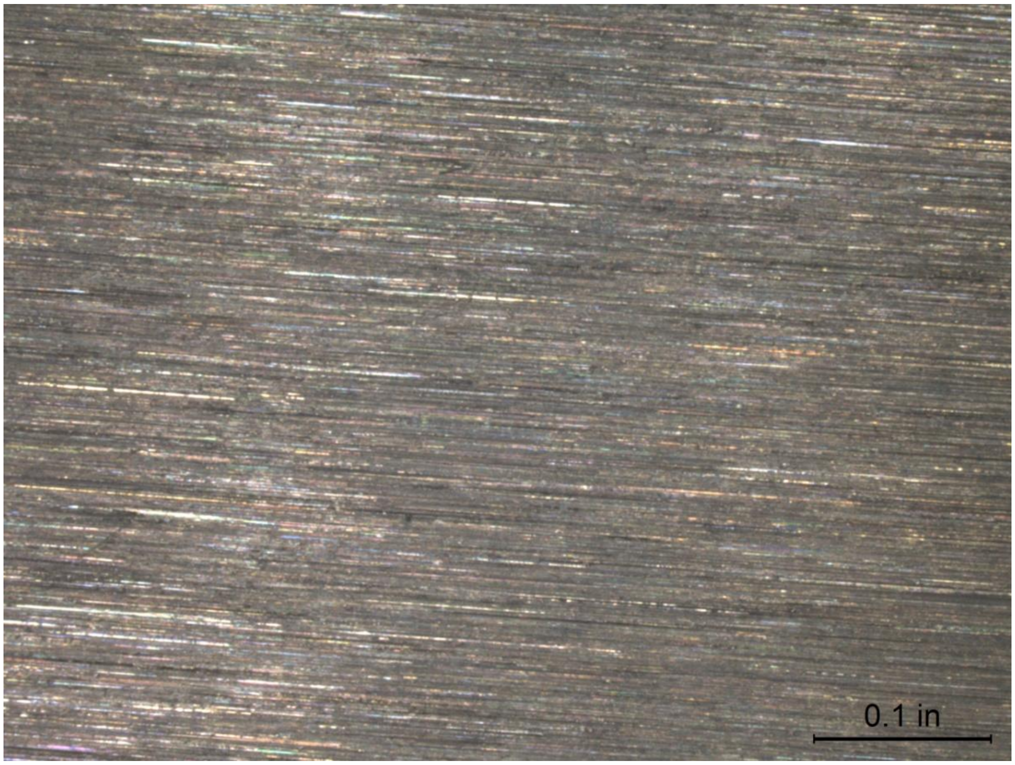
(a) CDA 706 Baseline Plate

Figure 11 Photograph of the CDA 706 baseline plate.

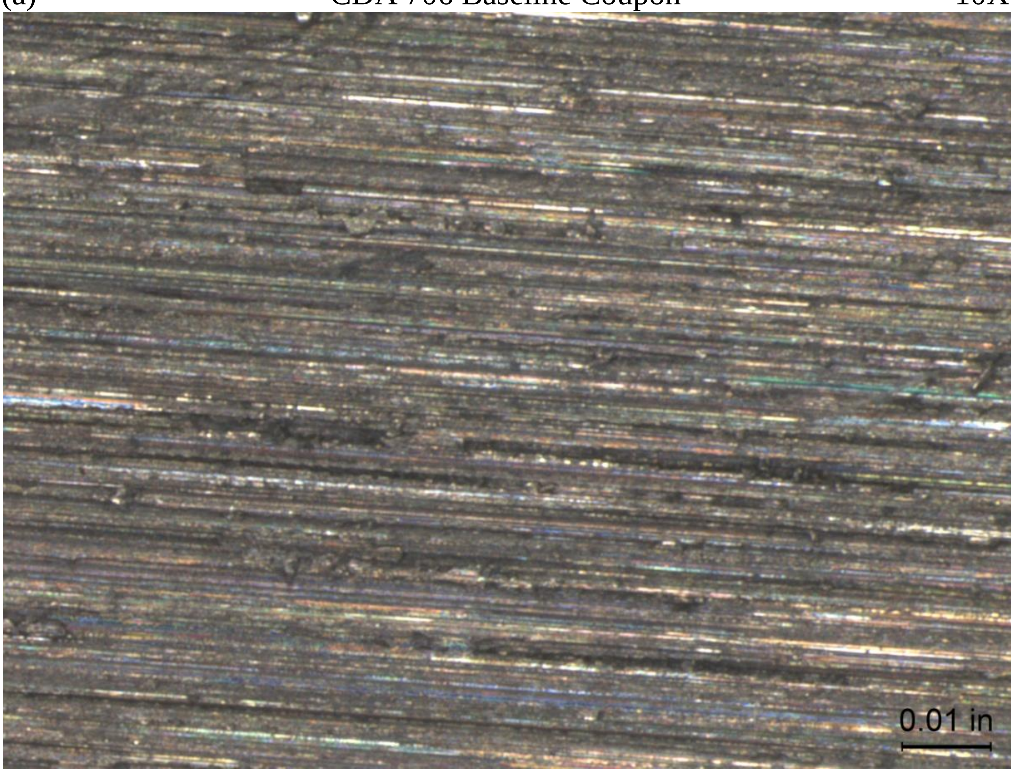


(a) CDA 706 Plate

Figure 12 Photograph of CDA 706 plate after a 12 month corrosion test.

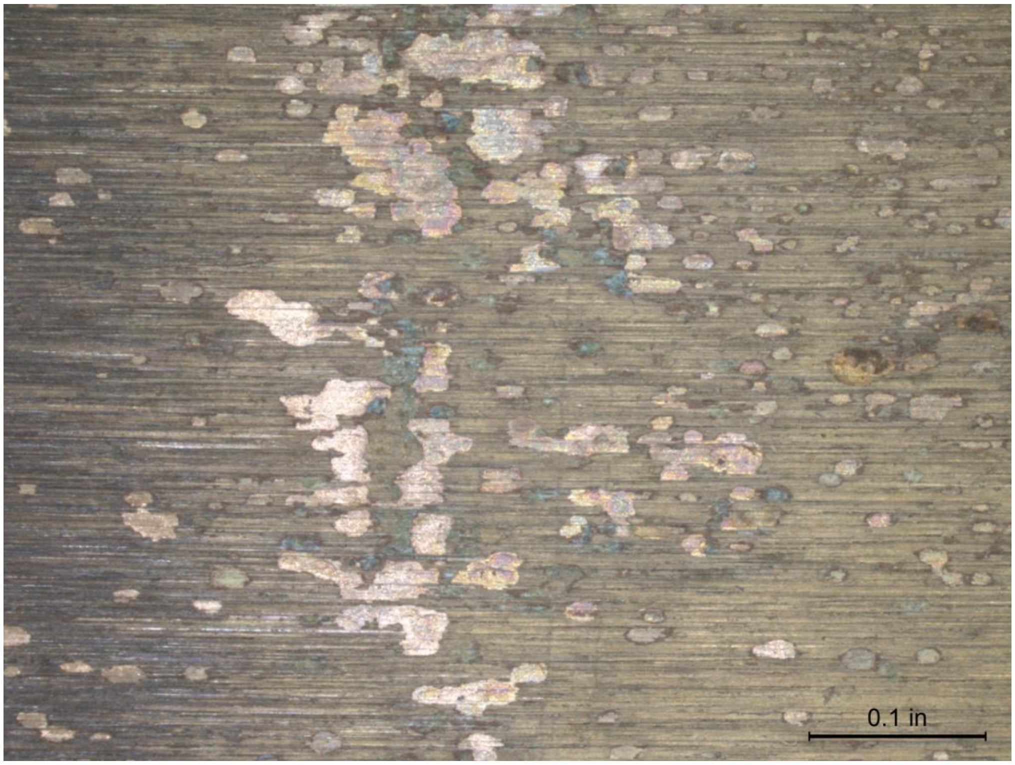


(a) CDA 706 Baseline Coupon 10X

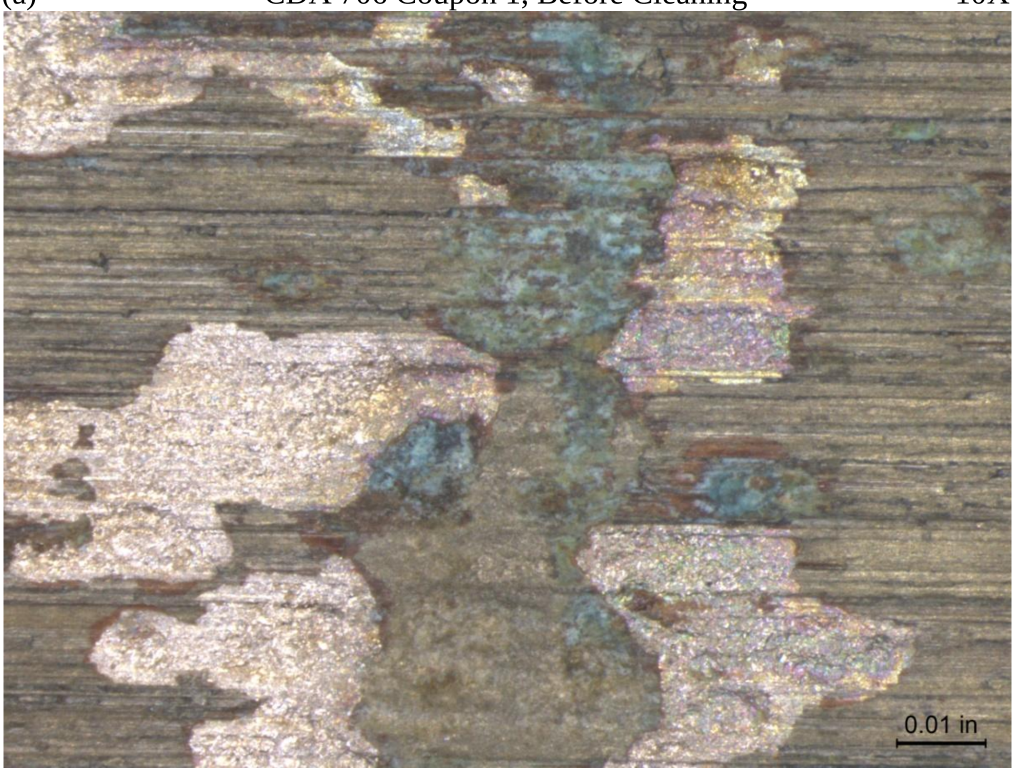


(b) CDA 706 Baseline Coupon 50X

Figure 13 Optical macrographs of the CDA 706 baseline coupon.



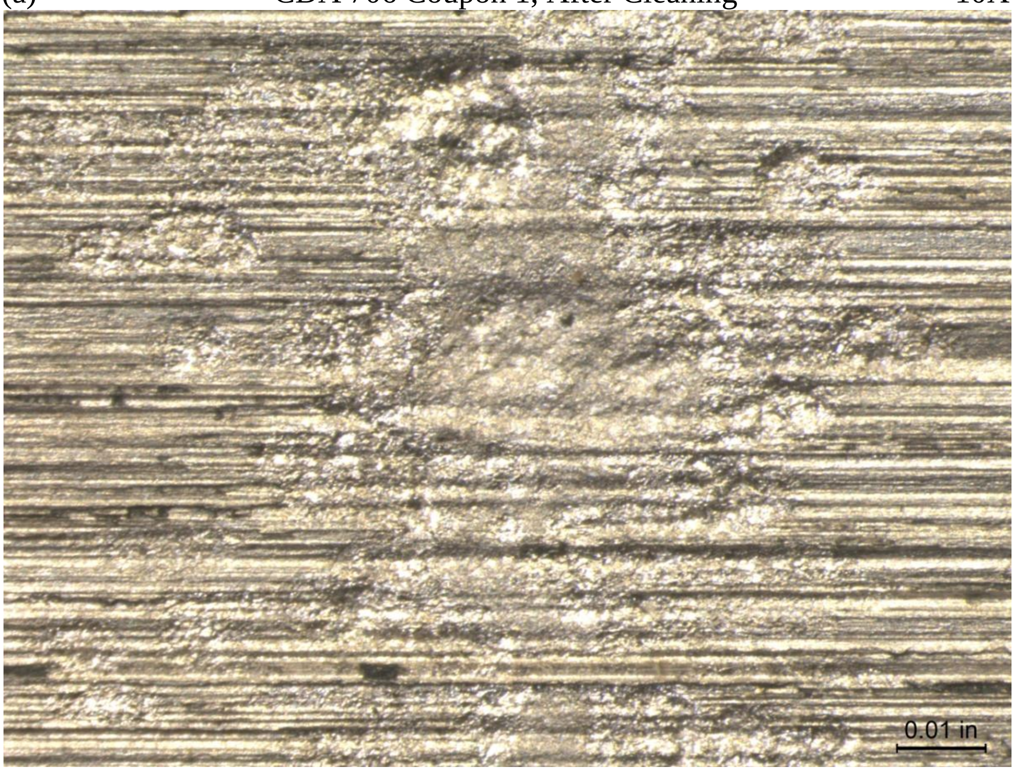
(a) CDA 706 Coupon 1, Before Cleaning 10X



(b) CDA 706 Coupon 1, Before Cleaning 50X

Figure 14 Optical macrographs of CDA 706 coupon 1 after a 3 month corrosion test, before cleaning.

(a) CDA 706 Coupon 1, After Cleaning 10X



(b) CDA 706 Coupon 1, After Cleaning 50X

Figure 15 Optical macrographs of CDA 706 coupon 1 after a 3 month corrosion test, after cleaning.

(a) CDA 706 Coupon 2, Before Cleaning 10X

(b) CDA 706 Coupon 2, Before Cleaning 50X

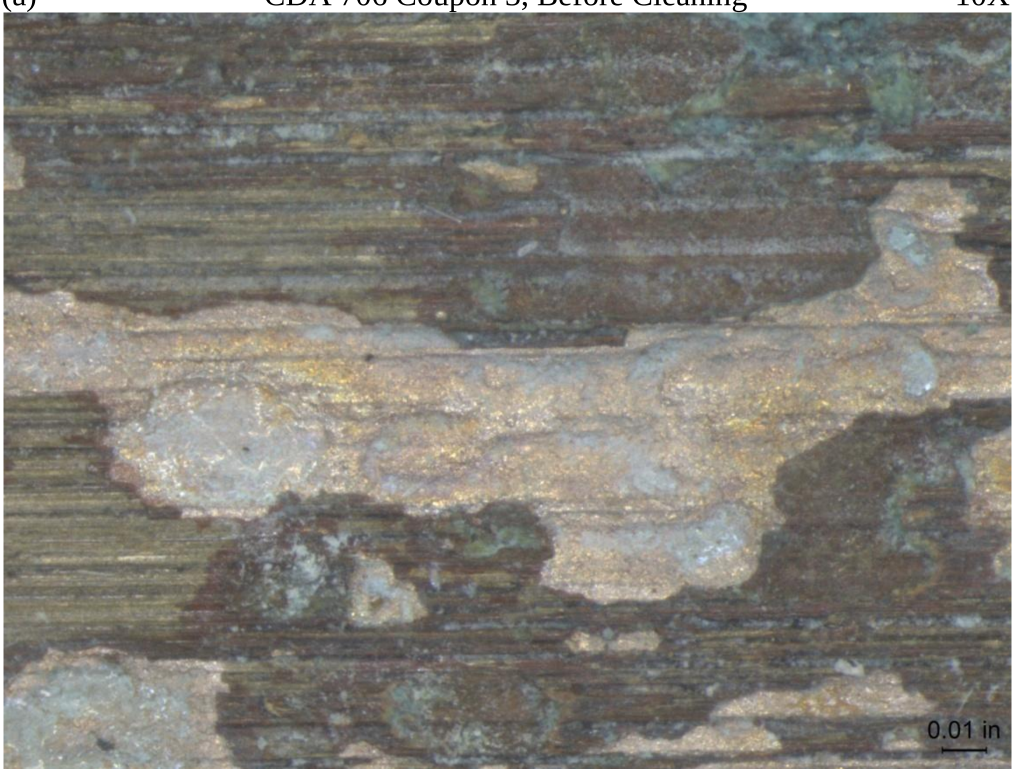
Figure 16 Optical macrographs of CDA 706 coupon 2 after a 6 month corrosion test, before cleaning.

(a) CDA 706 Coupon 2, After Cleaning 10X

(b) CDA 706 Coupon 2, After Cleaning 50X

Figure 17 Optical macrographs of CDA 706 coupon 2 after a 6 month corrosion test, after cleaning.

(a) CDA 706 Coupon 3, Before Cleaning 10X



(b) CDA 706 Coupon 3, Before Cleaning 50X

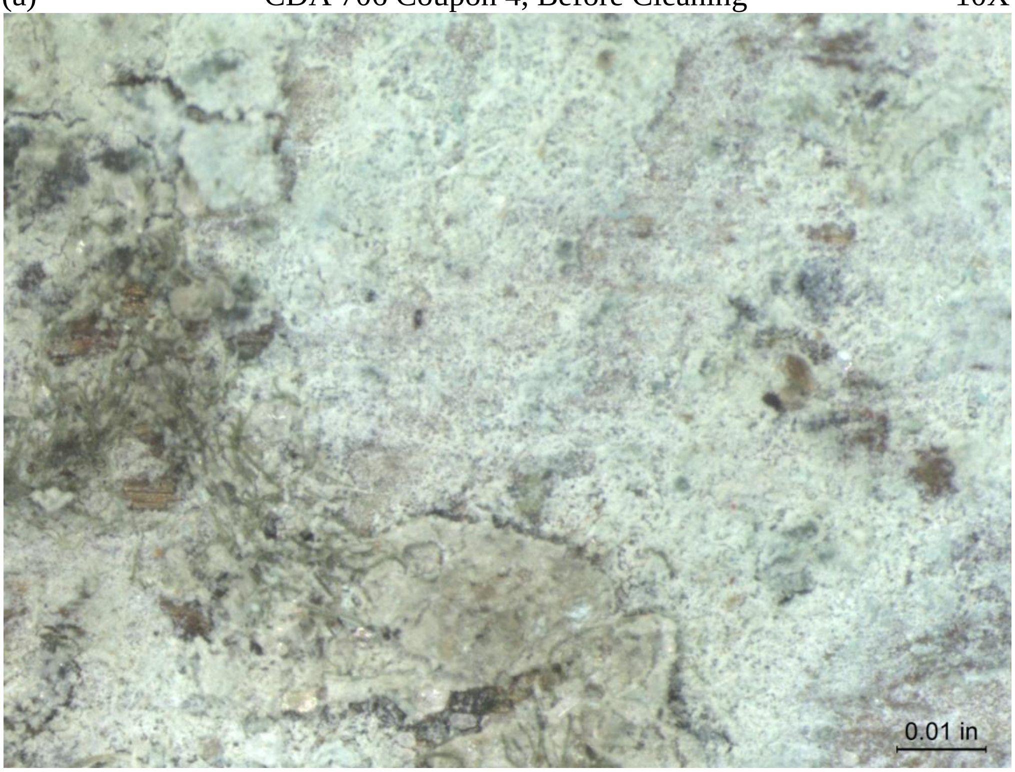
Figure 18 Optical macrographs of CDA 706 coupon 3 after a 10 month corrosion test, before cleaning.

(a) CDA 706 Coupon 3, After Cleaning 10X

(b) CDA 706 Coupon 3, After Cleaning 50X

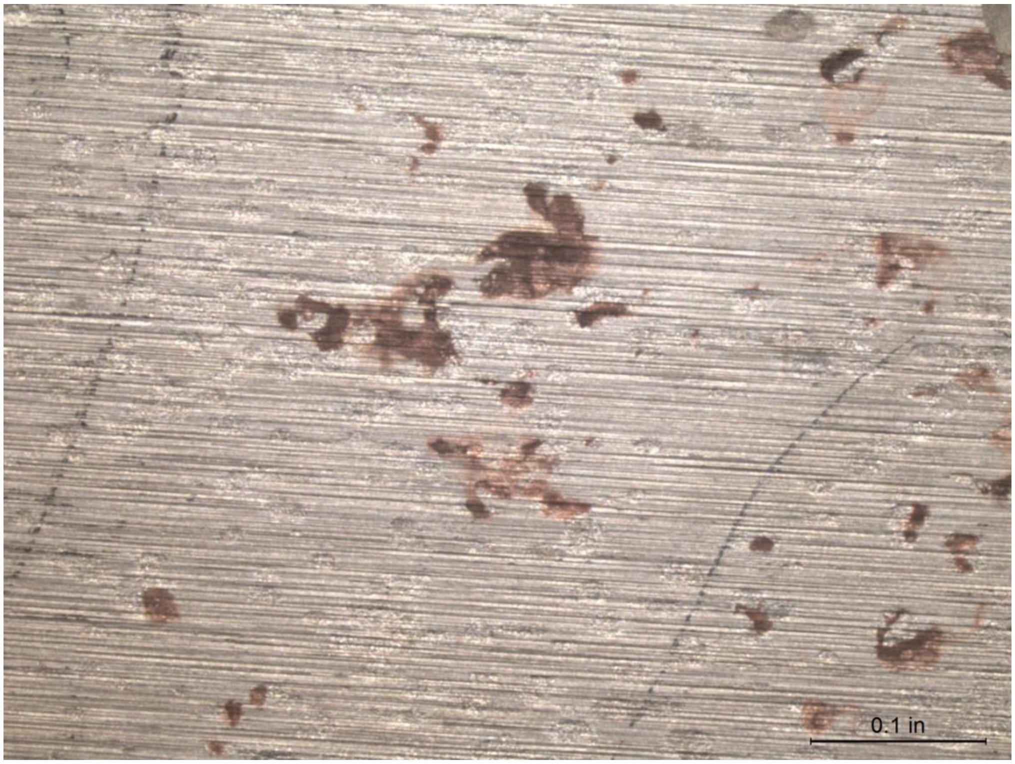
Figure 19 Optical macrographs of CDA 706 coupon 3 after a 10 month corrosion test, after cleaning.

(a) CDA 706 Coupon 4, Before Cleaning 10X

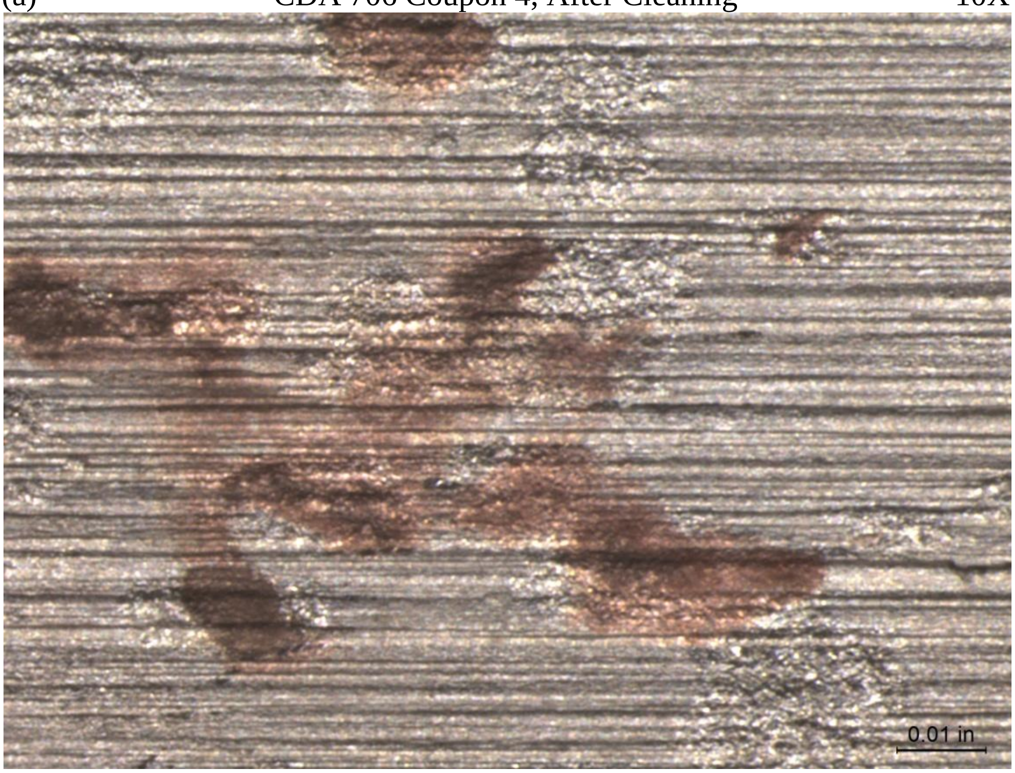


(b) CDA 706 Coupon 4, Before Cleaning 50X

Figure 20 Optical macrographs of CDA 706 coupon 4 after a 12 month corrosion test, before cleaning.

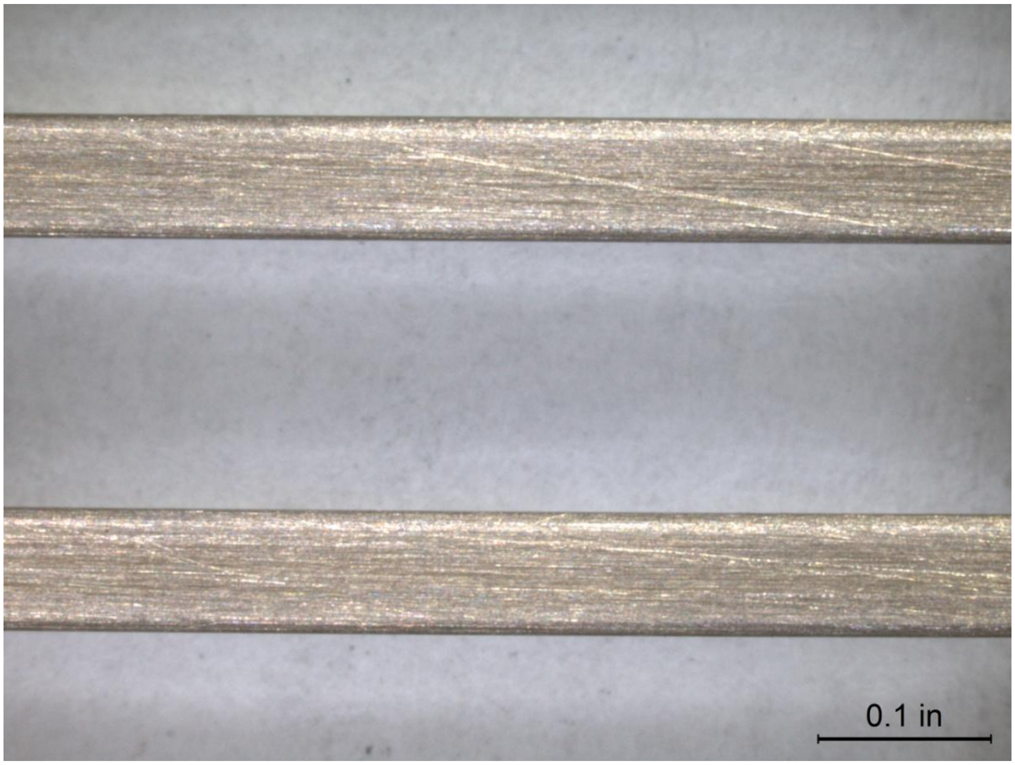


(a) CDA 706 Coupon 4, After Cleaning 10X

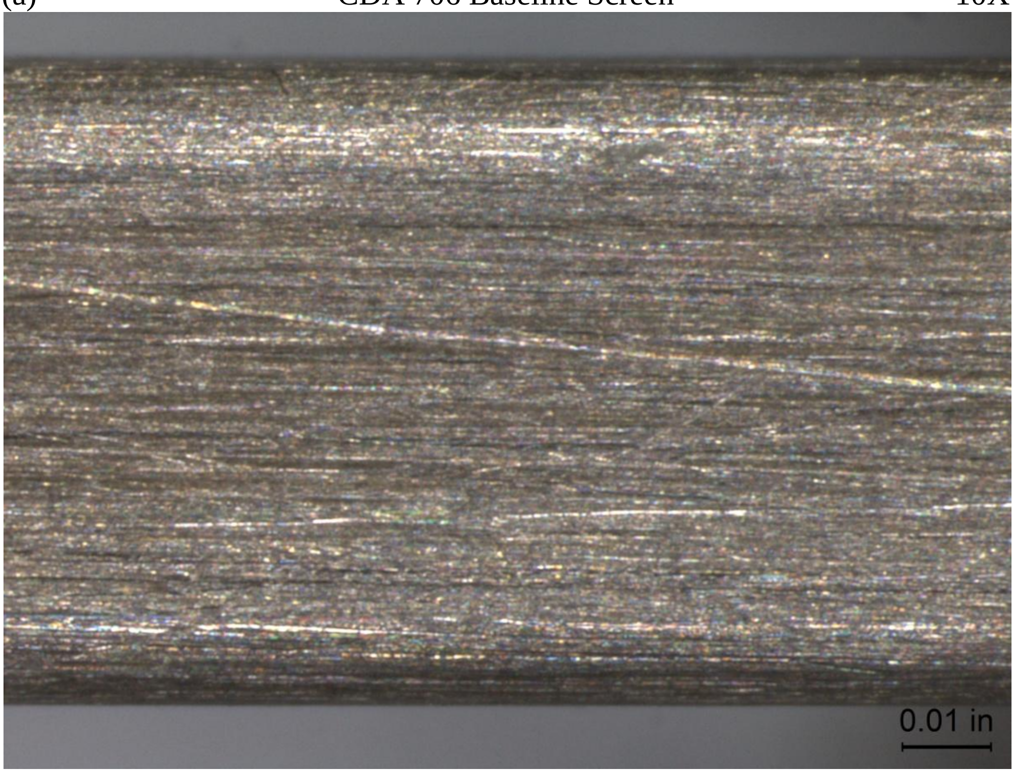


(b) CDA 706 Coupon 4, After Cleaning 50X

Figure 21 Optical macrographs of CDA 706 coupon 4 after a 12 month corrosion test, after cleaning.

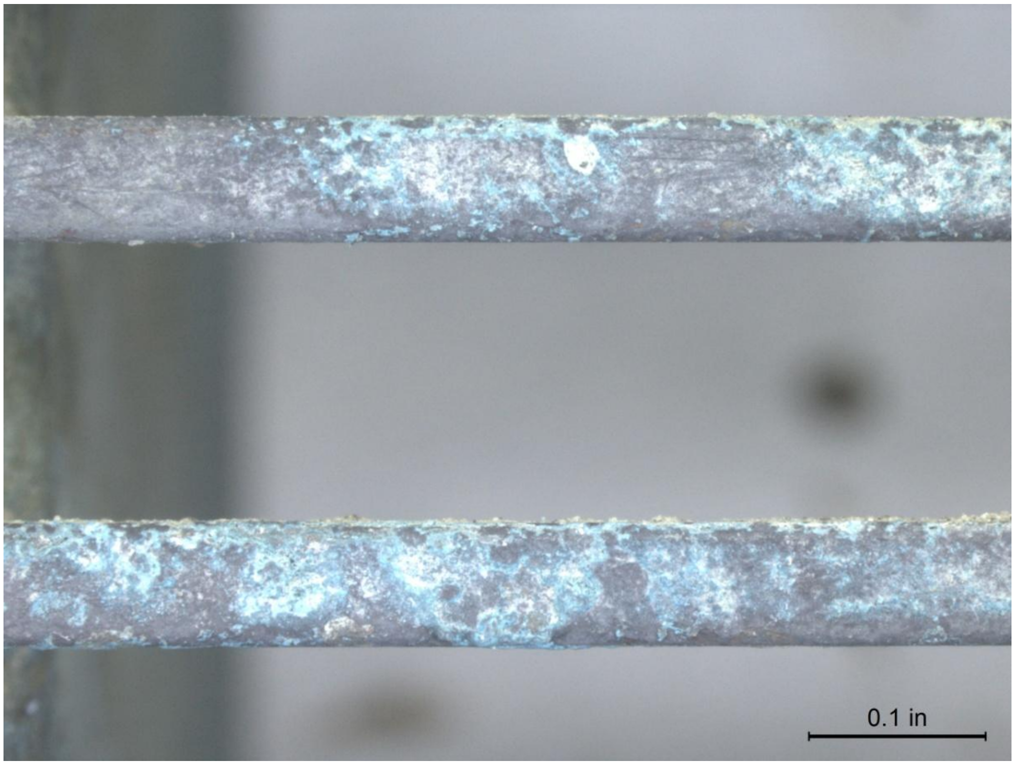


(a) CDA 706 Baseline Screen 10X

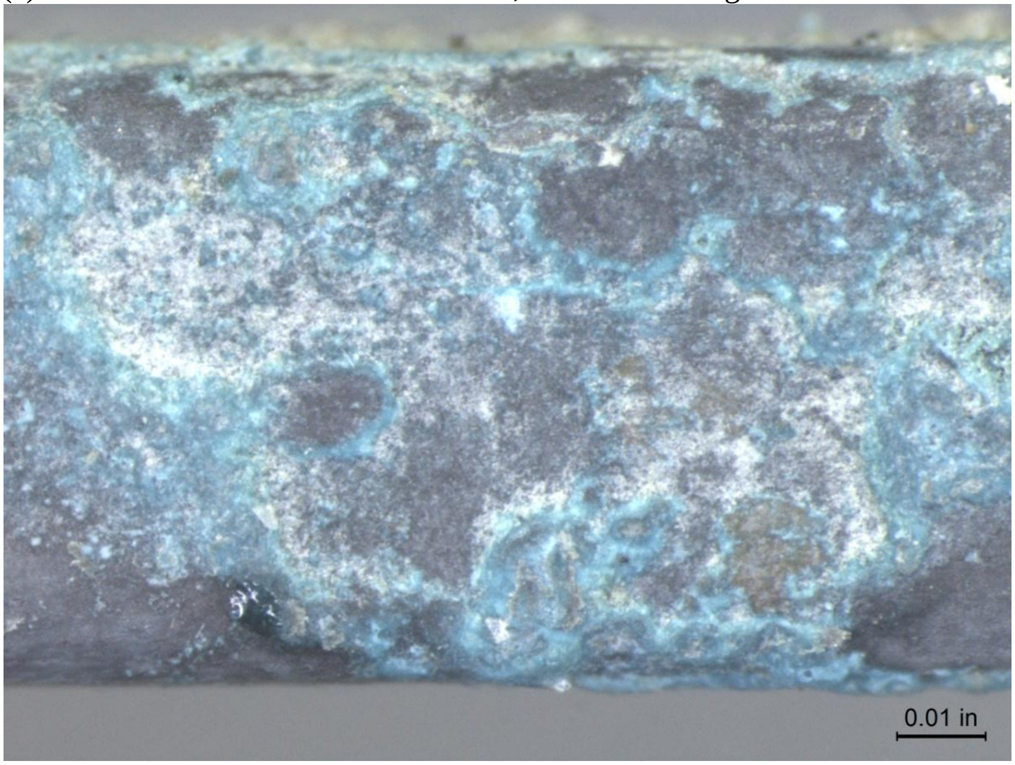


(b) CDA 706 Baseline Screen 50X

Figure 22 Optical macrographs of the CDA 706 baseline screen.

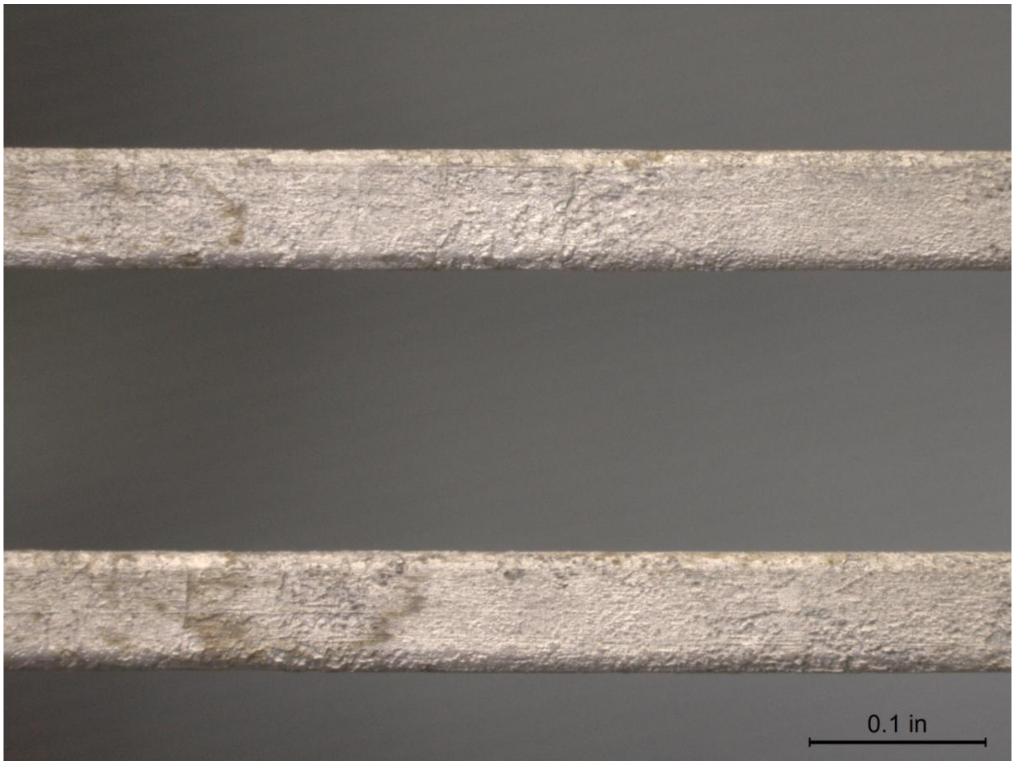


(a) CDA 706 Screen 1, Before Cleaning 10X



(b) CDA 706 Screen 1, Before Cleaning 50X

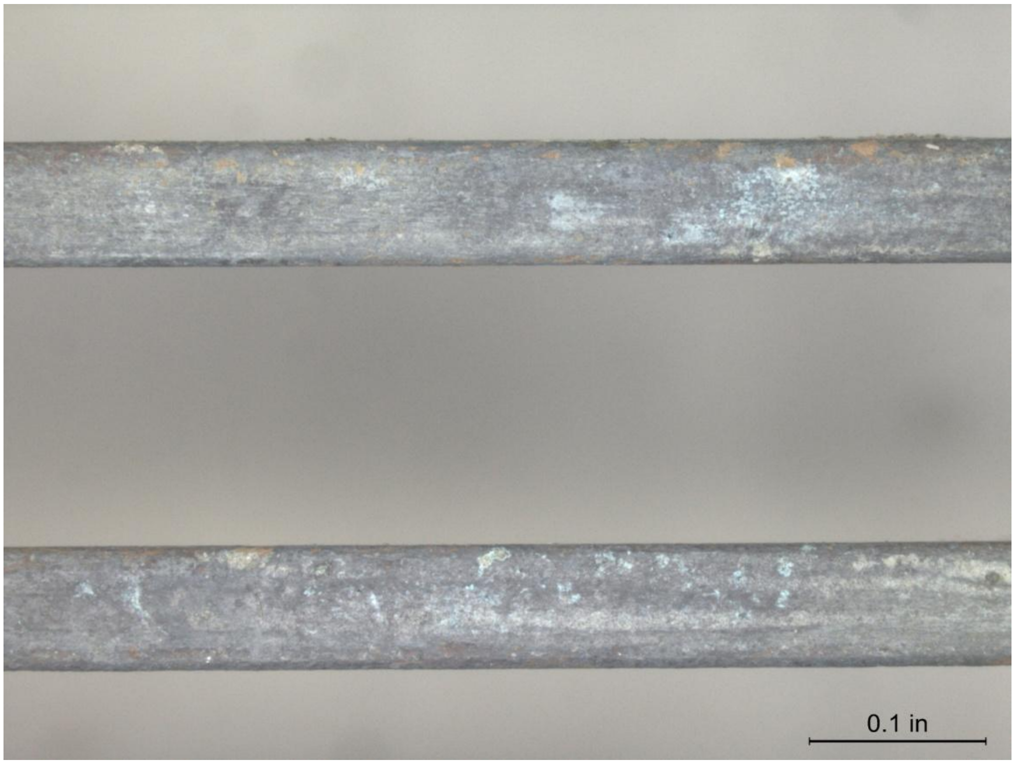
Figure 23 Optical macrographs of CDA 706 screen 1 after a 3 month corrosion test, before cleaning.



(a) CDA 706 Screen 1, After Cleaning 10X

(b) CDA 706 Screen 1, After Cleaning 50X

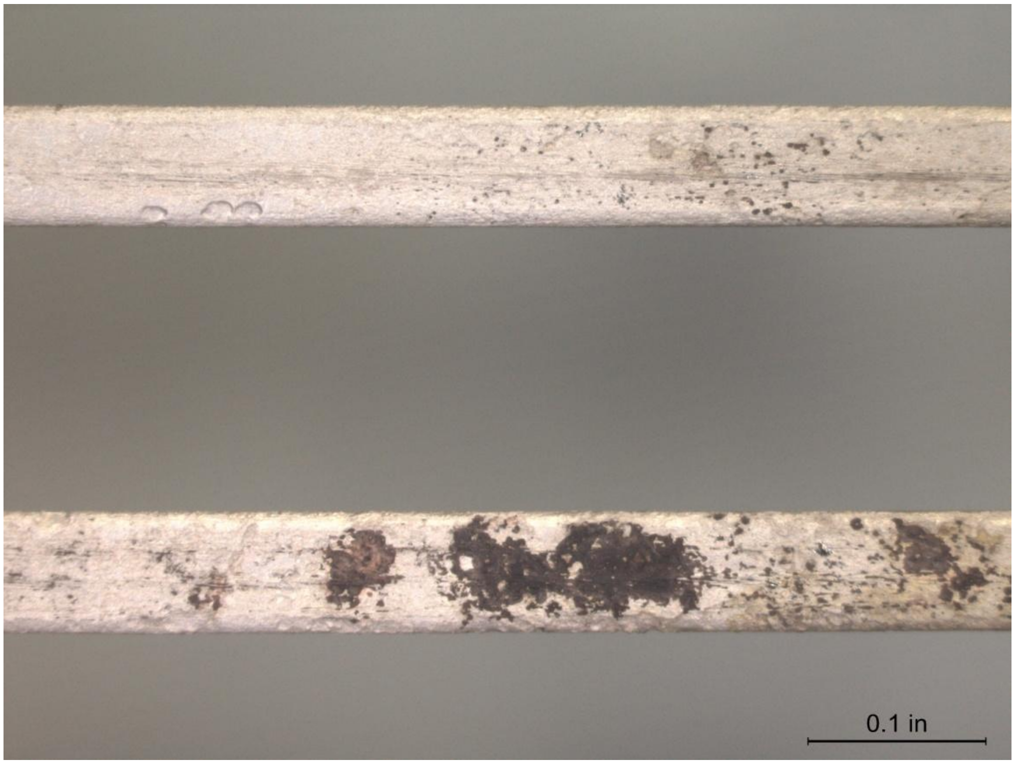
Figure 24 Optical macrographs of CDA 706 screen 1 after a 3 month corrosion test, after cleaning.



(a) CDA 706 Screen 2, Before Cleaning 10X

(b) CDA 706 Screen 2, Before Cleaning 50X

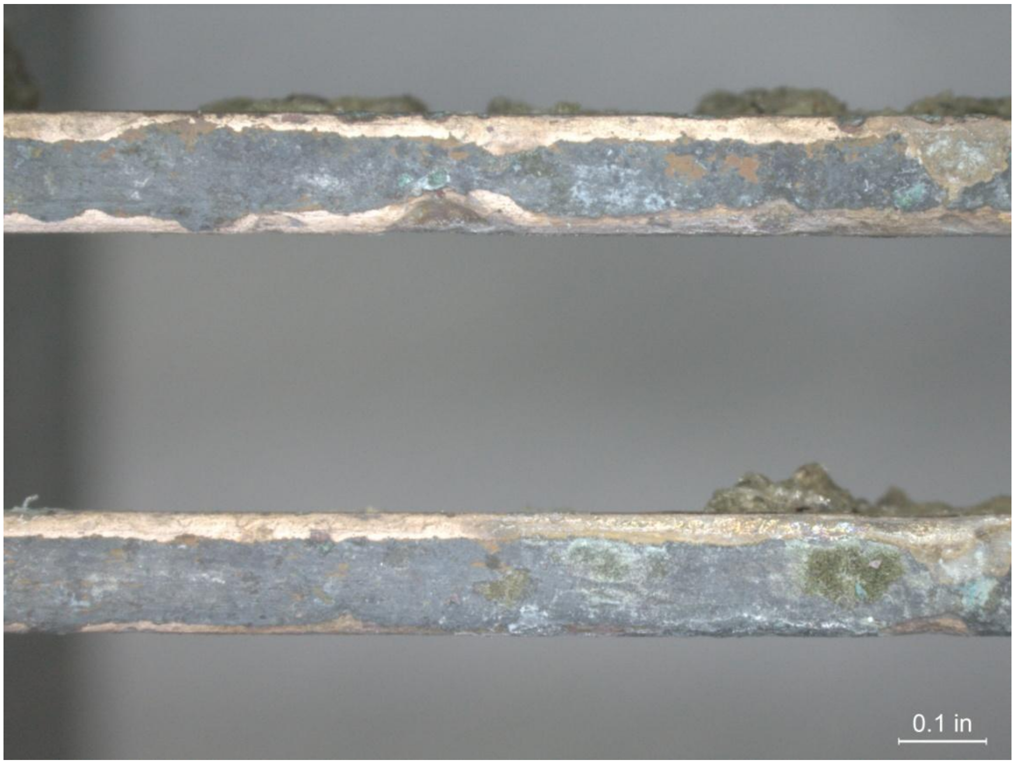
Figure 25 Optical macrographs of CDA 706 screen 2 after a 6 month corrosion test, before cleaning.



(a) CDA 706 Screen 2, After Cleaning 10X

(b) CDA 706 Screen 2, After Cleaning 50X

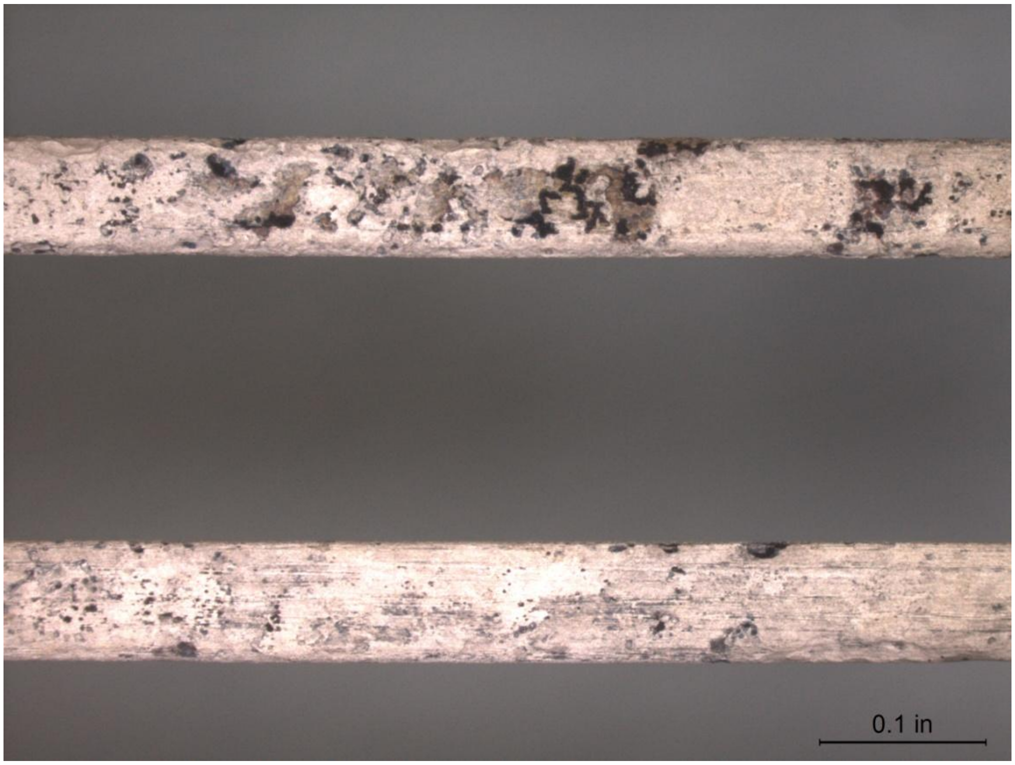
Figure 26 Optical macrographs of CDA 706 screen 2 after a 6 month corrosion test, after cleaning.



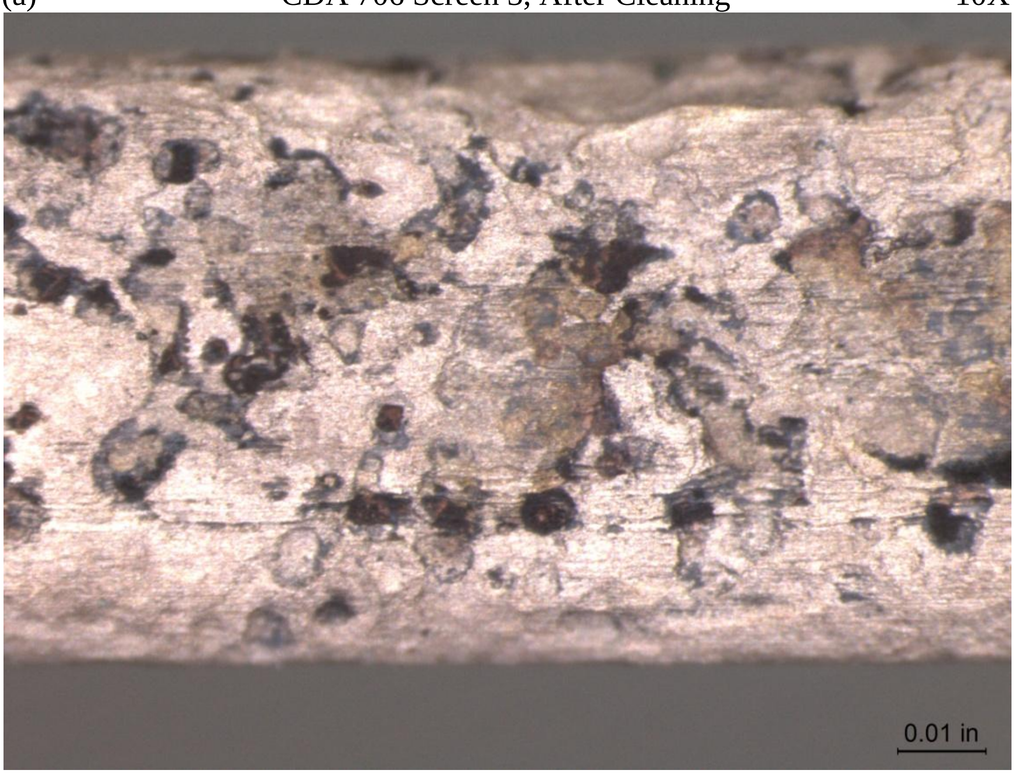
(a) CDA 706 Screen 3, Before Cleaning 10X

(b) CDA 706 Screen 3, Before Cleaning 50X

Figure 27 Optical macrographs of CDA 706 screen 3 after a 10 month corrosion test, before cleaning.

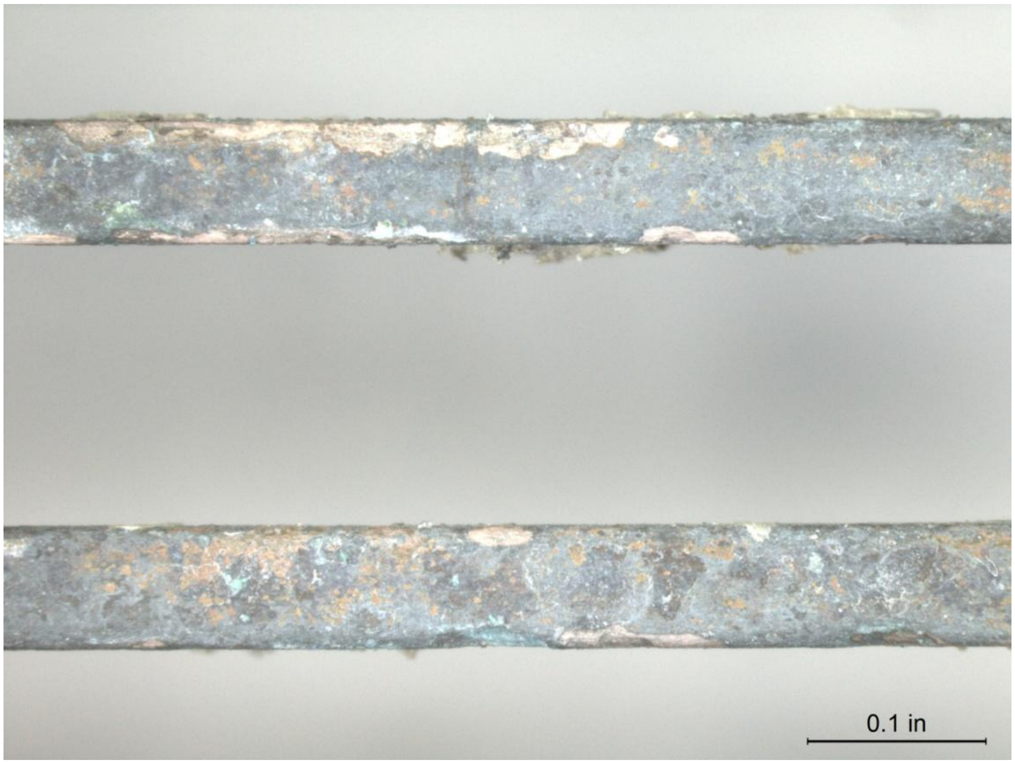


(a) CDA 706 Screen 3, After Cleaning 10X

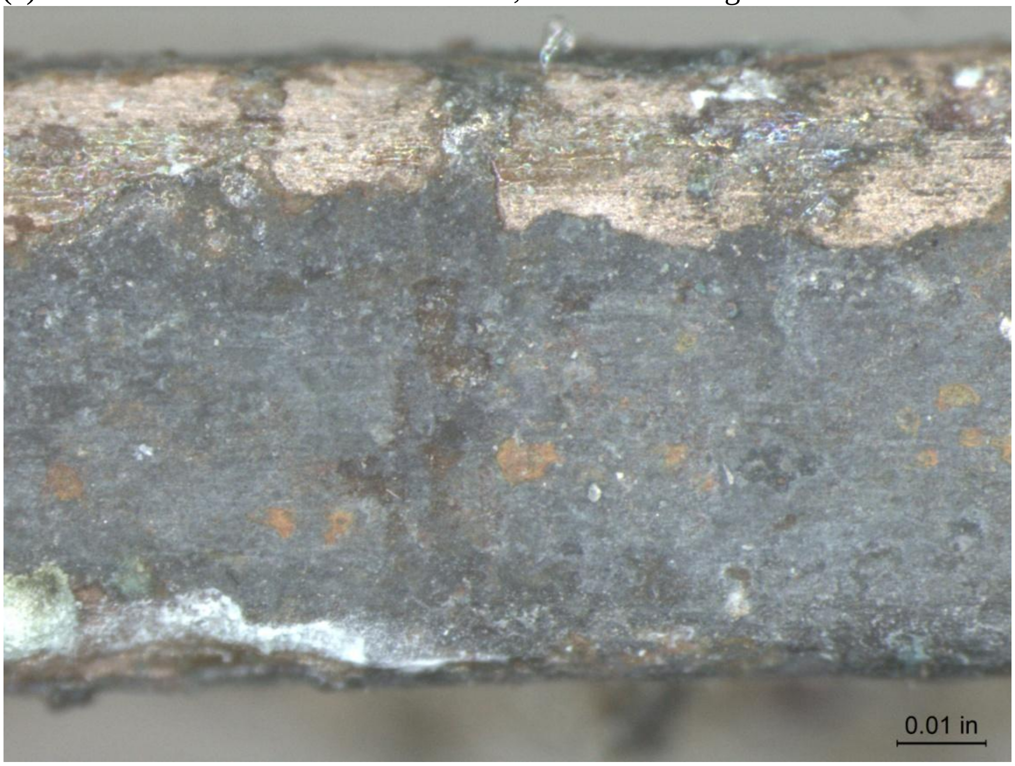


(b) CDA 706 Screen 3, After Cleaning 50X

Figure 28 Optical macrographs of CDA 706 screen 3 after a 10 month corrosion test, after cleaning.

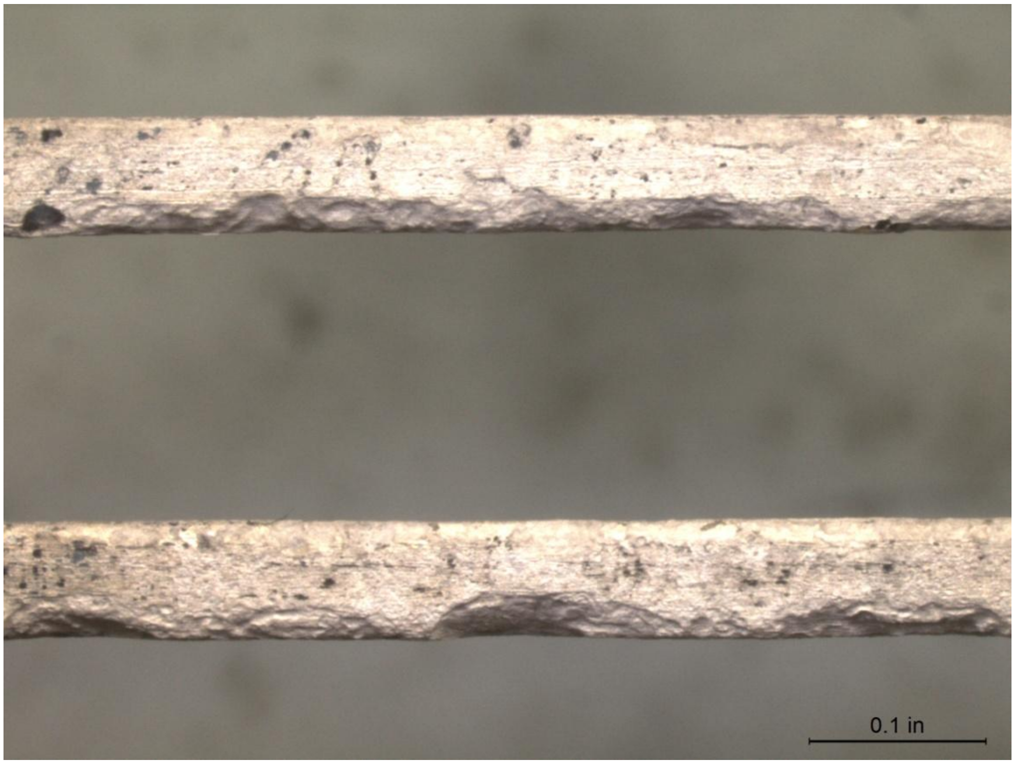


(a) CDA 706 Screen 4, Before Cleaning 10X

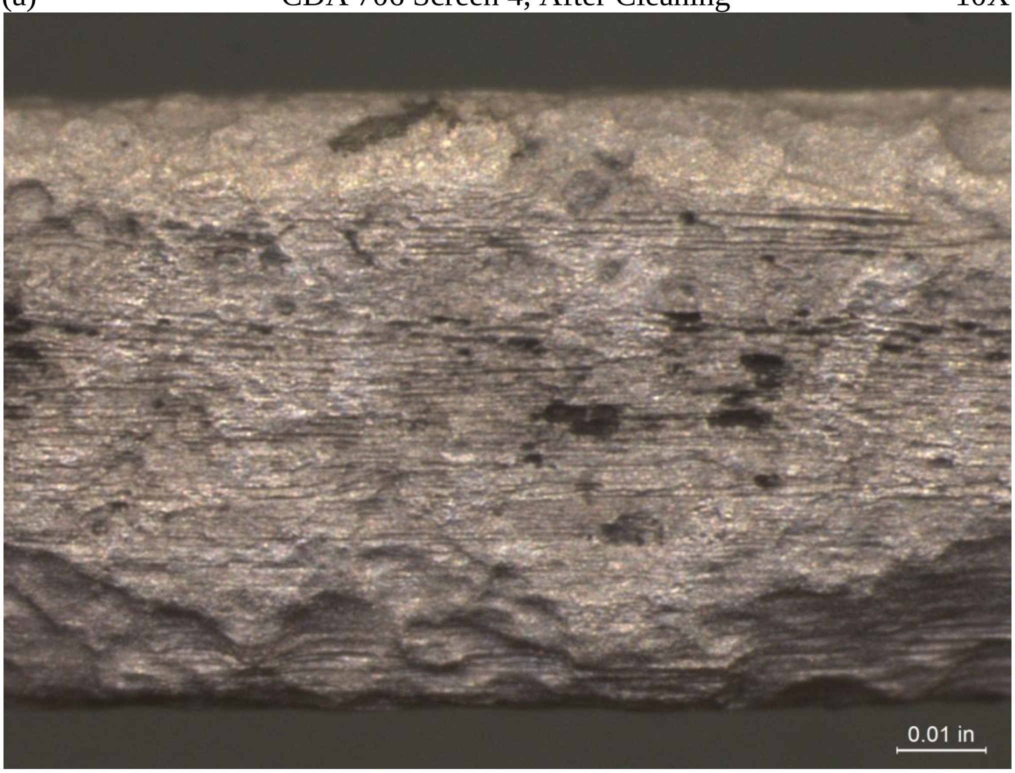


(b) CDA 706 Screen 4, Before Cleaning 50X

Figure 29 Optical macrographs of CDA 706 screen 4 after a 12 month corrosion test, before cleaning.

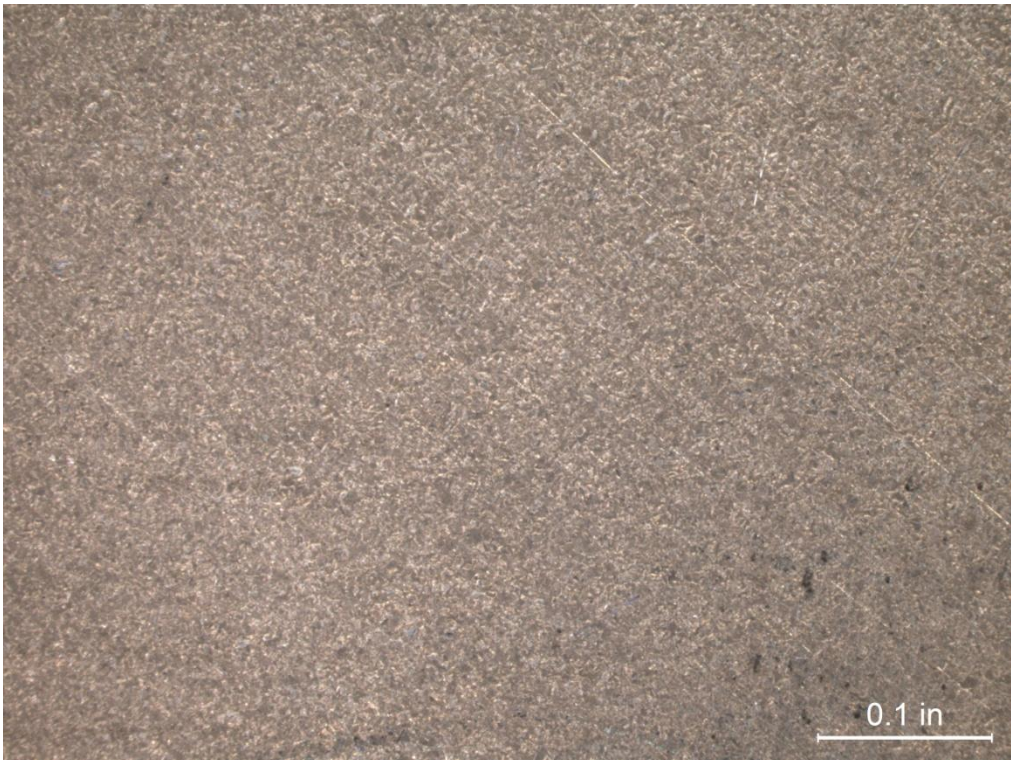


(a) CDA 706 Screen 4, After Cleaning 10X

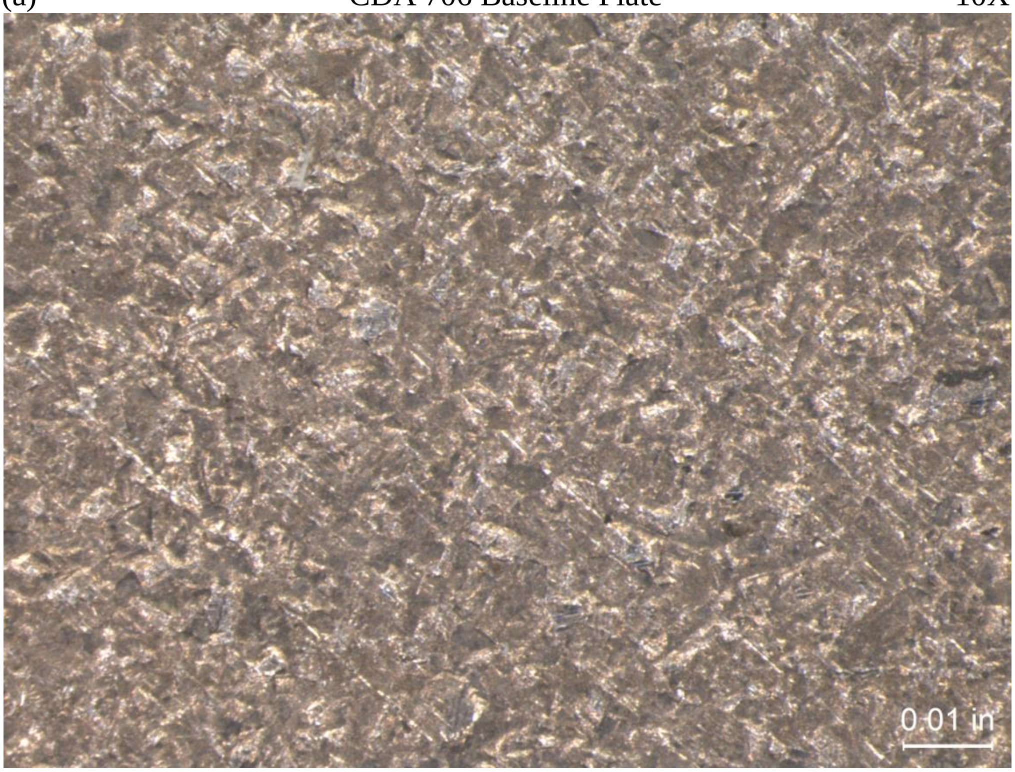


(b) CDA 706 Screen 4, After Cleaning 50X

Figure 30 Optical macrographs of CDA 706 screen 4 after a 12 month corrosion test, after cleaning.

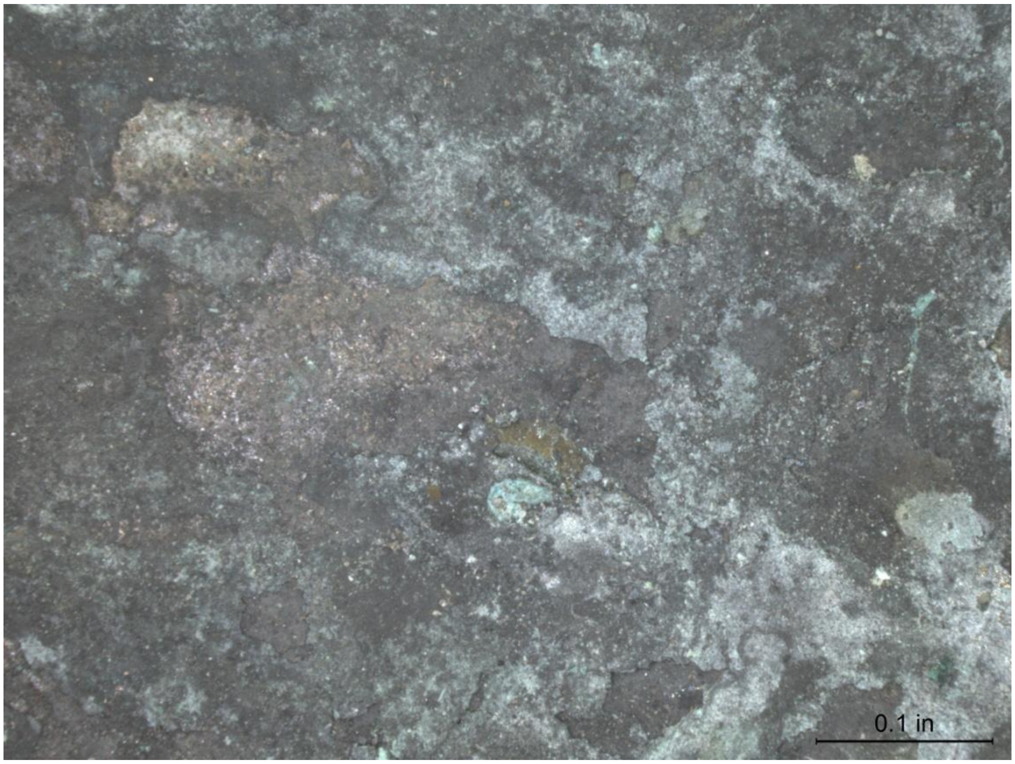


(a) CDA 706 Baseline Plate 10X



(b) CDA 706 Baseline Plate 50X

Figure 31 Optical macrographs of the CDA 706 baseline plate.

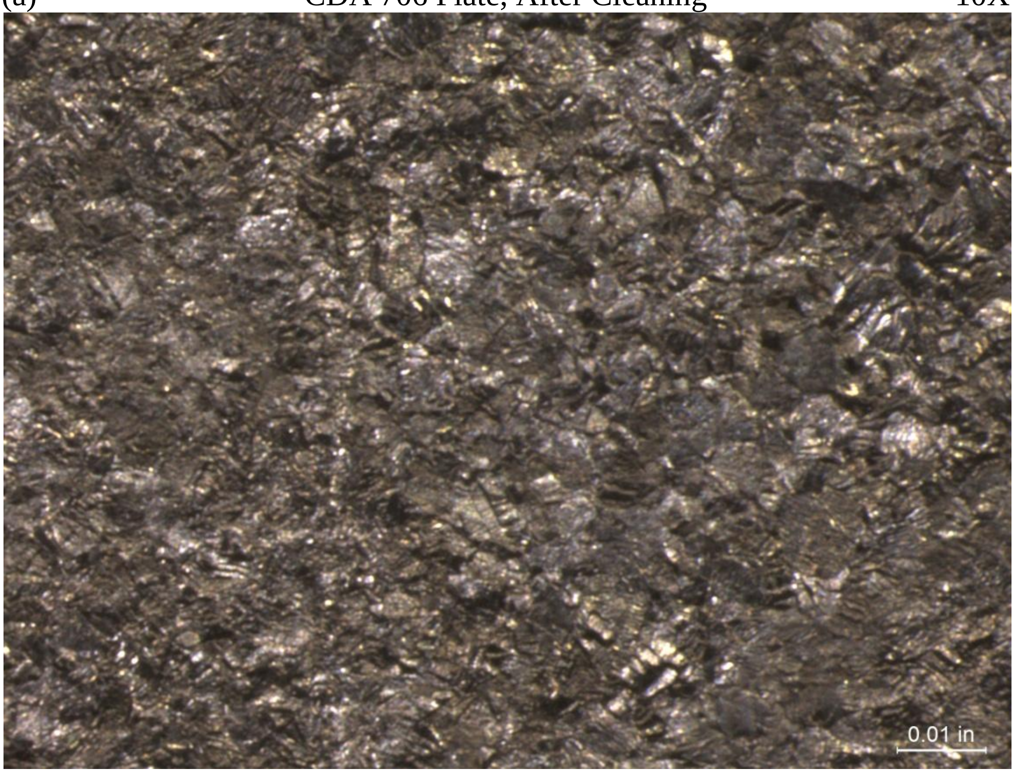


(a) CDA 706 Plate, Before Cleaning 10X

(b) CDA 706 Plate, Before Cleaning 50X

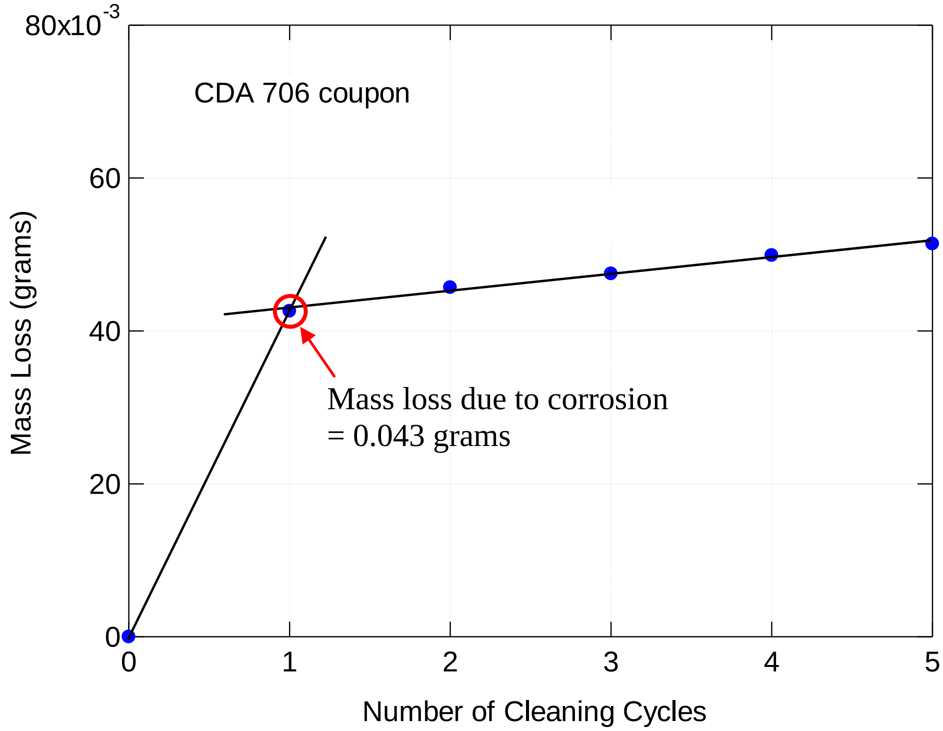
Figure 32 Optical macrographs of CDA 706 plate after a 12 month corrosion test, before cleaning.

(a) CDA 706 Plate, After Cleaning 10X

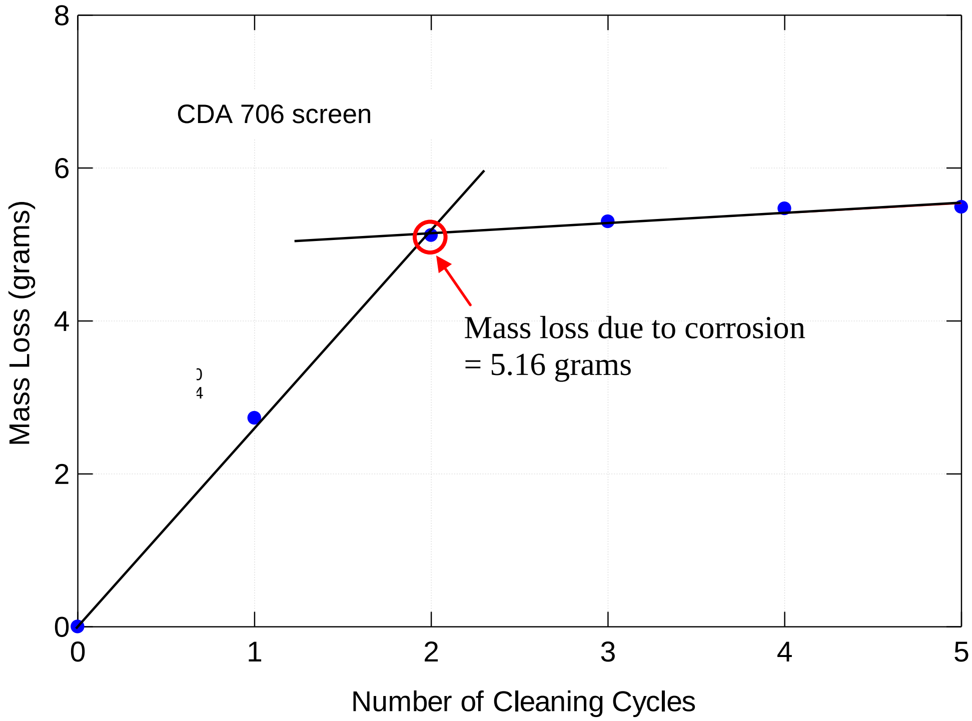


(b) CDA 706 Plate, After Cleaning 50X

Figure 33 Optical macrographs of CDA 706 plate after a 12 month corrosion test, after cleaning.

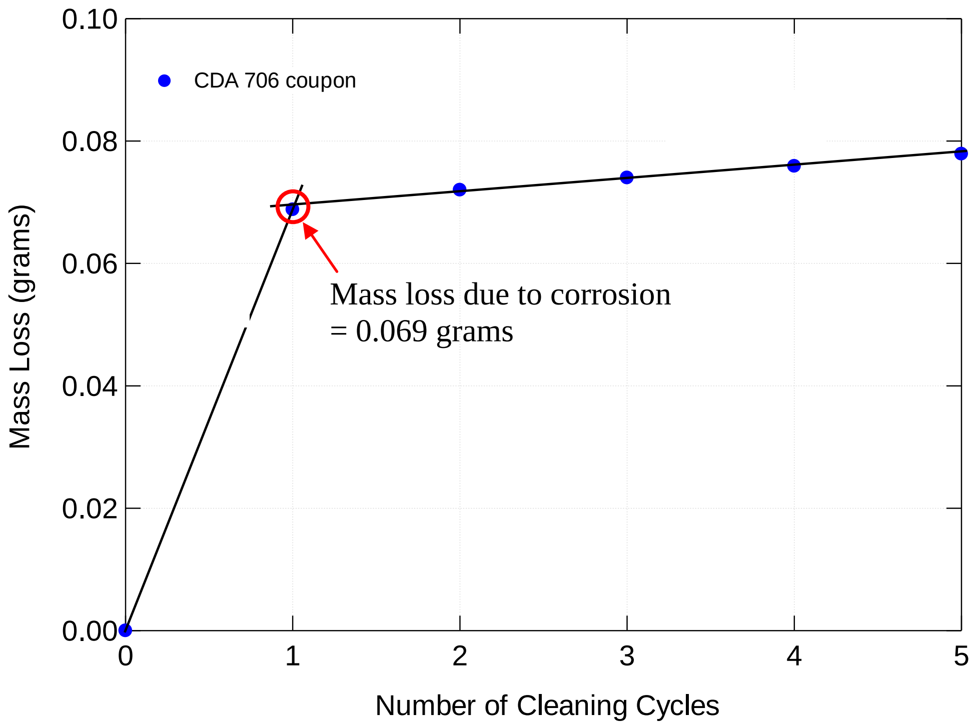


(a)

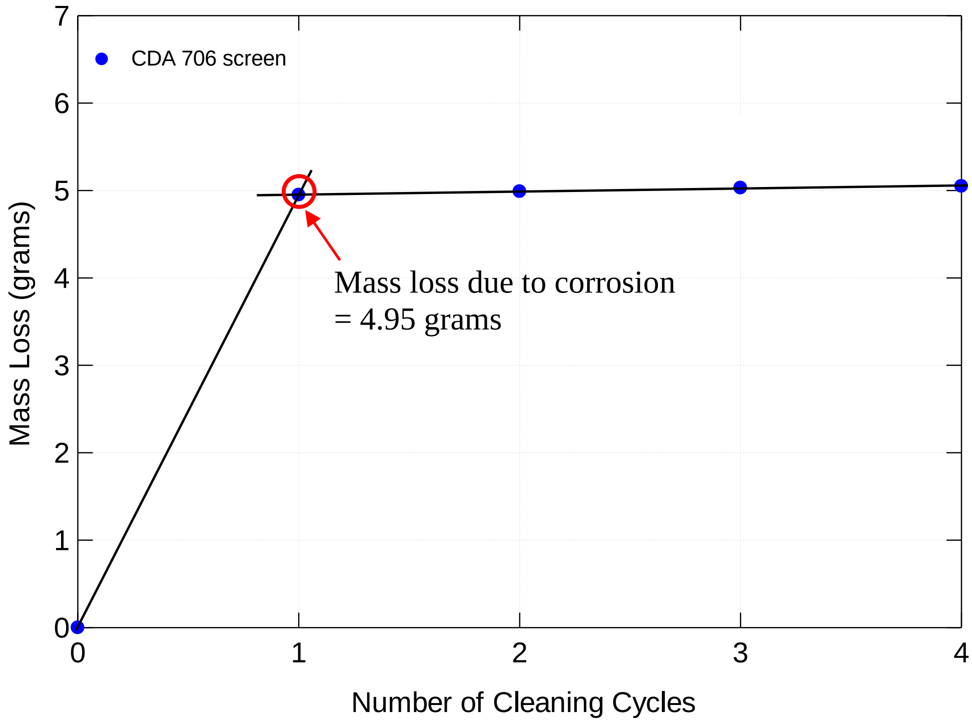


(b)

Figure 34 Mass loss of CDA 706 (a) coupon 1 and (b) screen 1 during cleaning.

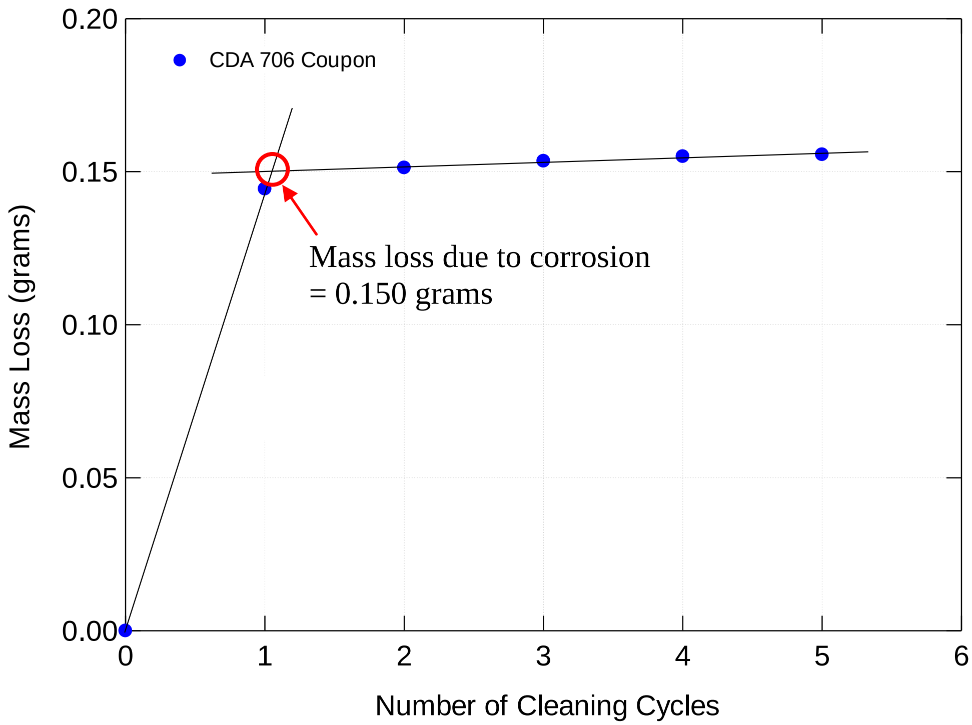


(a)

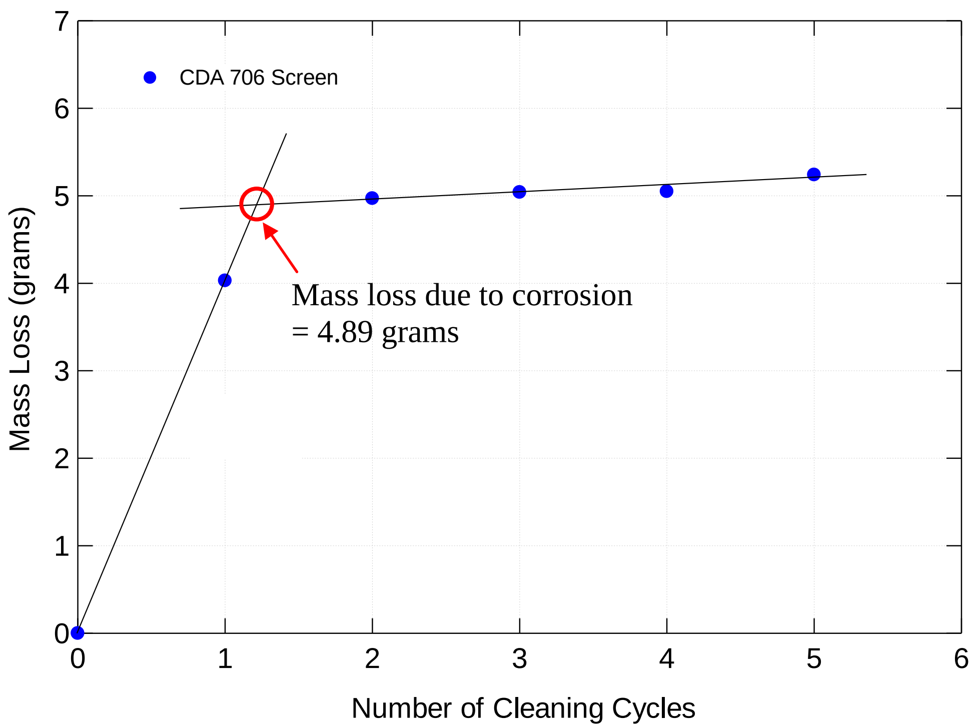


(b)

Figure 35 Mass loss of CDA 706 (a) coupon 2 and (b) screen 2 during cleaning.

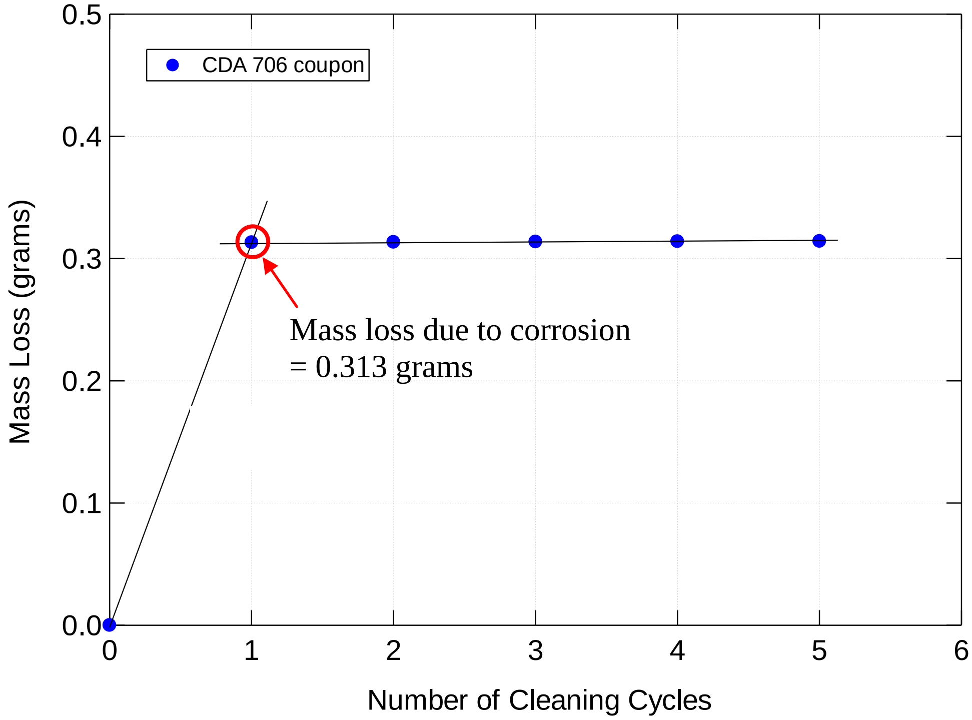


(a)

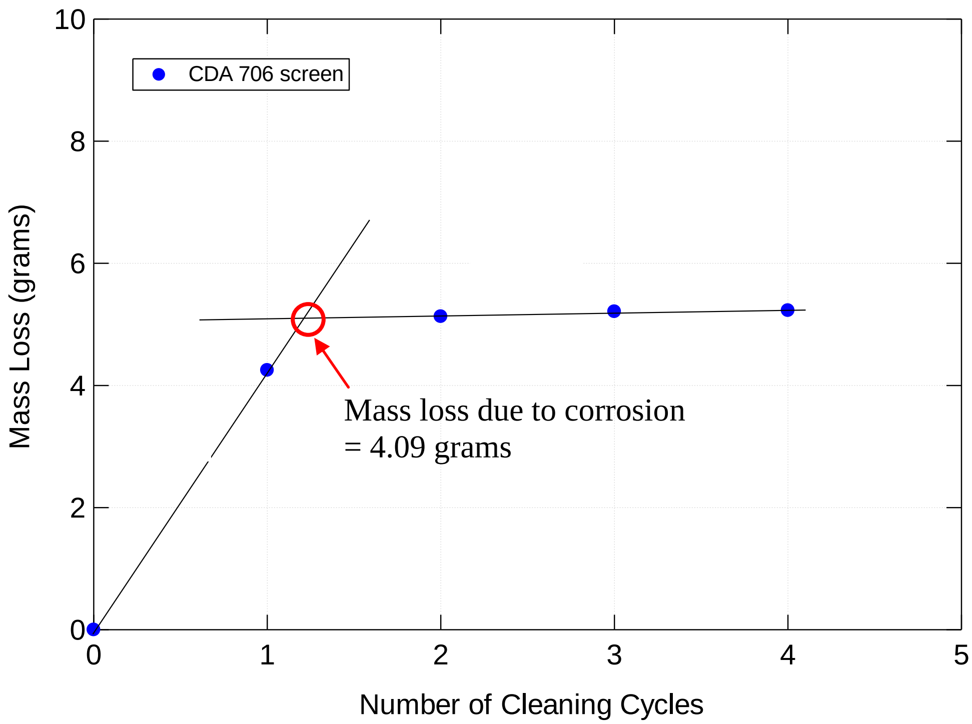


(b)

Figure 36 Mass loss of CDA 706 (a) coupon 3 and (b) screen 3 during cleaning.

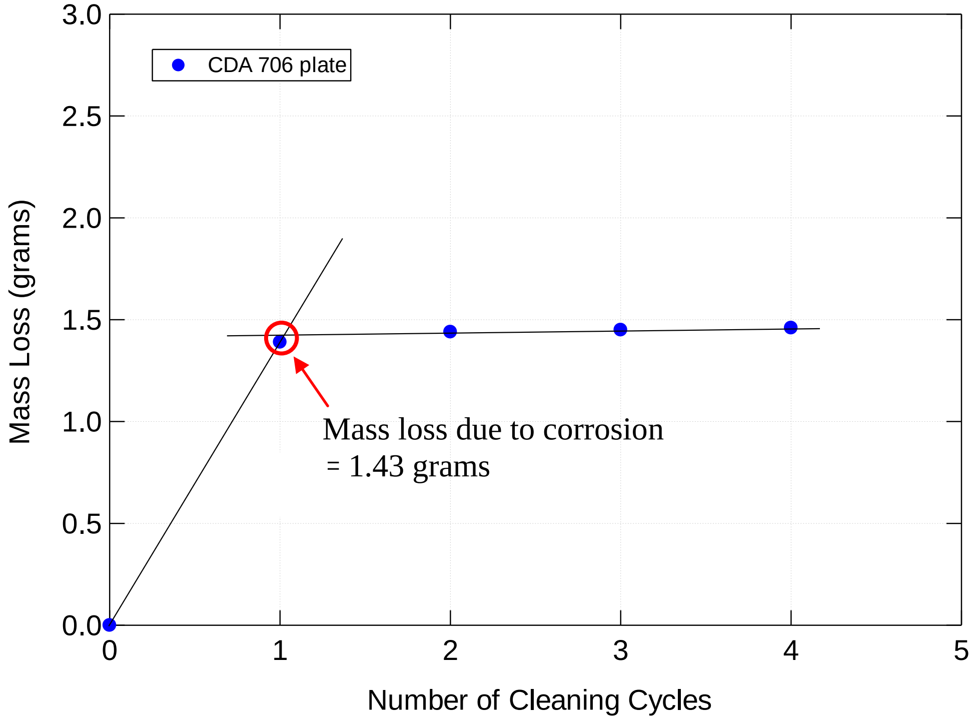


(a)



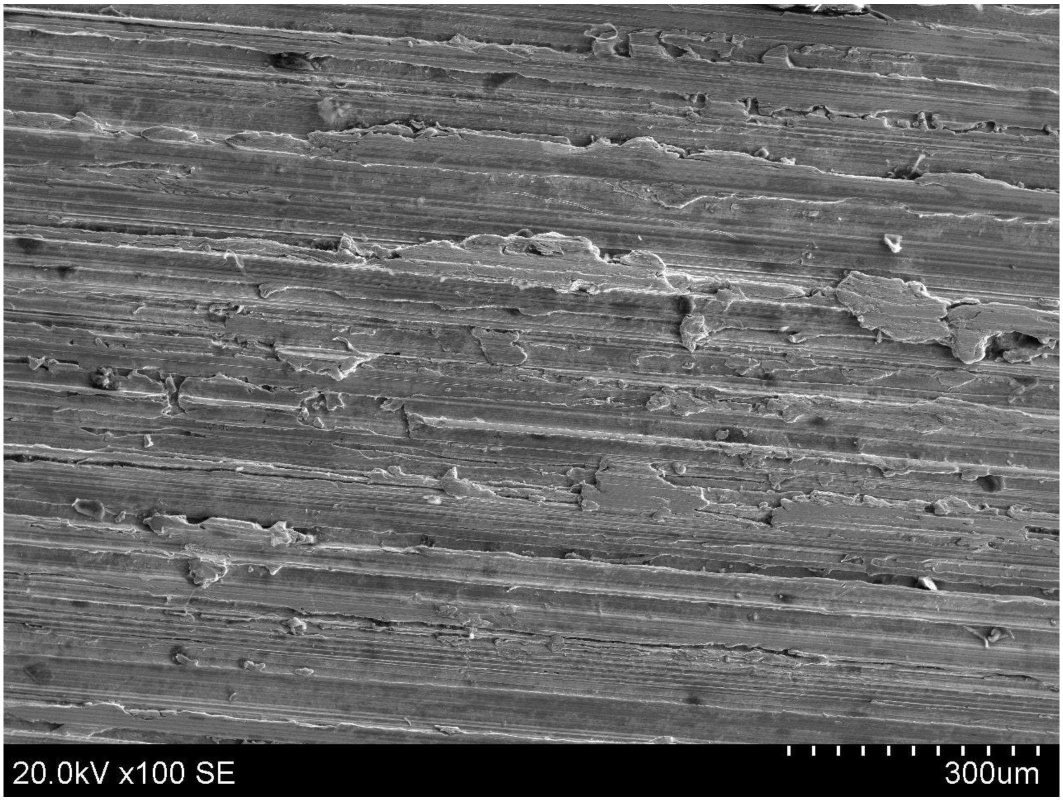
(b)

Figure 37 Mass loss of CDA 706 (a) coupon 4 and (b) screen 4 during cleaning.

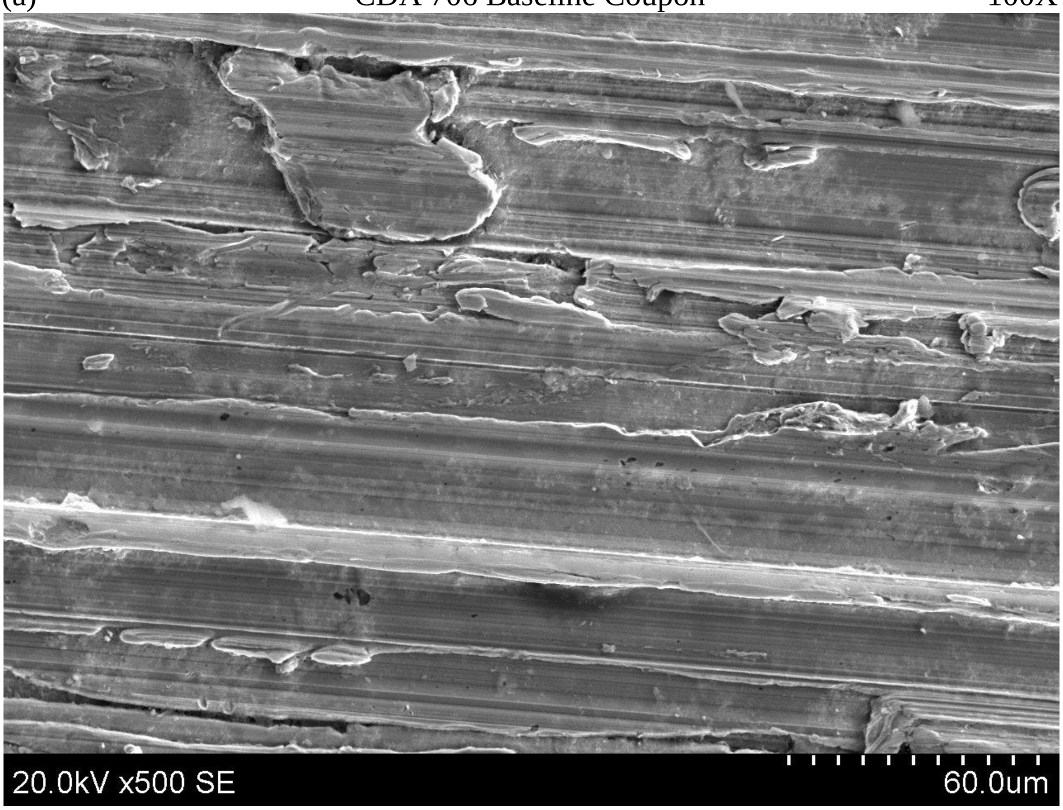


(b)

Figure 38 Mass loss of CDA 706 plate during cleaning.

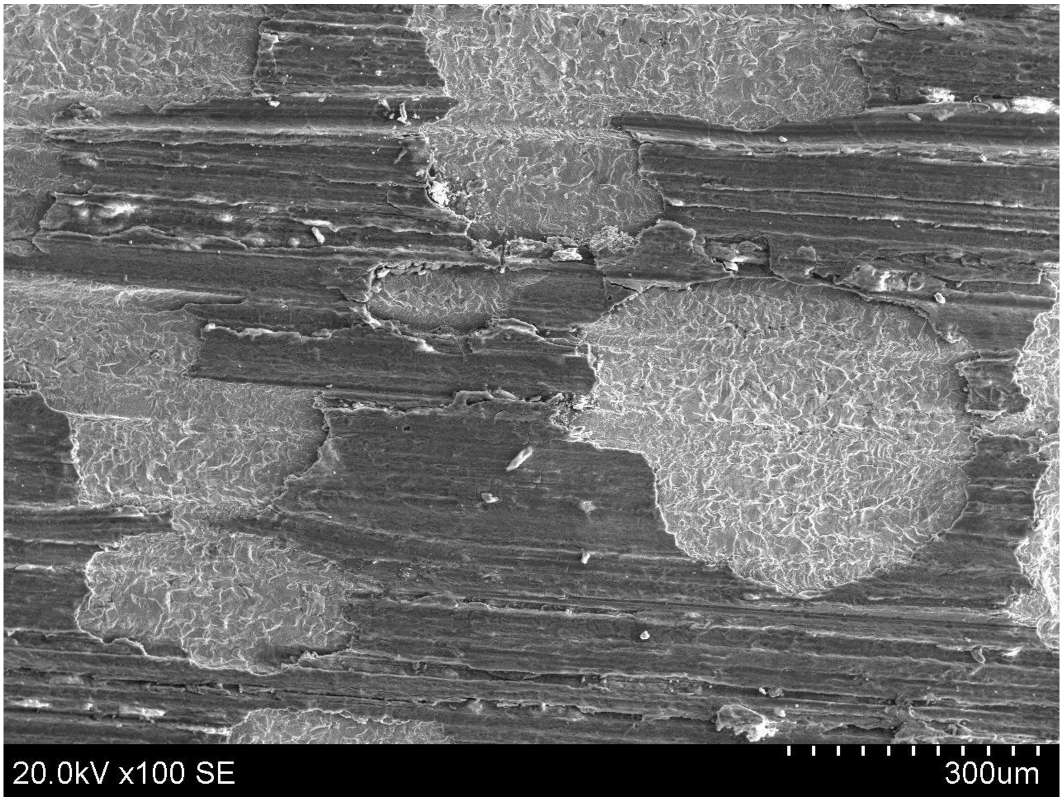


(a) CDA 706 Baseline Coupon 100X

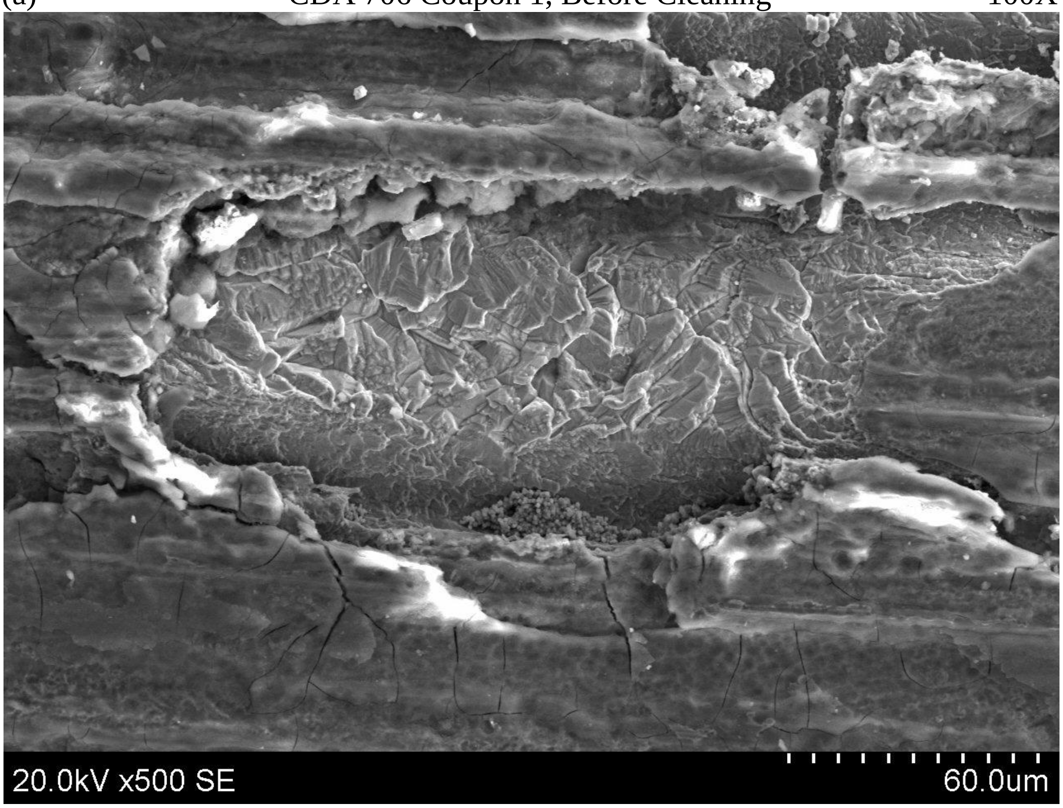


(b) CDA 706 Baseline Coupon 500X

Figure 39 Scanning electron micrographs of the CDA 706 baseline coupon.

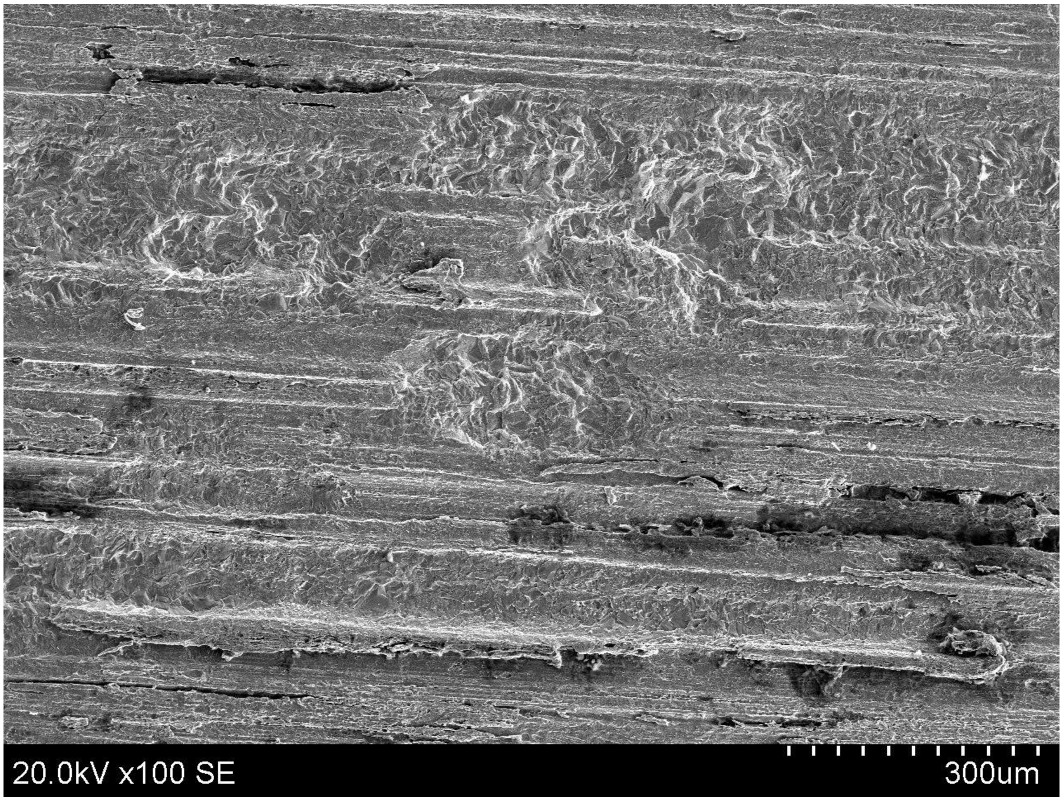


(a) CDA 706 Coupon 1, Before Cleaning 100X

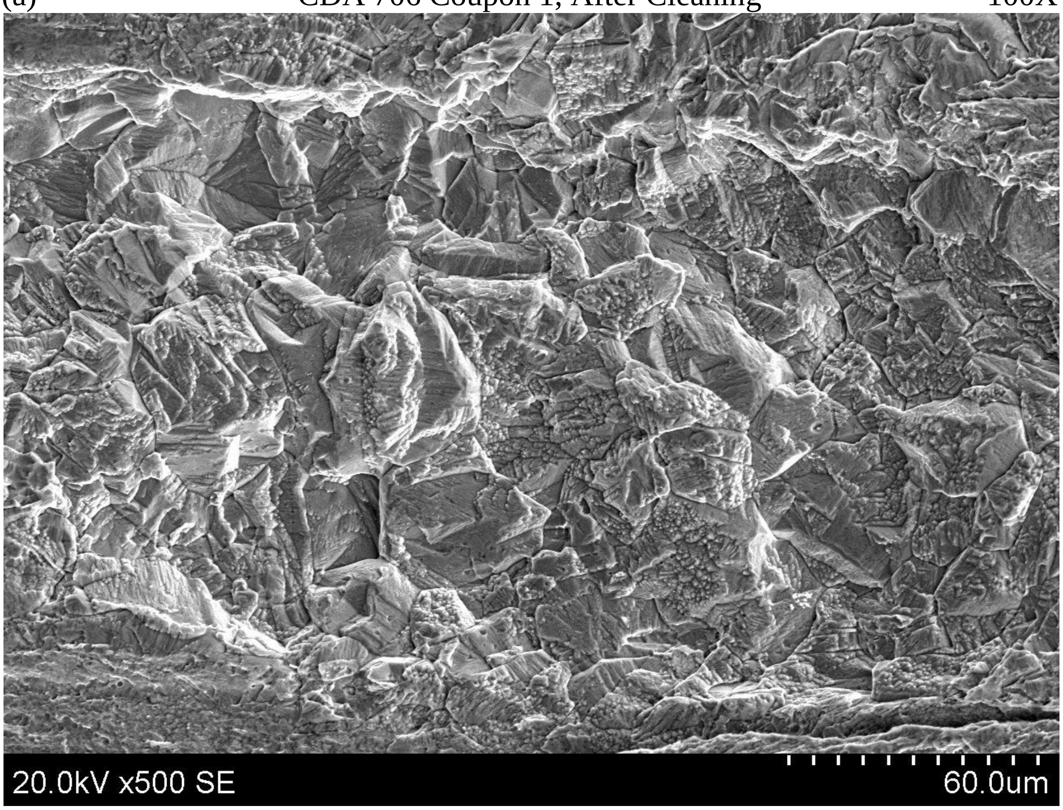


(b) CDA 706 Coupon 1, Before Cleaning 500X

Figure 40 Scanning electron micrographs of CDA 706 coupon 1 after a 3 month corrosion test, before cleaning.

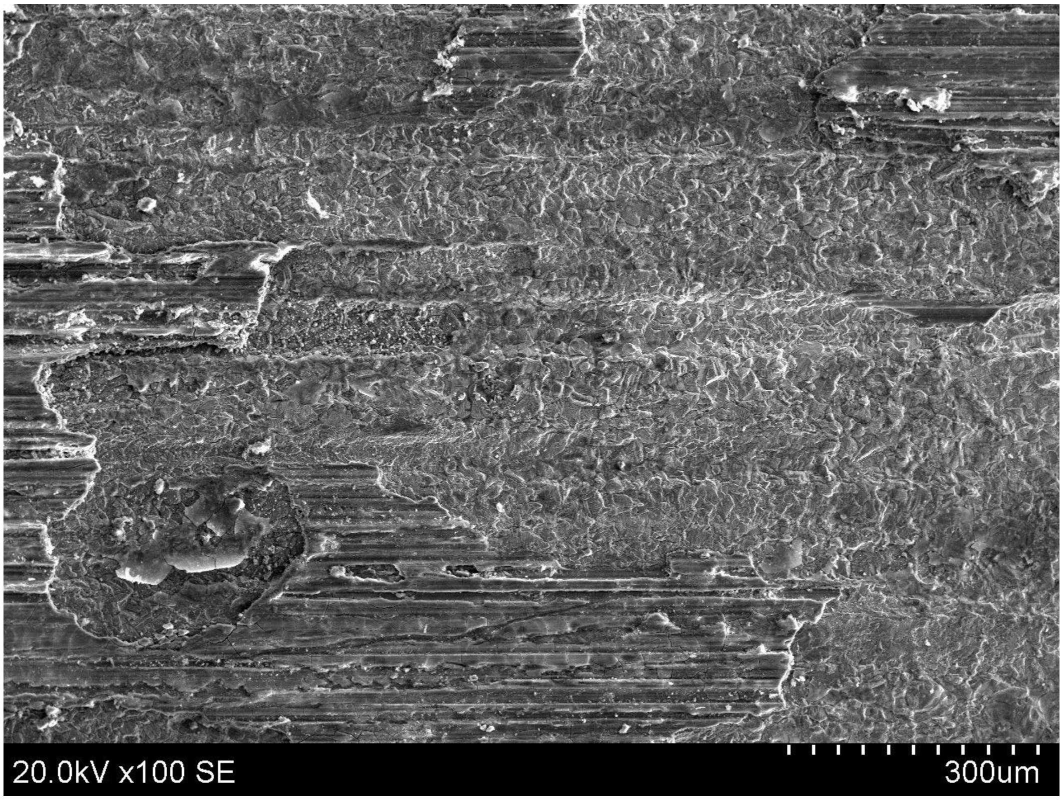


(a) CDA 706 Coupon 1, After Cleaning 100X

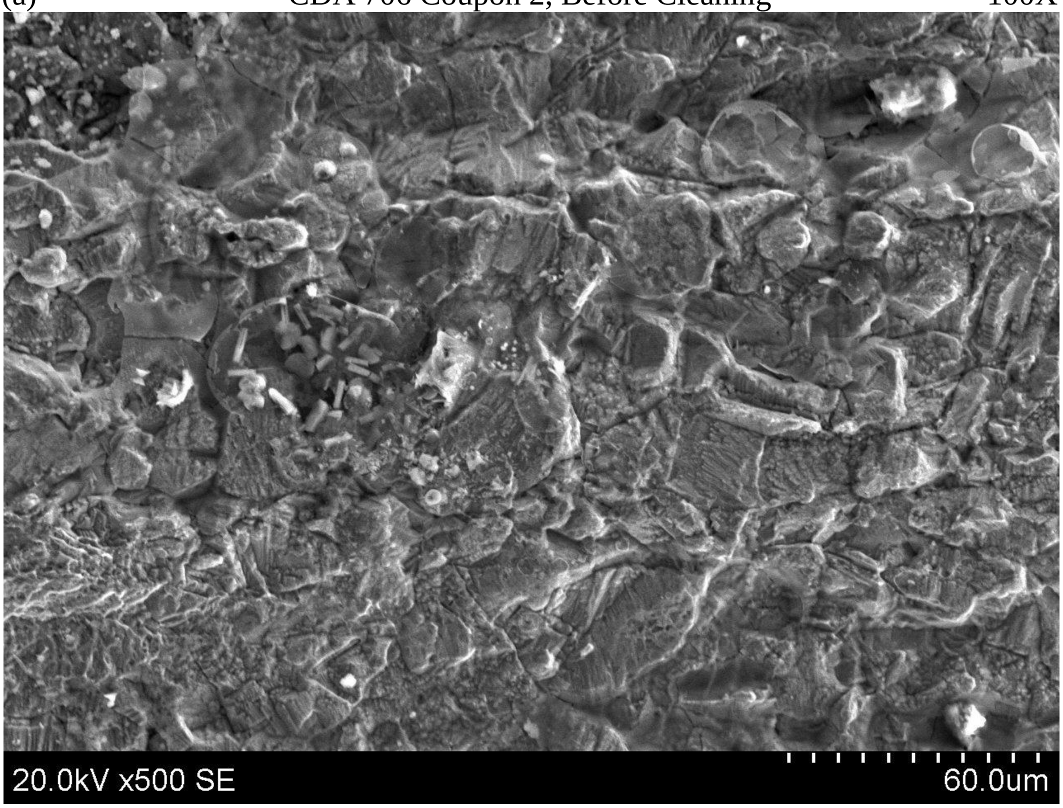


(b) CDA 706 Coupon 1, After Cleaning 500X

Figure 41 Scanning electron micrographs of CDA 706 coupon 1 after a 3 month corrosion test, after cleaning.

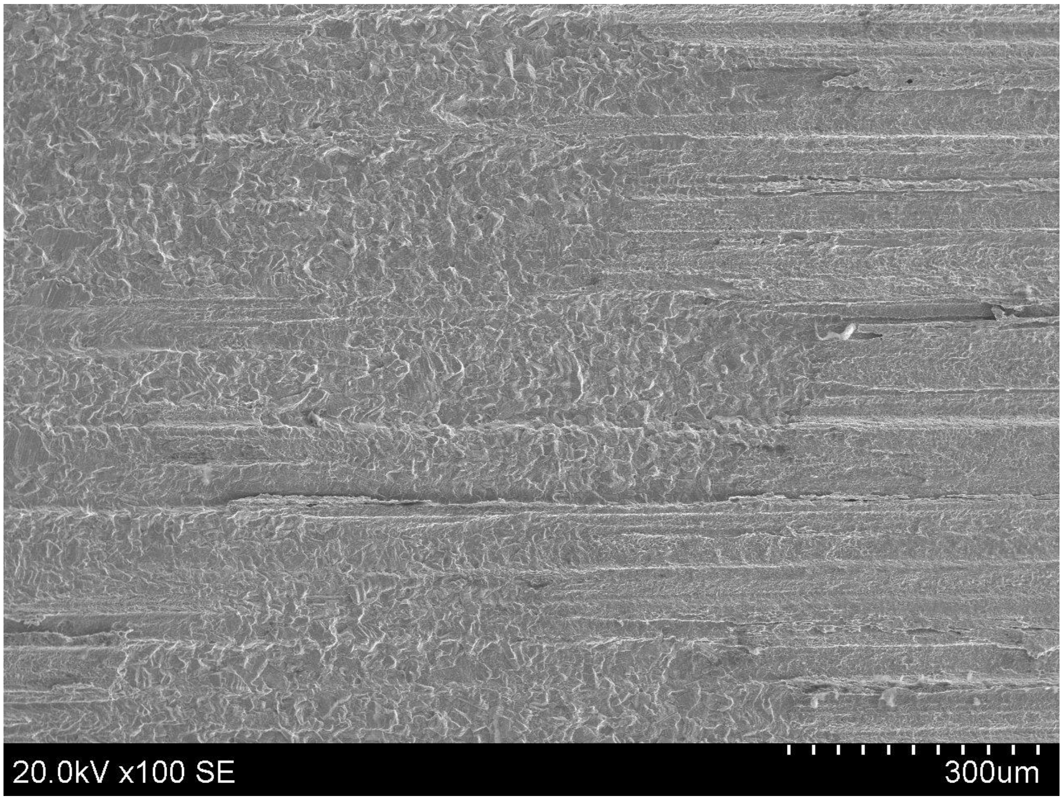


(a) CDA 706 Coupon 2, Before Cleaning 100X

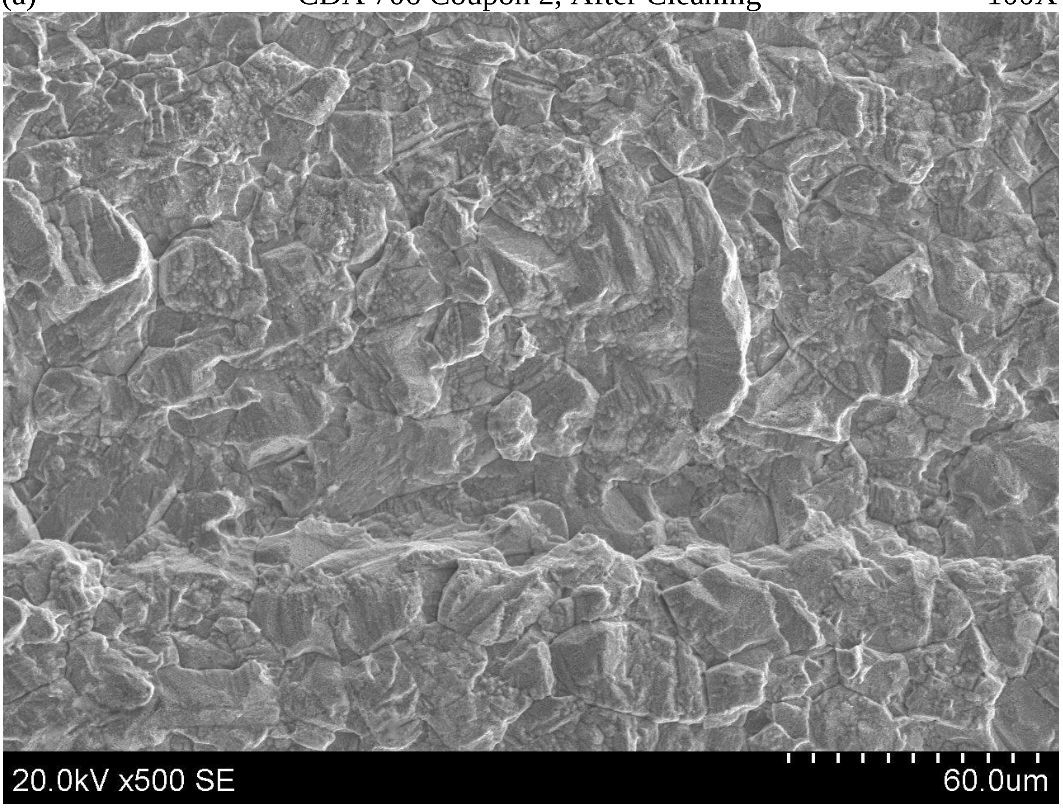


(b) CDA 706 Coupon 2, Before Cleaning 500X

Figure 42 Scanning electron micrographs of CDA 706 coupon 2 after a 6 month corrosion test, before cleaning.

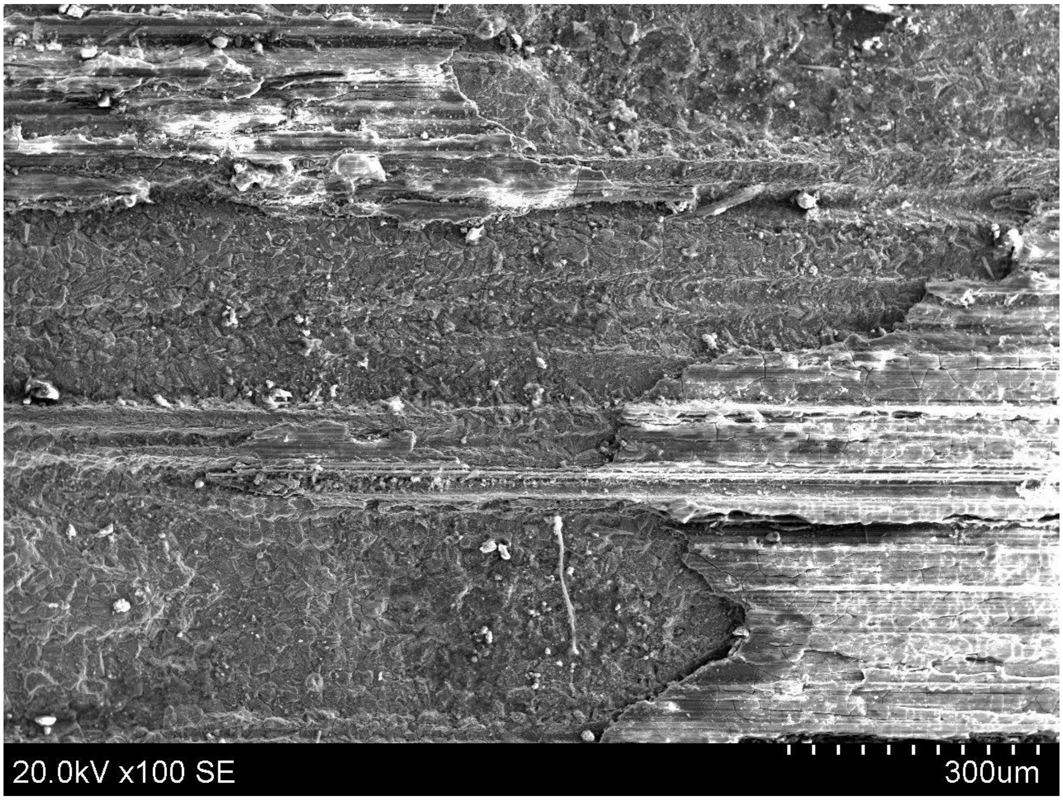


(a) CDA 706 Coupon 2, After Cleaning 100X

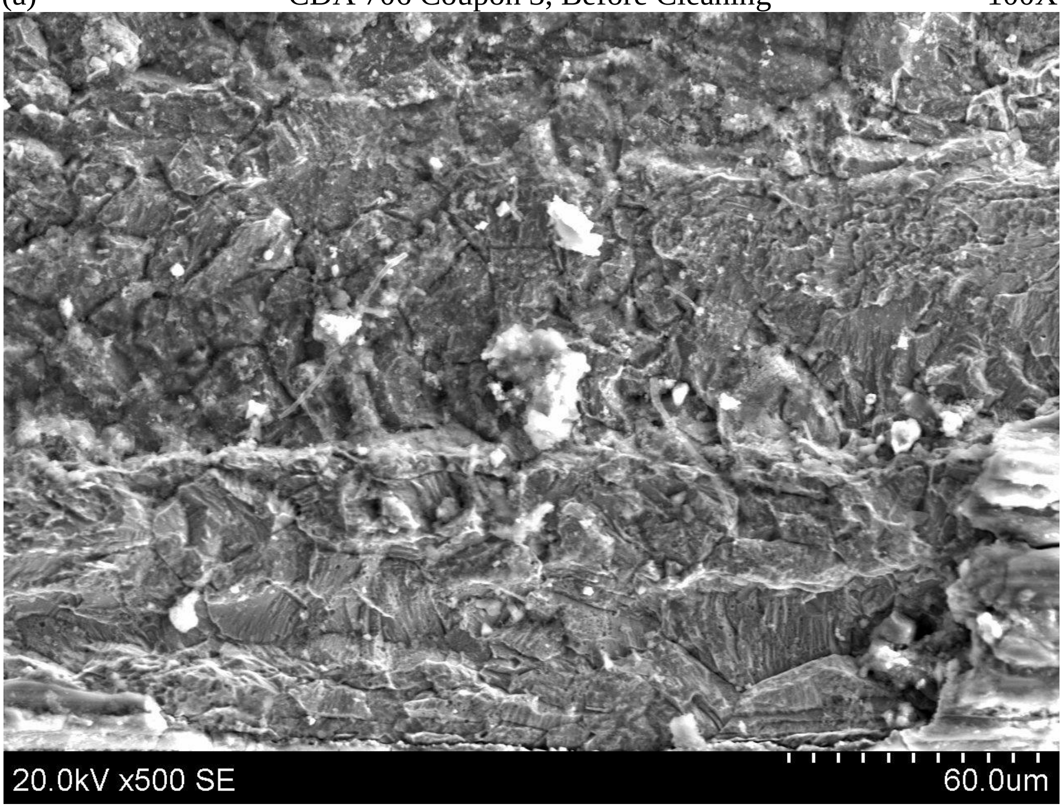


(b) CDA 706 Coupon 2, After Cleaning 500X

Figure 43 Scanning electron micrographs of CDA 706 coupon 2 after a 6 month corrosion test, after cleaning.

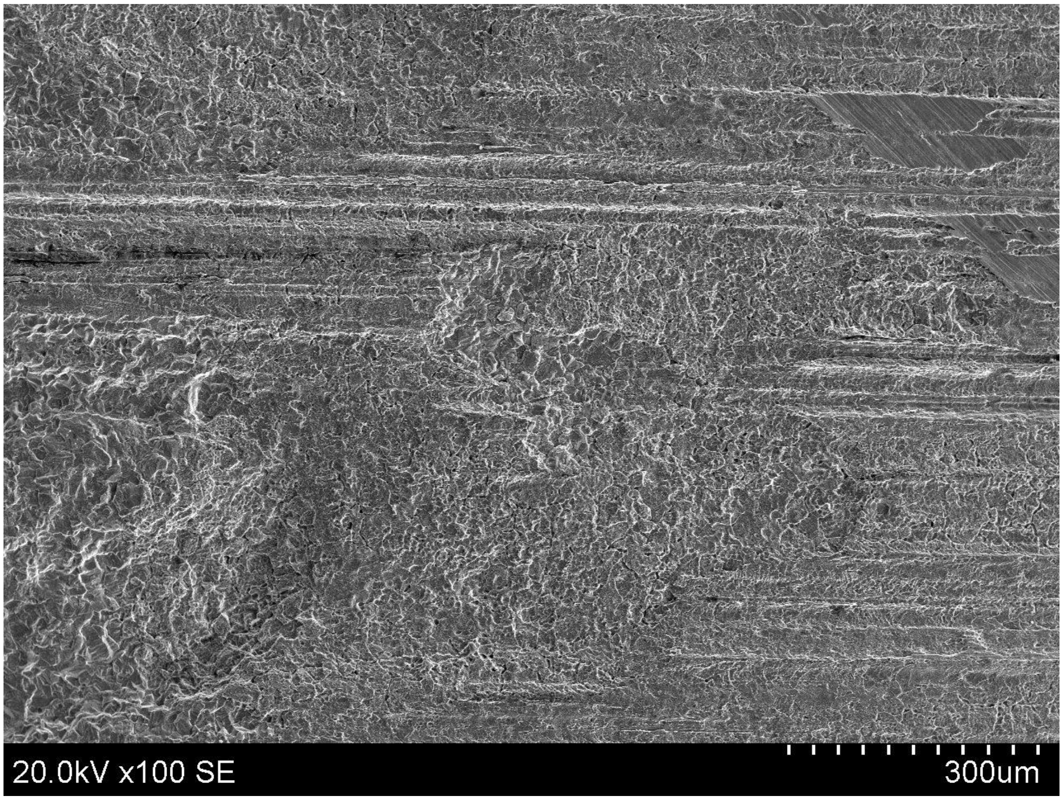


(a) CDA 706 Coupon 3, Before Cleaning 100X

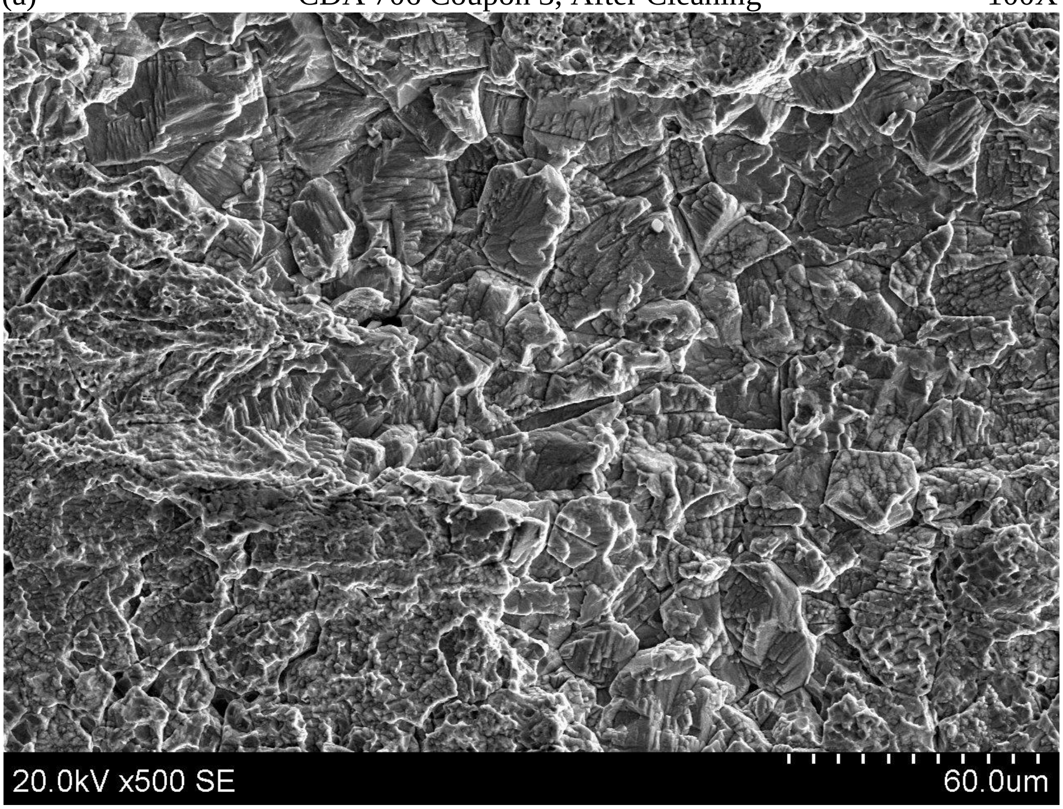


(b) CDA 706 Coupon 3, Before Cleaning 500X

Figure 44 Scanning electron micrographs of CDA 706 coupon 3 after a 10 month corrosion test, before cleaning.

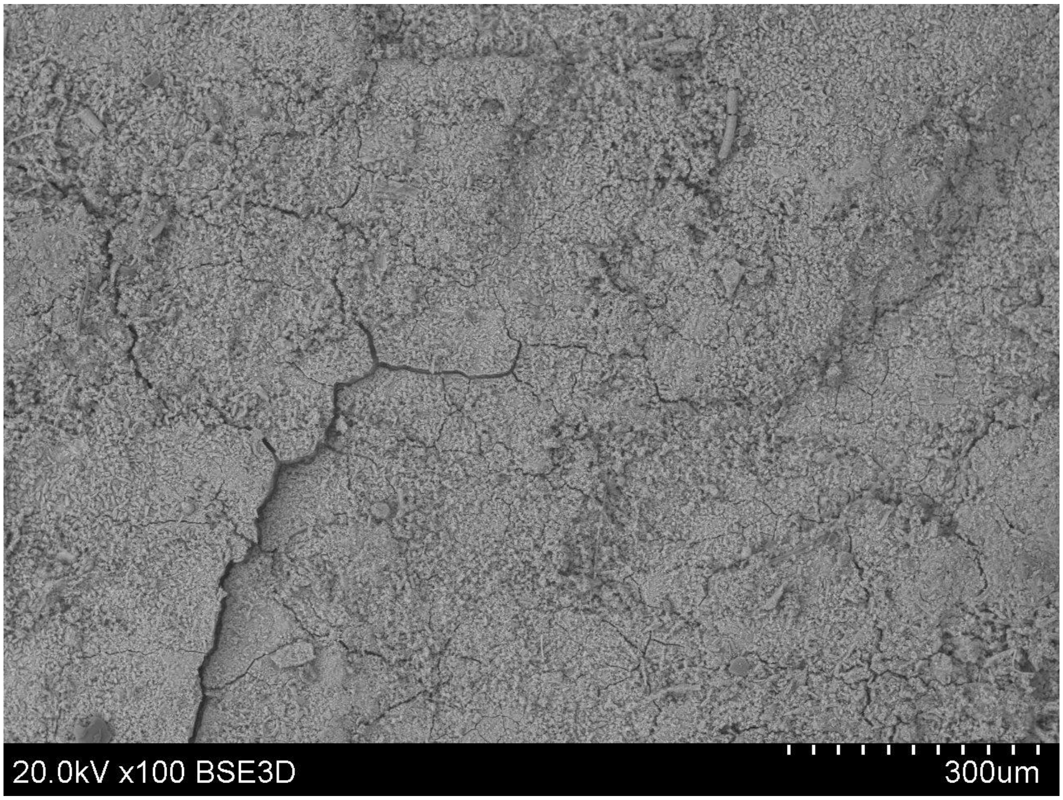


(a) CDA 706 Coupon 3, After Cleaning 100X

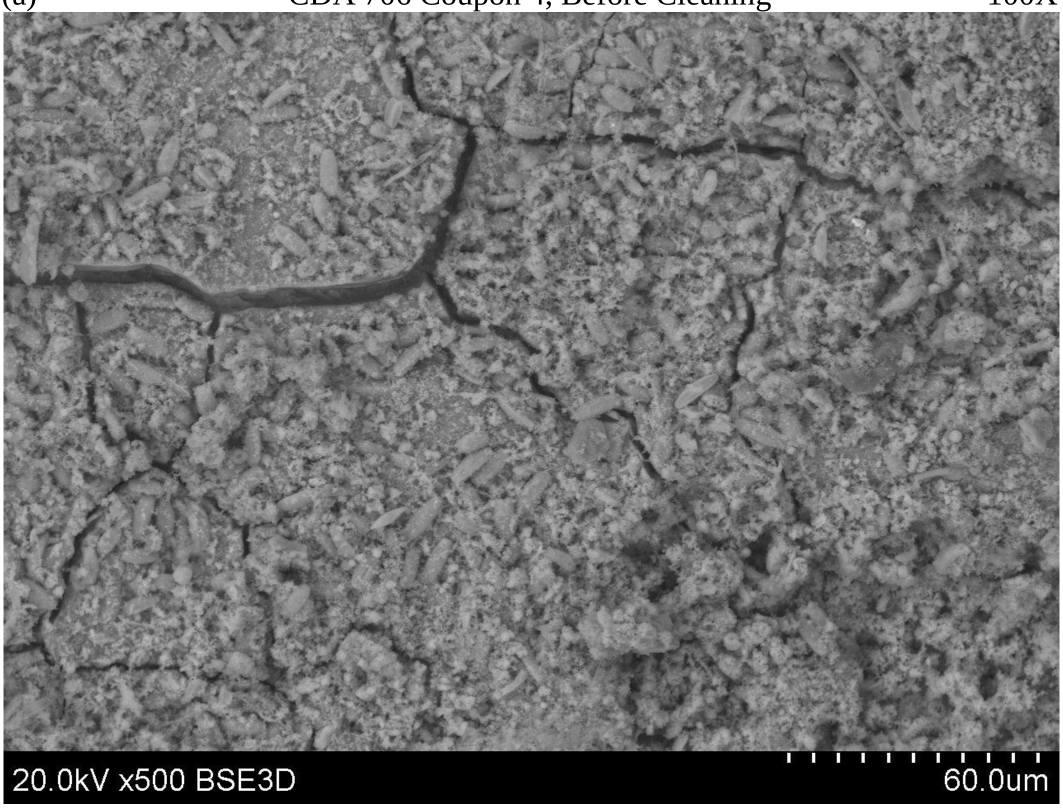


(b) CDA 706 Coupon 3, After Cleaning 500X

Figure 45 Scanning electron micrographs of CDA 706 coupon 3 after a 10 month corrosion test, after cleaning.

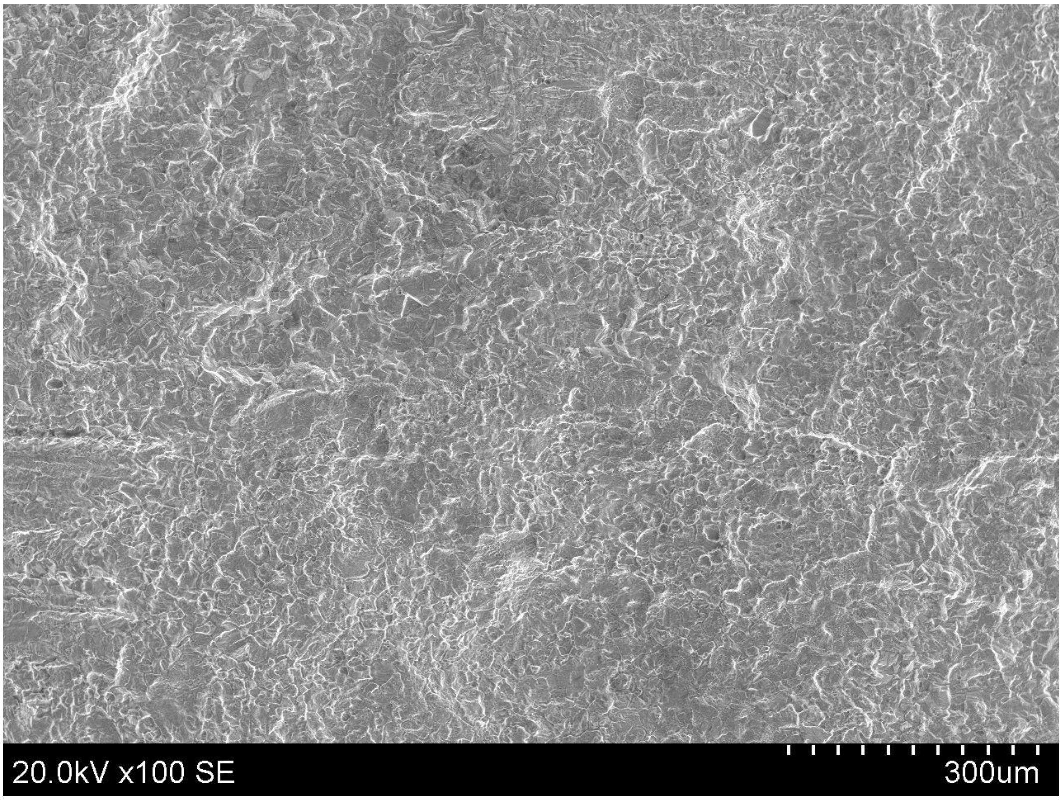


(a) CDA 706 Coupon 4, Before Cleaning 100X

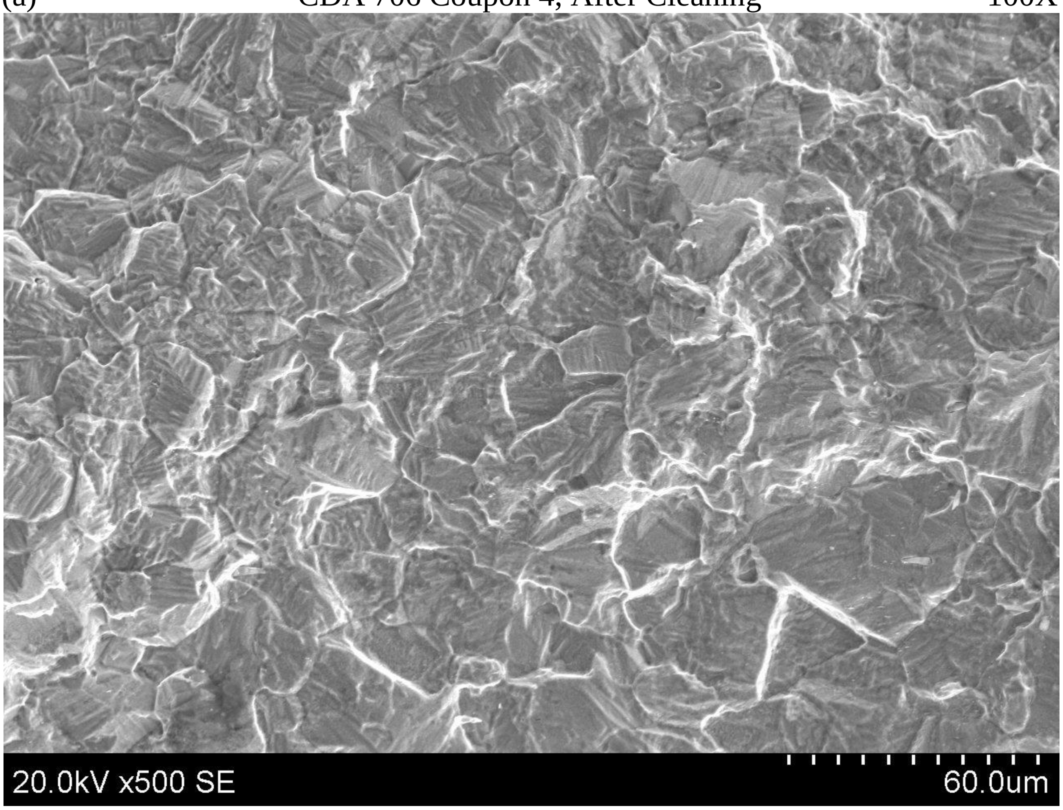


(b) CDA 706 Coupon 4, Before Cleaning 500X

Figure 46 Scanning electron micrographs of CDA 706 coupon 4 after a 12 month corrosion test, before cleaning.

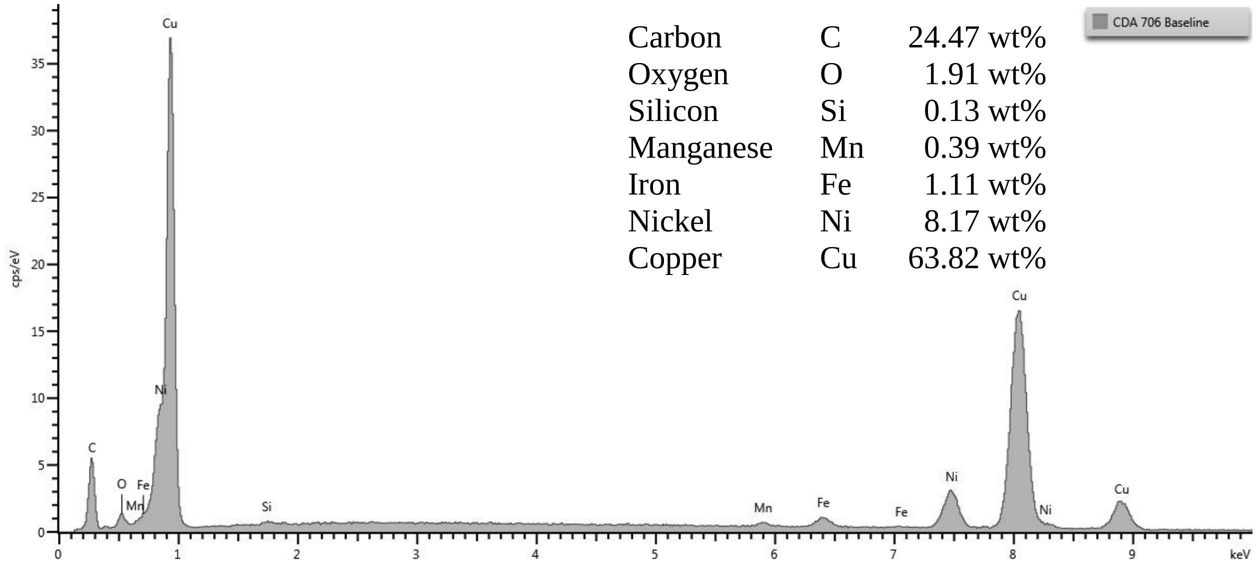


(a) CDA 706 Coupon 4, After Cleaning 100X



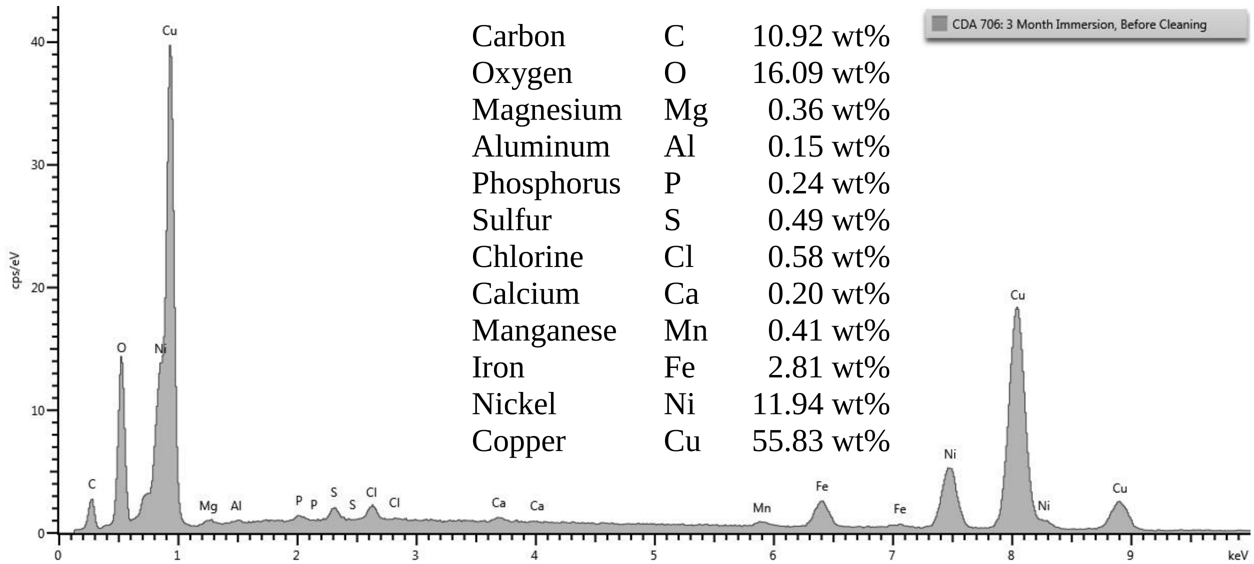
(b) CDA 706 Coupon 4, After Cleaning 500X

Figure 47 Scanning electron micrographs of CDA 706 coupon 4 after a 15 month corrosion test, after cleaning.



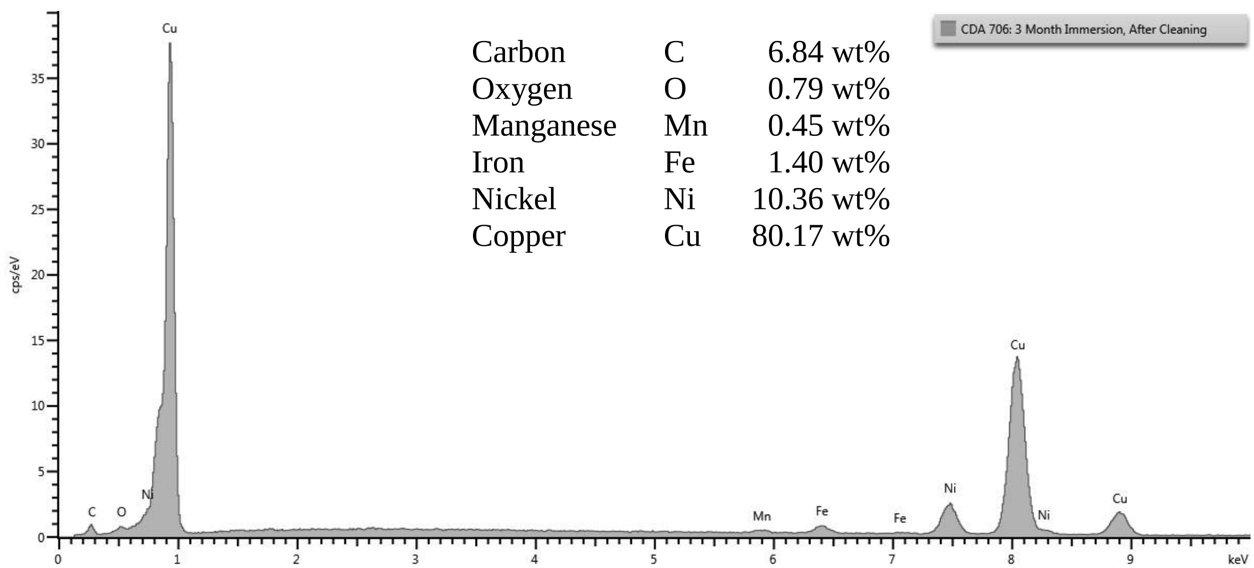
(b) CDA 706 Baseline Coupon

Figure 48 Energy dispersive x-ray spectra of the CDA 706 baseline coupon.



Carbon	C	10.92 wt%
Oxygen	O	16.09 wt%
Magnesium	Mg	0.36 wt%
Aluminum	Al	0.15 wt%
Phosphorus	P	0.24 wt%
Sulfur	S	0.49 wt%
Chlorine	Cl	0.58 wt%
Calcium	Ca	0.20 wt%
Manganese	Mn	0.41 wt%
Iron	Fe	2.81 wt%
Nickel	Ni	11.94 wt%
Copper	Cu	55.83 wt%

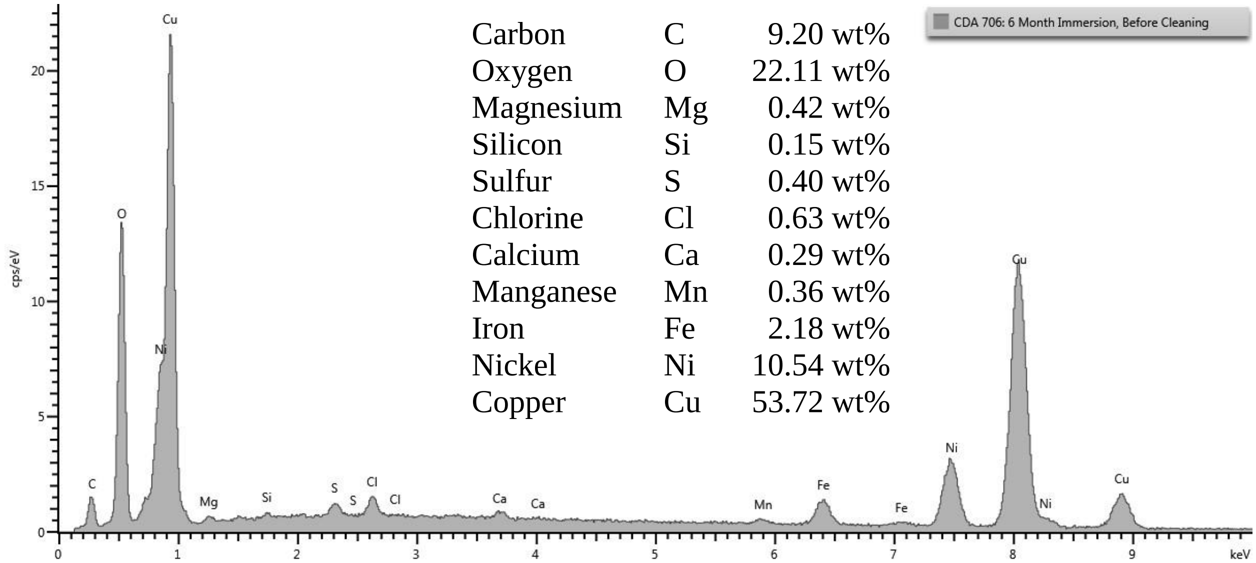
(a) CDA 706 Coupon 1, Before Cleaning



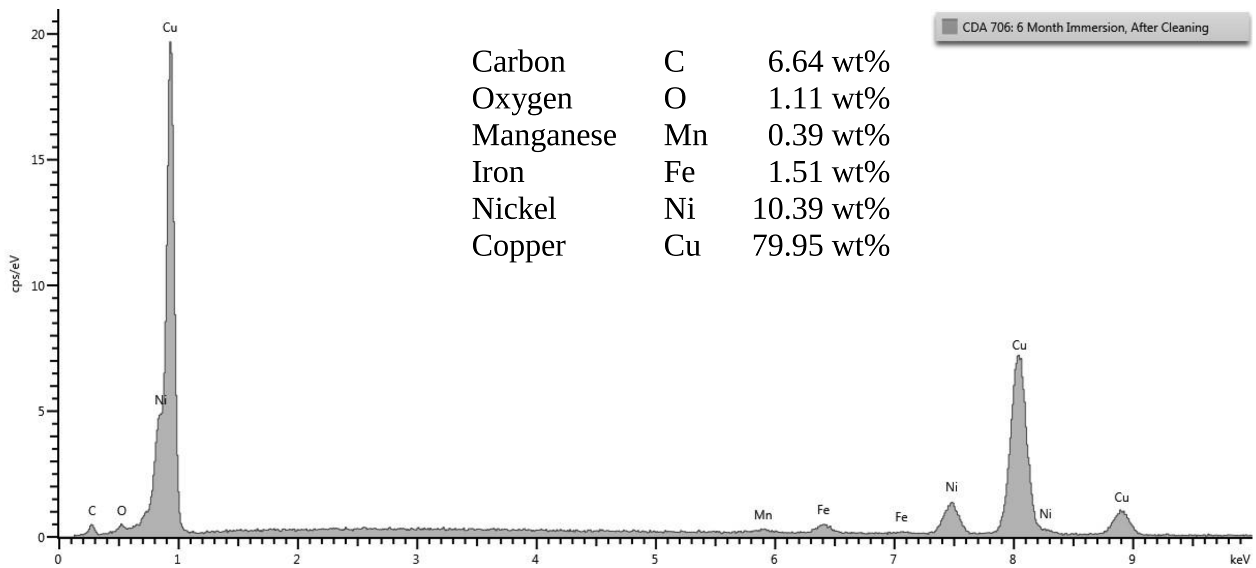
Carbon	C	6.84 wt%
Oxygen	O	0.79 wt%
Manganese	Mn	0.45 wt%
Iron	Fe	1.40 wt%
Nickel	Ni	10.36 wt%
Copper	Cu	80.17 wt%

(b) CDA 706 Coupon 1, After Cleaning

Figure 49 Energy dispersive x-ray spectra of CDA 706 coupon 1 after a 3 month corrosion test (a) before cleaning and (b) after cleaning.

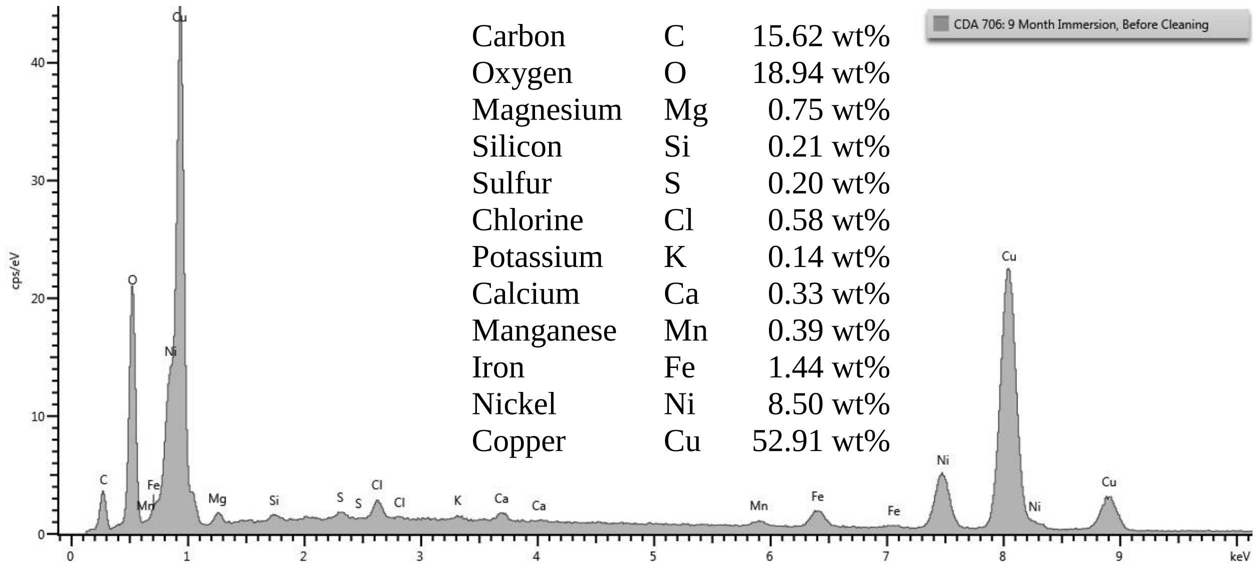


(a) CDA 706 Coupon 2, Before Cleaning



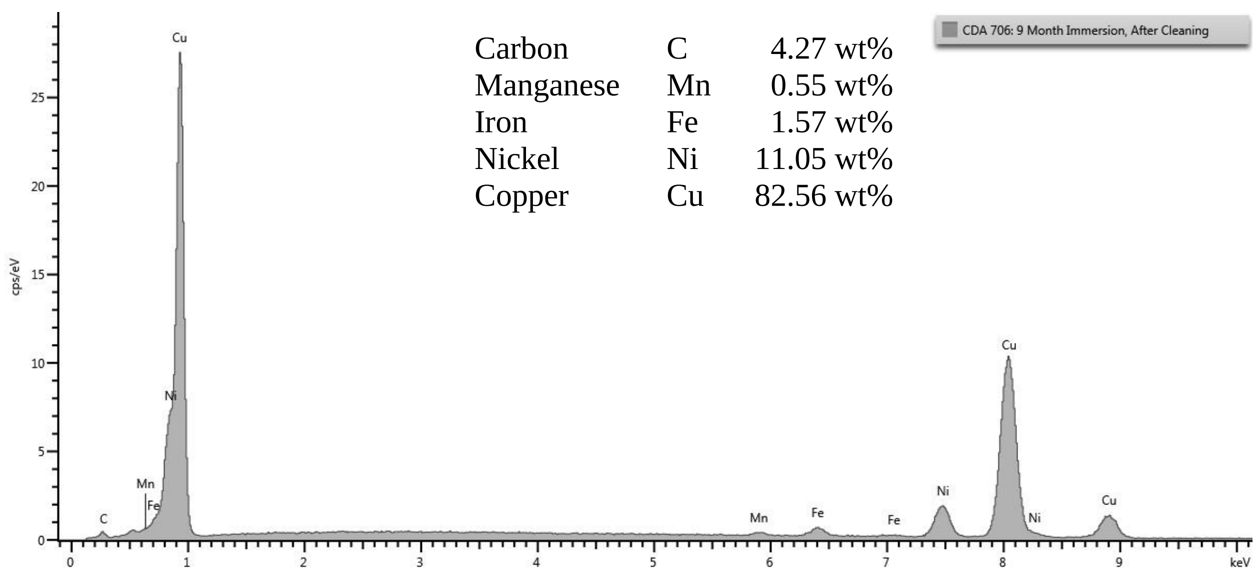
(b) CDA 706 Coupon 2, After Cleaning

Figure 50 Energy dispersive x-ray spectra of CDA 706 coupon 2 after a 6 month corrosion test (a) before cleaning and (b) after cleaning.



Carbon	C	15.62 wt%
Oxygen	O	18.94 wt%
Magnesium	Mg	0.75 wt%
Silicon	Si	0.21 wt%
Sulfur	S	0.20 wt%
Chlorine	Cl	0.58 wt%
Potassium	K	0.14 wt%
Calcium	Ca	0.33 wt%
Manganese	Mn	0.39 wt%
Iron	Fe	1.44 wt%
Nickel	Ni	8.50 wt%
Copper	Cu	52.91 wt%

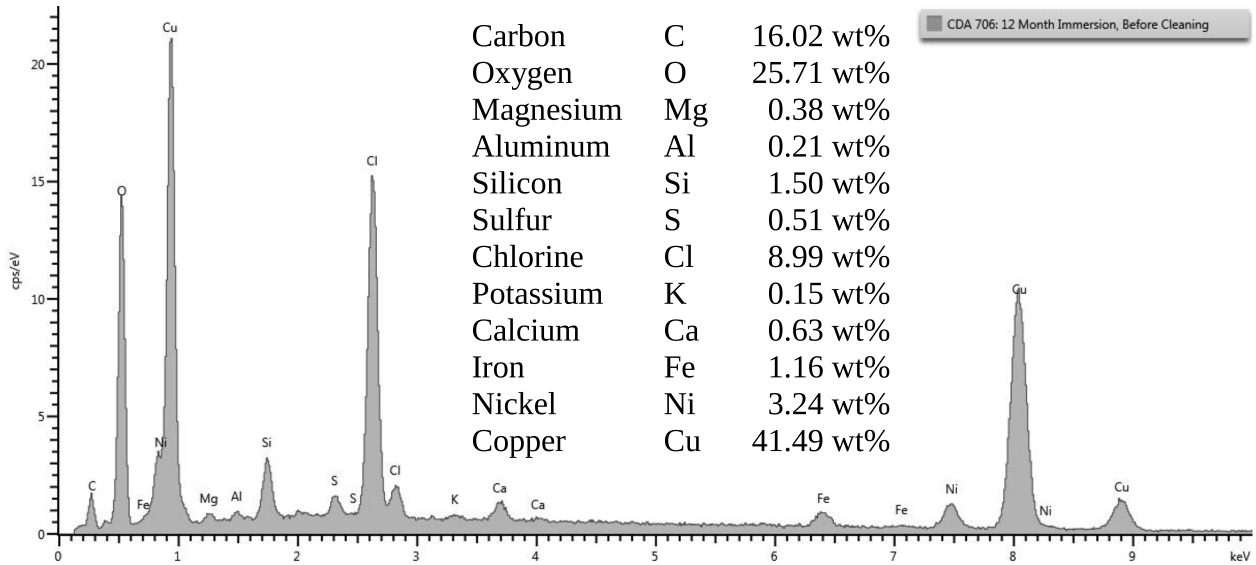
(a) CDA 706 Coupon 3, Before Cleaning



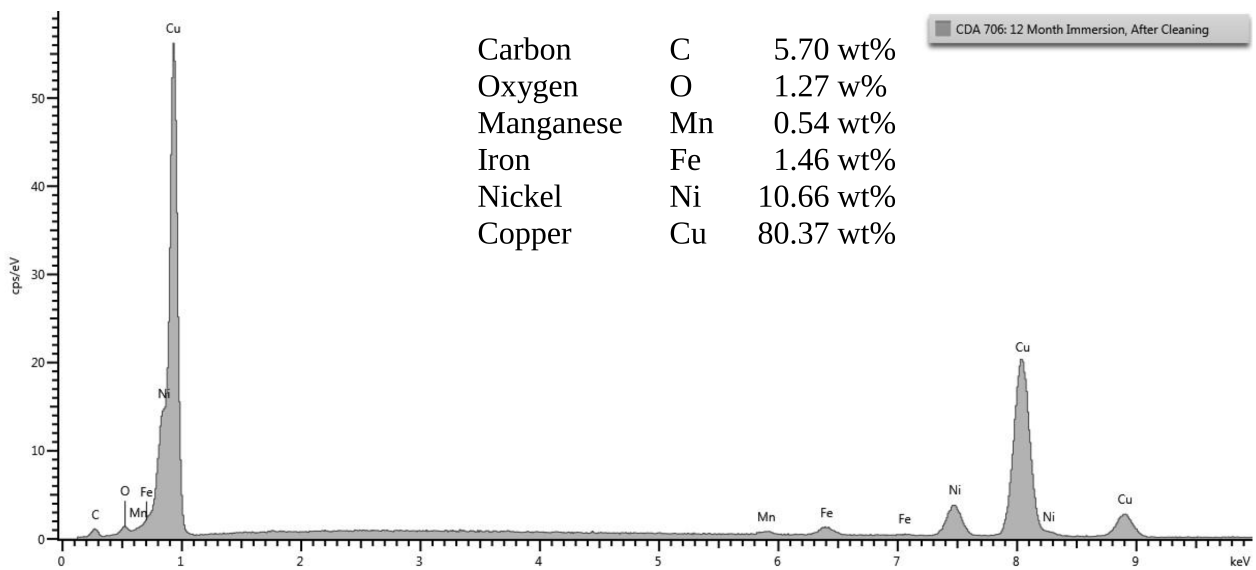
Carbon	C	4.27 wt%
Manganese	Mn	0.55 wt%
Iron	Fe	1.57 wt%
Nickel	Ni	11.05 wt%
Copper	Cu	82.56 wt%

(b) CDA 706 Coupon 3, After Cleaning

Figure 51 Energy dispersive x-ray spectra of CDA 706 coupon 3 after a 10 month corrosion test (a) before cleaning and (b) after cleaning.



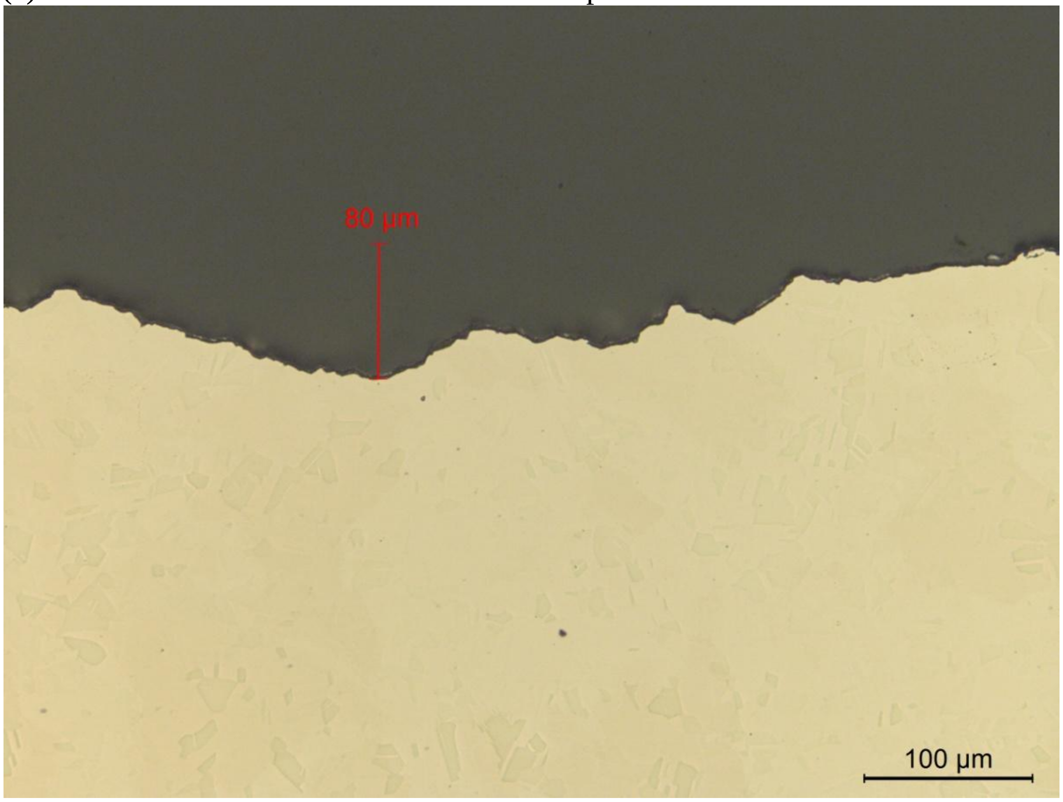
(a) CDA 706 Coupon 4, Before Cleaning



(b) CDA 706 Coupon 4, After Cleaning

Figure 52 Energy dispersive x-ray spectra of CDA 706 coupon 4 after a 12 month corrosion test (a) before cleaning and (b) after cleaning.

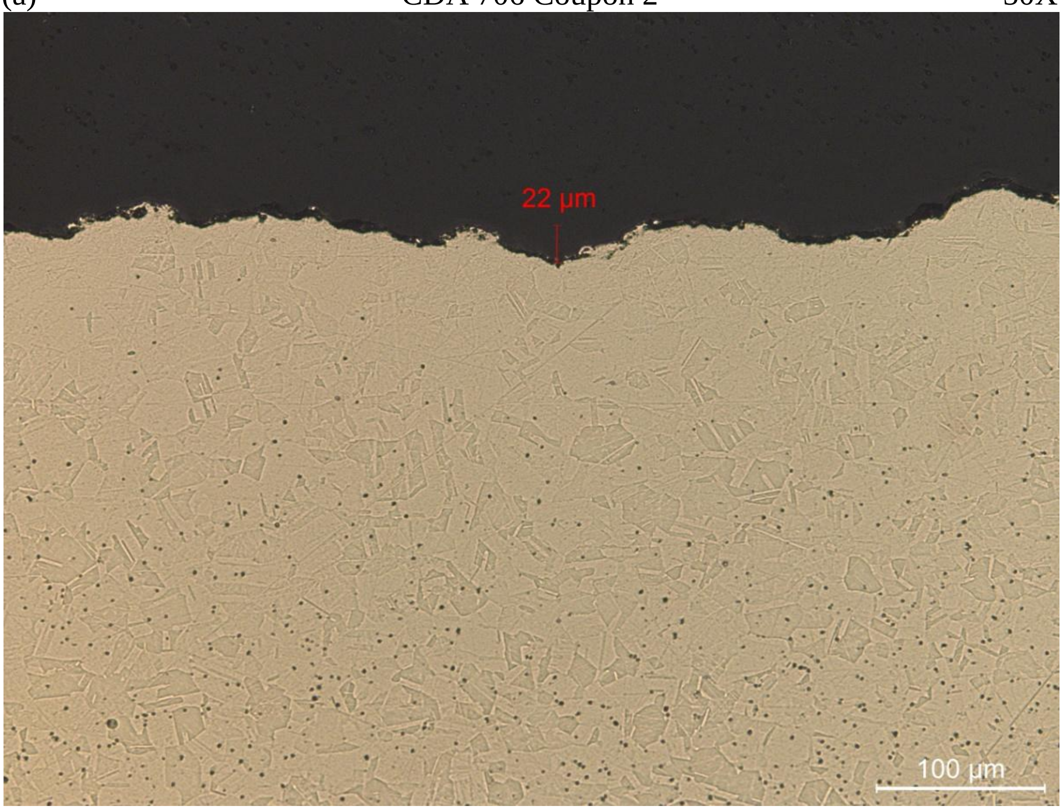
(a) CDA 706 Coupon 1 50X



(b) CDA 706 Coupon 1 200X

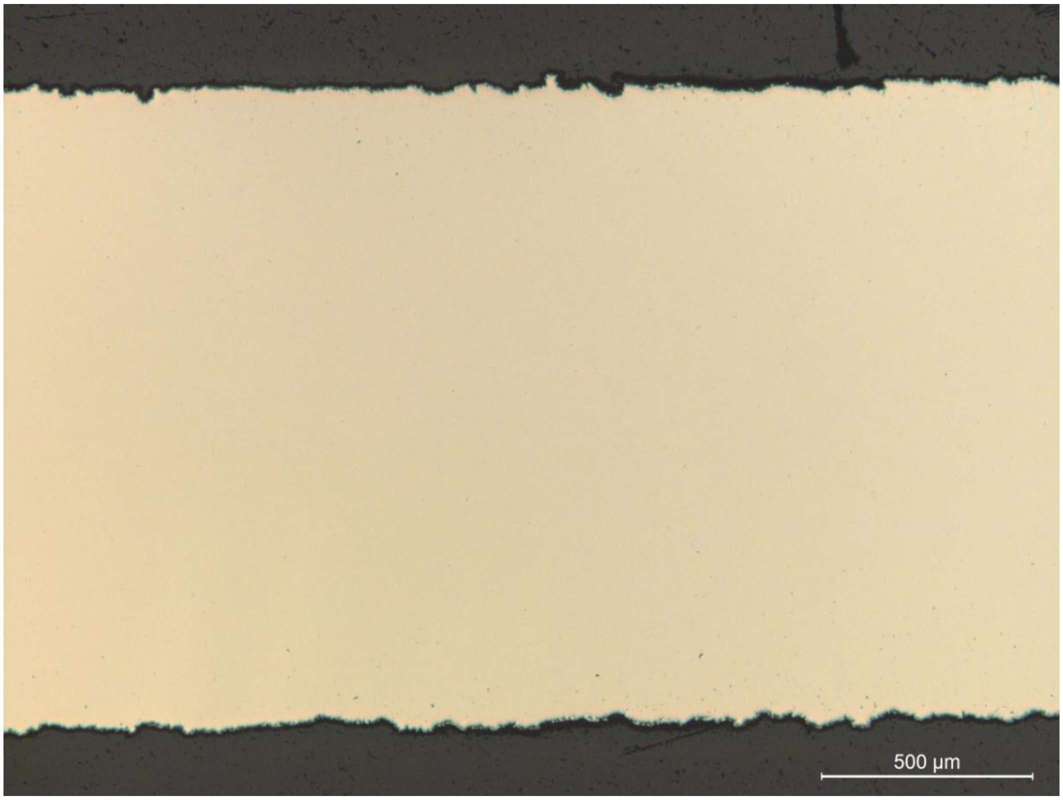
Figure 53 Optical micrographs of CDA 706 coupon 1.

(a) CDA 706 Coupon 2 50X

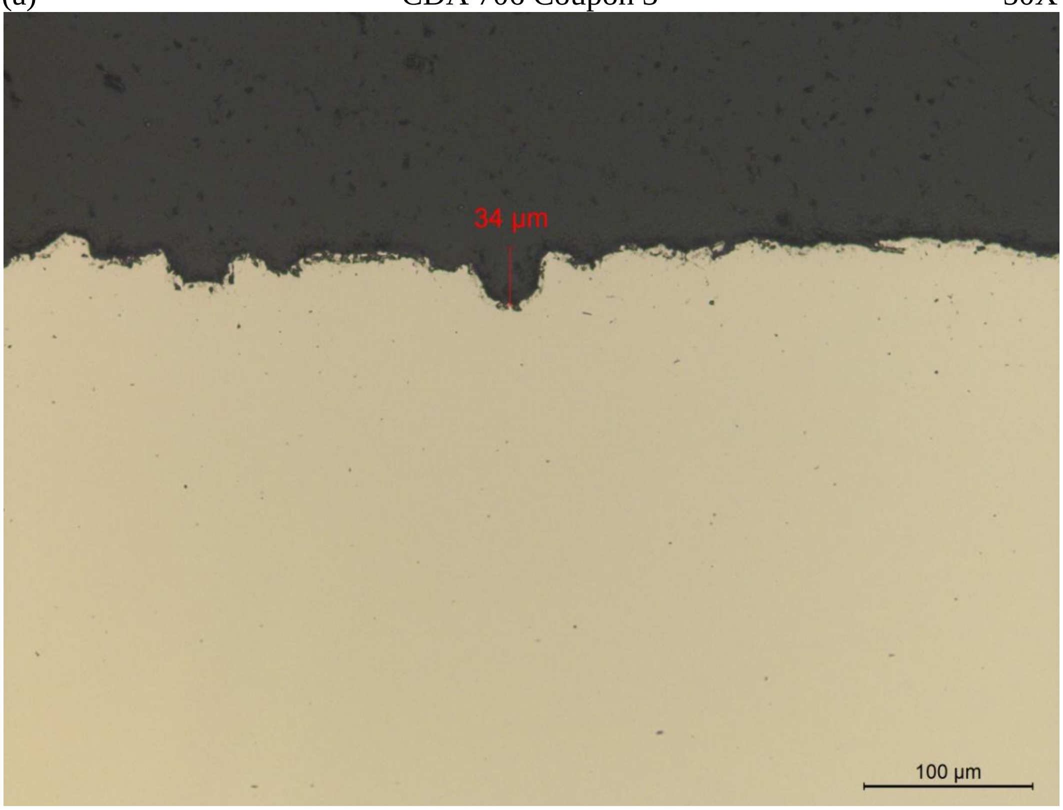


(b) CDA 706 Coupon 2 200X

Figure 54 Optical micrographs of CDA 706 coupon 2.

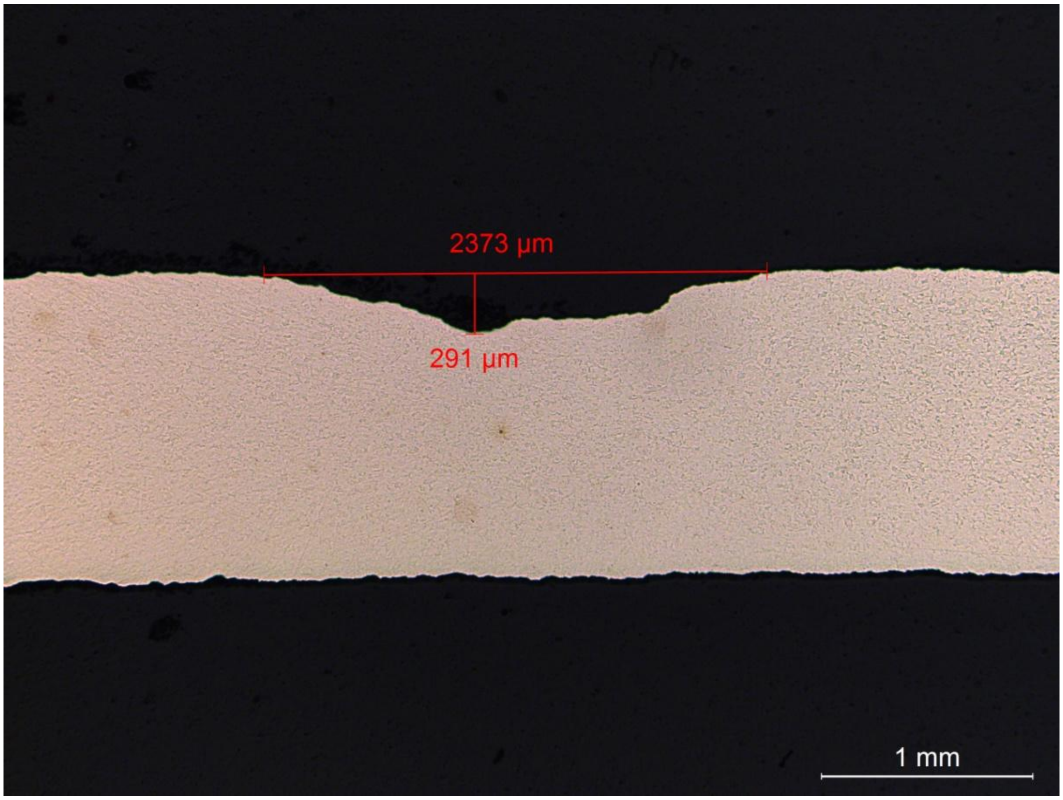


(a) CDA 706 Coupon 3 50X

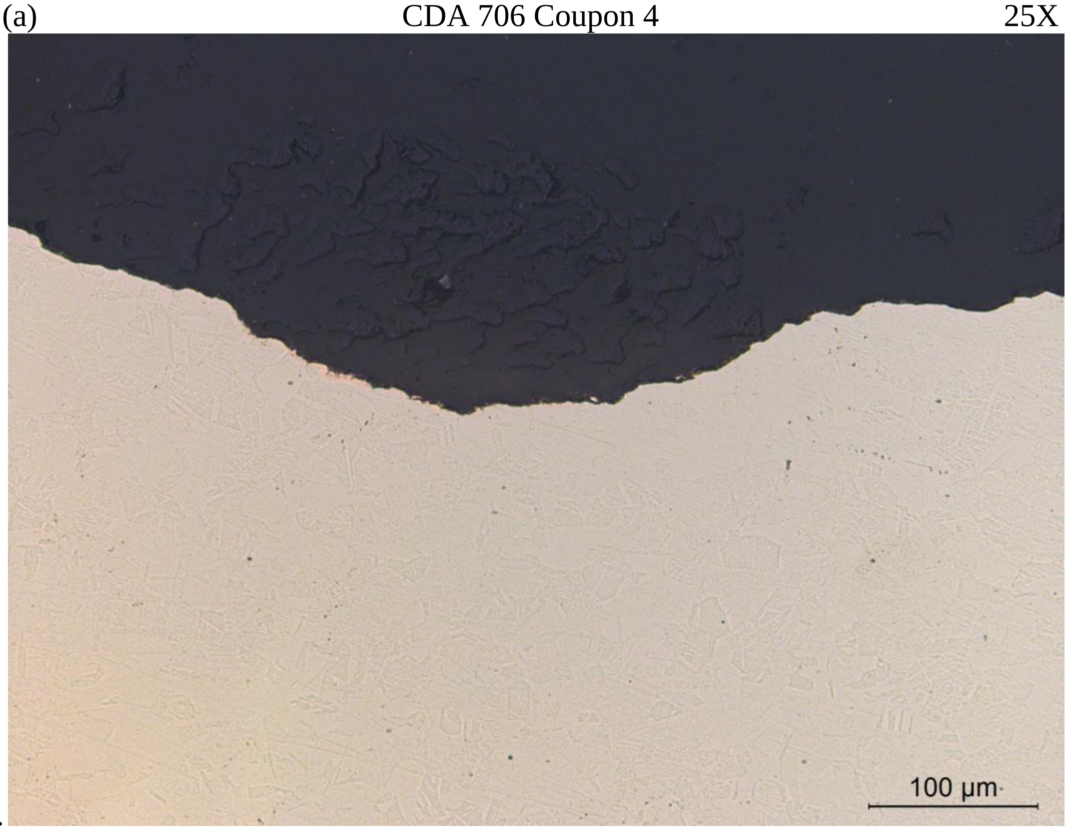


(b) CDA 706 Coupon 3 200X

Figure 55 Optical micrographs of CDA 706 coupon 3.



(a) CDA 706 Coupon 4 25X



(b) CDA 706 Coupon 4 200X

Figure 56 Optical micrographs of CDA 706 coupon 4.

Report No. 5005.0361E **July 17, 2015**

CORROSION EVALUATION OF Z-ALLOY COUPONS AND SCREENS

Customer Authorization: Verbal

Report To: V & A Engineering
Attn: Manuel Najar
155 Grand Avenue, Suite 700
Oakland, CA 94612

1.0 INTRODUCTION

Five coupons, five wedge wire screens, and one plate made from Z-Alloy, a proprietary material from Johnson Screens, were submitted by V&A Engineering for corrosion evaluation. The coupons were 1-inch by 3-inches by ¼-inch thick. The wedge wire screens were 4-inches by 4-inches by 1-inch tall with 2 mm spacing. The plate was 4-inches by 4-inches by 1/8-inch thick.

Four coupons, four screens, and one plate were to be placed in seawater for a period up to one year. After every 3 month interval, one coupon and one screen were to be removed from the test system and examined for corrosion. After 12 months, the plate was removed from the test system and examined for corrosion. The purpose of this evaluation was to document the samples in the baseline as-received condition, then again after 3, 6, 10, and 12 months of water exposure, record any loss in mass, examine for any pitting corrosion, and estimate the corrosion rate.

The samples were evaluated by the following laboratory procedures:

1) Visual examination and weighing
2) Cleaning per ASTM G1[1]
3) Scanning electron microscopy and energy dispersive x-ray spectroscopy
4) Metallography

The results of the evaluation showed a minimal mass loss and corrosion rate for the coupon and screen after 3, 6, 10, and 12 months of corrosion testing. The coupons, after 3, 6, 10, and 12 months of corrosion testing, had a corrosion rate of 0.015, 0.010, 0.006, and 0.006 millimeters per year, respectively. The screens, after 3, 6, 10, and 12 months of corrosion testing, had a corrosion rate of 0.113, 0.062, 0.044, and 0.045 millimeters per year, respectively. The plate, after 12 months of corrosion testing, had a corrosion rate of 0.006 millimeters per year. Both the coupons and screens lost more material over time, but had a decreasing corrosion rate over the duration of the corrosion test.

[1] G1: Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

2.0 EVALUATION[2]

2.1 Visual Examination

The sample identifications for the coupons and wedge wire screens and their corresponding immersion times are shown in Table 1. The coupons had identification numbers stamped on the front face by V&A Engineering. A number of notches, corresponding to the sample number, were sawed at the edge of each screen for identification after the corrosion test. The weights of the samples were recorded. Coupons 1 – 4 and screens 1 – 5 were sent back to V&A for corrosion testing. Coupons 5 and 6 were the baseline samples and documented by photography, optical stereoscopy and scanning electron microscopy for comparison to the tested samples. Screen 5 was documented as a baseline by photography and optical stereoscopy, and then sent to V&A for testing.

Photographs of the baseline coupon are shown in Figure 1. Photographs of coupons 1 – 4, after 3, 6, 10, and 12 months of corrosion testing, are shown in Figures 2 – 5. A photograph of the baseline screen is shown in Figure 6. Photographs of screens 1 – 4, after 3, 6, 10, and 12 months of corrosion testing, are shown in Figures 7 – 10. A photograph of the baseline plate is shown in Figure 11 and a photograph of the plate after 12 months of corrosion testing is shown in Figure 12.

2.2 Cleaning

The coupons, screens, and plate were cleaned with solution C.2.1 per ASTM G1.[3] One cleaning cycle was approximately 1 minute. After each cleaning cycle, the samples were rinsed in water, dried, and weighed. The cleaning and weighing cycle was completed five times for the coupon and screen. The weights of the samples as-received, after corrosion testing but before cleaning, and after each cleaning cycle are presented in Table 2.

Optical macrographs of the baseline coupon, screen, and plate are shown in Figures 13, 22, and 31, respectively. Representative optical macrographs of coupons 1 – 4 after 3, 6, 10, and 12 months of corrosion testing, before and after cleaning, are shown in Figures 14 – 21. Representative optical macrographs of screens 1 – 4 after 3, 6, 10, and 12 months of corrosion testing, before and after cleaning, are shown in Figures 23 – 30. Representative optical macrographs of the plate after 12 months of corrosion testing, before and after cleaning, are shown in Figures 32 – 33.

The mass loss versus the number of cleaning cycles was plotted, shown in Figures 34 – 38. The equations for best fit lines AB and BC, calculated using IGOR Pro, are listed in Table 3. Point B, indicated by the red circle in each plot, corresponds to the mass loss due to corrosion during the cleaning process for each sample. This mass loss was subtracted from the weight of the sample before cleaning and from the weight of the sample as-received to determine the total mass loss from corrosion. The corrosion rate of each sample was determined by the formula specified in Section 8.1 of ASTM G1:

[2] The magnifications of the optical and scanning electron micrographs in this report are approximate and should not be used as a basis for dimensional analyses unless otherwise indicated.
[3] 500 mL hydrochloric acid + 500 ml reagent water.

$$Corrosion\ Rate = \frac{K\ x\ W}{A\ x\ T\ x\ D}$$

where K = 8.76 x 10^4, T = time of exposure in hours, A = area in cm^2, W = mass loss in grams, and D = density in g/cm^3. The density of the Z-Alloy was determined by cutting a section out of the baseline coupon, measuring the length, width, and thickness, and weighing the section with a balance. The total mass loss from corrosion and the calculated corrosion rate of each sample is shown in Table 4.

2.3 Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy

The baseline coupon and coupons 1 – 4 were examined with a scanning electron microscope. Representative scanning electron micrographs of the baseline coupon are shown in Figure 39. Representative scanning electron micrographs of coupons 1 – 4, before and after cleaning, are shown in Figures 40 – 47. Energy dispersive x-ray spectra of the baseline coupon and coupons 1 – 4, before and after cleaning, are shown in Figures 48 – 52.

2.4 Metallography

Cross sections were taken from the coupon and prepared for a metallographic examination. Optical micrographs of the surfaces of coupons 1 – 4 are shown in Figures 53 – 56. A wide, shallow pit, measuring 0.2 mm, was observed in coupon 1. Small pits were observed in coupons 2, 3, and 4, the deepest of which measured 15 um.

3.0 DISCUSSION

The coupon and screen showed minimal mass loss and pitting overall after 3, 6, 10, and 12 months of corrosion testing. The coupons had more material loss over time, but had a decreasing corrosion rate over the duration of the corrosion test. The screens had more material loss over time, but had a decreasing corrosion rate over the duration of the corrosion test.

4.0 CONCLUSIONS[4]

The following conclusions are based upon the submitted samples and the evidence gathered:

1. The coupons, after 3, 6, 10, and 12 months of corrosion testing, had a mass loss of 0.172 grams, 0.236 grams, 0.236 grams and 0.288 grams, respectively. The coupons had more mass loss over the duration of the corrosion test.

2. The coupons, after 3, 6, 10, and 12 months of corrosion testing, had a corrosion rate of 0.015 mm / year, 0.010 mm / year, 0.006 mm / year, and 0.006 mm / year, respectively. The coupons had a decreasing corrosion rate over the duration of the corrosion test.

3. The screens, after 3, 6, 10, and 12 months of corrosion testing, had a mass loss of 14.96 grams, 16.71 grams, 20.00 grams, and 24.20 grams, respectively. The screens had more mass loss over the duration of the corrosion test.

4. The screens, after 3, 6, 10, and 12 months of corrosion testing, had a corrosion rate of 0.113 mm / year, 0.062 mm / year, 0.044 mm / year, and 0.045 mm / year, respectively. The screens had a decreasing corrosion rate over the duration of the corrosion test.

5. The plate, after 12 months of corrosion test, had a mass loss of 1.20 grams and a corrosion rate of 0.006 mm / year.

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[4] The conclusions in this report are based upon the available information and evidence provided by the client and gathered by Anamet, within the scope of work authorized by the client, and they are hereby presented by Anamet to a reasonable degree of engineering and scientific certainty. Anamet reserves the right to amend or supplement its conclusions or opinions presented in this report should additional data or information become available, or further work be approved by the client.

Table 1
Sample Identifications

Description		V&A Engineering Identification (As-Received)	Anamet Identification (in report)	Notes
Alloy	Part			
Z Alloy	**Flat Plate** 4-inch x 4-inch x 1/8-inch	Z	Plate	None
	Coupon 1-inch x 3-inch x 1/8-inch with autogenous weld bead	1	Coupon 1	3 Month Immersion
		2	Coupon 2	6 Month Immersion
		3	Coupon 3	10 Month Immersion
		4	Coupon 4	12 Month Immersion
		5	Coupon 5	Baseline Sample (no exposure)
		6	Coupon 6	Baseline Sample (no exposure)
	Wedge Wire Screen 4-inch x 4-inch x 1-inch with 2 mm spacing	None	Screen 1	3 Month Immersion
		None	Screen 2	6 Month Immersion
		None	Screen 3	10 Month Immersion
		None	Screen 4	12 Month Immersion
		None	Screen 5	12 Month Immersion

Table 2
Sample Weights

Sample	Baseline Measurement	Measurements after 3 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 1	26.8665	26.7135	26.6958	26.6926	26.6911	26.6887	26.6872
Screen 1	361.74	352.24	348.56	346.76	346.62	346.50	346.48

Sample	Baseline Measurement	Measurements after 6 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 2	27.0660	26.8593	26.8299	26.8273	26.8255	26.8230	26.8211
Screen 2	359.36	347.99	342.66	342.58	342.48	342.44	-

Sample	Baseline Measurement	Measurements after 10 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 3	27.4856	27.2842	27.2500	27.2471	27.2452	27.2435	27.2423
Screen 3	361.61	347.00	342.58	341.57	341.36	341.30	341.23

Sample	Baseline Measurement	Measurements after 12 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Coupon 4	27.7407	27.4903	27.4520	27.4520	27.4516	27.4516	-
Screen 4	360.25	342.42	337.20	336.01	335.95	335.86	-
Plate	594.80	593.91	593.61	593.59	593.58	-	-

Table 3
Equations of Line AB and BC for Corrosion Testing Samples

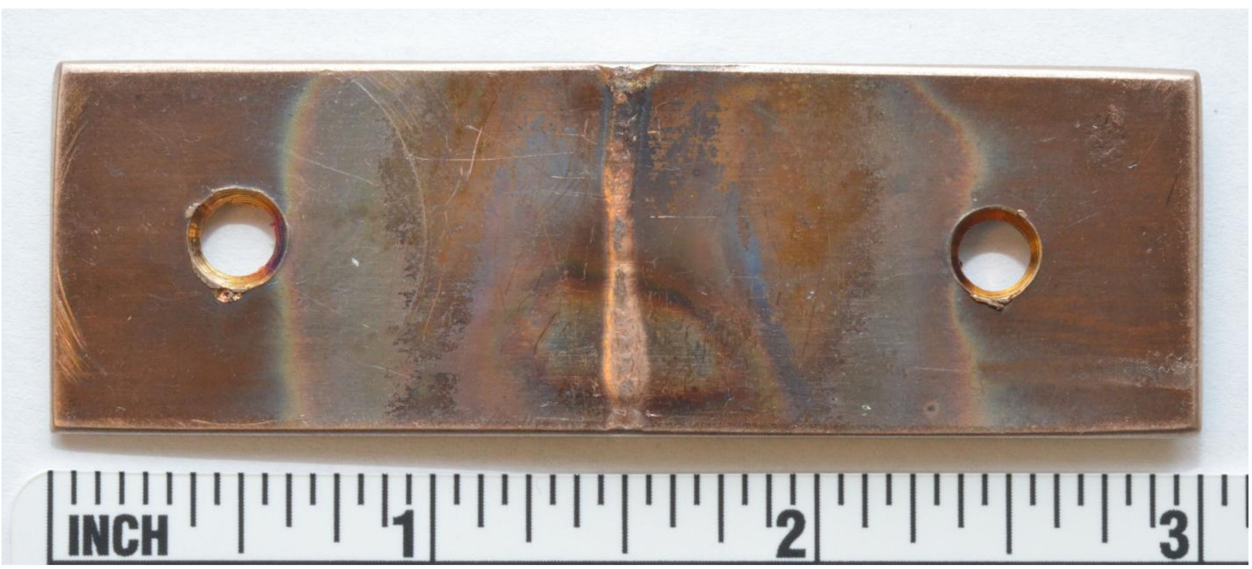
Sample	Line AB	Line BC	Point B (Approximate Mass Loss from Corrosion During Cleaning)
Coupon 1	y = 0.018x	y = 0.002x + 0.017	0.019 grams
Coupon 2	y = 0.029x	y = 0.002x + 0.027	0.029 grams
Coupon 3	y = 0.034x	y = 0.002x + 0.033	0.035 grams
Coupon 4	y = 0.038x	y = 0.038	0.038 grams
Screen 1	y = 3.68x	y = 0.10x + 5.31	5.46 grams
Screen 2	y = 5.33x	y = 0.08x + 5.26	5.34 grams
Screen 3	y = 4.42x	y = 0.11x + 5.26	5.39 grams
Screen 4	y = 5.22x	y = 0.08x + 6.26	6.36 grams
Plate	y = 0.30x	y = 0.02x + 0.29	0.31 grams

Table 4
Total Mass Loss from Corrosion and Corrosion Rate

Sample	Total Mass Loss from Corrosion*	Corrosion Rate
Coupon 1	0.172 grams	0.015 mm / year
Coupon 2	0.236 grams	0.010 mm / year
Coupon 3	0.236 grams	0.006 mm / year
Coupon 4	0.288 grams	0.006 mm / year
Screen 1	14.96 grams	0.113 mm / year
Screen 2	16.71 grams	0.062 mm / year
Screen 3	20.00 grams	0.044 mm / year
Screen 4	24.20 grams	0.045 mm / year
Plate	1.20 grams	0.006 mm / year

* Weight As-Received – (Weight Before Cleaning – Mass Loss from Corrosion During Cleaning)

(a) Z-Alloy Baseline Coupon, Front Side



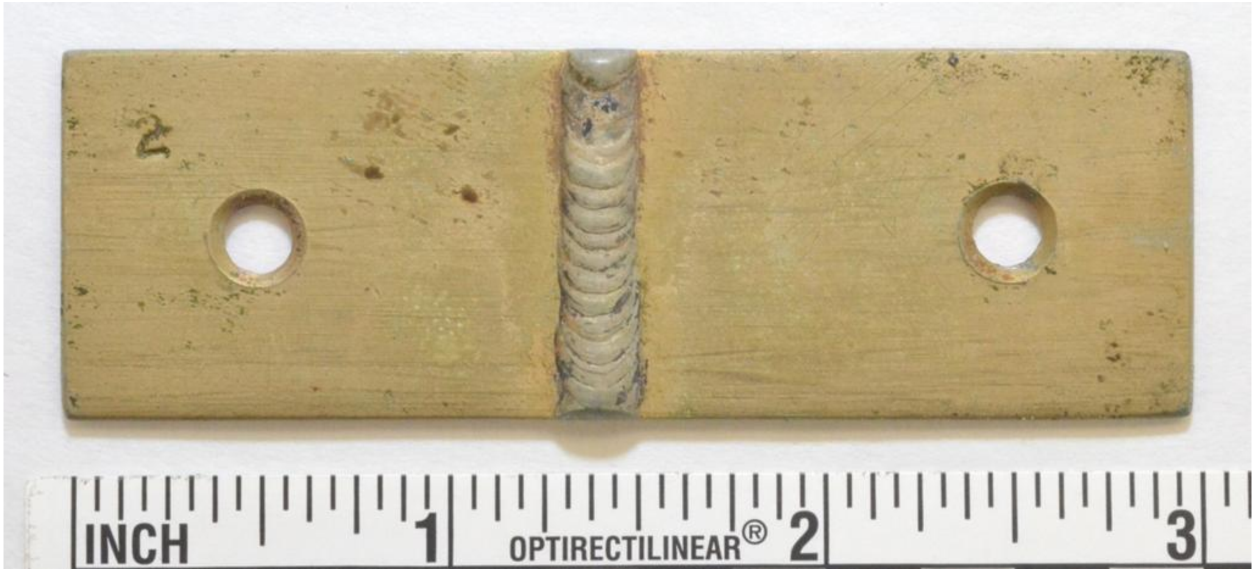
(b) Z-Alloy Baseline Coupon, Back Side

Figure 1 Photographs of the Z-Alloy baseline coupon (a) front and (b) back side.

(a) Z-Alloy Coupon 1 Front Side

(b) Z-Alloy Coupon 1 Back Side

Figure 2 Photographs of Z-Alloy coupon 1 (a) front and (b) back side after a 3 month corrosion test.

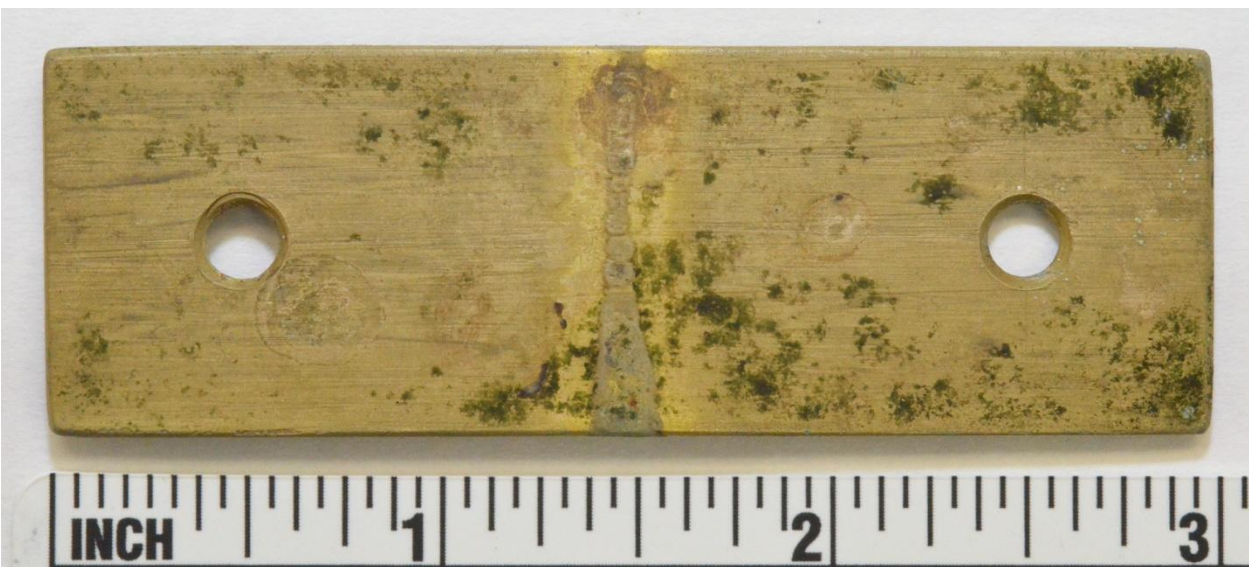


(a) Z-Alloy Coupon 2 Front Side

(b) Z-Alloy Coupon 2 Back Side

Figure 3 Photographs of Z-Alloy coupon 2 (a) front and (b) back side after a 6 month corrosion test.

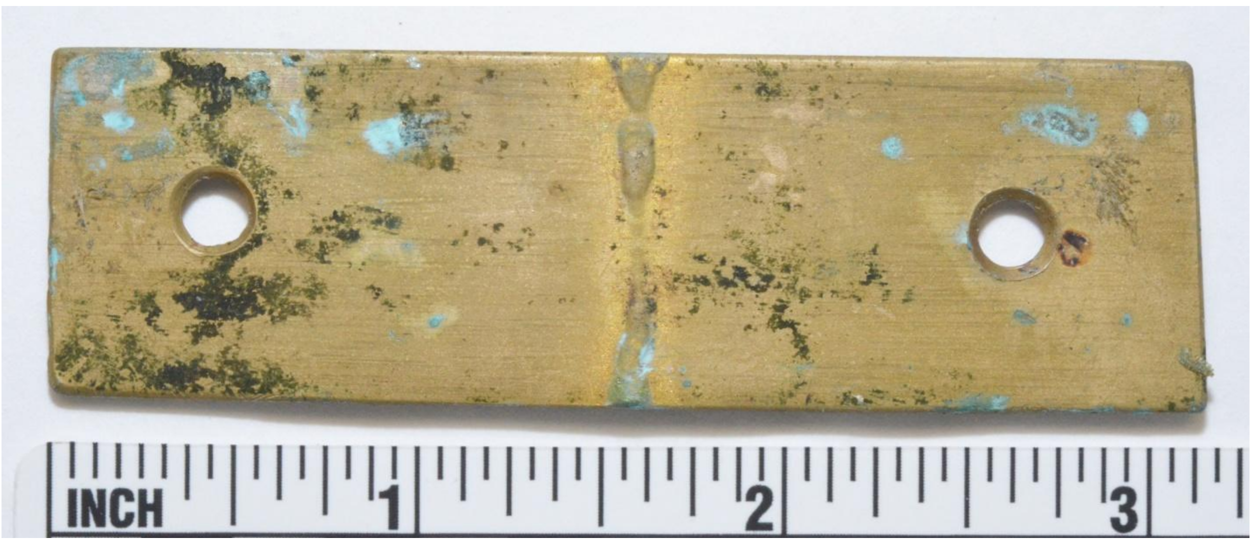
(a) Z-Alloy Coupon 3 Front Side



(b) Z-Alloy Coupon 3 Back Side

Figure 4 Photographs of Z-Alloy coupon 3 (a) front and (b) back side after a 10 month corrosion test.

(a) Z-Alloy Coupon 4 Front Side

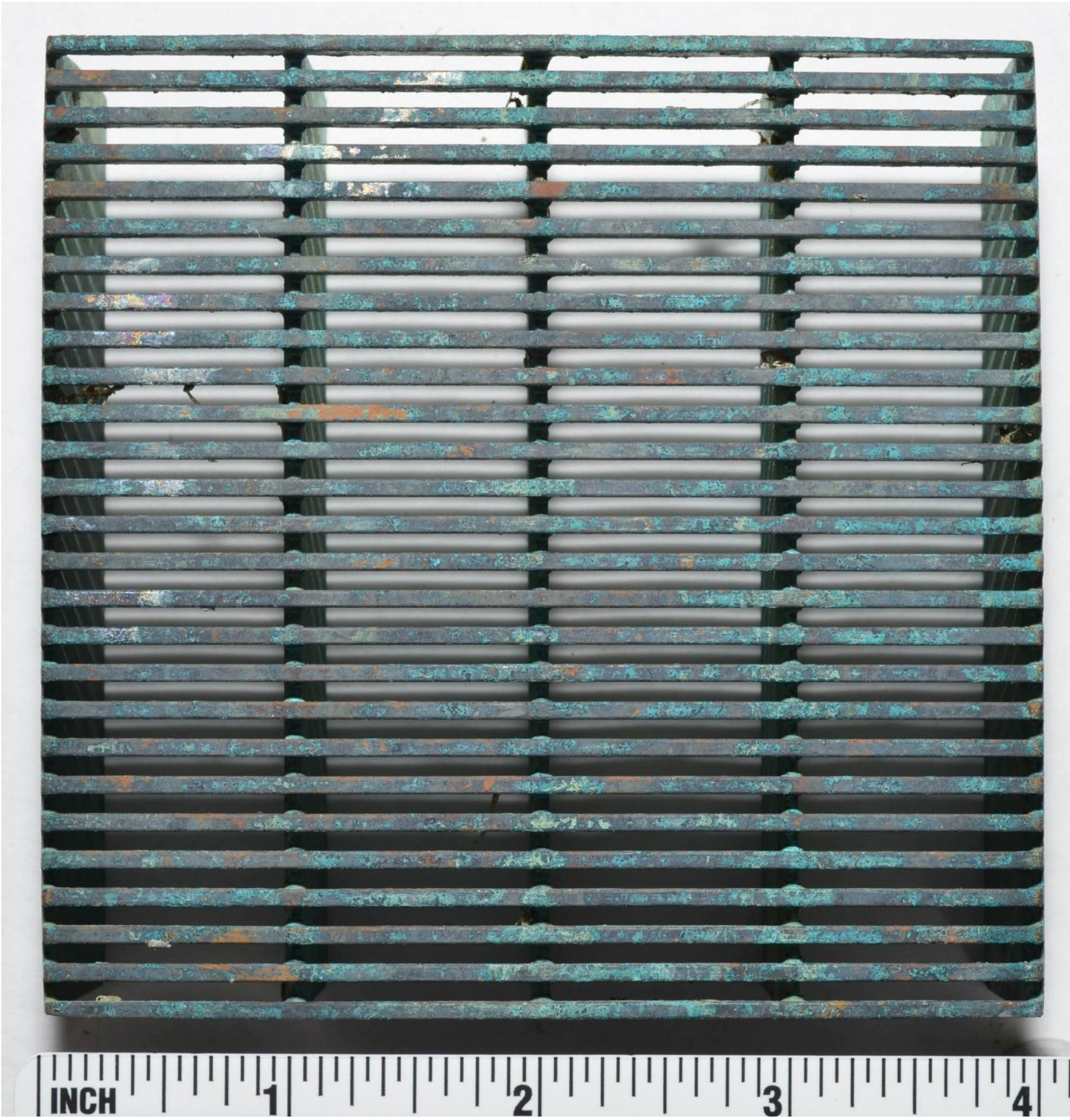


(b) Z-Alloy Coupon 4 Back Side

Figure 5 Photographs of Z-Alloy coupon 4 (a) front and (b) back side after a 12 month corrosion test.

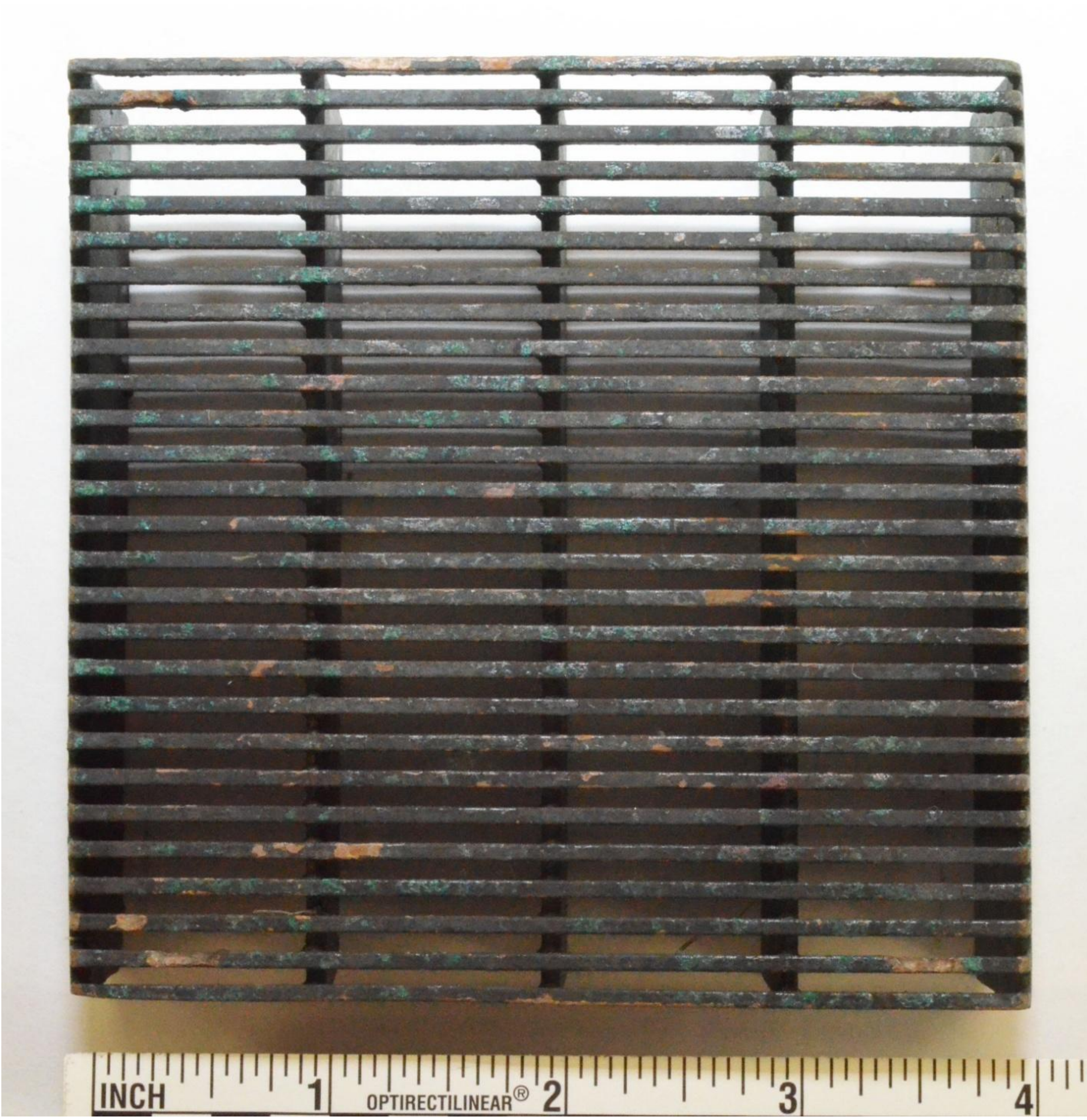
(a) Z-Alloy Baseline Screen

Figure 6 Photograph of the Z-Alloy baseline screen.



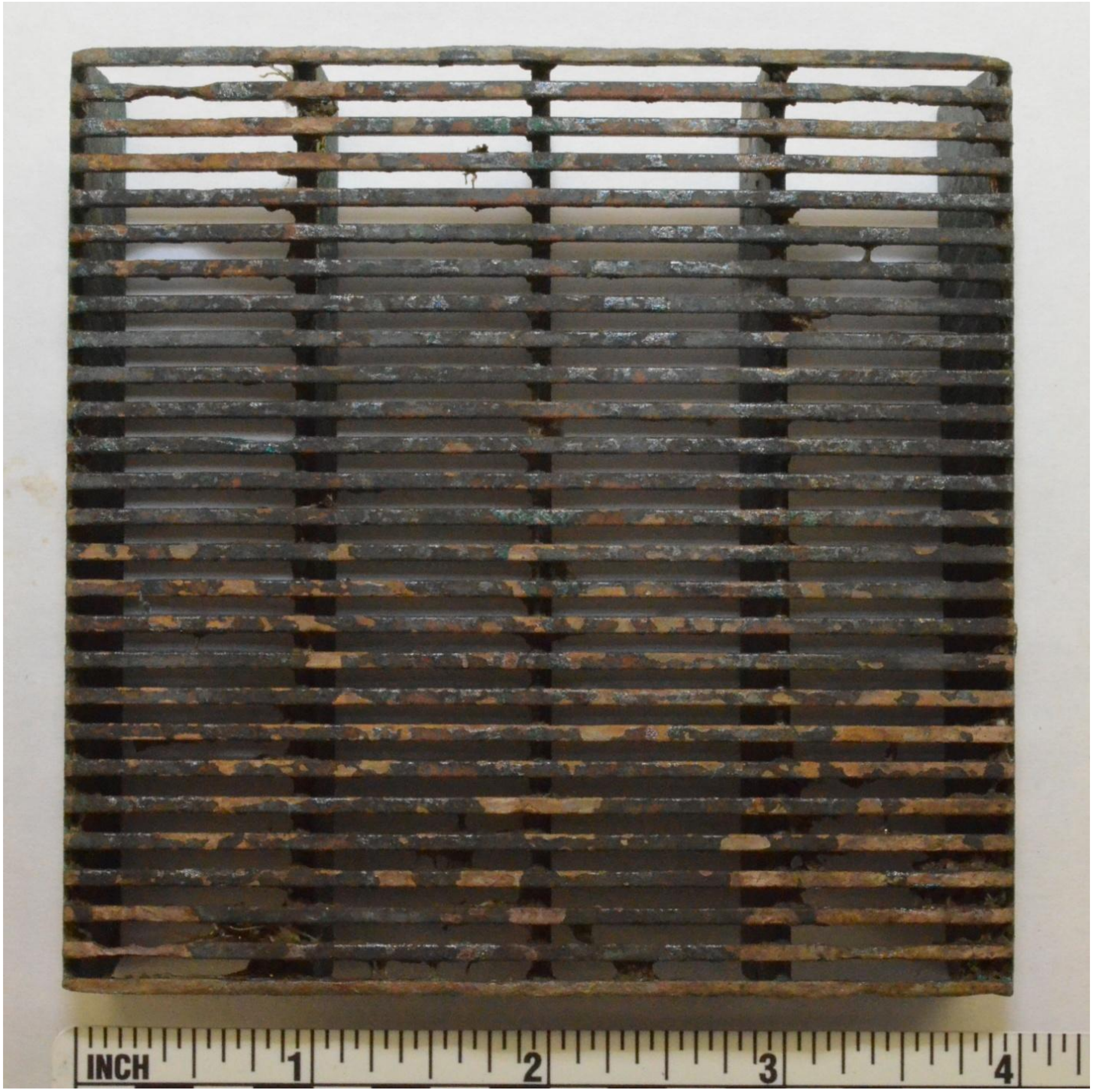
(a) Z-Alloy Screen 1

Figure 7 Photograph of Z-Alloy screen 1 after a 3 month corrosion test.



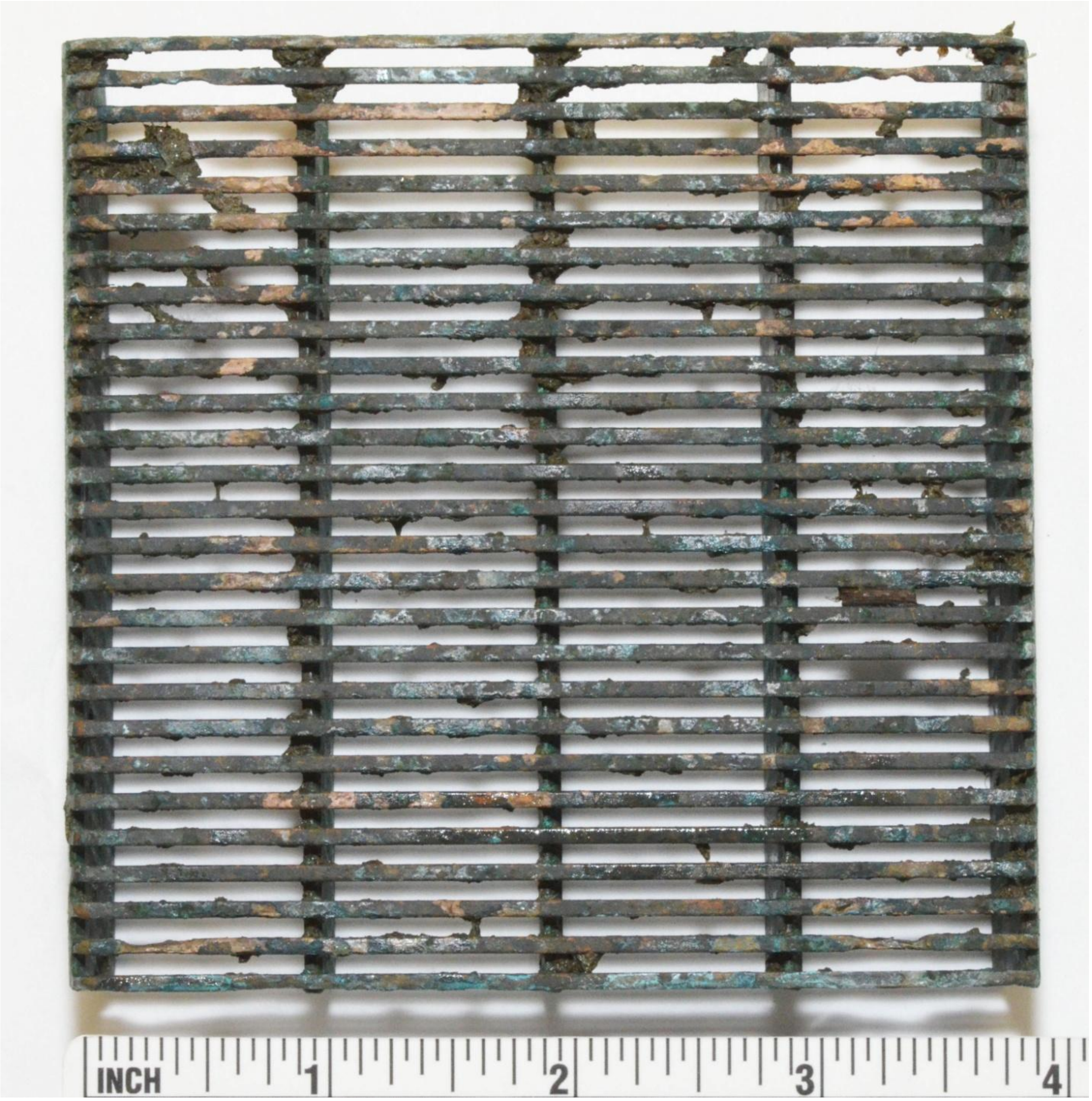
(a) Z-Alloy Screen 2

Figure 8 Photograph of Z-Alloy screen 2 after a 6 month corrosion test.



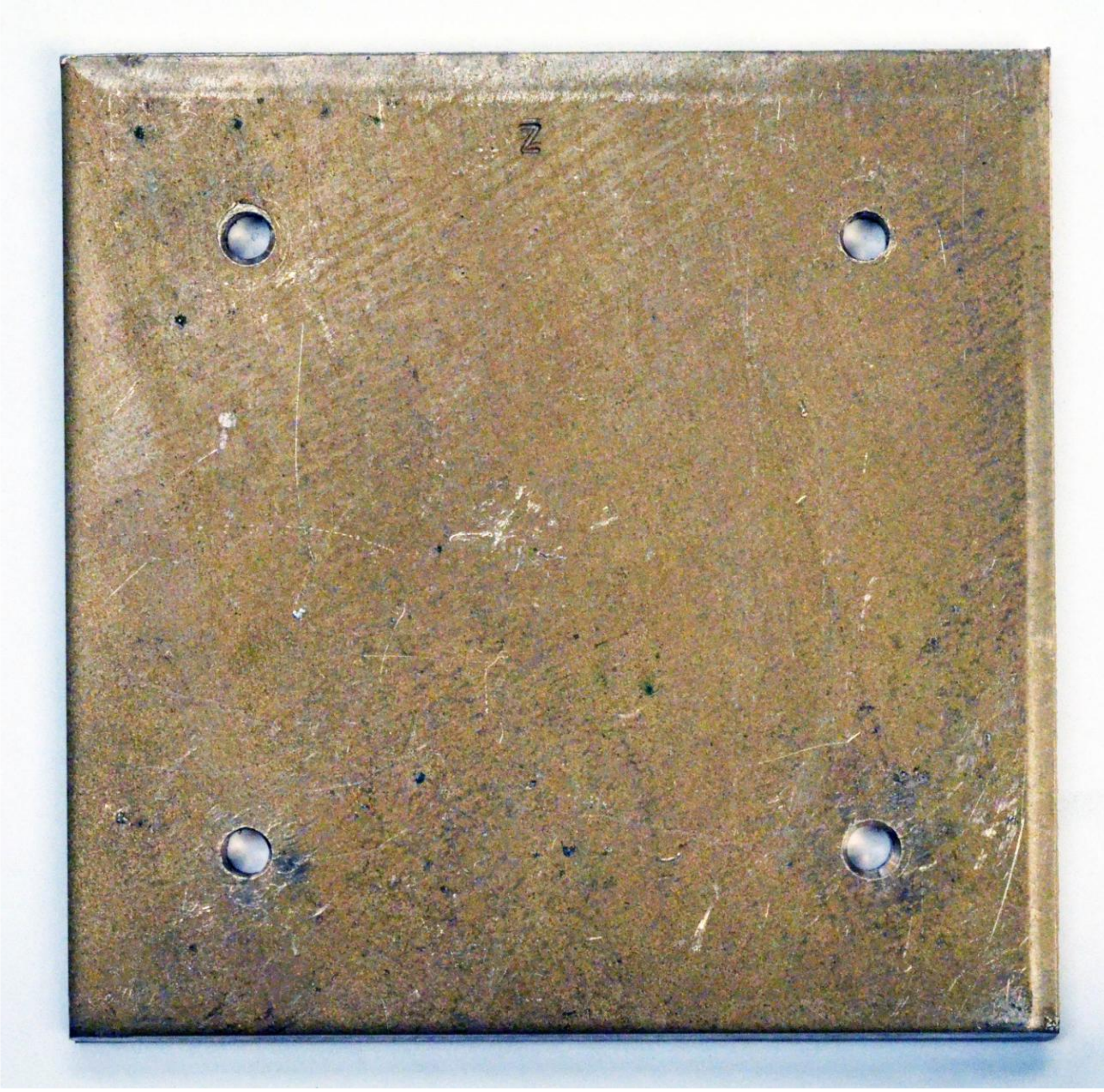
(a) Z-Alloy Screen 3

Figure 9 Photograph of Z-Alloy screen 3 after a 10 month corrosion test.



(a) Z-Alloy Screen 4

Figure 10 Photograph of Z-Alloy screen 4 after a 12 month corrosion test.

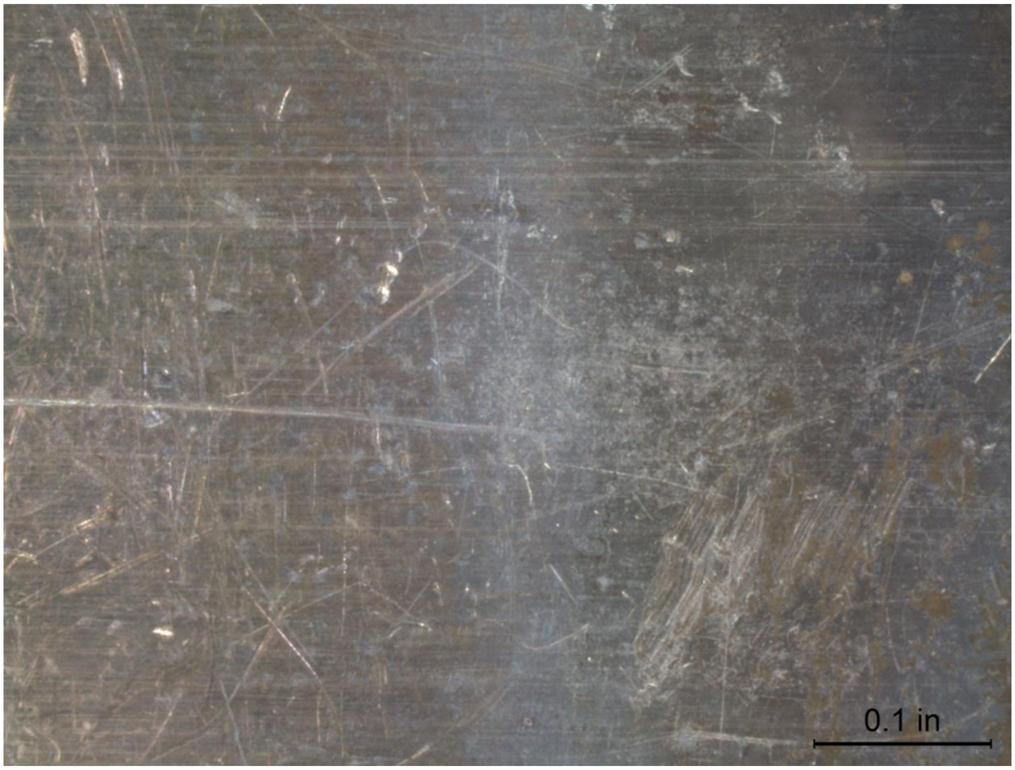


(a) Z-Alloy Baseline Plate

Figure 11 Photograph of the Z-Alloy baseline plate.

(a) Z-Alloy Plate

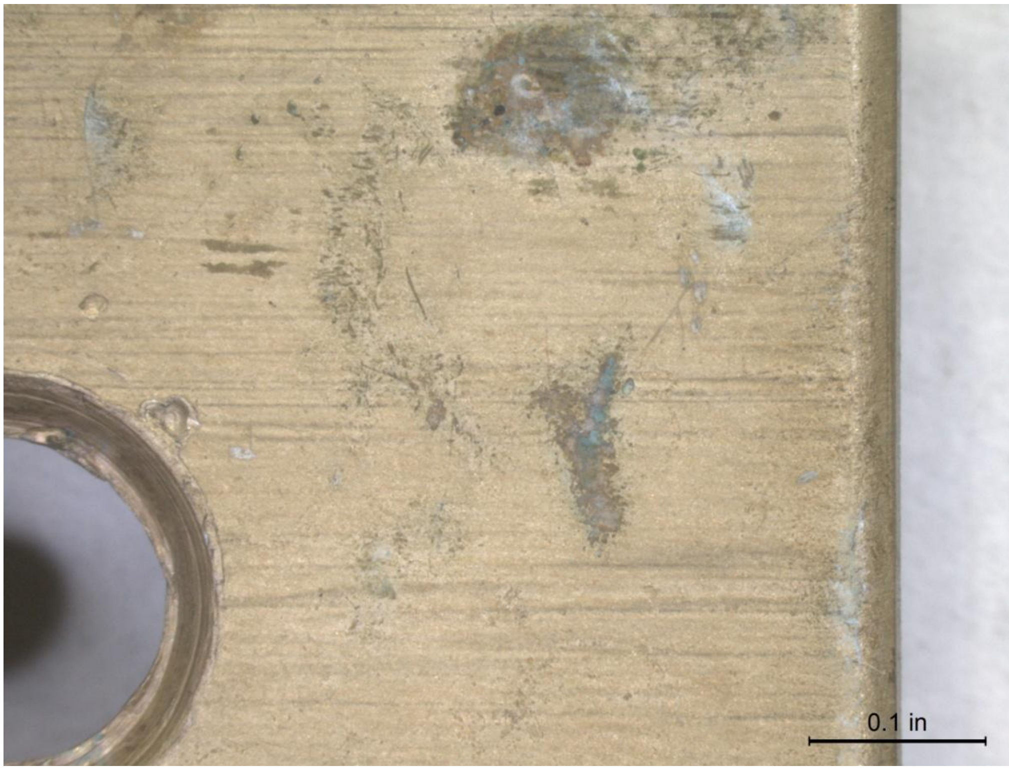
Figure 12 Photograph of the Z- Alloy plate after a 12 month corrosion test.



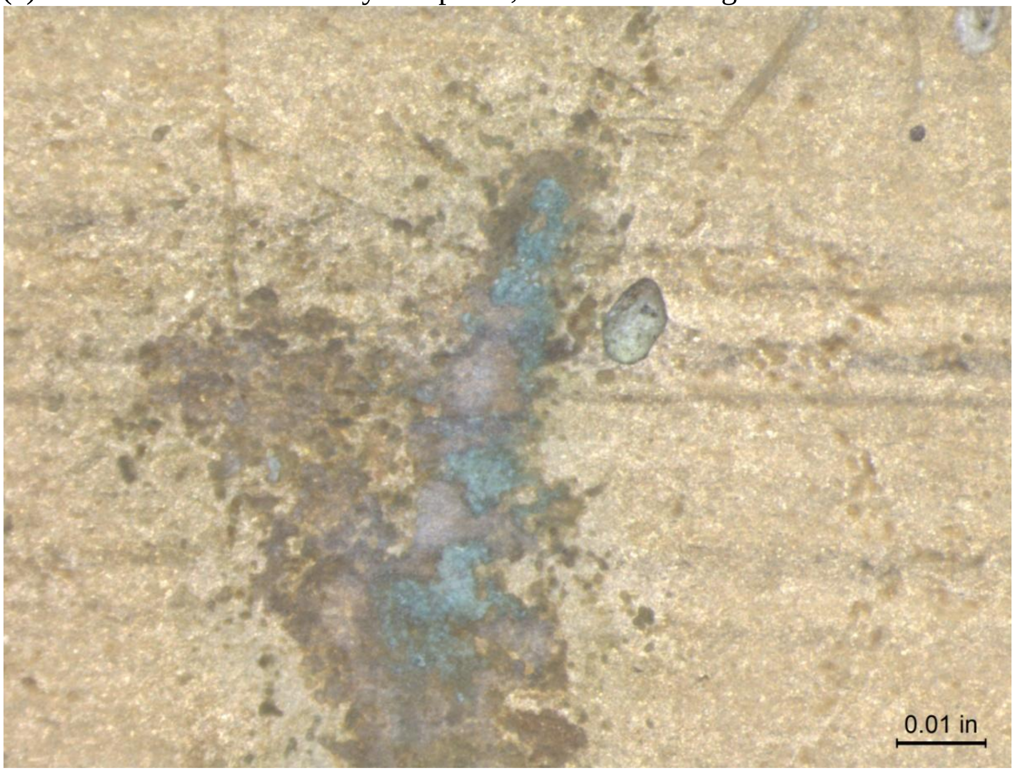
(a) Z-Alloy Baseline Coupon 10X

(b) Z-Alloy Baseline Coupon 50X

Figure 13 Optical macrographs of the Z-Alloy baseline coupon.

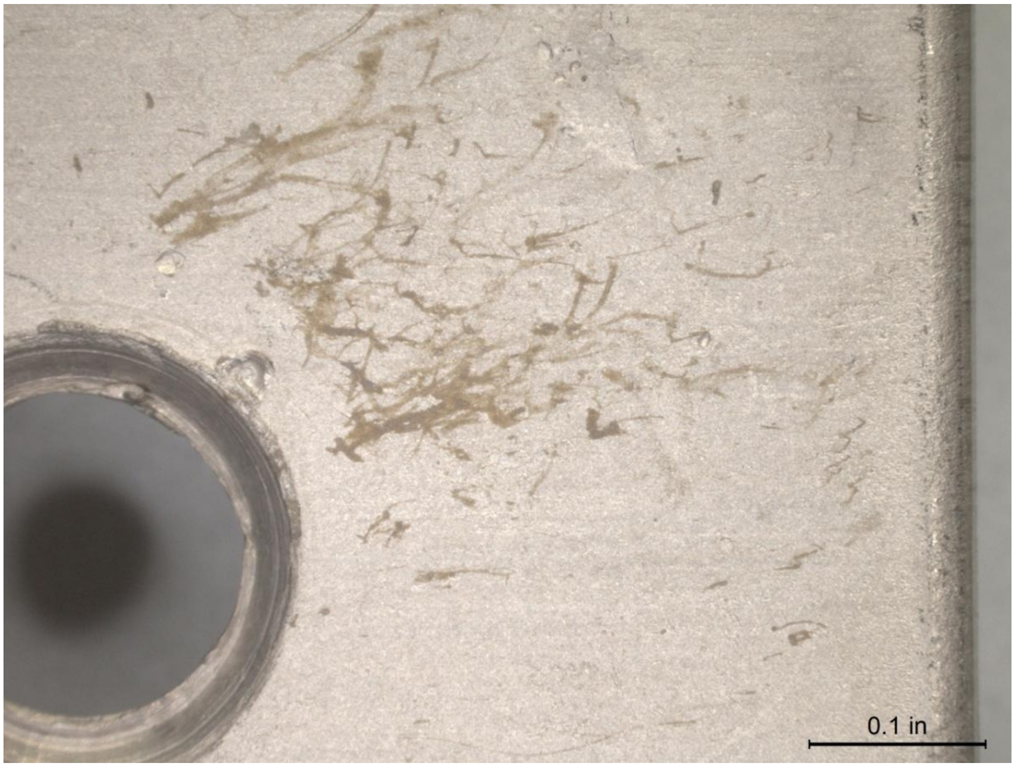


(a) Z-Alloy Coupon 1, Before Cleaning 10X



(b) Z-Alloy Coupon 1, Before Cleaning 50X

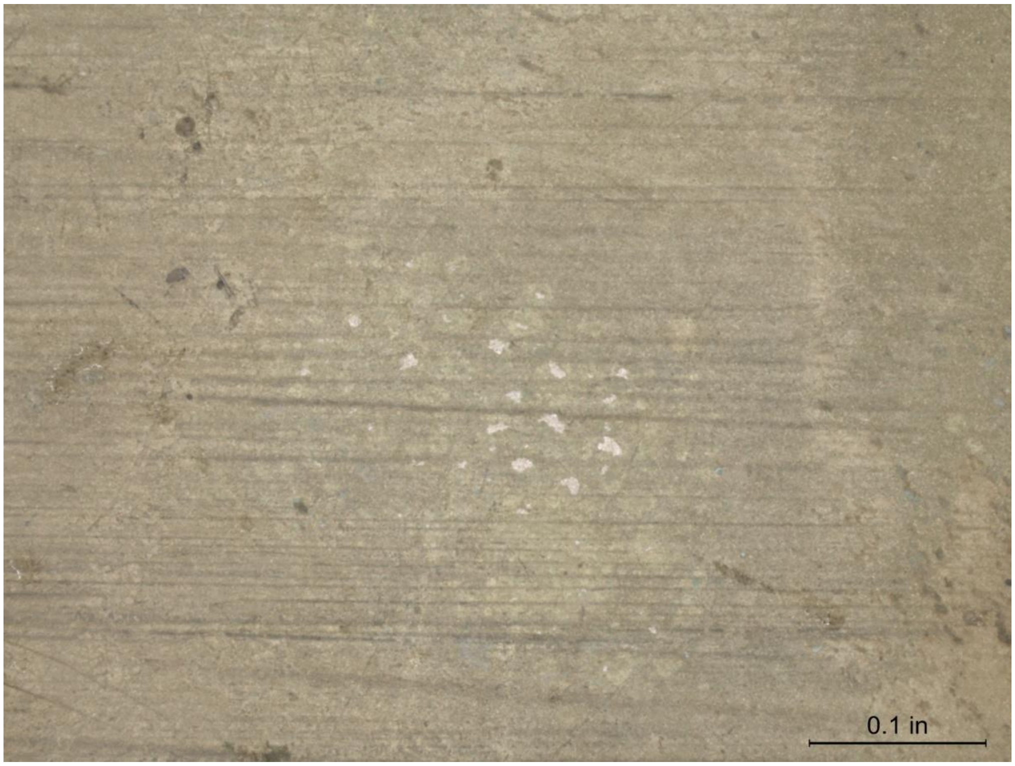
Figure 14 Optical macrographs of Z-Alloy coupon 1 after a 3 month corrosion test, before cleaning.



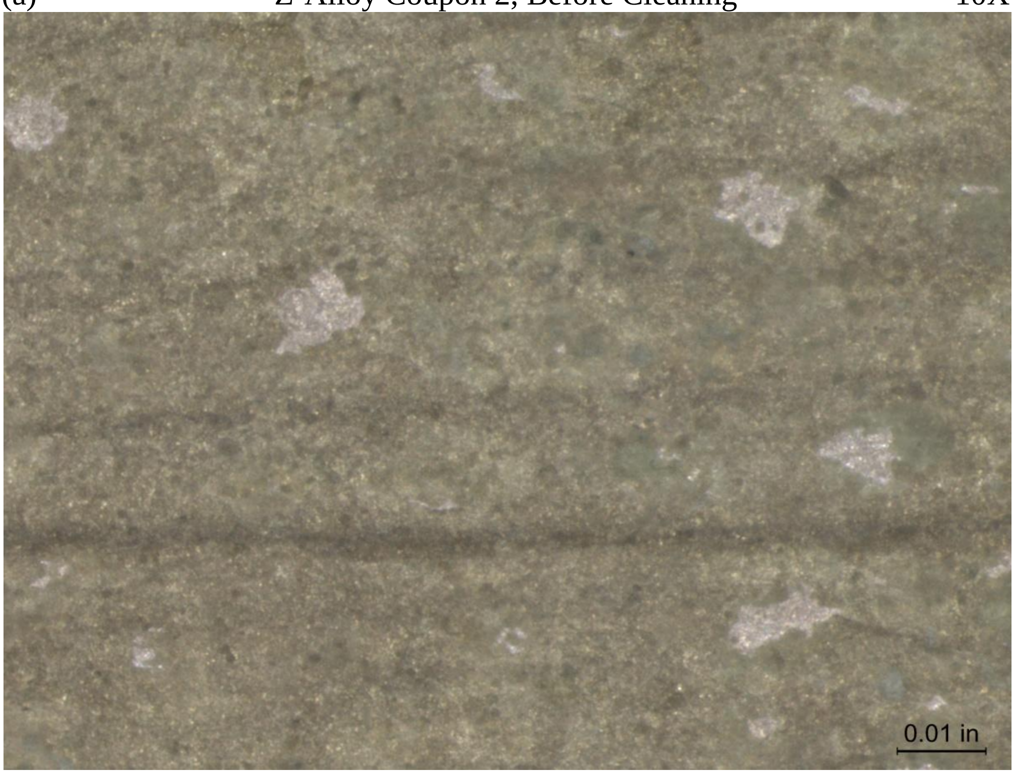
(a) Z-Alloy Coupon 1, After Cleaning 10X

(b) Z-Alloy Coupon 1, After Cleaning 50X

Figure 15 Optical macrographs of Z-Alloy coupon 1 after a 3 month corrosion test, after cleaning.



(a) Z-Alloy Coupon 2, Before Cleaning 10X



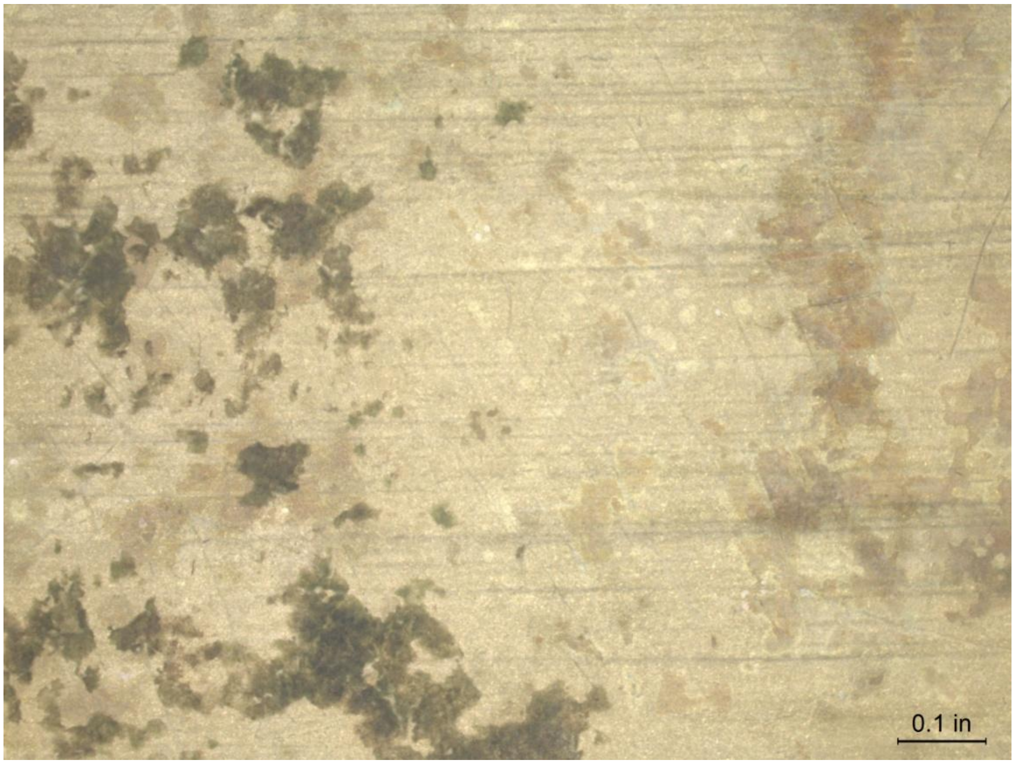
(b) Z-Alloy Coupon 2, Before Cleaning 50X

Figure 16 Optical macrographs of Z-Alloy coupon 2 after a 6 month corrosion test, before cleaning.

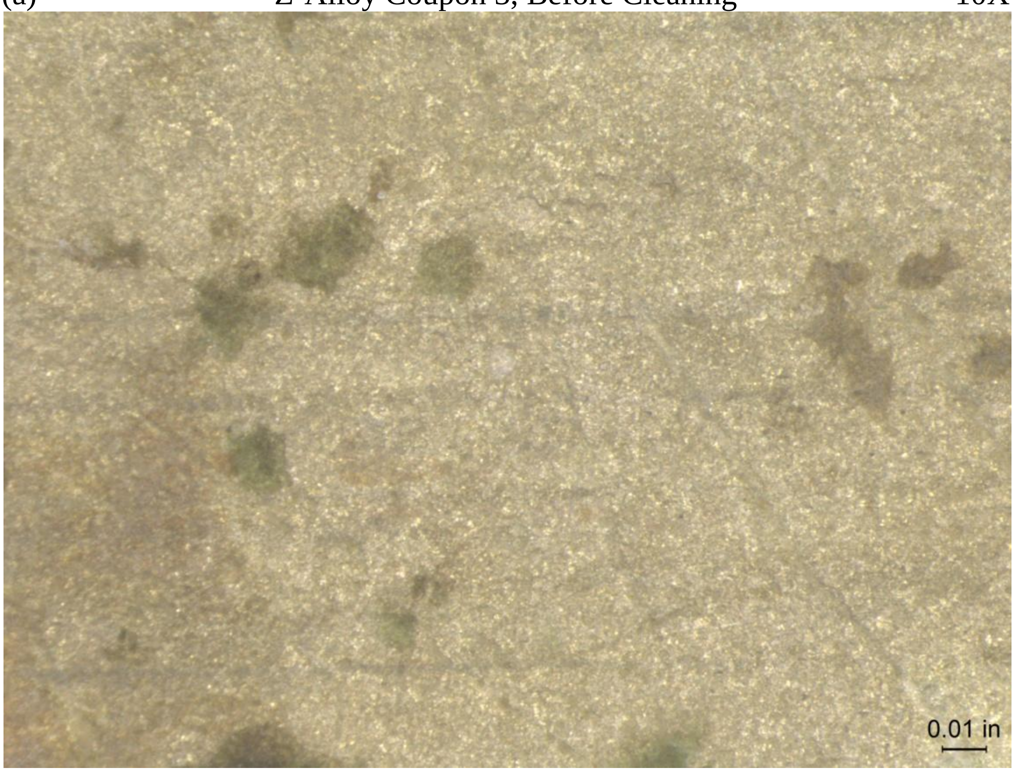
(a) Z-Alloy Coupon 2, After Cleaning 10X

(b) Z-Alloy Coupon 2, After Cleaning 50X

Figure 17 Optical macrographs of Z-Alloy coupon 2 after a 6 month corrosion test, after cleaning.

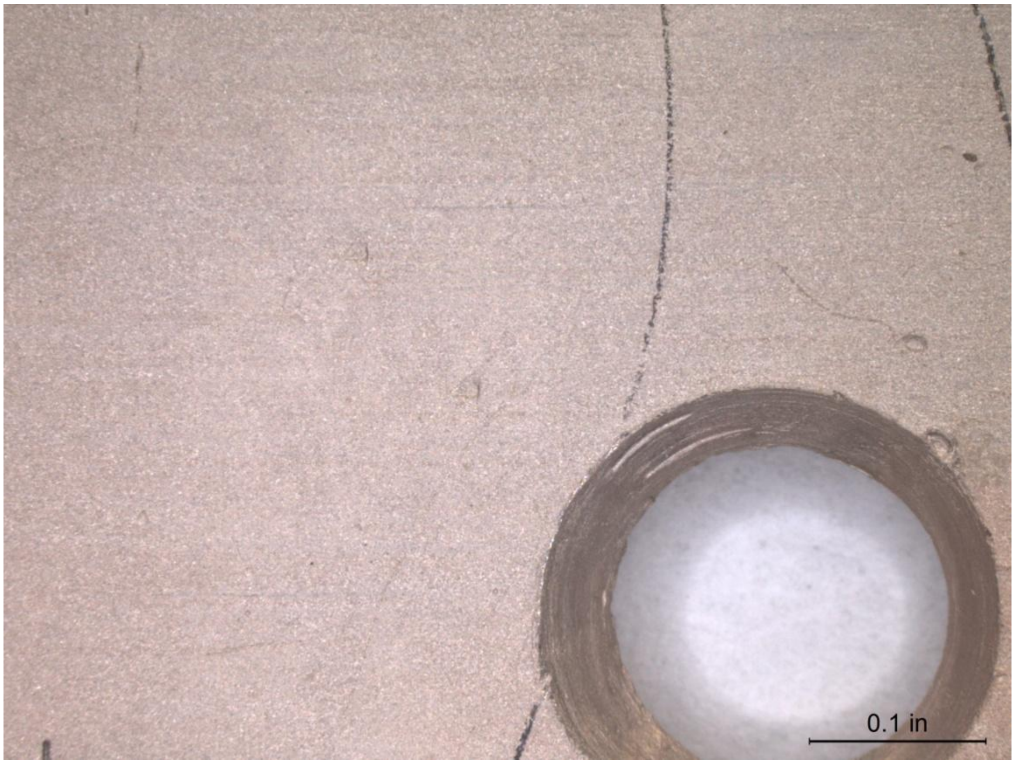


(a) Z-Alloy Coupon 3, Before Cleaning 10X



(b) Z-Alloy Coupon 3, Before Cleaning 50X

Figure 18 Optical macrographs of Z-Alloy coupon 3 after a 10 month corrosion test, before cleaning.

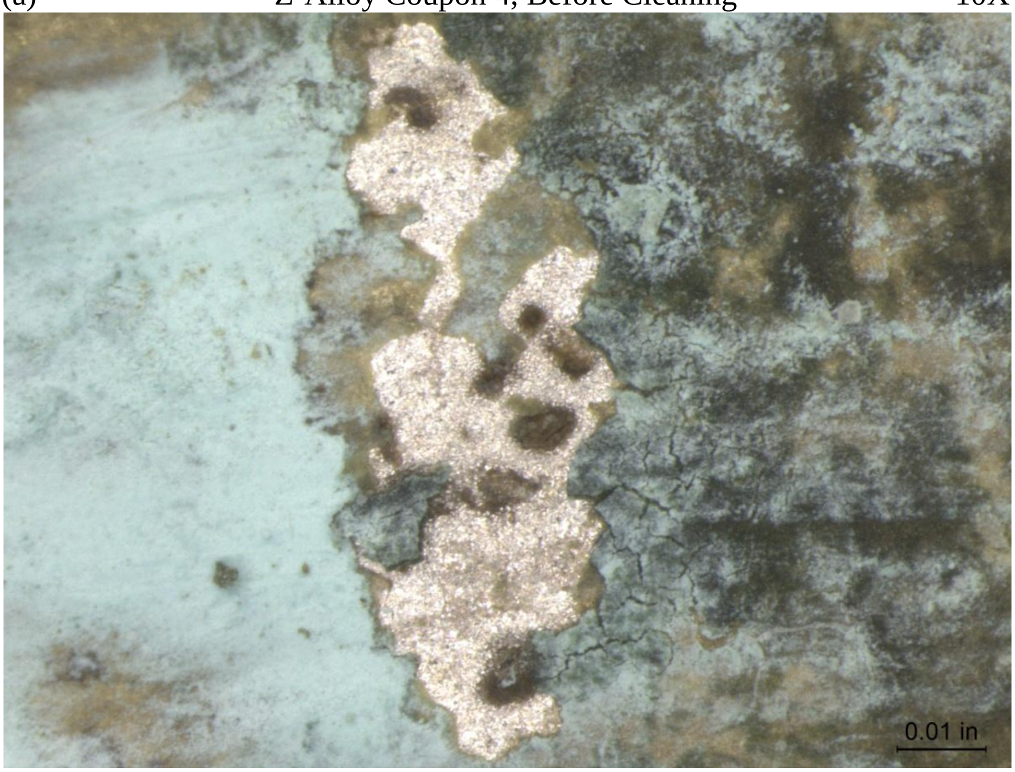


(a) Z-Alloy Coupon 3, After Cleaning 10X

(b) Z-Alloy Coupon 3, After Cleaning 50X

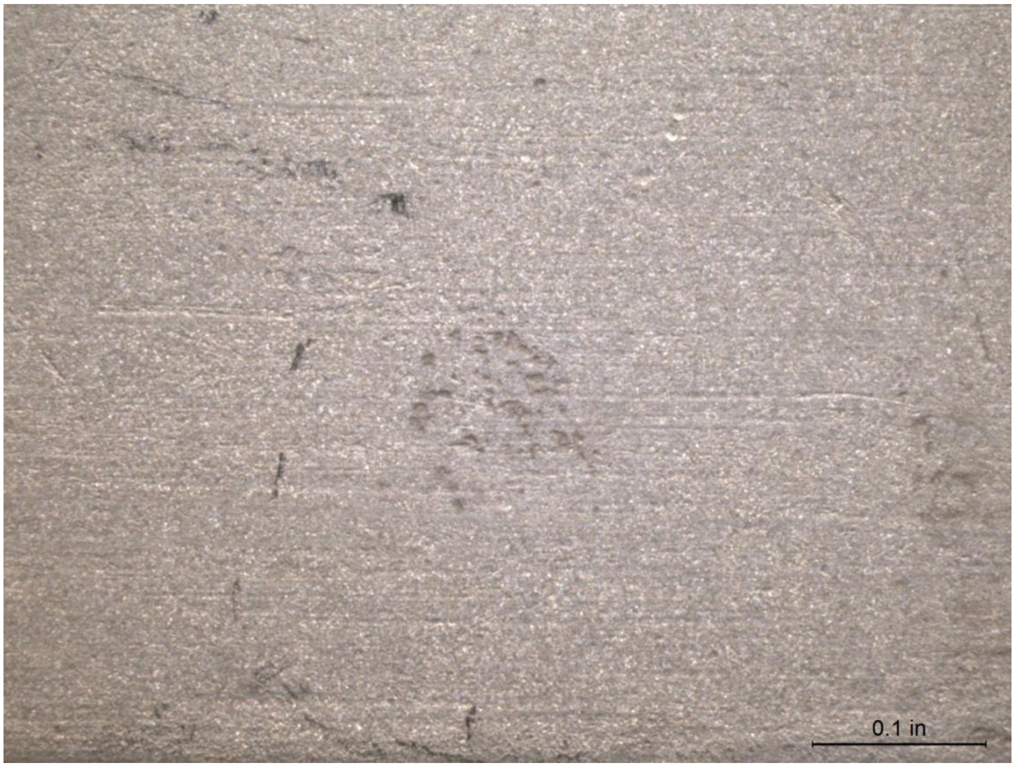
Figure 19 Optical macrographs of Z-Alloy coupon 3 after a 10 month corrosion test, after cleaning.

(a) Z-Alloy Coupon 4, Before Cleaning 10X

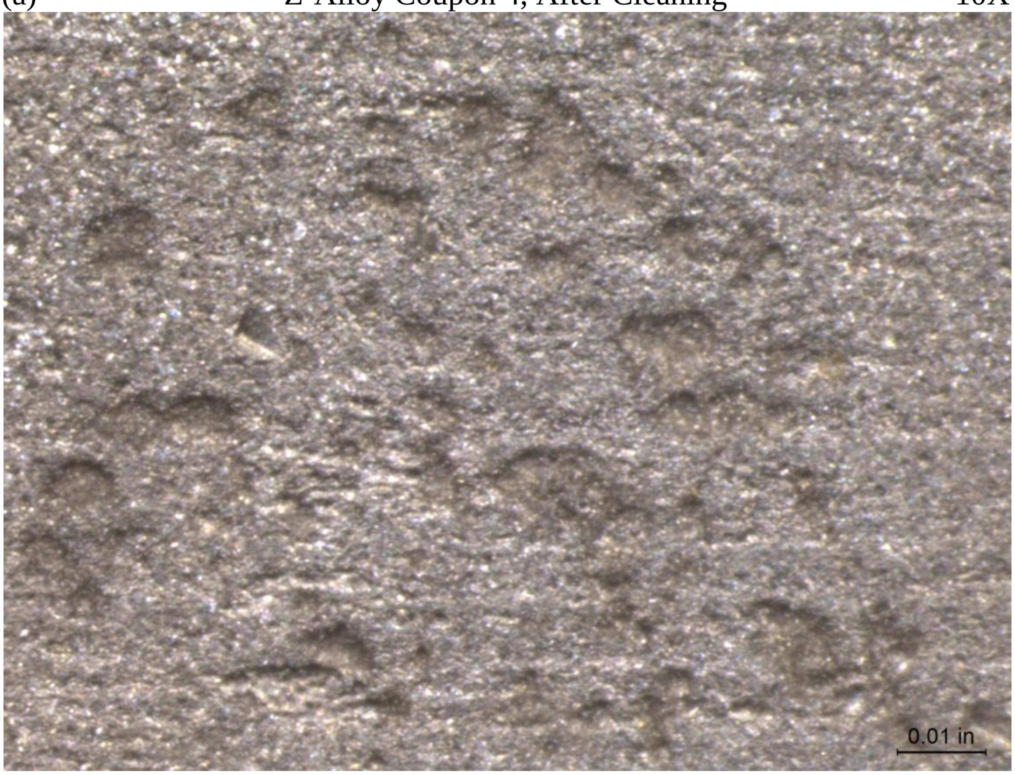


(b) Z-Alloy Coupon 4, Before Cleaning 50X

Figure 20 Optical macrographs of Z-Alloy coupon 4 after a 12 month corrosion test, before cleaning.

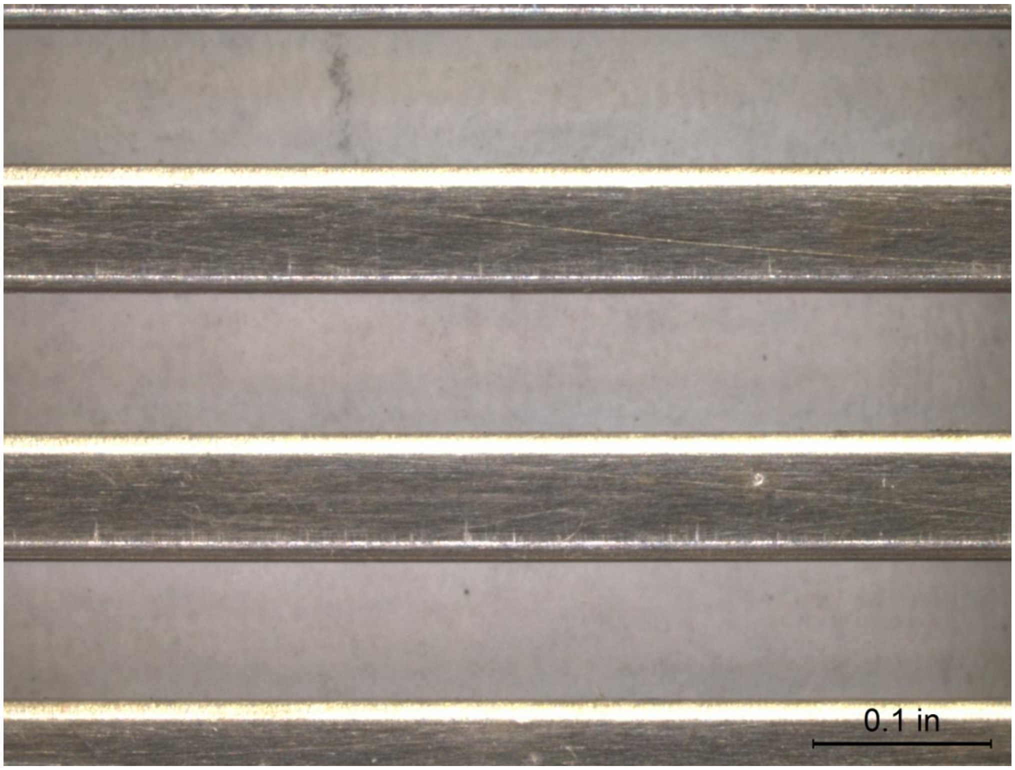


(a) Z-Alloy Coupon 4, After Cleaning 10X

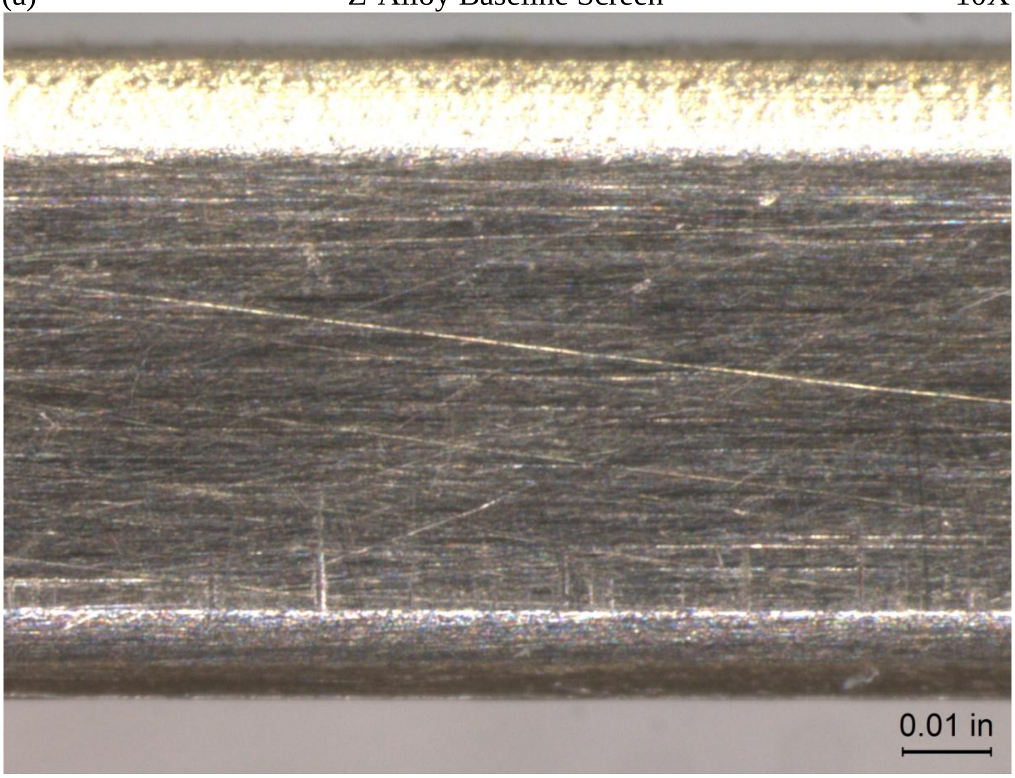


(b) Z-Alloy Coupon 4, After Cleaning 50X

Figure 21 Optical macrographs of Z-Alloy coupon 4 after a 12 month corrosion test, after cleaning.

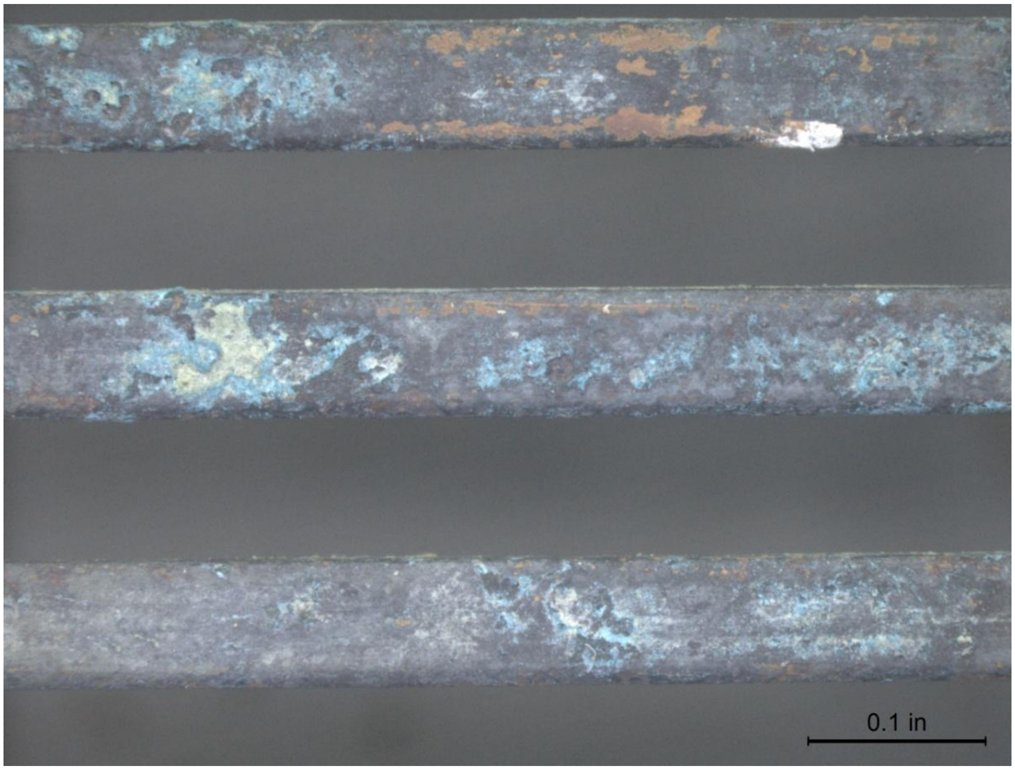


(a) Z-Alloy Baseline Screen 10X

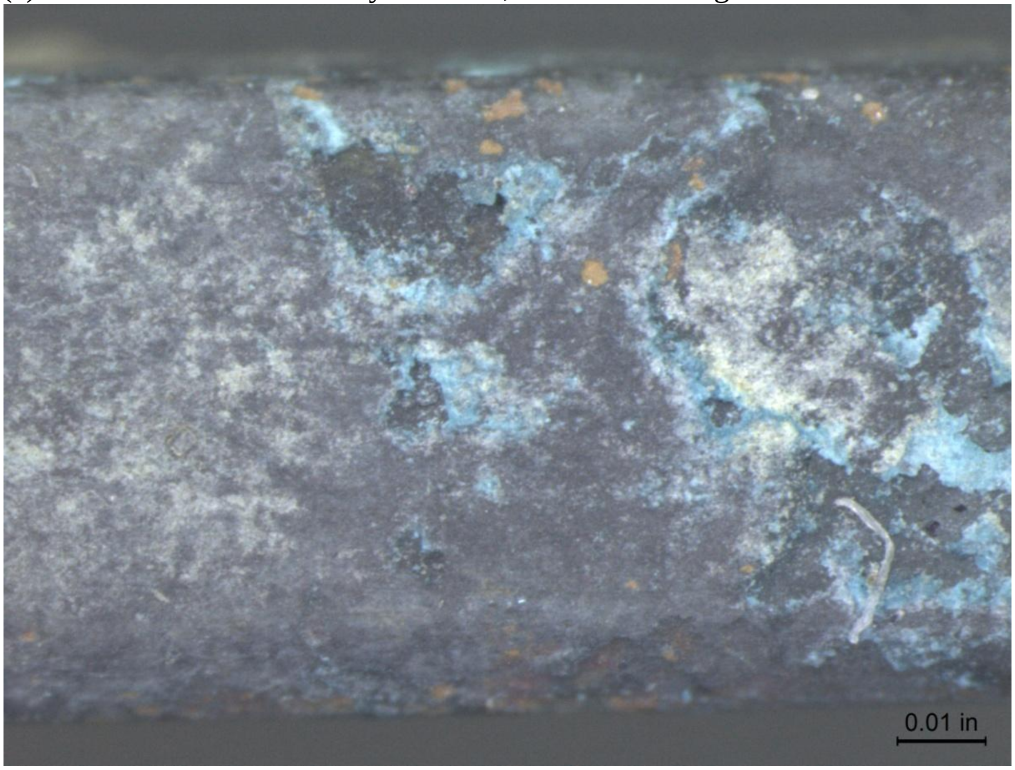


(b) Z-Alloy Baseline Screen 50X

Figure 22 Optical macrographs of the Z-Alloy baseline screen.

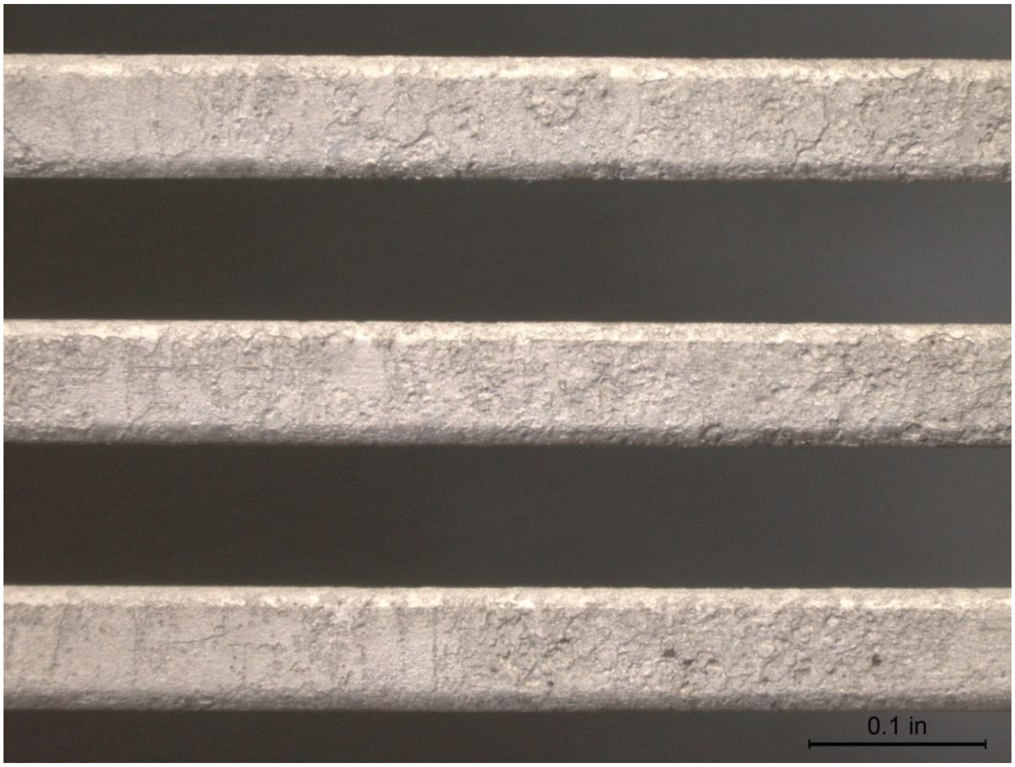


(a) Z-Alloy Screen 1, Before Cleaning 10X

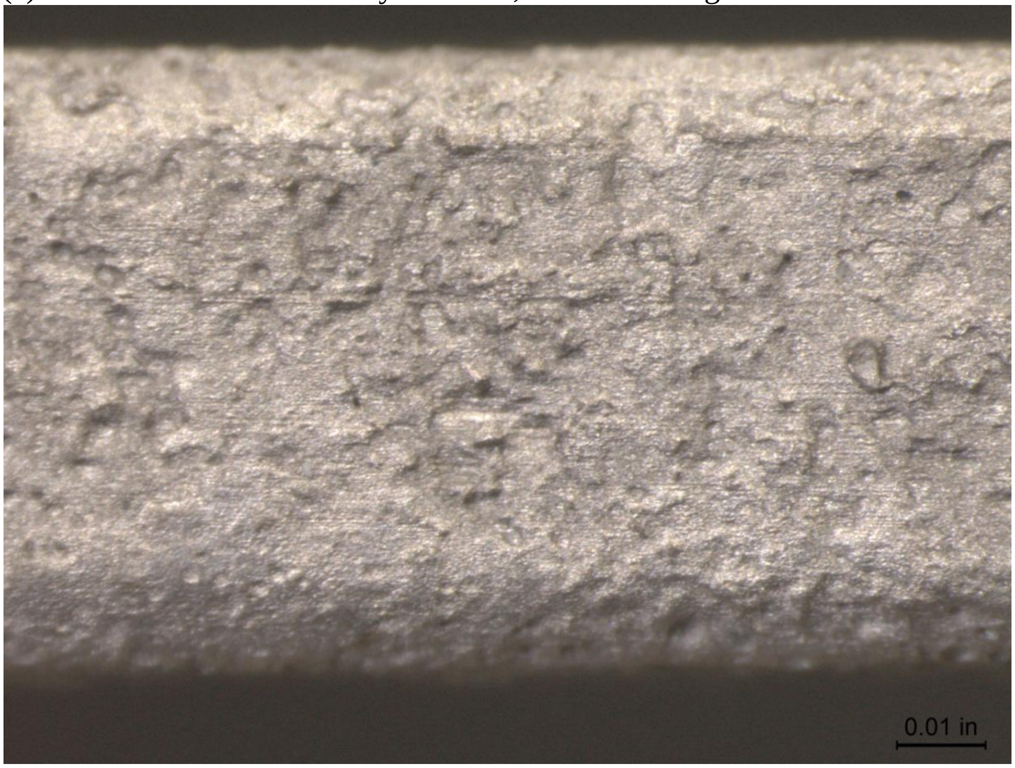


(b) Z-Alloy Screen 1, Before Cleaning 50X

Figure 23 Optical macrographs of Z-Alloy screen 1 after a 3 month corrosion test, before cleaning.

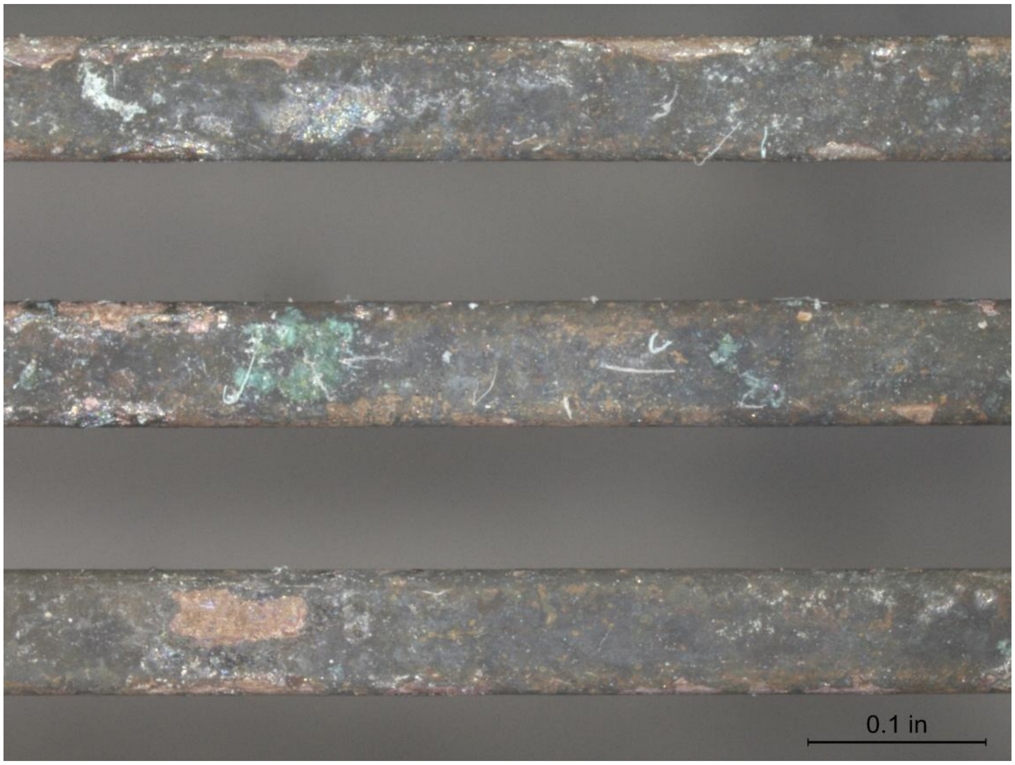


(a) Z-Alloy Screen 1, After Cleaning 10X



(b) Z-Alloy Screen 1, After Cleaning 50X

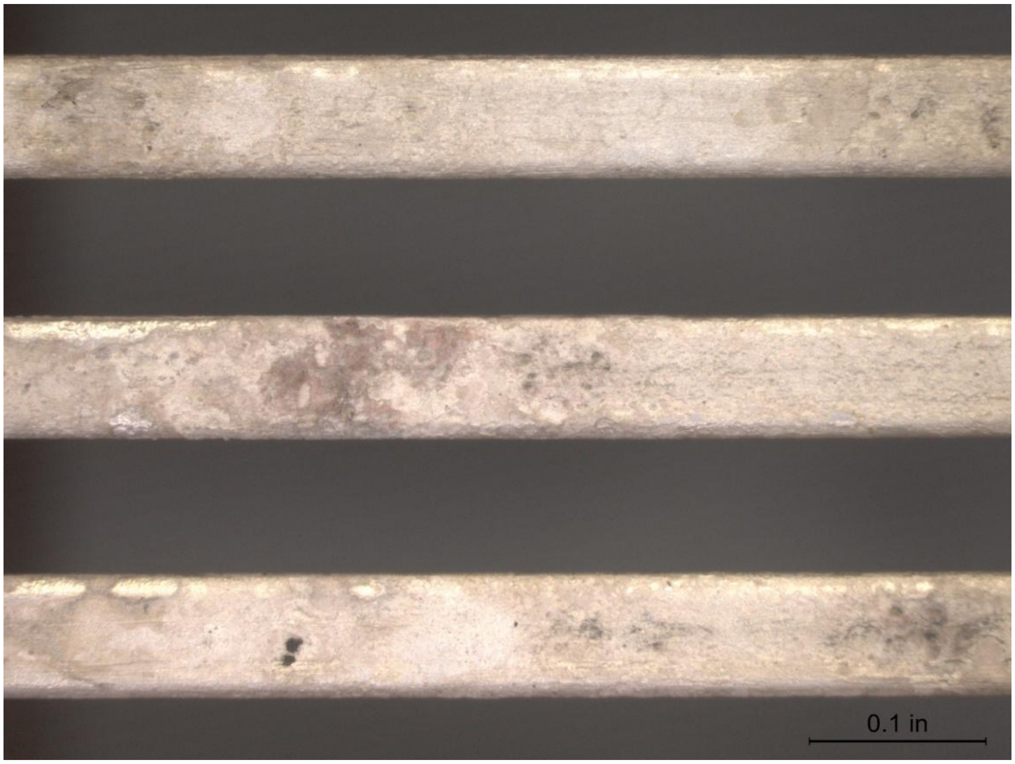
Figure 24 Optical macrographs of Z-Alloy screen 1 after a 3 month corrosion test, after cleaning.



(a) Z-Alloy Screen 2, Before Cleaning 10X

(b) Z-Alloy Screen 2, Before Cleaning 50X

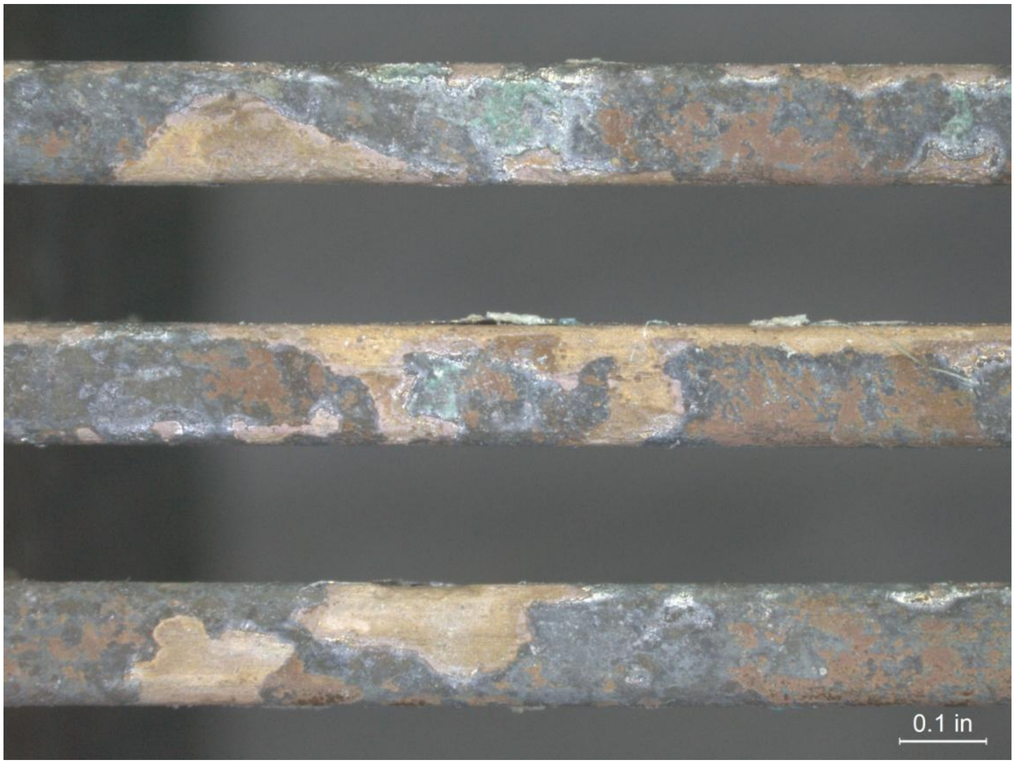
Figure 25 Optical macrographs of Z-Alloy screen 2 after a 6 month corrosion test, before cleaning.



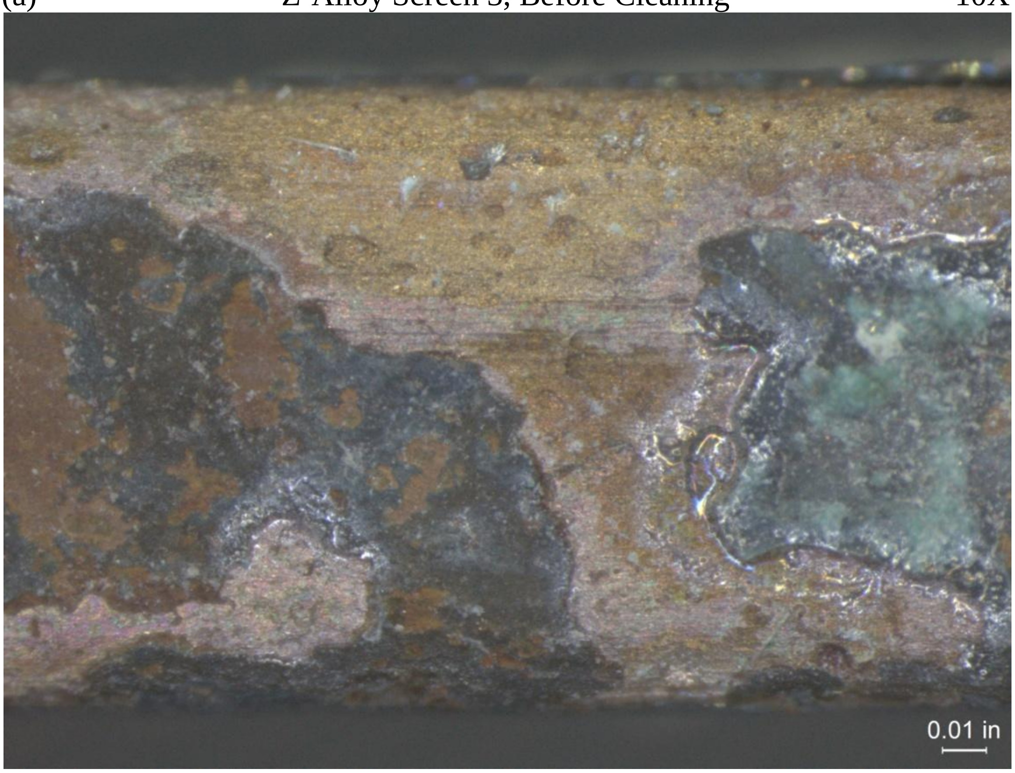
(a) Z-Alloy Screen 2, After Cleaning 10X

(b) Z-Alloy Screen 2, After Cleaning 50X

Figure 26 Optical macrographs of Z-Alloy screen 2 after a 6 month corrosion test, after cleaning.

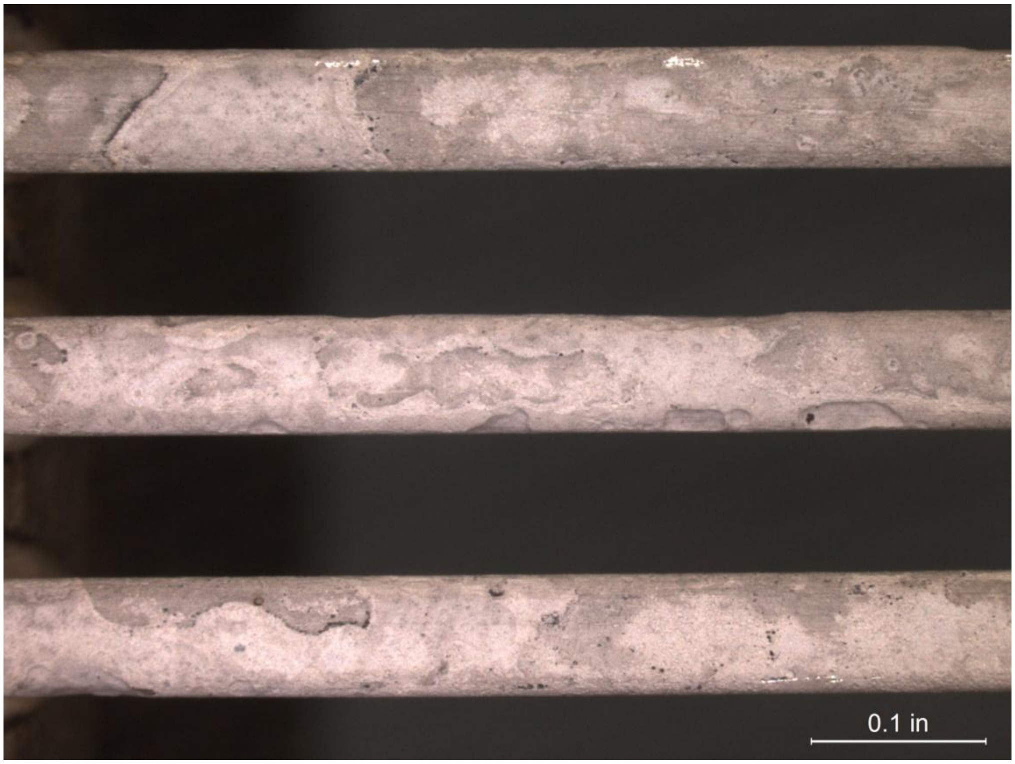


(a) Z-Alloy Screen 3, Before Cleaning 10X

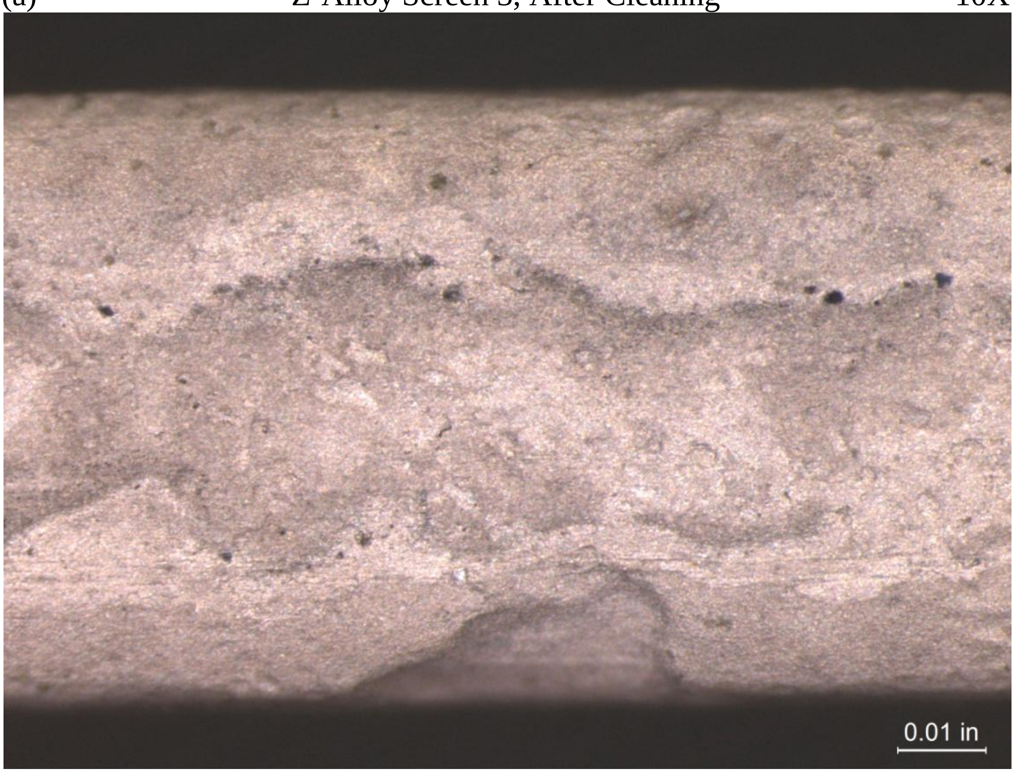


(b) Z-Alloy Screen 3, Before Cleaning 50X

Figure 27 Optical macrographs of Z-Alloy screen 3 after a 10 month corrosion test, before cleaning.

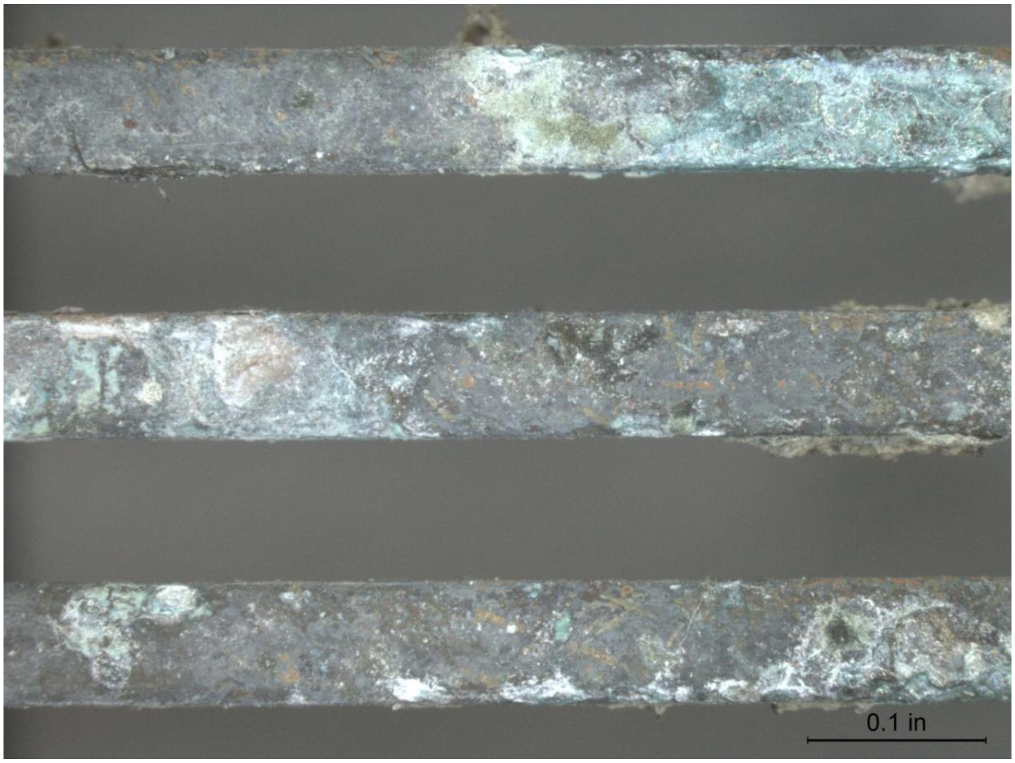


(a) Z-Alloy Screen 3, After Cleaning 10X

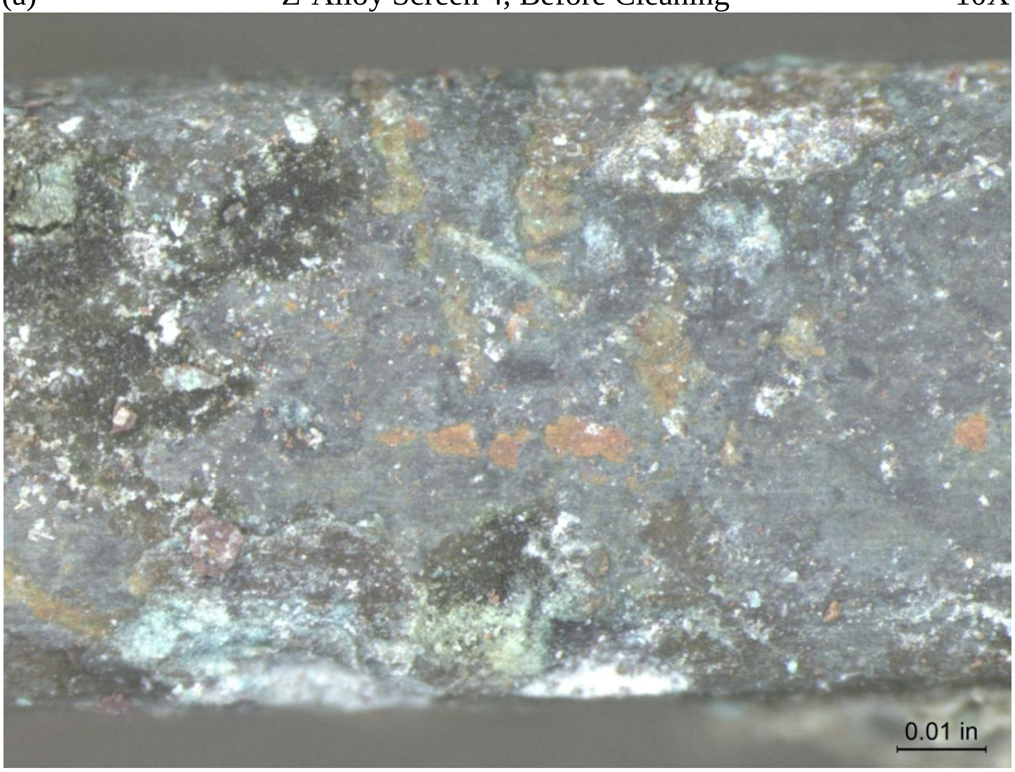


(b) Z-Alloy Screen 3, After Cleaning 50X

Figure 28 Optical macrographs of Z-Alloy screen 3 after a 10 month corrosion test, after cleaning.

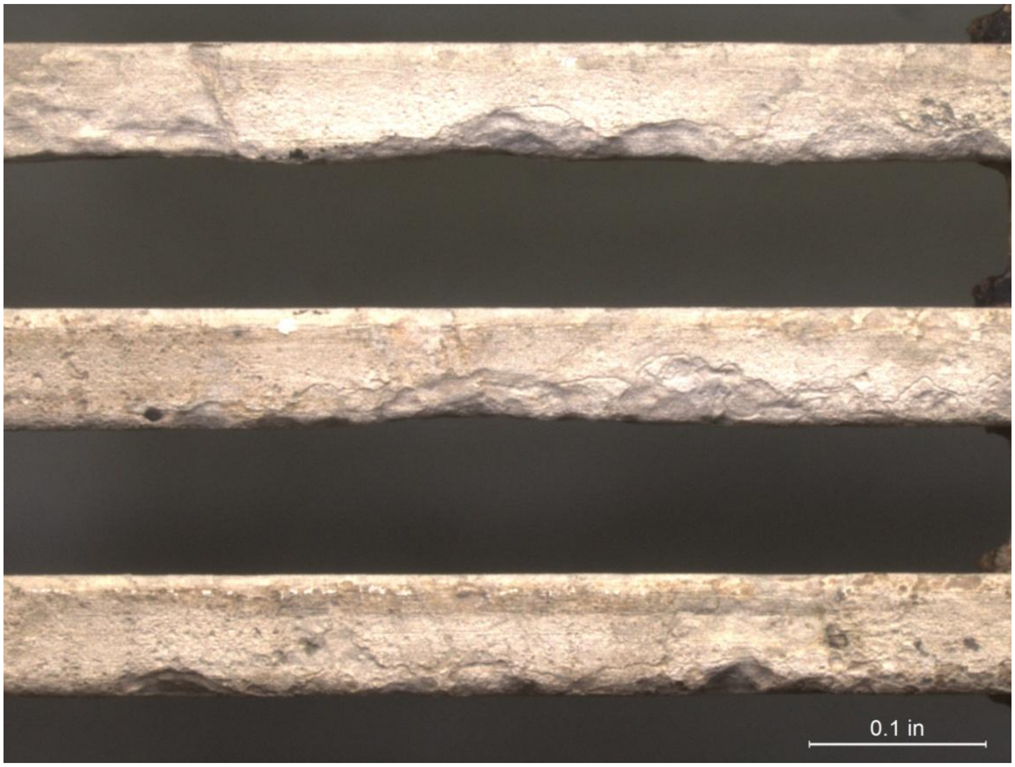


(a) Z-Alloy Screen 4, Before Cleaning 10X



(b) Z-Alloy Screen 4, Before Cleaning 50X

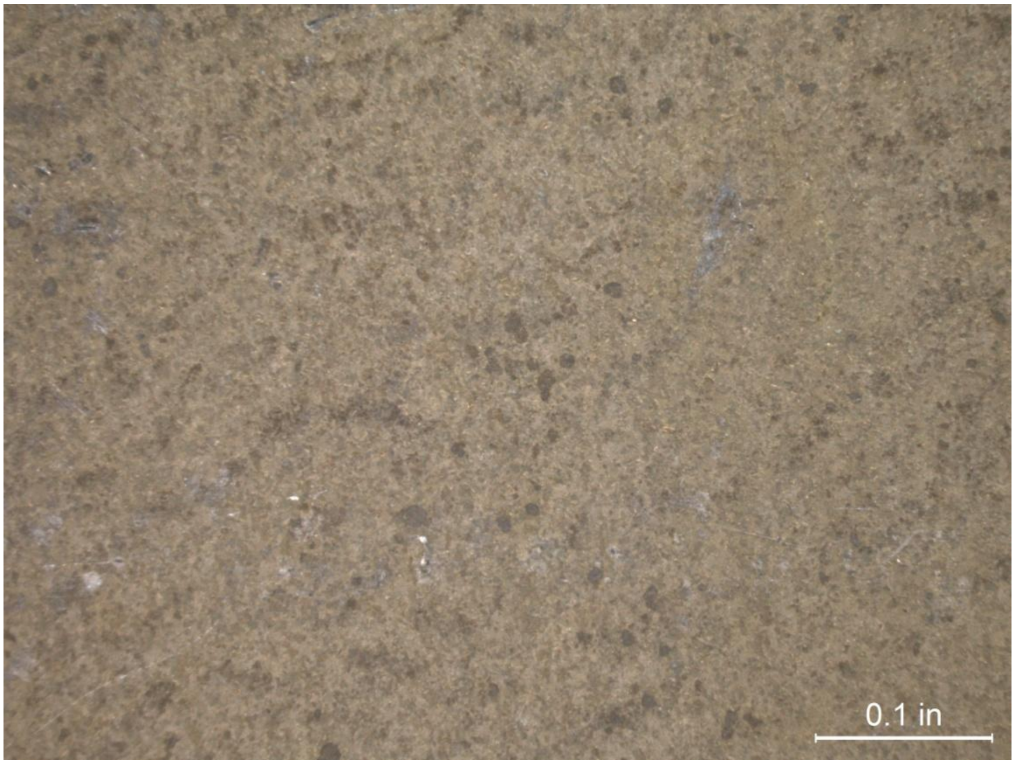
Figure 29 Optical macrographs of Z-Alloy screen 4 after a 12 month corrosion test, before cleaning.



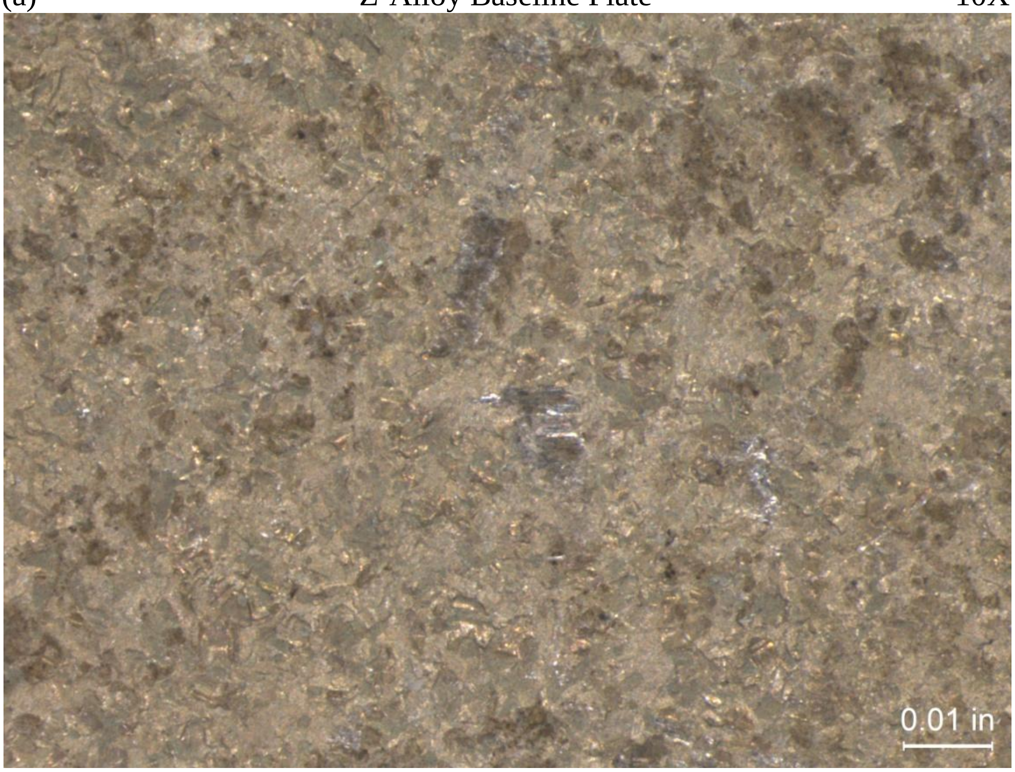
(a) Z-Alloy Screen 4, After Cleaning 10X

(b) Z-Alloy Screen 4, After Cleaning 50X

Figure 30 Optical macrographs of Z-Alloy screen 4 after a 12 month corrosion test, after cleaning.

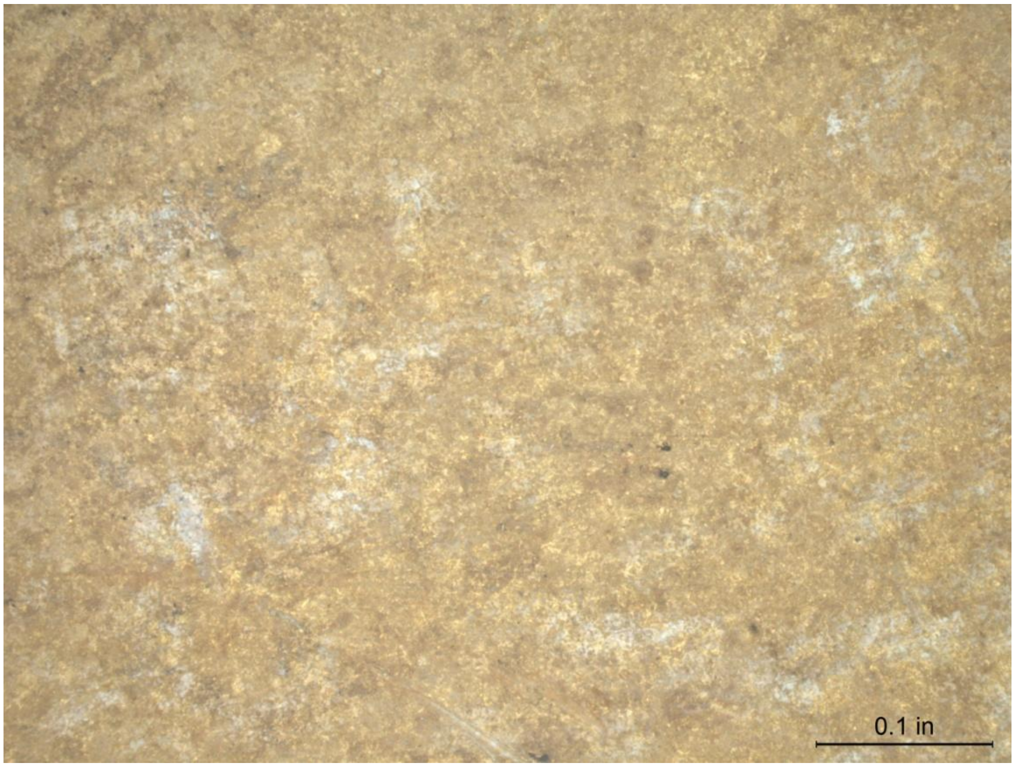


(a) Z-Alloy Baseline Plate 10X

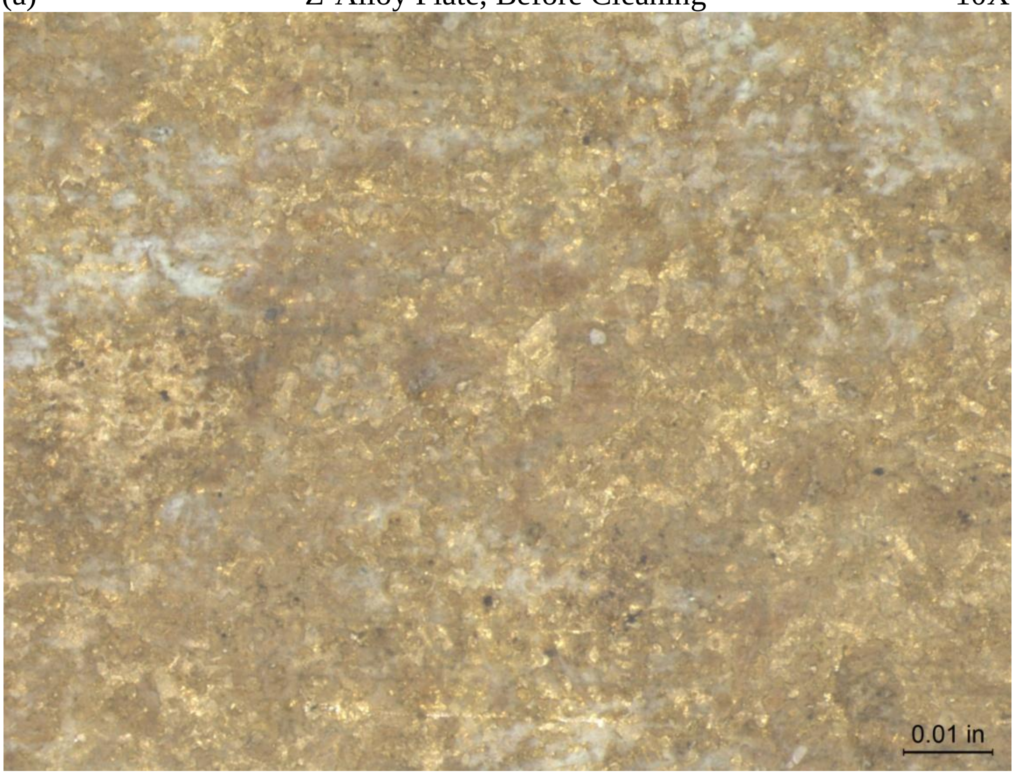


(b) Z-Alloy Baseline Plate 50X

Figure 31 Optical macrographs of Z-Alloy baseline plate.

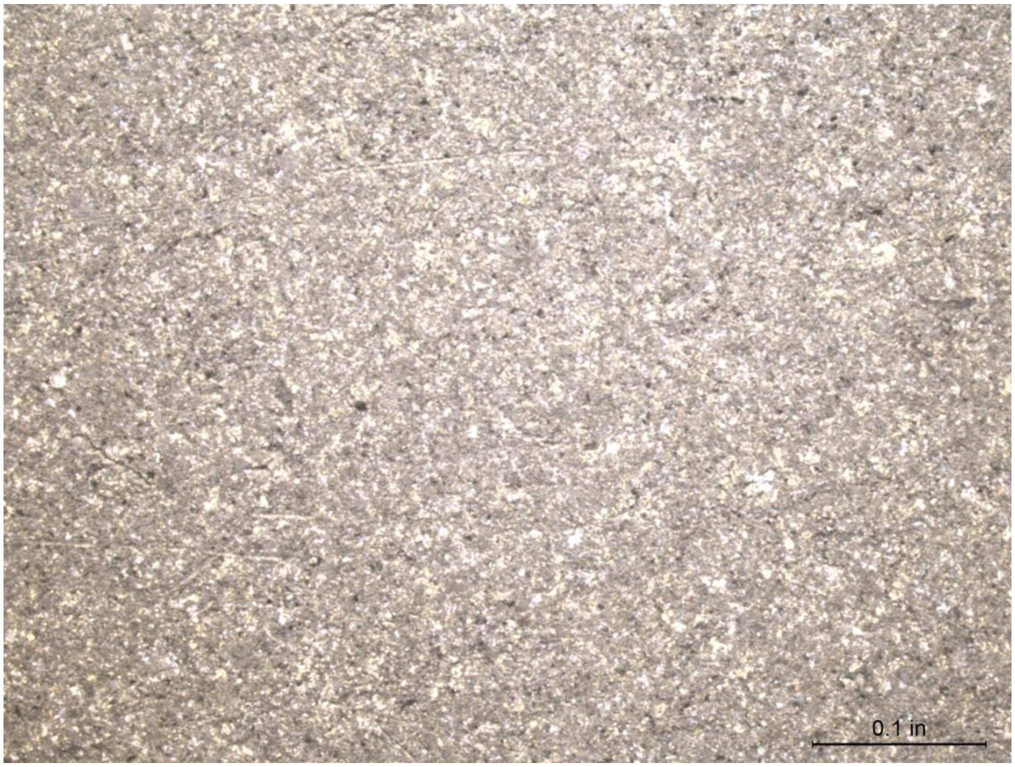


(a) Z-Alloy Plate, Before Cleaning 10X

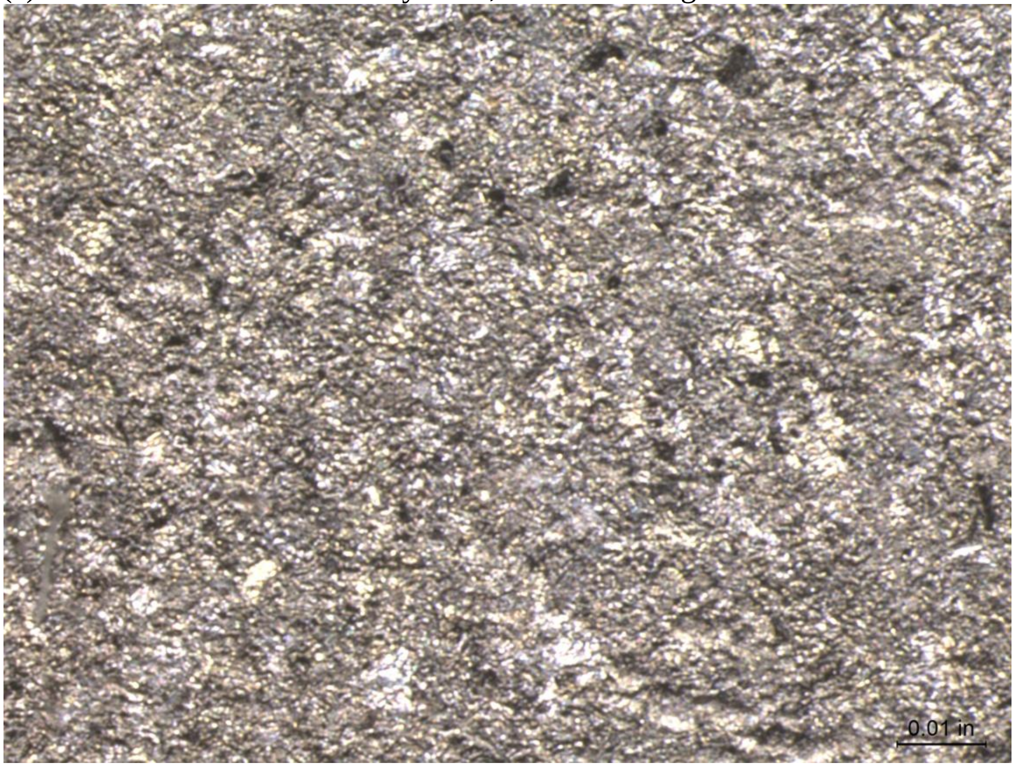


(b) Z-Alloy Plate, Before Cleaning 50X

Figure 32 Optical macrographs of Z-Alloy plate after a 12 month corrosion test, before cleaning.

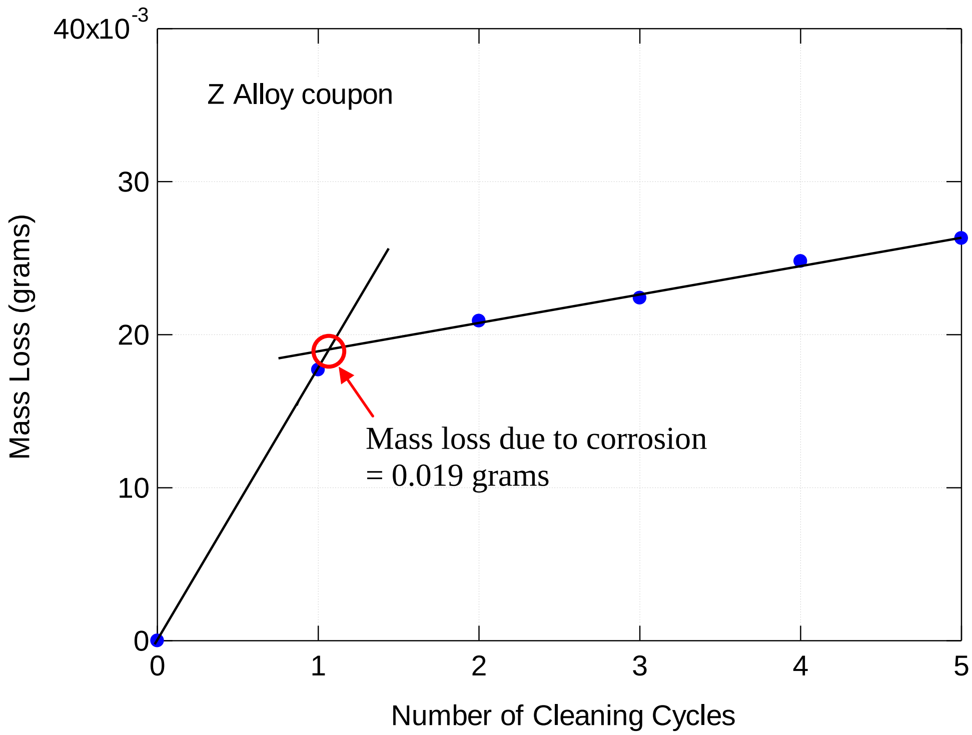


(a) Z-Alloy Plate, After Cleaning 10X

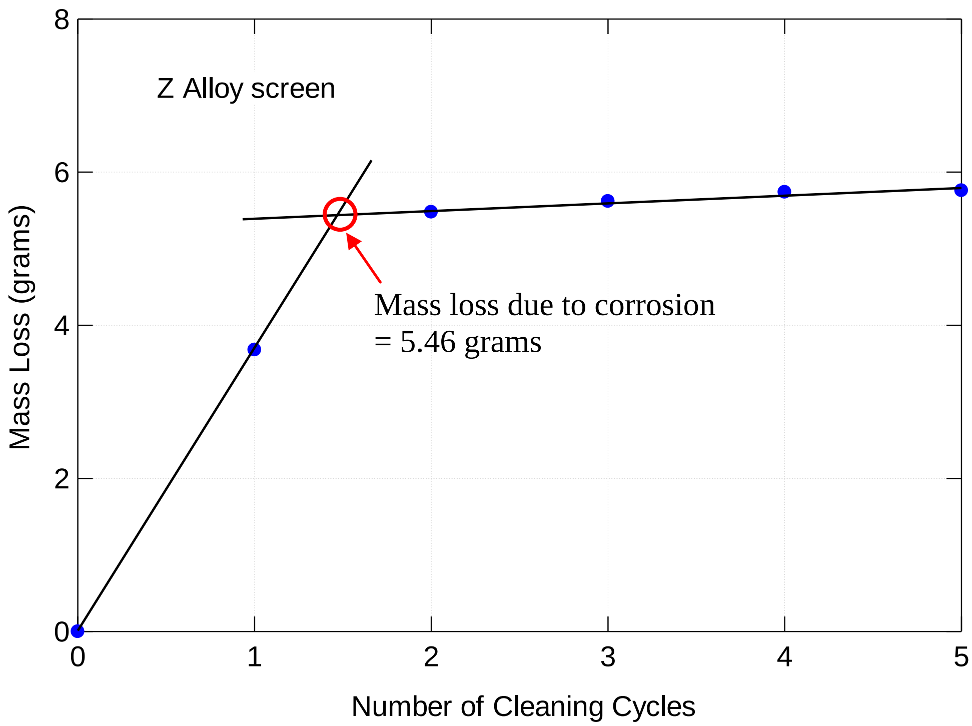


(b) Z-Alloy Plate, After Cleaning 50X

Figure 33 Optical macrographs of Z-Alloy plate after a 12 month corrosion test, after cleaning.

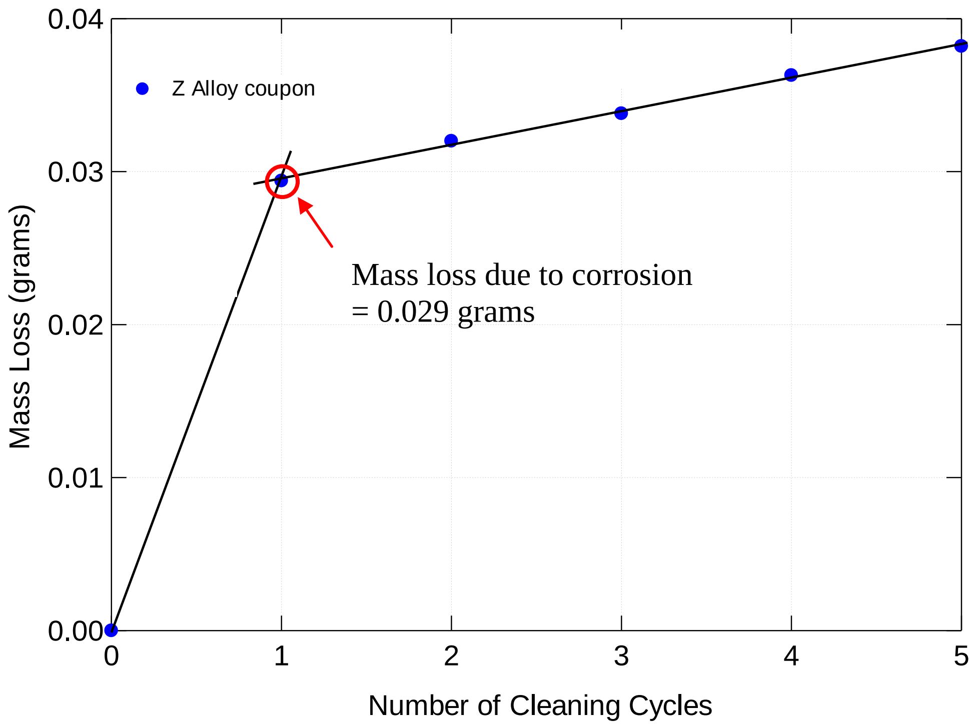


(a)



(b)

Figure 34 Mass loss of the Z-Alloy (a) coupon 1 and (b) screen 1 during cleaning.



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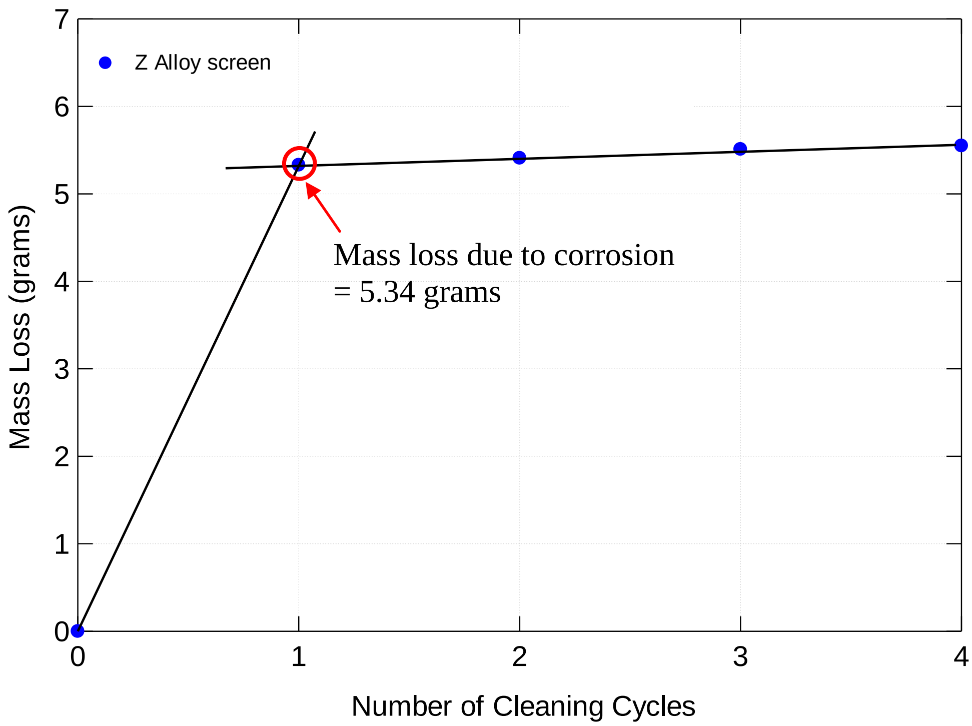
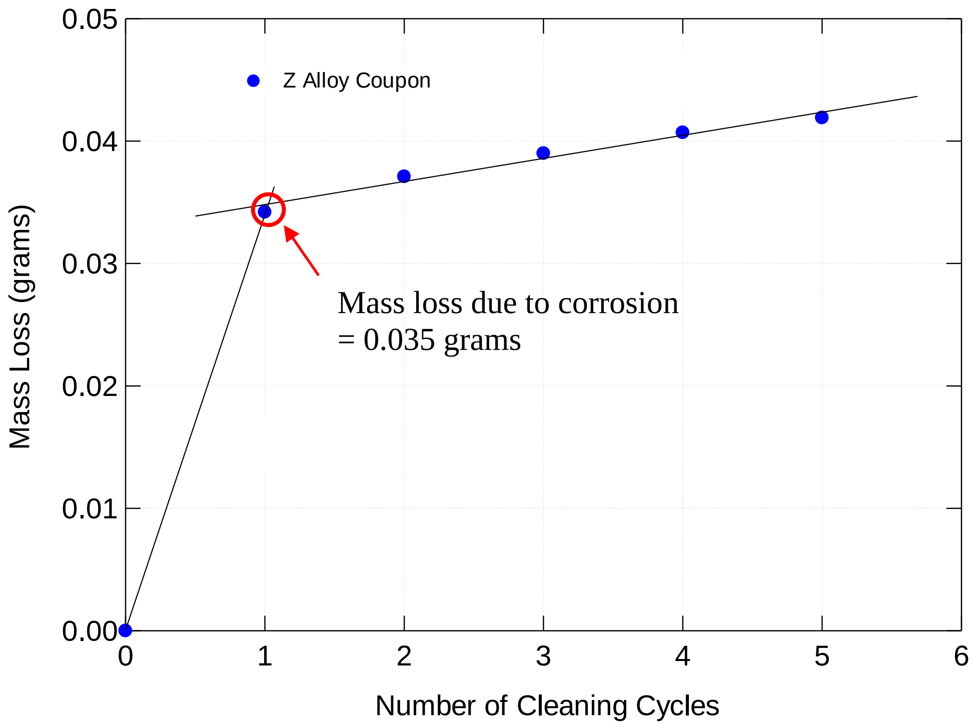


(b)

Figure 35 Mass loss of the Z-Alloy (a) coupon 2 and (b) screen 2 during cleaning.



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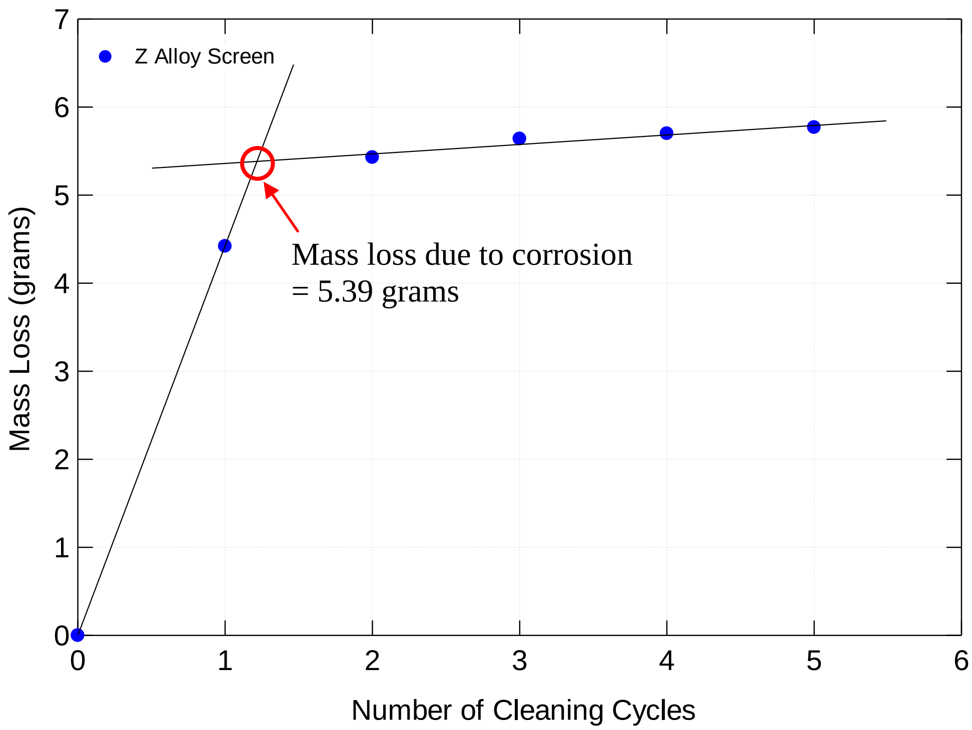
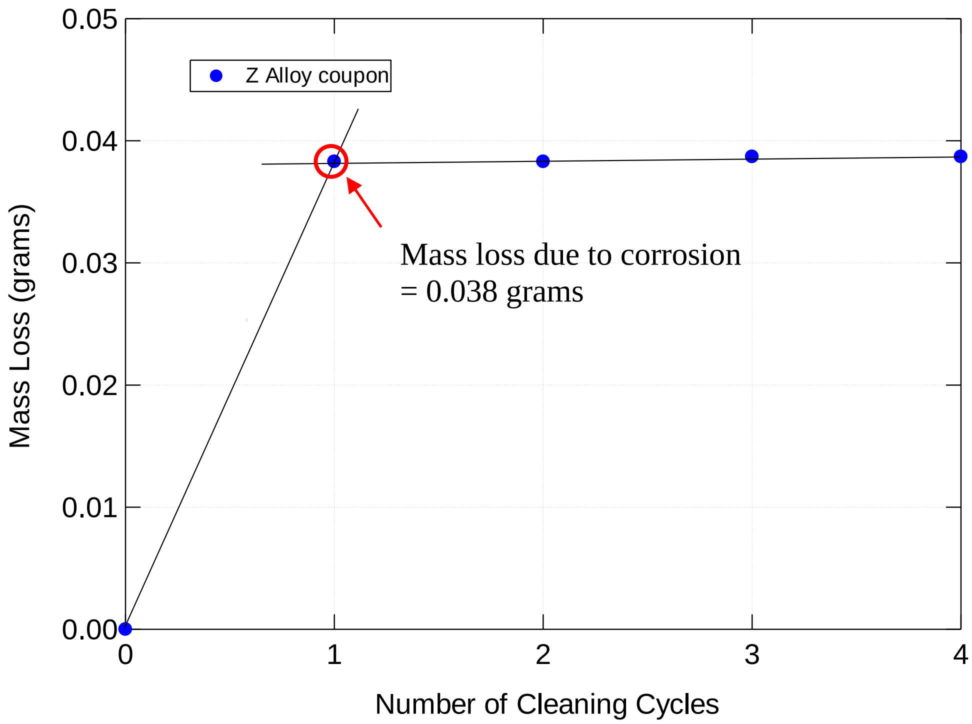
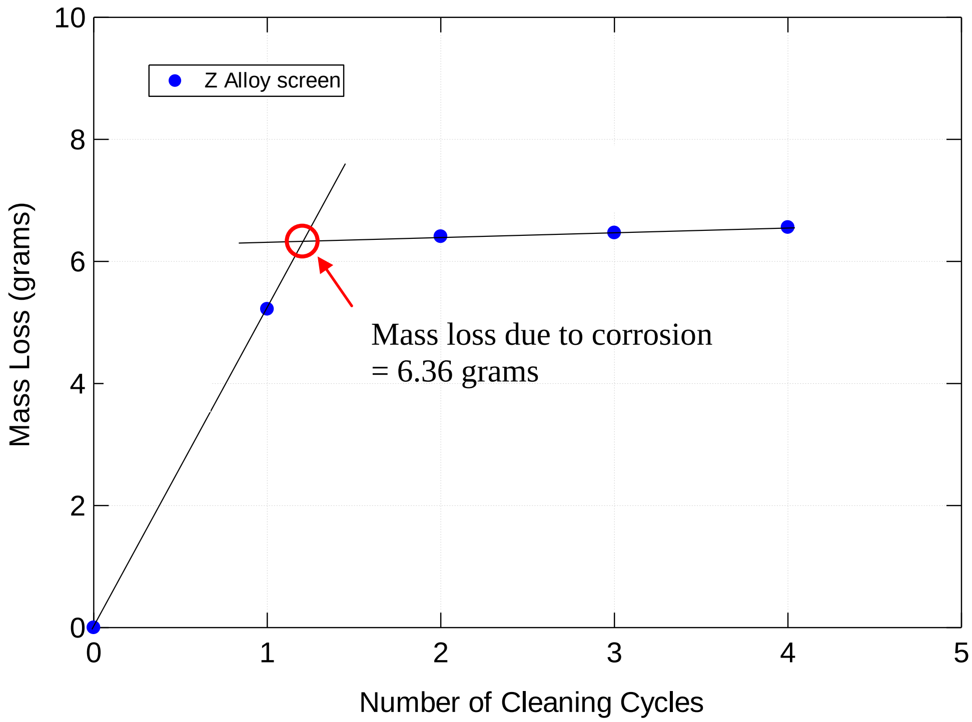


(b)

Figure 36 Mass loss of the Z-Alloy (a) coupon 3 and (b) screen 3 during cleaning.

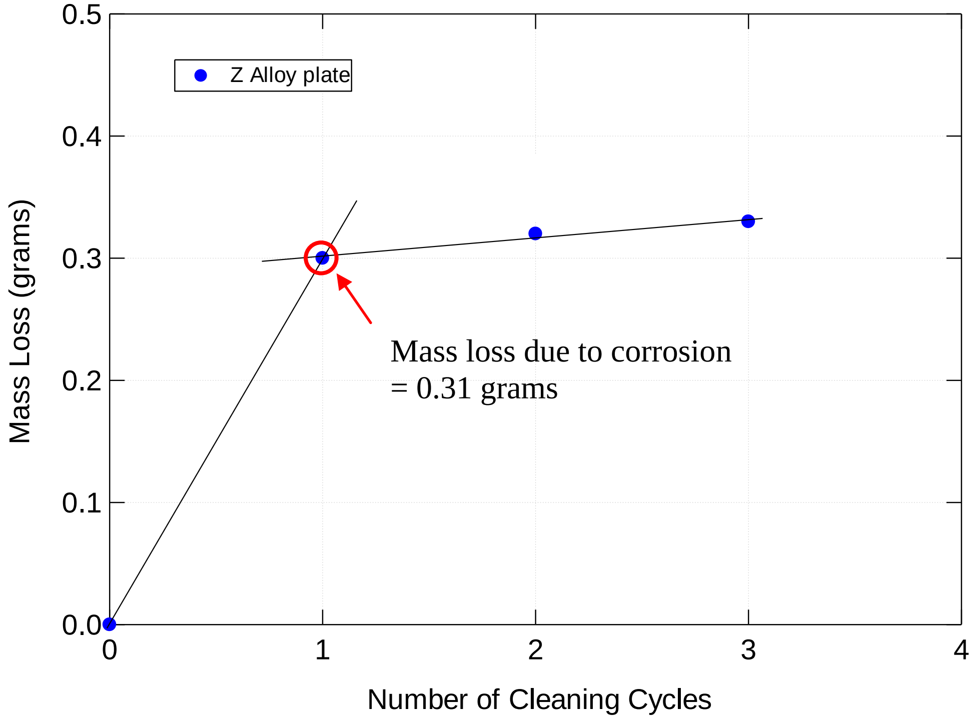


(a)



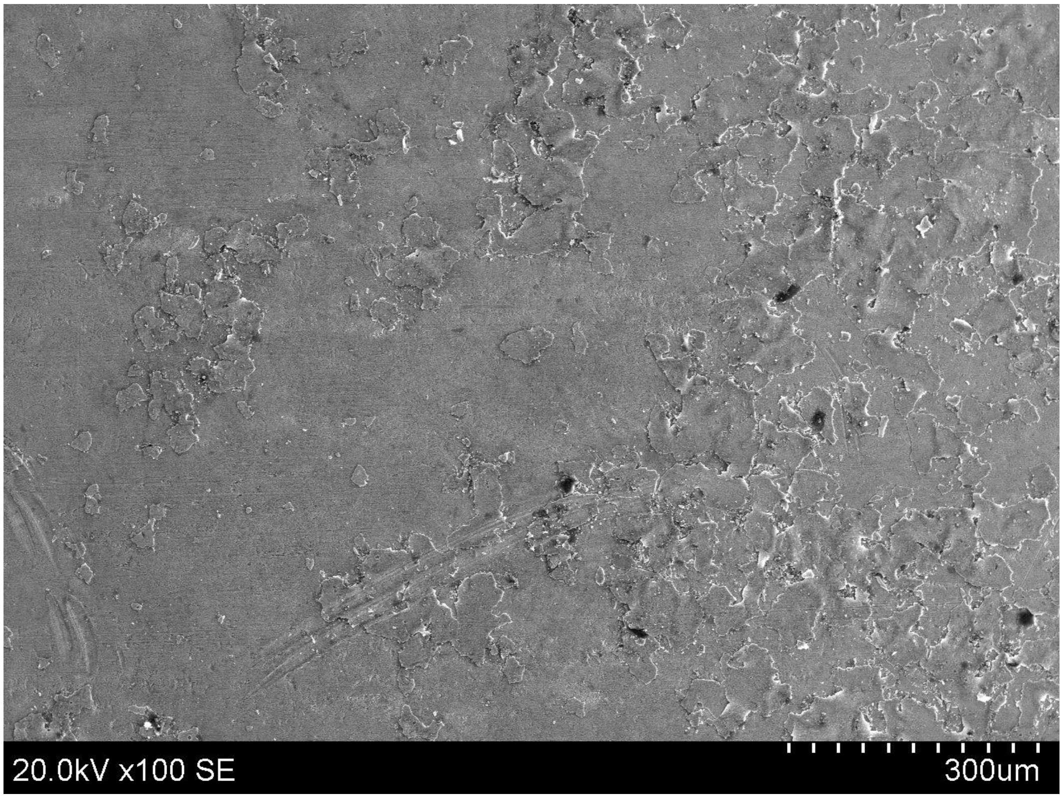
(b)

Figure 37 Mass loss of the Z-Alloy (a) coupon 4 and (b) screen 4 during cleaning.

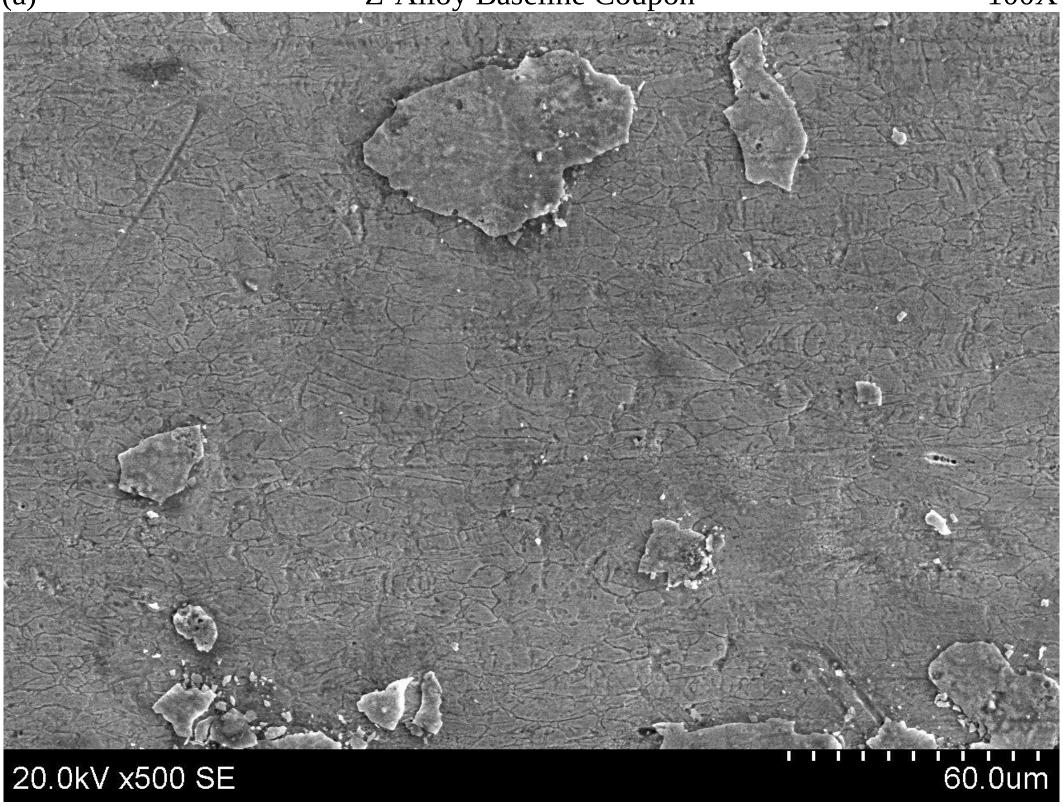


(a)

Figure 38 Mass loss of the Z-Alloy plate during cleaning.

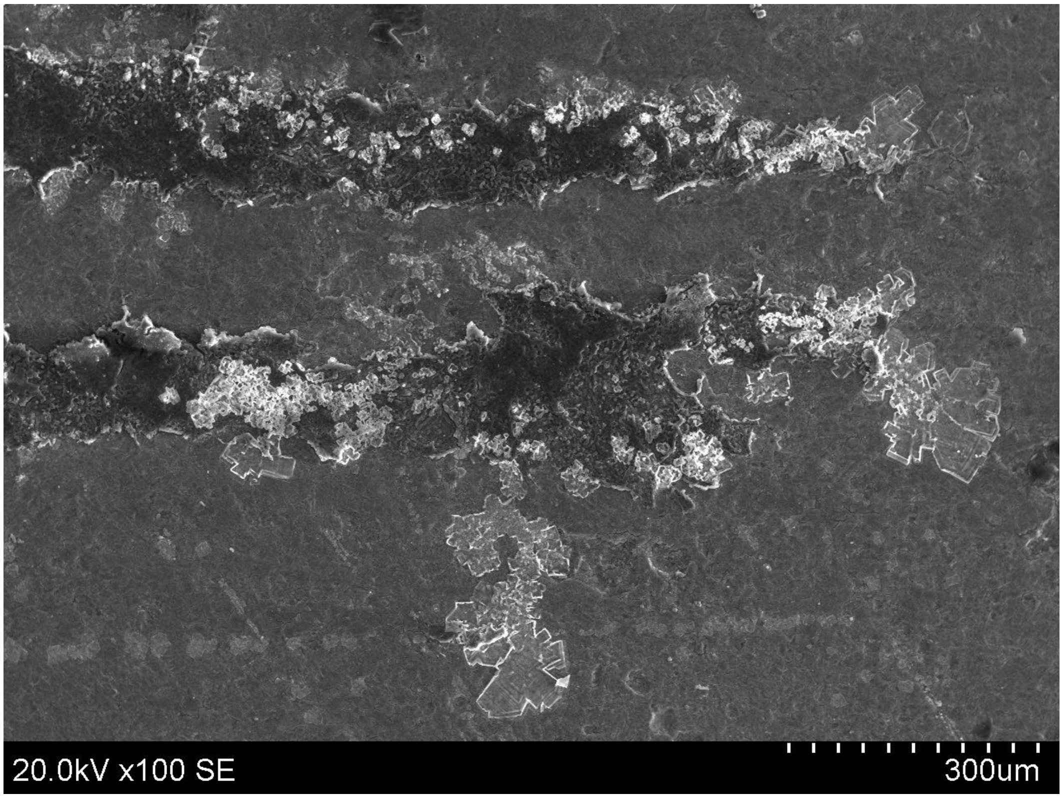


(a) Z-Alloy Baseline Coupon 100X

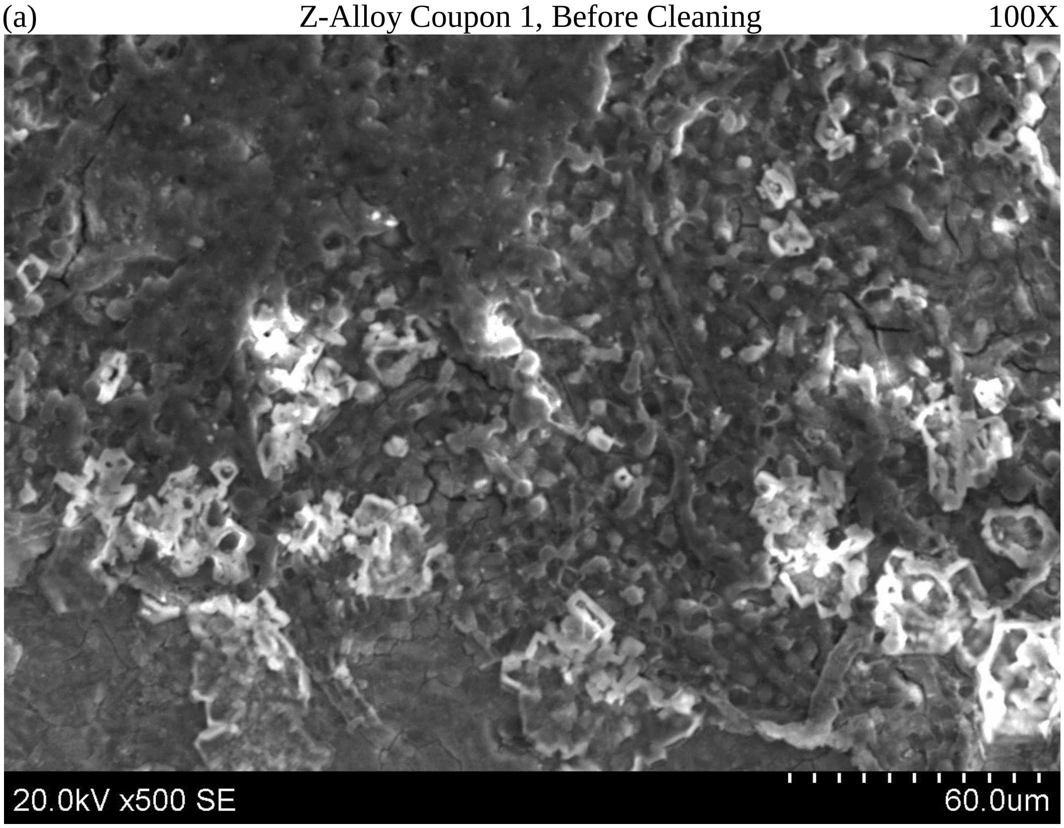


(b) Z-Alloy Baseline Coupon 500X

Figure 39 Scanning electron micrographs of Z-Alloy baseline coupon.



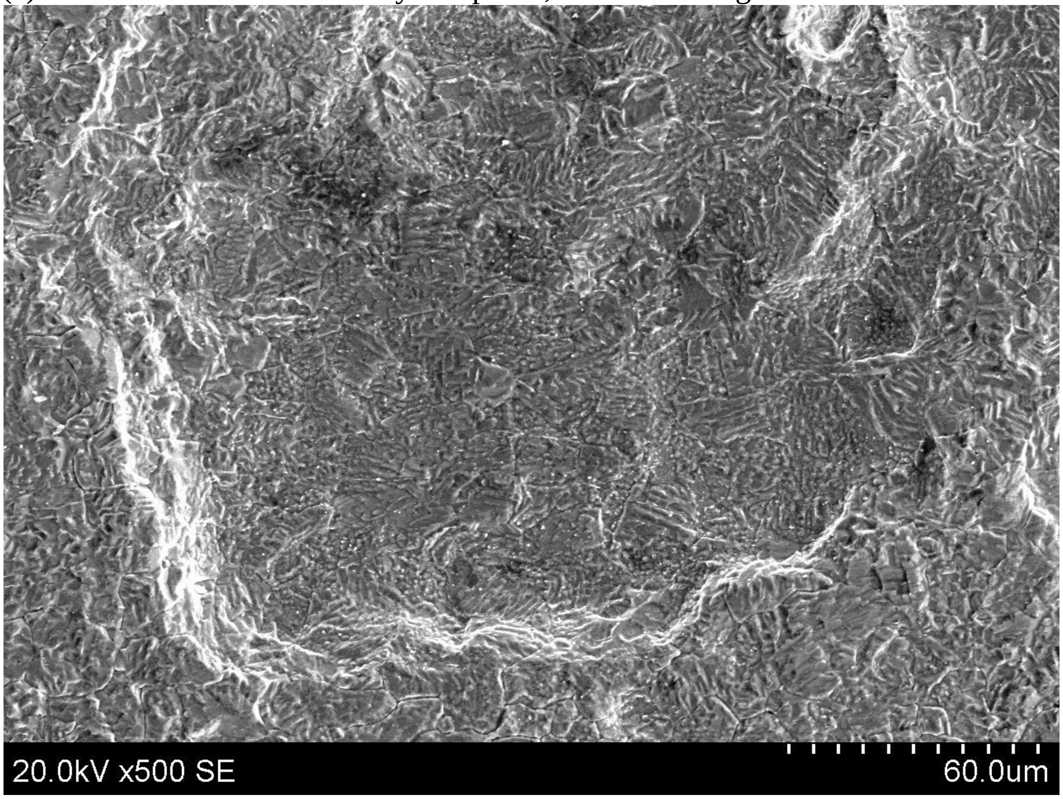
(a) Z-Alloy Coupon 1, Before Cleaning 100X



(b) Z-Alloy Coupon 1, Before Cleaning 500X

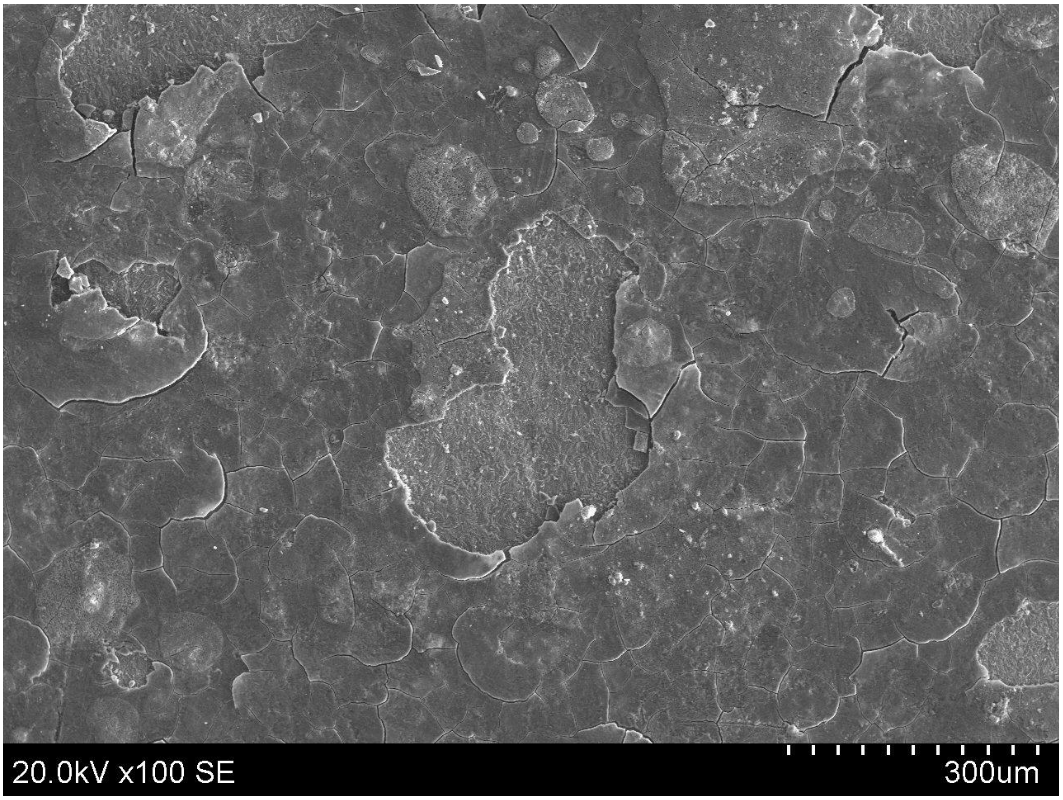
Figure 40 Scanning electron micrographs of Z-Alloy coupon 1 after a 3 month corrosion test, before cleaning.

(a) Z-Alloy Coupon 1, After Cleaning 100X

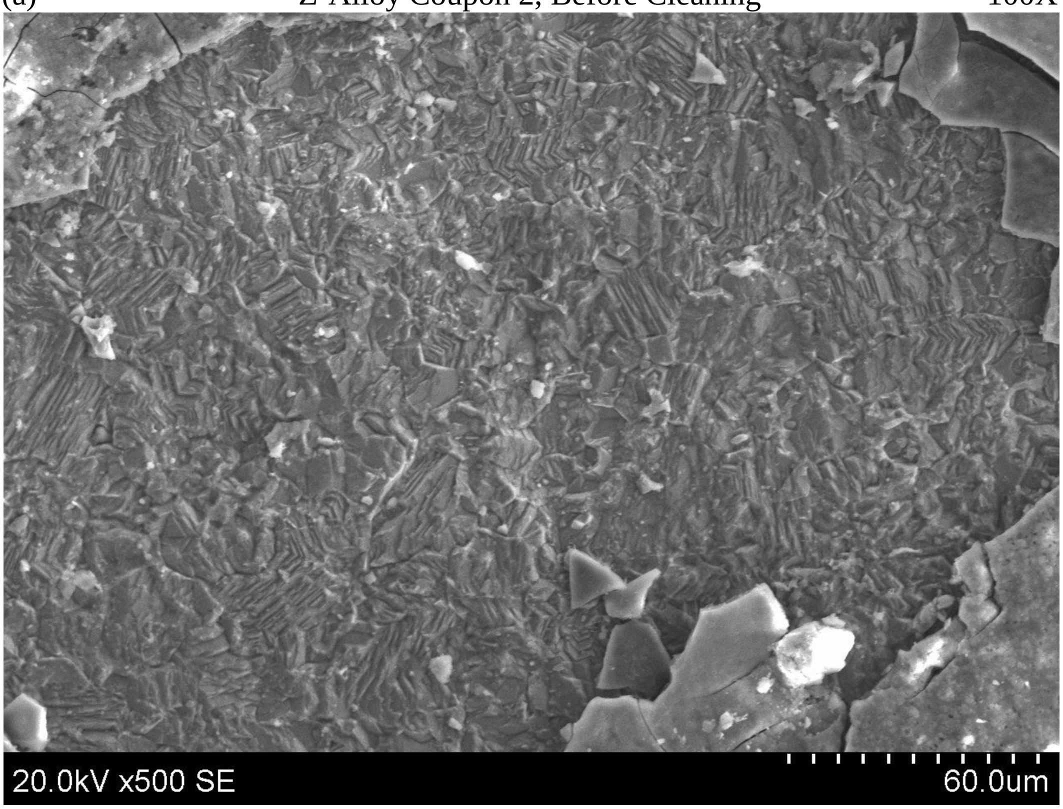


(b) Z-Alloy Coupon 1, After Cleaning 500X

Figure 41 Scanning electron micrographs of Z-Alloy coupon 1 after a 3 month corrosion test, after cleaning.

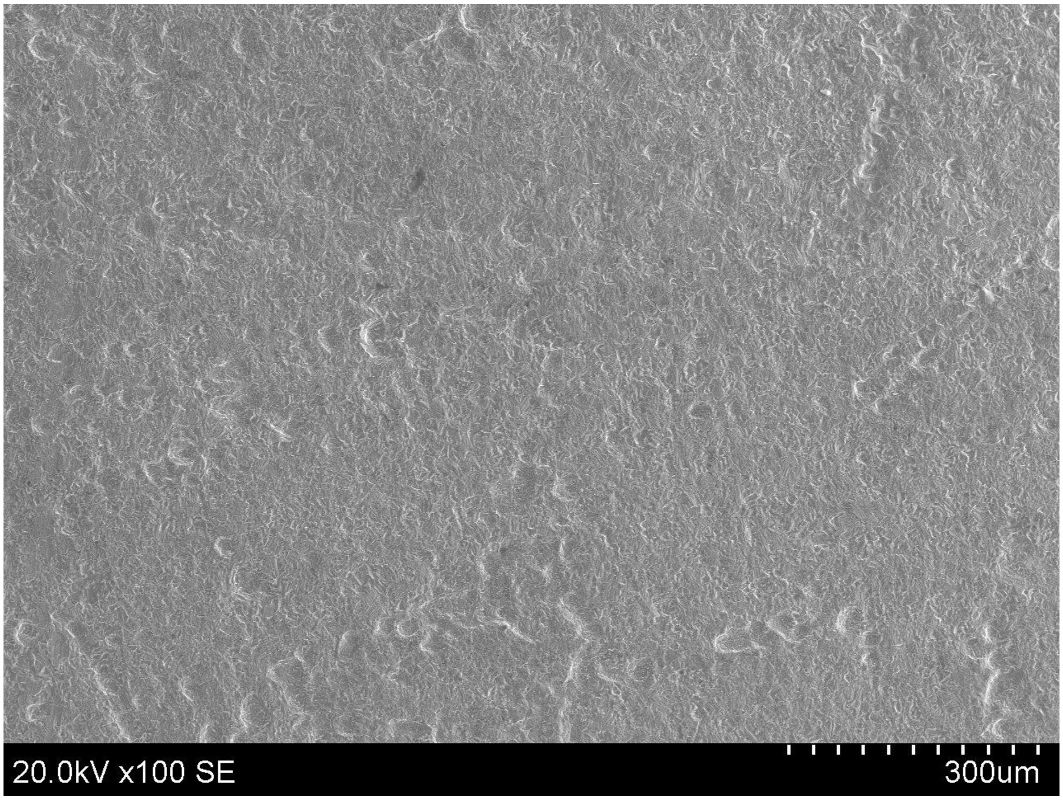


(a) Z-Alloy Coupon 2, Before Cleaning 100X

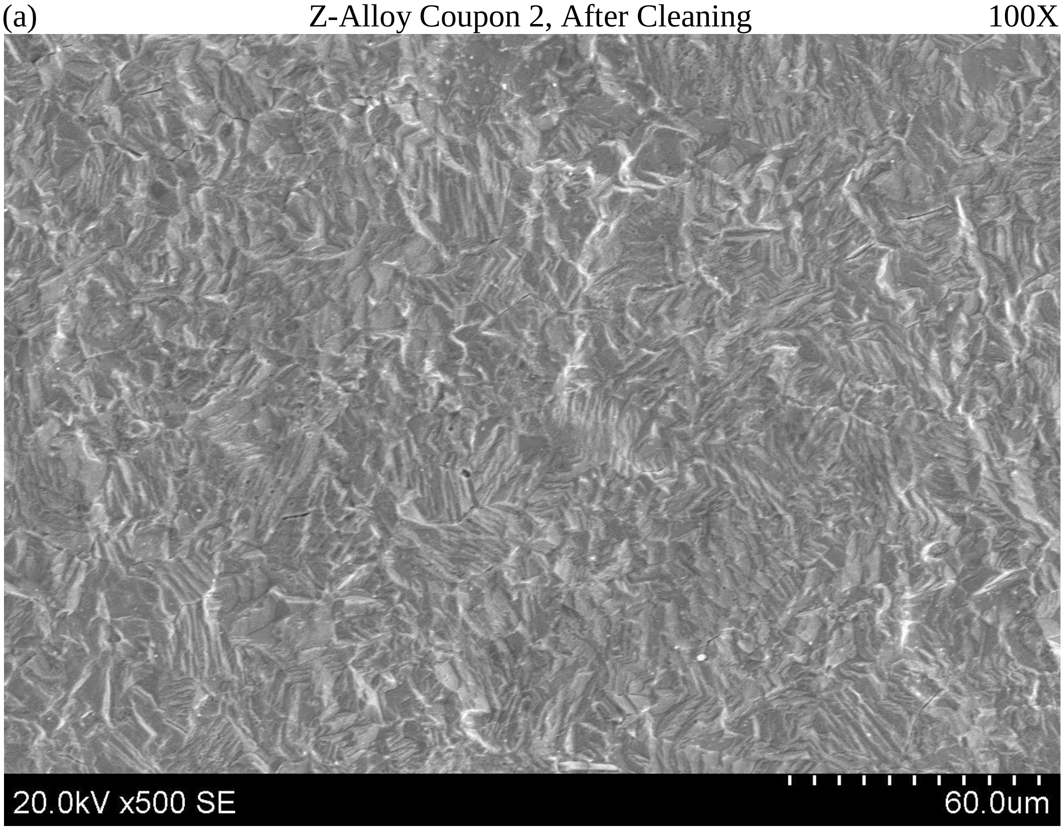


(b) Z-Alloy Coupon 2, Before Cleaning 500X

Figure 42 Scanning electron micrographs of Z-Alloy coupon 2 after a 6 month corrosion test, before cleaning.

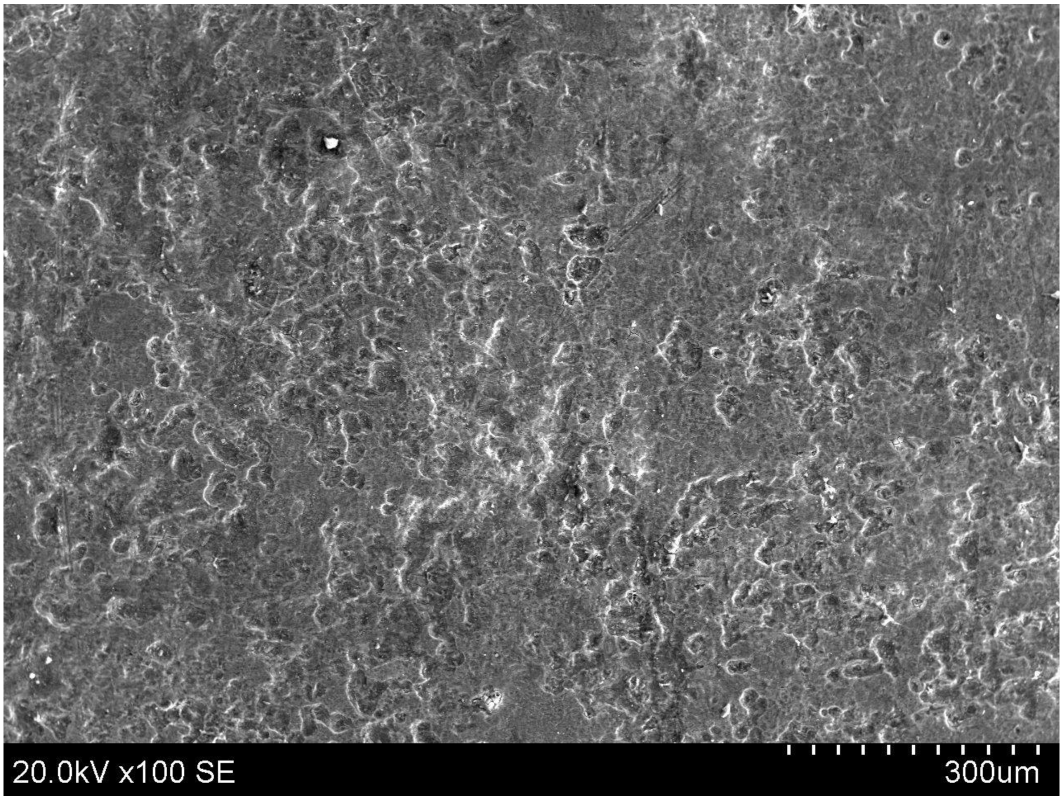


(a) Z-Alloy Coupon 2, After Cleaning 100X

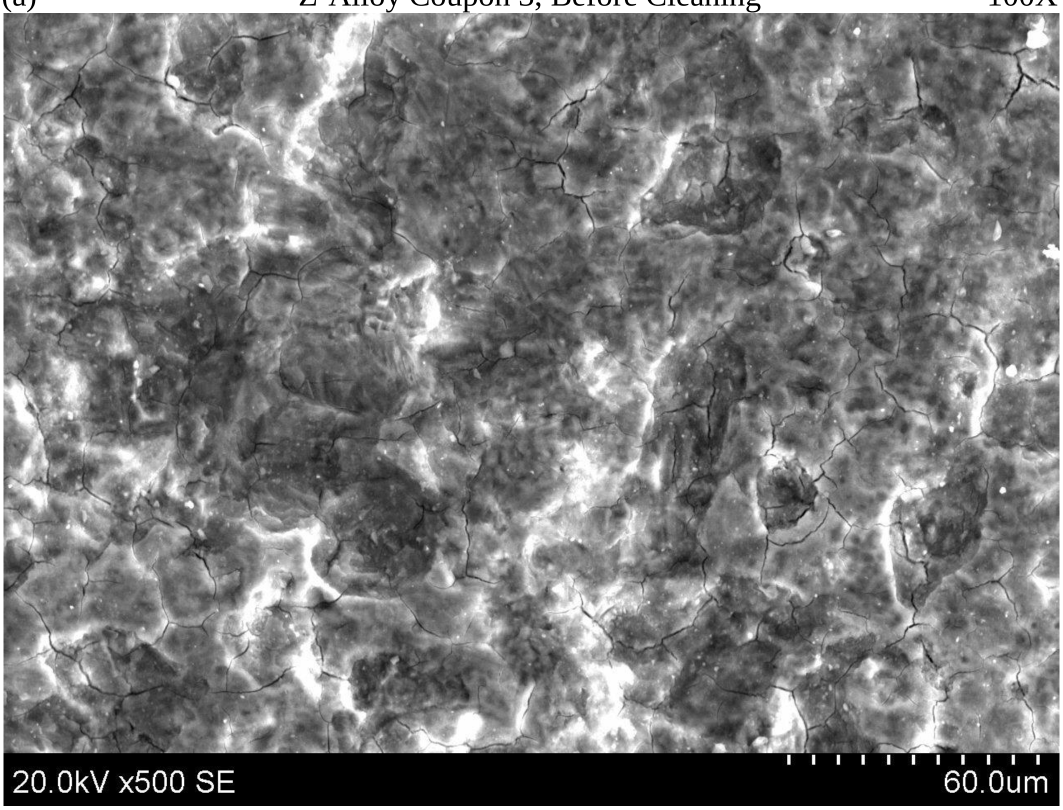


(b) Z-Alloy Coupon 2, After Cleaning 500X

Figure 43 Scanning electron micrographs of Z-Alloy coupon 2 after a 6 month corrosion test, after cleaning.

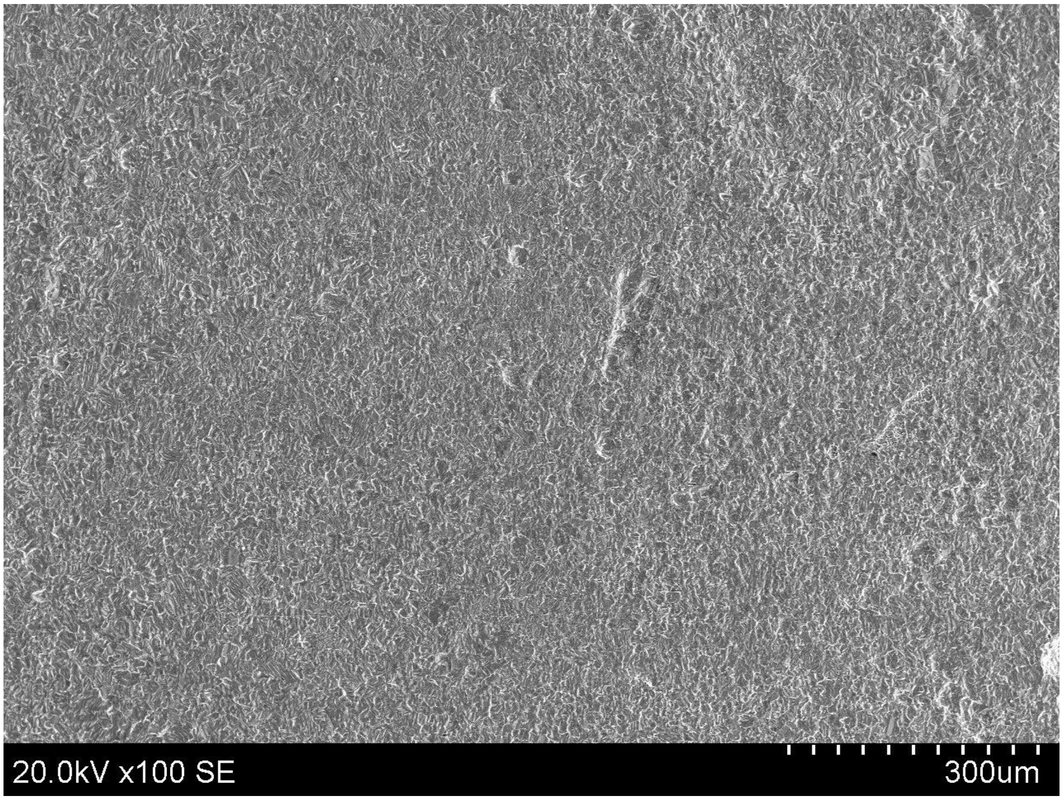


(a) Z-Alloy Coupon 3, Before Cleaning 100X

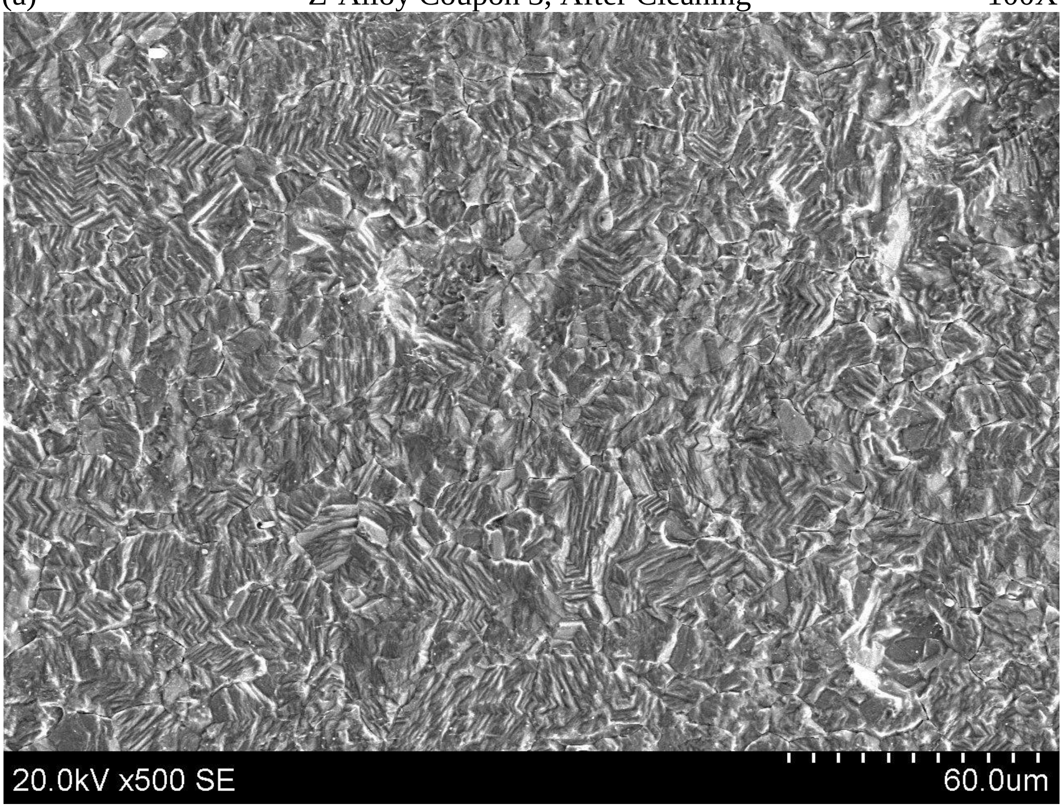


(b) Z-Alloy Coupon 3, Before Cleaning 500X

Figure 44 Scanning electron micrographs of Z-Alloy coupon 3 after a 10 month corrosion test, before cleaning.

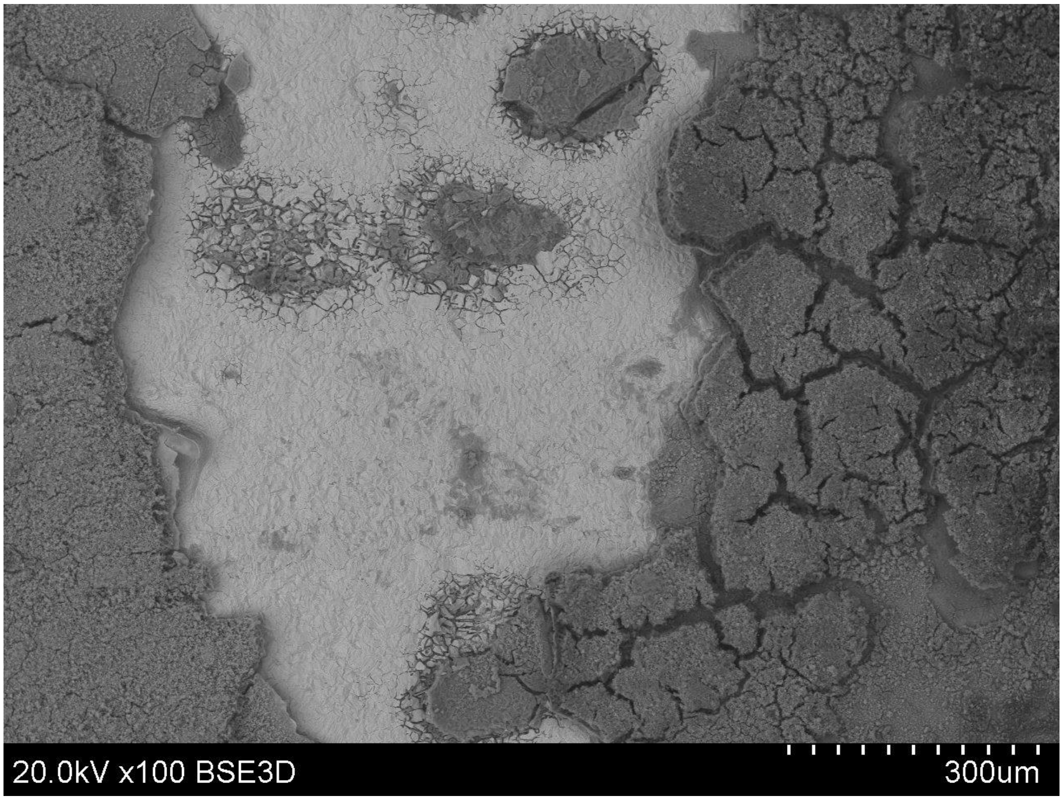


(a) Z-Alloy Coupon 3, After Cleaning 100X

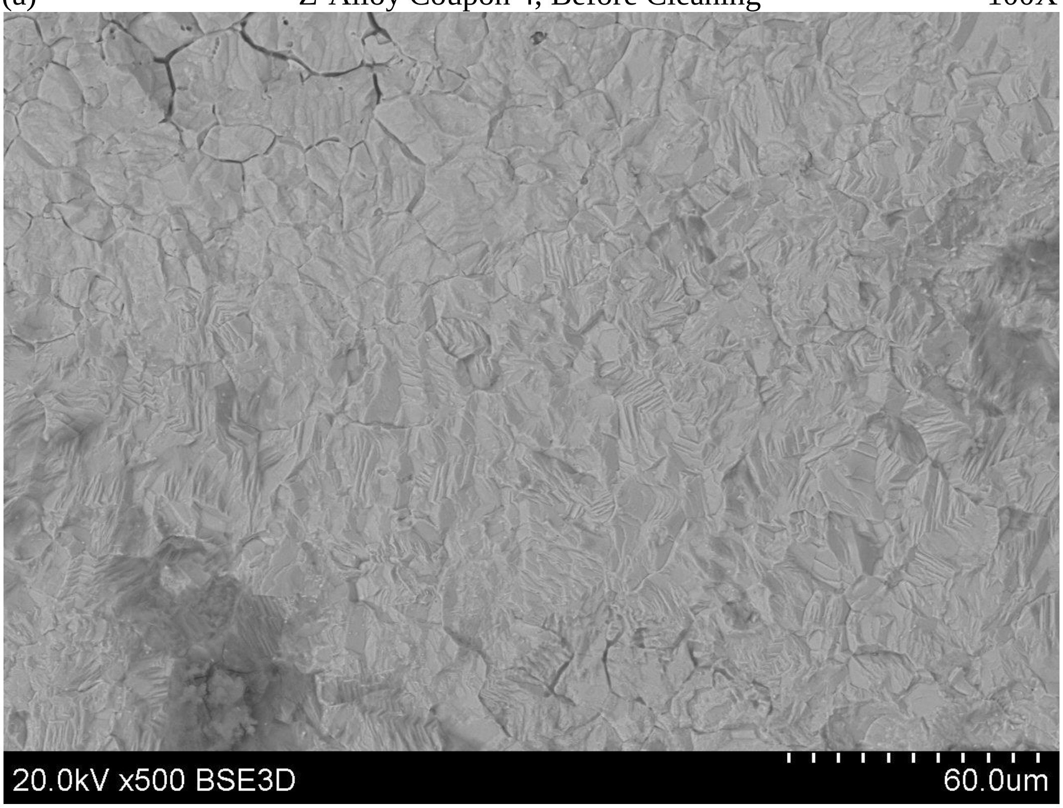


(b) Z-Alloy Coupon 3, After Cleaning 500X

Figure 45 Scanning electron micrographs of Z-Alloy coupon 3 after a 10 month corrosion test, after cleaning.

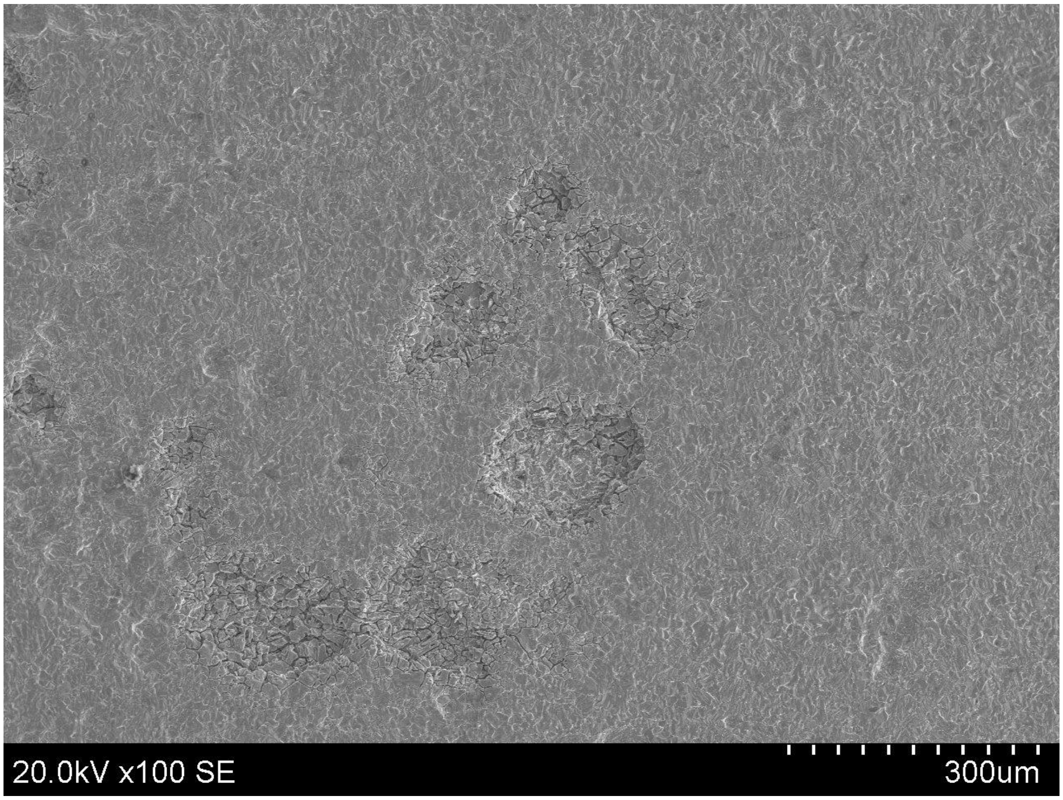


(a) Z-Alloy Coupon 4, Before Cleaning 100X

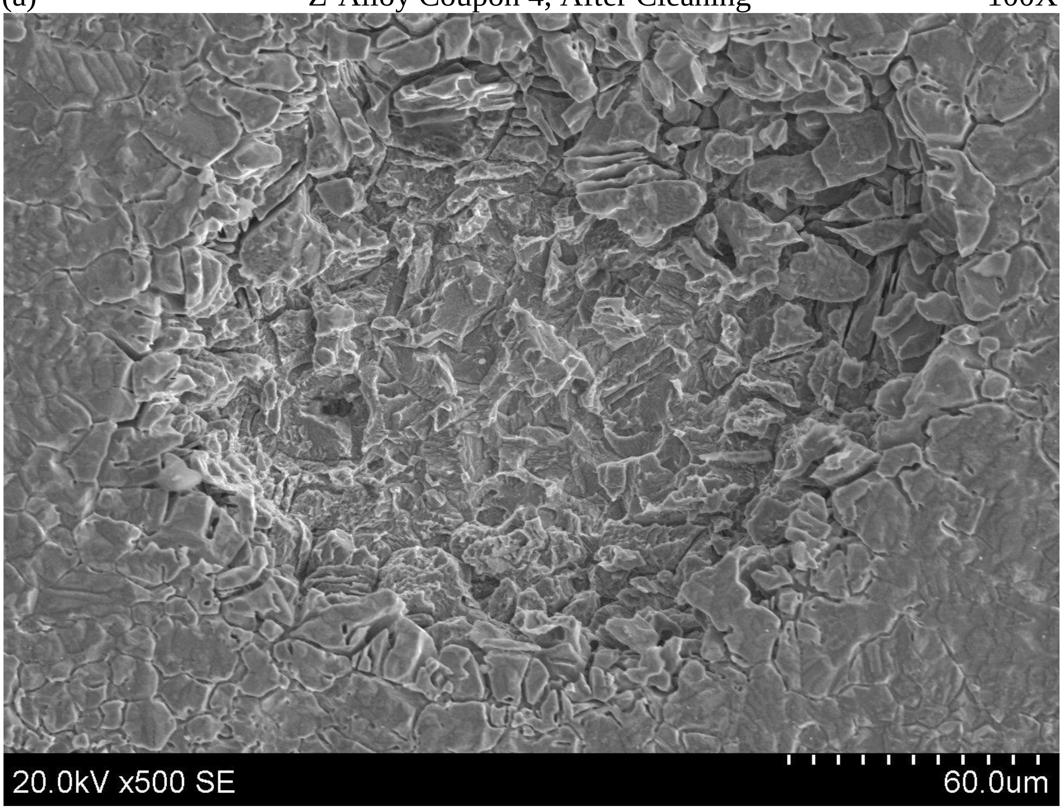


(b) Z-Alloy Coupon 4, Before Cleaning 500X

Figure 46 Scanning electron micrographs of Z-Alloy coupon 4 after a 12 month corrosion test, before cleaning.

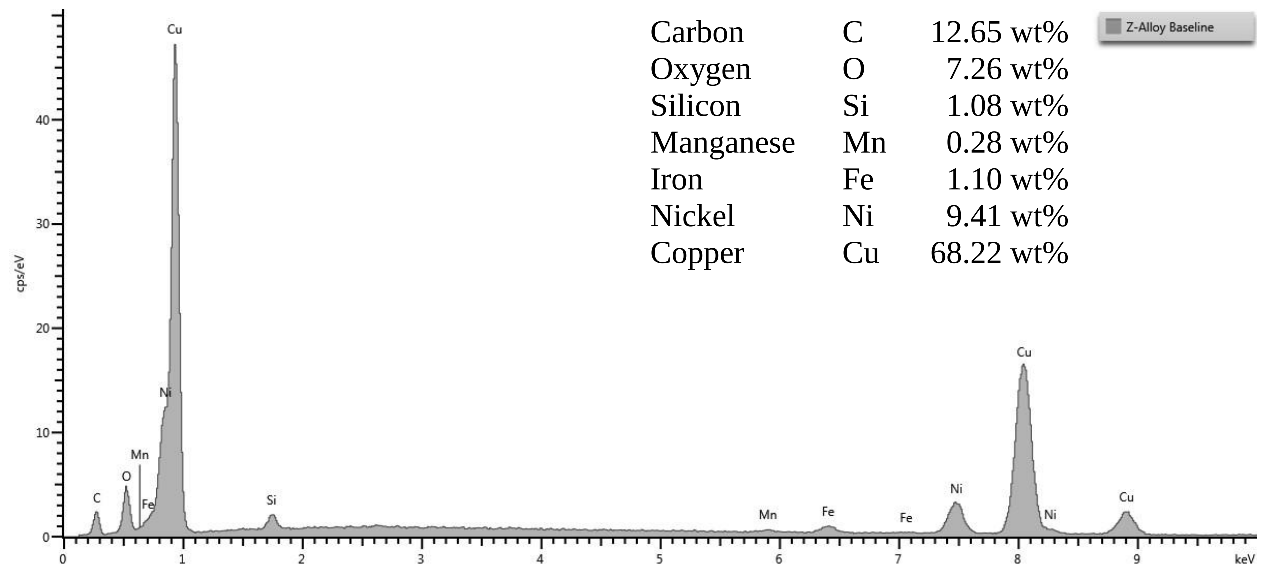


(a) Z-Alloy Coupon 4, After Cleaning 100X



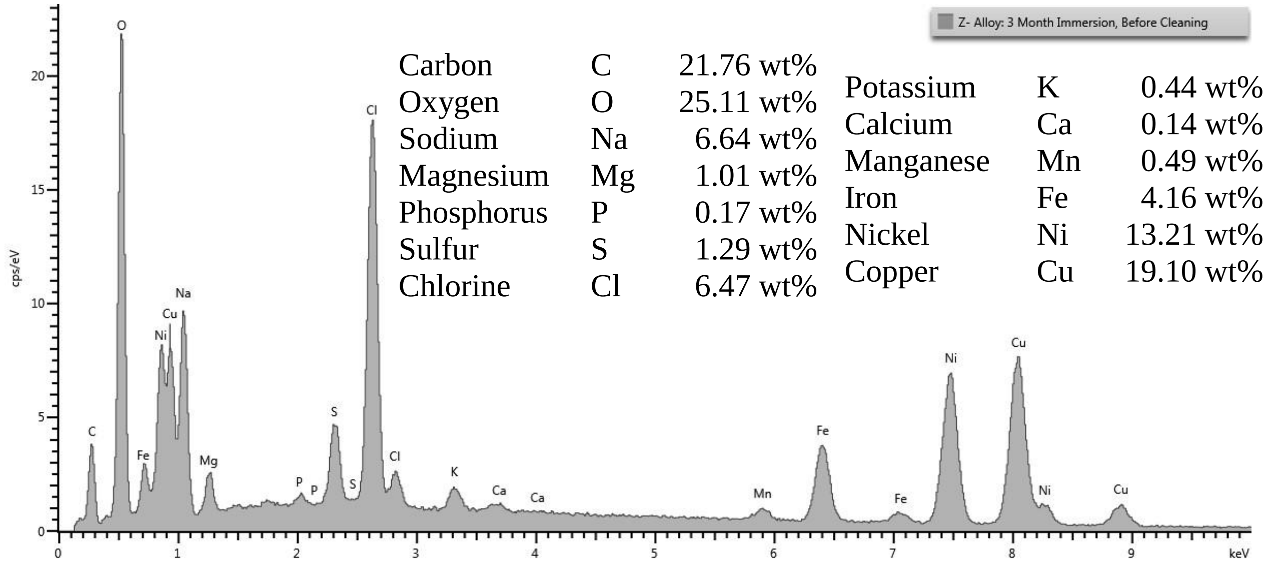
(b) Z-Alloy Coupon 4, After Cleaning 500X

Figure 47 Scanning electron micrographs of Z-Alloy coupon 4 after a 12 month corrosion test, after cleaning.

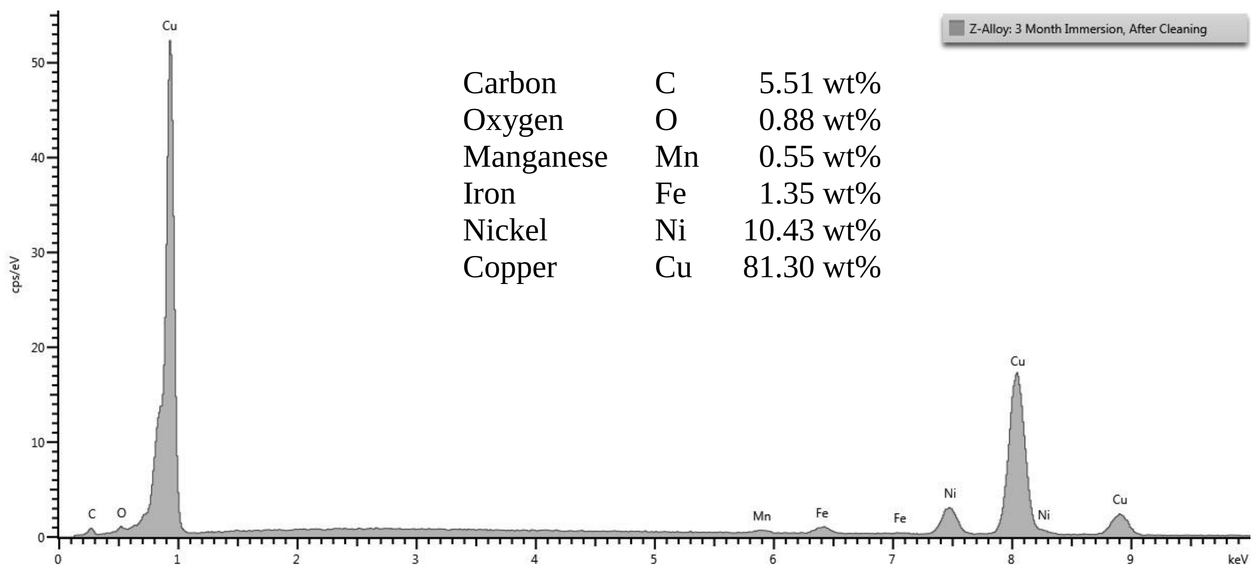


(a) Z-Alloy Baseline Coupon

Figure 48 Energy dispersive x-ray spectra of Z-Alloy baseline coupon 1.

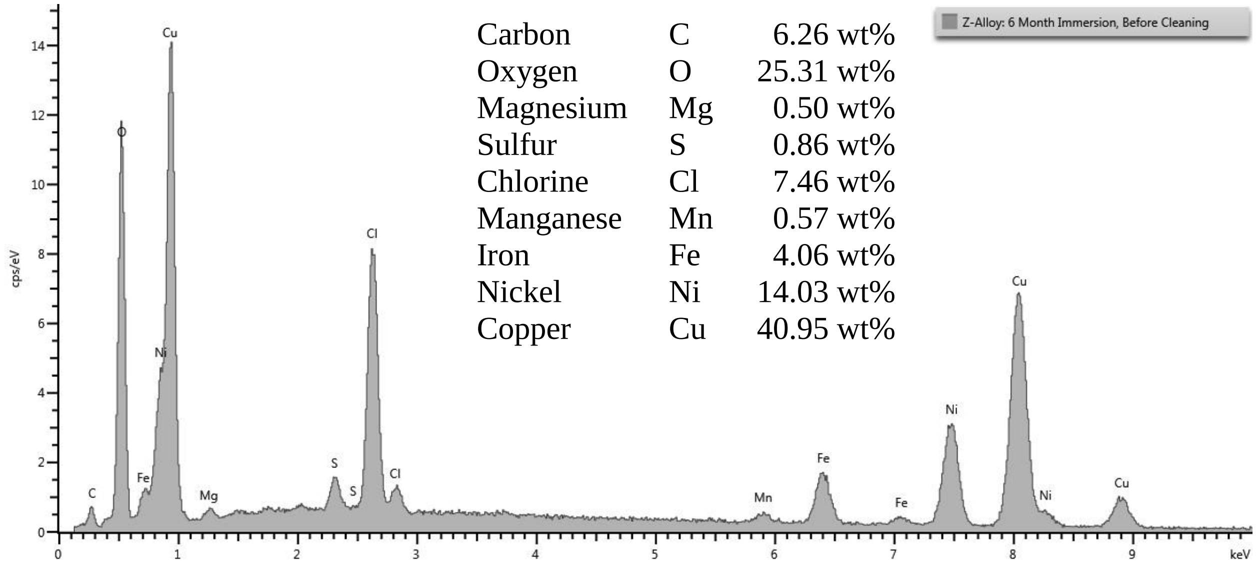


(a) Z-Alloy Coupon 1, Before Cleaning

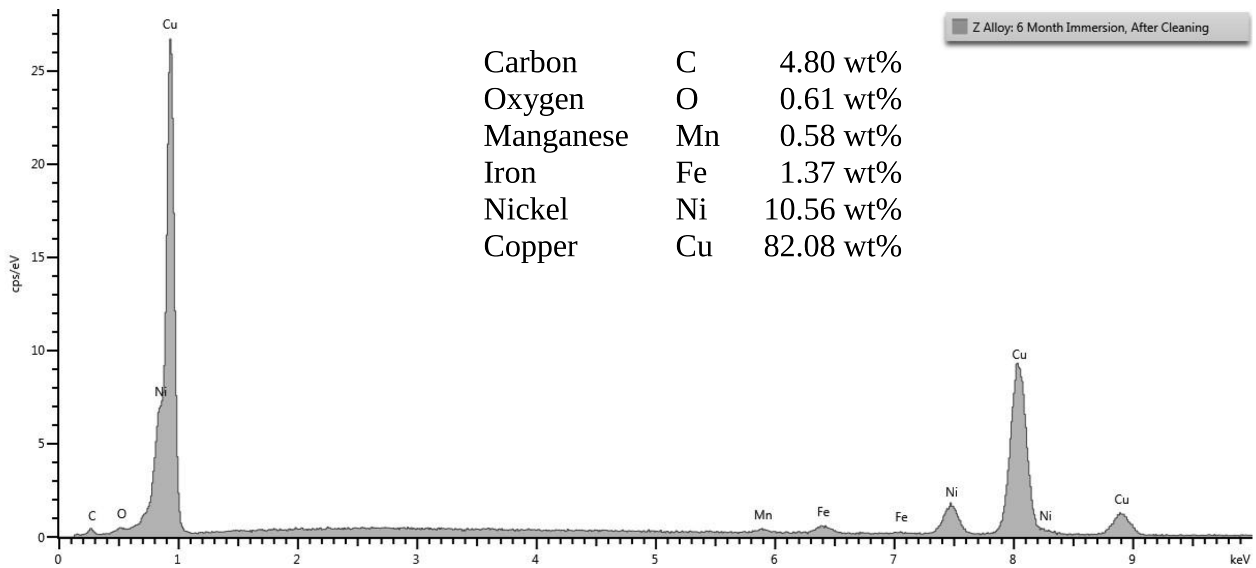


(b) Z-Alloy Coupon 1, After Cleaning

Figure 49 Energy dispersive x-ray spectra of Z-Alloy coupon 1 after a 3 month corrosion test (a) before cleaning and (b) after cleaning.

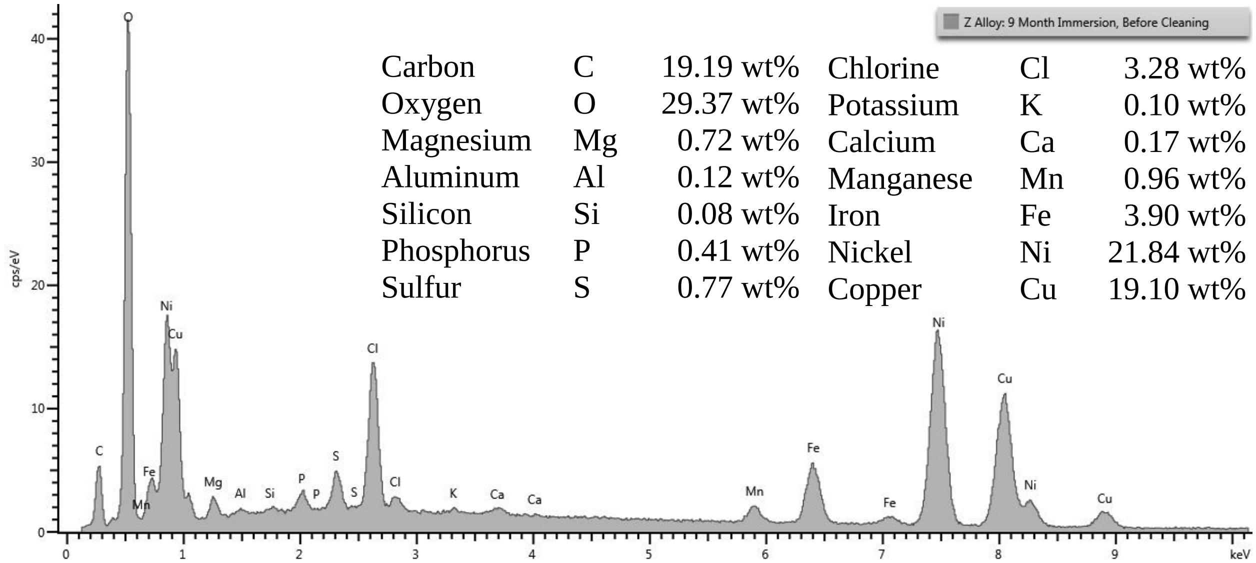


(a) Z-Alloy Coupon 2, Before Cleaning

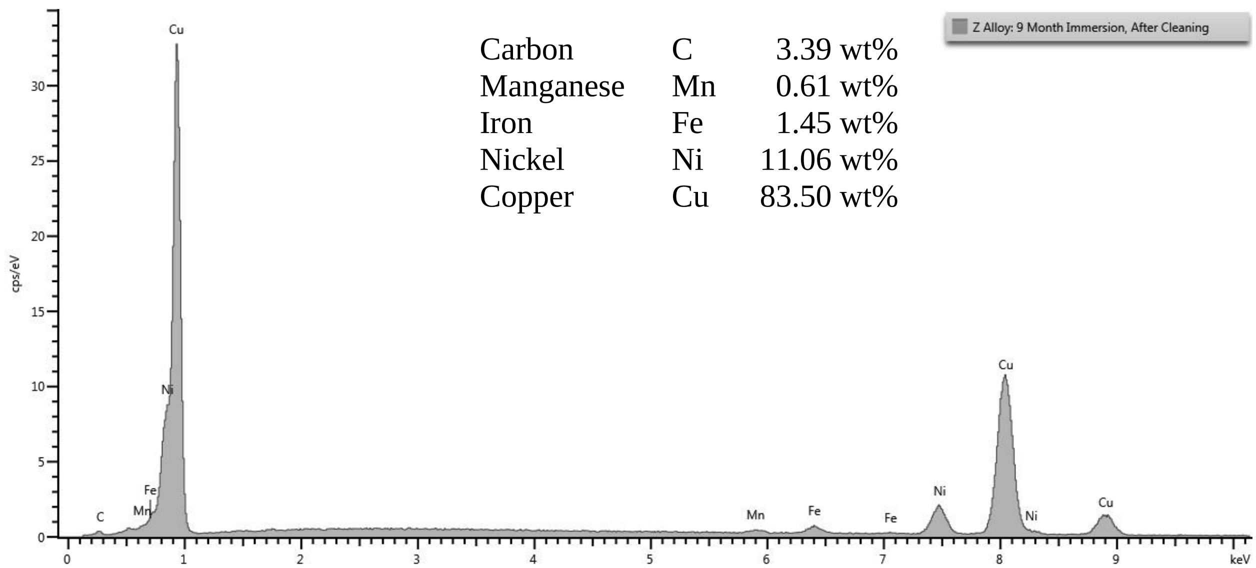


(b) Z-Alloy Coupon 2, After Cleaning

Figure 50 Energy dispersive x-ray spectra of Z-Alloy coupon 2 after a 6 month corrosion test (a) before cleaning and (b) after cleaning.

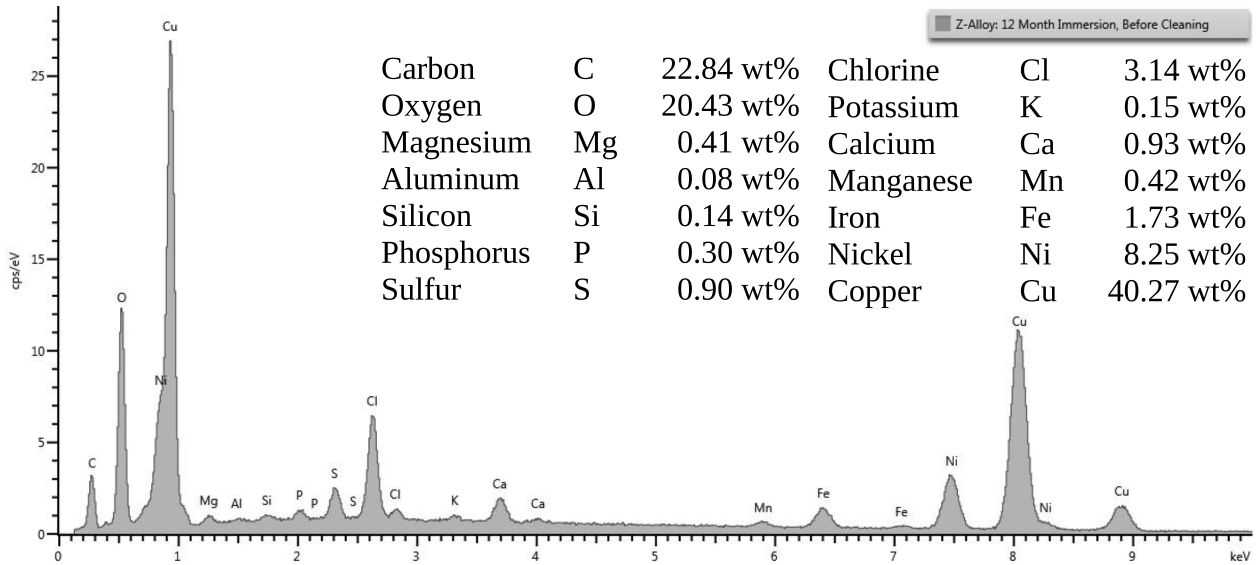


(a) Z-Alloy Coupon 3, Before Cleaning

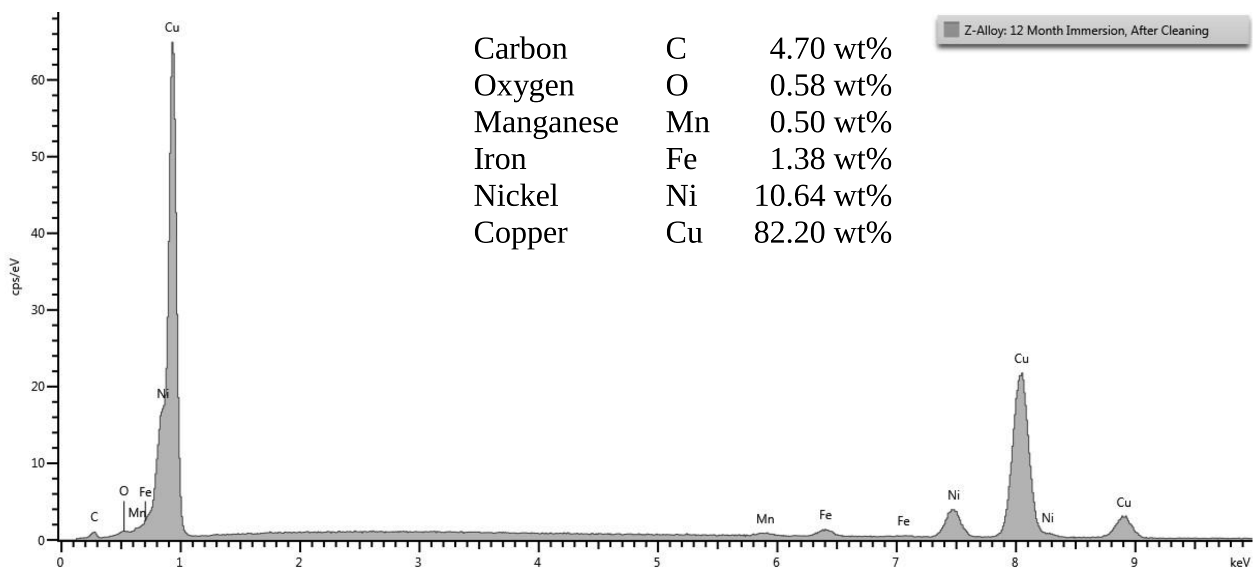


(b) Z-Alloy Coupon 3, After Cleaning

Figure 51 Energy dispersive x-ray spectra of Z-Alloy coupon 3 after a 10 month corrosion test (a) before cleaning and (b) after cleaning.

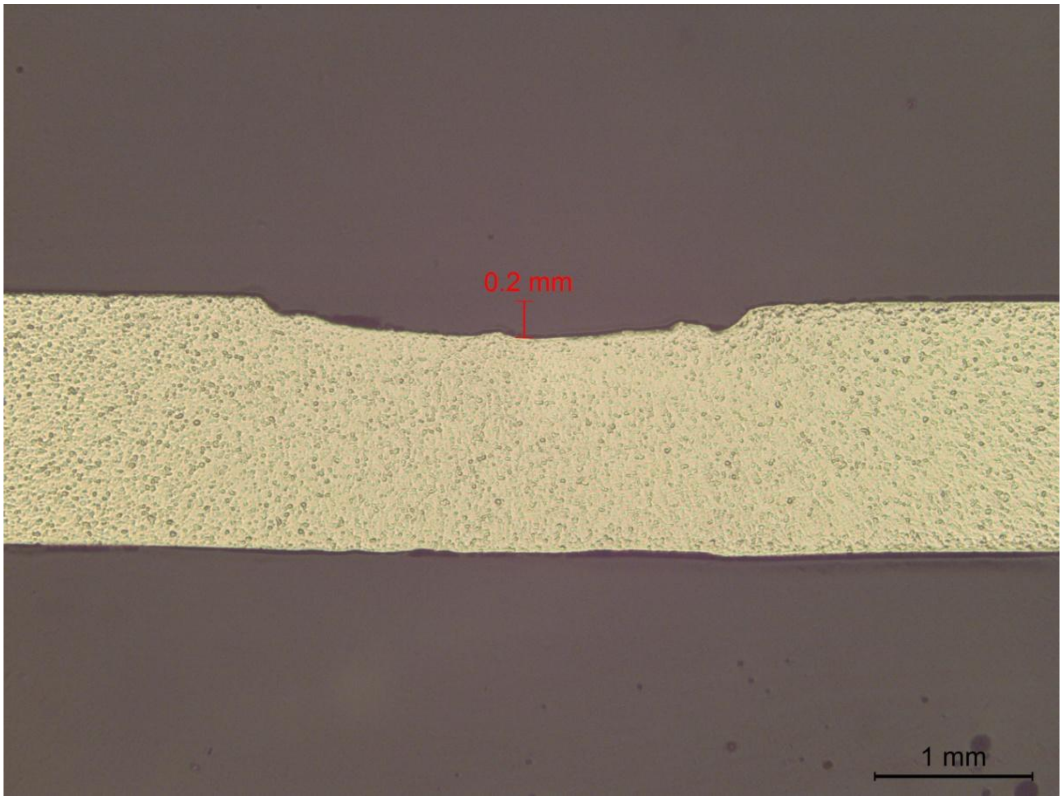


(a) Z-Alloy Coupon 4, Before Cleaning



(b) Z-Alloy Coupon 4, After Cleaning

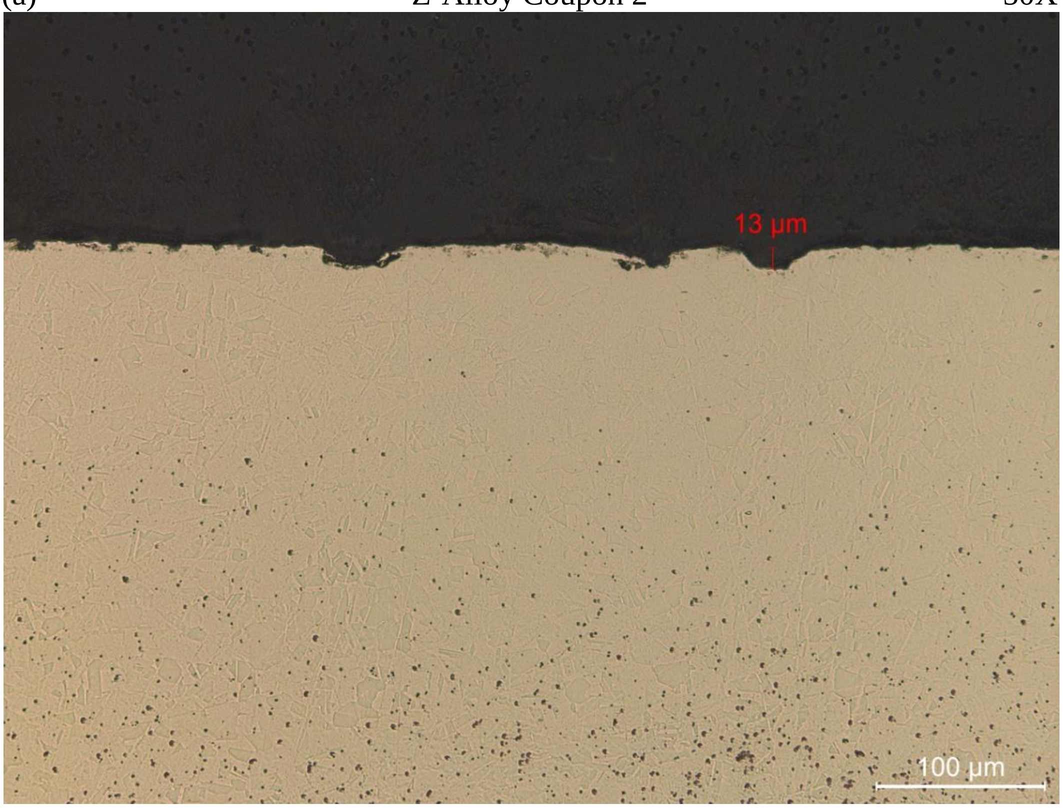
Figure 52 Energy dispersive x-ray spectra of Z-Alloy coupon 4 after a 12 month corrosion test (a) before cleaning and (b) after cleaning.



(a) Z-Alloy Coupon 1 18.75X

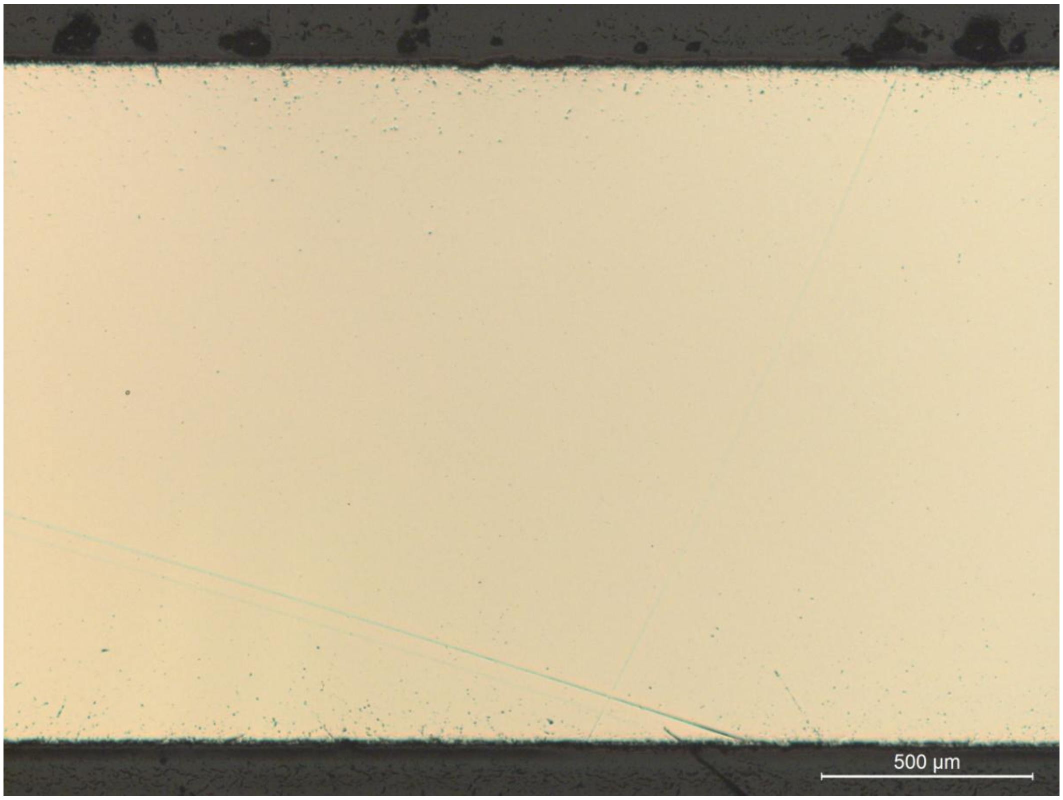
Figure 53 Optical micrograph of Z-Alloy coupon 1.

(a) Z-Alloy Coupon 2 50X

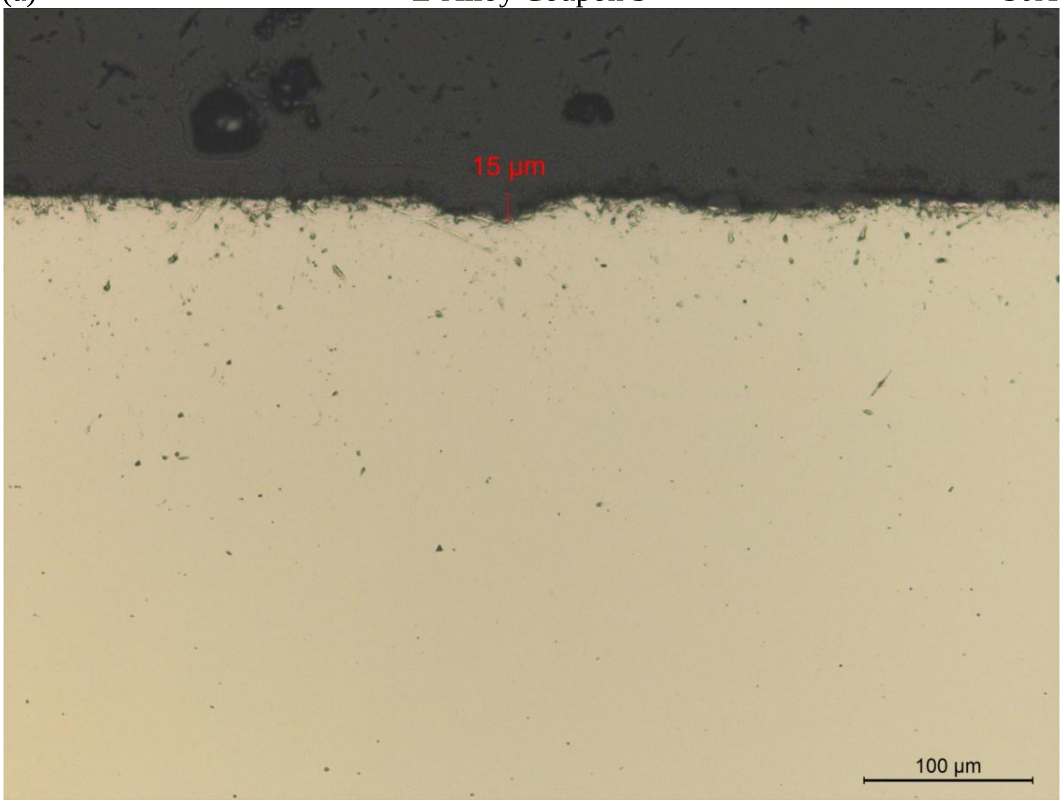


(a) Z-Alloy Coupon 2 200X

Figure 54 Optical micrographs of Z-Alloy coupon 2.

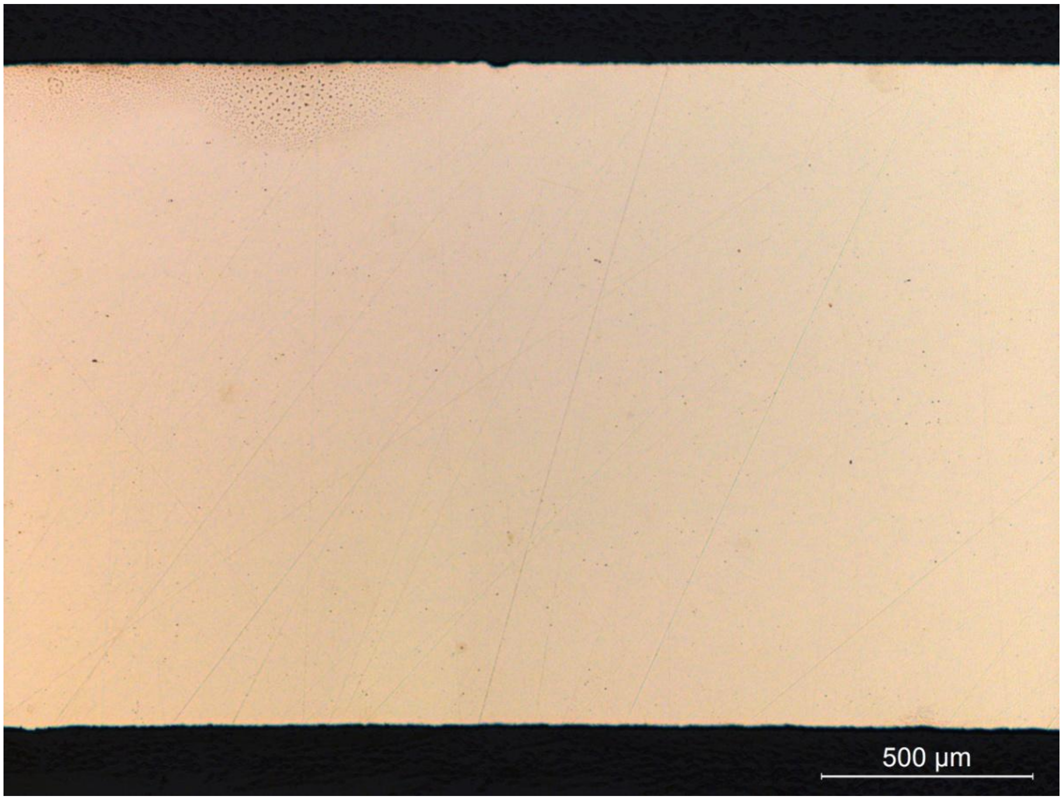


(a) Z-Alloy Coupon 3 50X

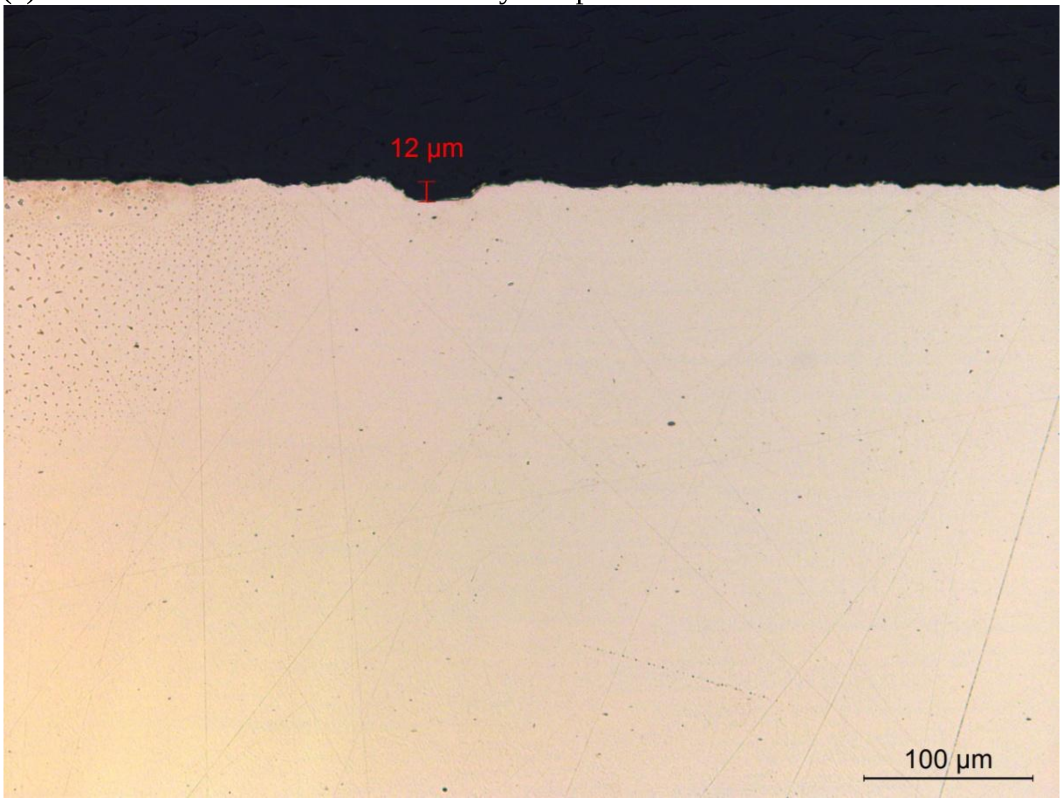


(a) Z-Alloy Coupon 3 200X

Figure 55 Optical micrographs of Z-Alloy coupon 3.



(a) Z-Alloy Coupon 4 50X



(a) Z-Alloy Coupon 4 200X

Figure 56 Optical micrographs of Z-Alloy coupon 4.

West Basin Municipal Water District Ocean Water Desalination Intake Corrosion Study – 3 Year Results

Prepared for: TETRA TECH

Date: March 12, 2018

Prepared by: V&A

V&A Project No.: 13-0376A

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ES EXECUTIVE SUMMARY

West Basin Municipal Water District (West Basin) is pursuing ocean water desalination as an added source of water for its clients. The intent of the study is to measure the extent of corrosion and biofouling on bare and coated metal samples. Metal coupons, wire screens and plate samples were made from four different alloys and installed on a testing apparatus at the West Basin Ocean Water Desalination Intake location near El Segundo, CA. Samples from each alloy were removed after 3, 6, 10, 12 and 36 months were sent to a laboratory for analysis. The purpose of the corrosion study is the following:

A. To determine the corrosion rates and modes of anticipated corrosion that will occur on the selected materials.
B. To determine the effectiveness of several antifouling control strategies for future design, implementation and operation of intake facilities.
C. To determine the effect that a foul release protective coating will have on biological growth on the test samples.
D. To determine proper materials selection, manufacturer quality control, and proper installation of screens.
E. To select materials that are readily available for manufacture of the wedge wire intake screen for use at the full-scale West Basin Desalination Plant.
F. To present information with materials selection options, showing overall capital cost and O&M costs.

The purpose of this report is to provide the results of the on-site and in-situ testing of metal wedge wire screen samples after nearly 3 years of immersion in the Pacific Ocean seawater. The samples were installed on June 17, 2014 and removed on May 23, 2017. Photos and details regarding the samples removed after 3, 6, 10, and 12 months may be found in previous reports by V&A.

Figure ES-1 and Table ES-1 summarize the results of the testing. The calculated average general corrosion rate for each alloy and sample type is plotted on the graph below for each exposure time. The graphs show the trend of change in general corrosion rates by time. Please note that the average corrosion rates were calculated per the procedures outlined in ASTM G1, and the graph below was used to present those average corrosion rates; the graph was not used to calculate the average corrosion rates.

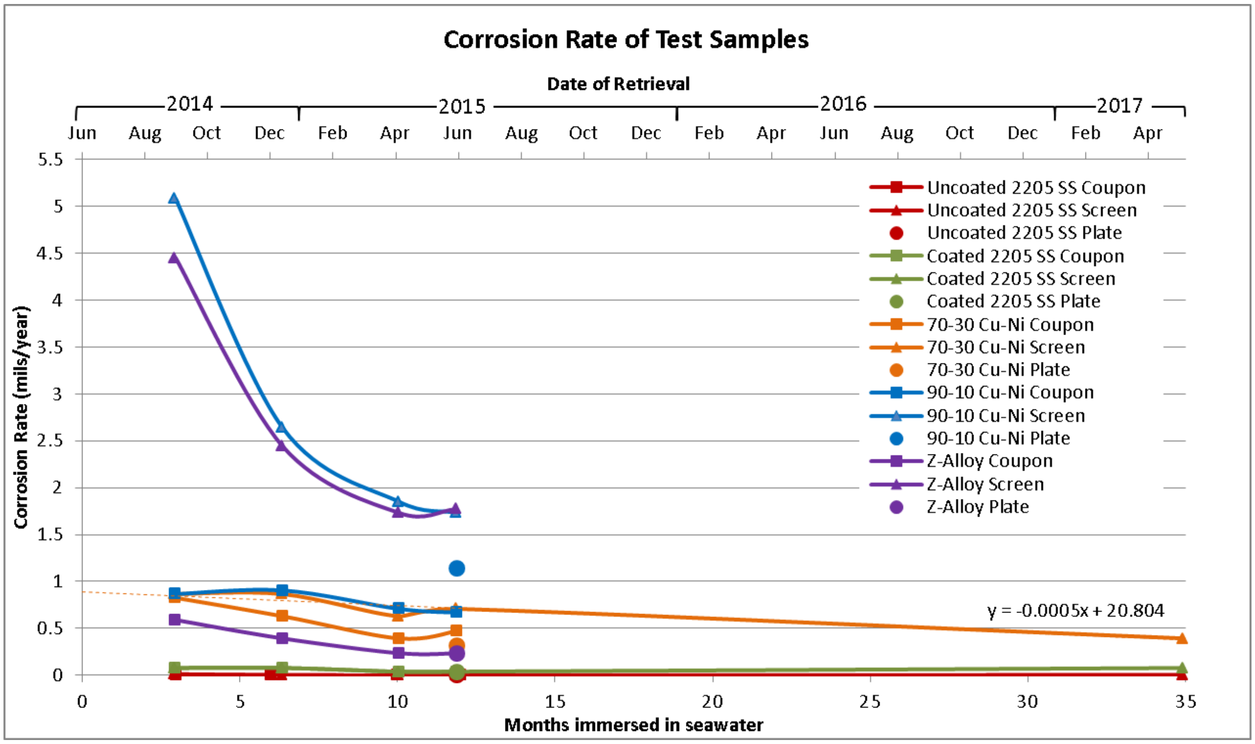

Figure ES-1. Corrosion Rates of Four Alloys after 3 years in Seawater Exposure

Generally, the average general corrosion rate for the samples decreased after 3 months after a protective passive film was established and the corrosion rate stabilized and became linear after 9 to 12 months as seen in the graph above. The passive film can be formed in three different ways: 1) by a metal surface reacting with an aqueous solution to form either a chemisorbed oxygen film or a multi-layered atomic layer comprised of an oxide or oxhydroxide; 2) dissolution precipitation which produces a passive layer by the formation of an oxide, oxyhydroxide, or hydroxide film by the precipitation of dissolved metal ions and; 3) anodic oxidation of metal ions in solution which forms an oxide film containing the metal ion in a higher oxidation state than the base metal. The determination of which passive film formation process occurred in each alloy is beyond the scope of this study however the passive film is likely to have decreased the corrosion rate when it was undisturbed.

Table ES-1. Average General Corrosion Rates of Alloys in Seawater Exposure

Alloy	Sample Type	Surface Area (sq. in.)	Maximum Pitting Depth after 1 and 3 Years (mils)	1 Year Average General Corrosion Rate (mils/year)	3 Year Average General Corrosion Rate (mils/year)
2205 Duplex SS Uncoated	1-inch by 3-inch coupon	8.2	1.38	0.0004	-
	Wedge Wire Screen	96.7	< 20 [A] (1 yr), <20 [A] (3 yr)	0.001	0.004
	4-inch by 4-inch plate	33.9	< 20 [A]	0.002	-
2205 Duplex SS with Foul Release Coating	1-inch by 3-inch coupon	8.2	1.30 [B]	0.039 [B]	-
	Wedge Wire Screen	96.7	< 20 [A] (1 yr), 0.9 (3 yr)	0.039 [B]	0.079
	4-inch by 4-inch plate	34.6	< 20 [A]	0.039	-
CDA 715 70-30 Cu-Ni	1-inch by 3-inch coupon	8.2	1.6	0.472	-
	Wedge Wire Screen	65.0	< 20 [A]	0.709	0.394
	4-inch by 4-inch plate	34.4	< 20 [A]	0.315	-
CDA 706 90-10 Cu-Ni	1-inch by 3-inch coupon	8.2	11.5 (93.4 wide)	0.669	-
	Wedge Wire Screen	79.1	< 20 [A]	1.732	-
	4-inch by 4-inch plate	34.1	< 20 [A]	1.142	-
Z Alloy	1-inch by 3-inch coupon	8.2	0.47	0.236	-
	Wedge Wire Screen	96.3	< 20 [A]	1.772	-
	4-inch by 4-inch plate	36.6	< 20 [A]	0.232	-

[A] Less than detectable/measurable. The screens were metallographically mounted and optical micrographs of the surface up to 200x, resolution of several micrometers, were examined.

[B] Mass loss and corrosion rate includes metal and coating material

In general, the wedge wire screens had a higher average general corrosion rate than the 1-inch by 3-inch flat coupons and the 4-inch by 4-inch flat plates of the same alloy. This could be due to the different shape, i.e., large ratio of edge area to total area, of the wedge wire screens as compared to the flat coupons and plates. It could also be due to different surface conditions and exposure conditions of test samples. The difference in the average general corrosion rates of the four alloys is likely due to a difference in the metallurgy, abrasion resistance, and corrosion resistance of the materials.

The 2205 Duplex SS uncoated and coated screens showed minimal mass loss and pitting overall after 3, 6, 10, 12, and 36 months of corrosion testing. However, the uncoated 2205 Duplex SS sample exhibited the most biofouling of all the alloys tested in this study. The average general corrosion rate is higher for the coated 2205 Duplex SS sample due to the missing anti-fouling coating that was damaged over time and does not necessarily indicated more corrosion has occurred than the uncoated sample.

The 70-30 Cu-Ni samples exhibited a moderate average general corrosion rate ranging between 0.32 mil/yr (plate sample exposed for 364 days) and 0.87 mils/yr (screen sample exposed for 91 days) during the 3-year study, with a steady decreasing trend over time. The average general corrosion rate decreases after 3 months after a protective passive film layer is established. The passivation layer acts as a shield to keep corrosive ions like chlorides away from the metal surface. The 70-30 Cu-Ni samples had less biofouling than other copper alloys after being immersed for 3 years.

The 90-10 Cu-Ni samples exhibited the highest average general corrosion rate of the 5 materials, ranging between 0.67 mil/yr (coupon sample exposed for 364 days) to 5.08 mils/yr (screen sample exposed for 91 days) during the 12-month study. The average general corrosion rate for the 90-10 Cu-Ni wedge wire screen samples quickly decreased after 3 months after a protective passive film was established, and the corrosion rate begins to stabilize after 9 to 12 months. A wedge wire sample could not be retrieved after 3 years. The sample was secured to the test rack with a plastic zip tie, which may have eroded the metal over time, and indicates that the alloy has a lower abrasion resistance than the 70-30 Cu-Ni alloy.

The Z Alloy samples high average general corrosion rate ranging between 0.24 mil/yr (coupon and plate samples exposed for 364 days) to 4.5 mils/yr (screen sample exposed for 91 days) during the 12-month study. The average general corrosion rate of the Z Alloy wedge wire screen samples quickly decreased after 3 months before a protective passive film was established, and the corrosion rate equalized after 9 to 12 months. A wedge wire sample could not be retrieved after 3 years. The sample was secured to the test rack with a plastic zip tie, which may have eroded the metal over time, and indicates that the alloy has a lower abrasion resistance than the 70-30 Cu-Ni alloy.

Based on the conclusions and V&A's experience with similar corrosion studies, the following recommendations are presented for WBMWD to consider for seawater exposures:

1. Intake screens should be manufactured with 70-30 Cu-Ni as it would provide adequate corrosion rate over a long-term service life, would not require a foul release coating, and had minimal biofouling.
2. Intake screens manufactured in 2205 Duplex Stainless Steel are recommended if they are coated with a foul-release coating and if the 70-30 Cu-Ni screens are not available.

1.0 INTRODUCTION

West Basin Municipal Water District (West Basin) is pursuing ocean water desalination as an added source of water for its clients. Four different alloys and one coating system were identified, through review of the literature for similar studies, and installed on a testing apparatus at the West Basin Ocean Water Desalination Intake location near El Segundo, CA. The intent of the study is to measure the extent of corrosion and biofouling on bare and coated metal coupons and wire screens. The samples were installed and removed at 3, 6, 10, 12, and 36 months. Once removed, the samples were sent to a lab for analysis. The overall objectives for the study are the following:

- To determine the corrosion rates and modes of anticipated corrosion that will occur on the selected materials.
- To determine the effectiveness of several antifouling control strategies for future design, implementation and operation of intake facilities.
- To determine the effect of a foul release that the protective coating will have on biological growth on the test samples. This will substantiate the ultimate selection of intake screen material and the benefit of providing an anti-fouling coating on the intake screen.
- To determine proper material selection, manufacturer quality control, and proper installation of screens.
- To select materials that are readily available for manufacture of the wedge wire intake screen for use at the full-scale West Basin Desalination Plant.
- To present information with material selection options, showing overall capital cost, and O&M costs.

The purpose of this report is to provide the results of the on-site and in-situ testing of metal wedge wire screen samples after nearly 3 years of immersion in the Pacific Ocean seawater.

2.0 METHODS

The purpose of this section of the report is to describe the testing study procedures for on-site and in-situ testing of metal coupons and wedge wire screen samples in order to assess corrosion impact relative to material selection and operating practices. The results presented in this report are for the samples that were removed after 3 years of seawater exposure.

2.1 Procurement of Materials

Five material types comprised of four alloys and one coating system were chosen:

1. 2205 Duplex Stainless Steel Uncoated
2. 2205 Duplex Stainless Steel with 18 mils Foul-Release Coating (see Section 2.2 for coating details)
3. CDA715 (also known as Cu 70 – Ni 30)
4. CDA 706 (also known as Cu 90 – Ni 10)

Metal coupons, wire screens and plates were made from each material type. A total of 50 samples were deployed to be removed at different time intervals (see Table 2-1).

Table 2-1. Number of Metal Samples Deployed in Study

	3 months	6 months	10 months	12 months	36 months
Coupon	5	5	5	5	0
Wire Screen	5	5	5	5	5
Plate	0	0	0	5	0

The metal coupons are 1 inch wide by 3 inches long by 1/16 of an inch thick and the wedge wire screens are 4 inches by 4 inches with 2 mm spacing. The 90-10 Cu-Ni screens have 4 mm spacing, between the screen wires. The metal plates are 4-inch by 4-inch by 1/8-inch thick.

V&A coordinated with the coupon vendors and screen manufacturers for the procurement of the testing samples. Metal Samples Company of Munford, Alabama, provided the 1-inch by 3-inch long by 1/16-inch thick coupons in 90-10 Copper-Nickel (Cu-Ni), 70-30 Cu-Ni, and the 2205 Duplex Stainless Steel. Metal Samples also provided the 4-inch by 4-inch by 1/8-inch thick flat plate in the same metal alloys. Holes were made on each 1-inch by 3-inch and 4-inch by 4-inch metal sample in order to secure it to the testing rack with plastic zip ties.

Johnson Screens/Bilfinger Water Technologies of New Brighton, Minnesota provided the 4-inch by 4-inch wedge wire screens in the 90-10 Cu-Ni, 2205 Duplex Stainless Steel, and Z alloys. They also provided the 1-inch by 3-inch by 1/16-inch thick coupons and the 4-inch by 4-inch flat plate in the Z alloy.

Hendrick Screen Company of Owensboro, Kentucky, provided the 4-inch by 4-inch wedge wire screens in 70-30 Cu-Ni.

2.2 Coating for Stainless Steel Screens and Coupons

V&A searched for a coating that would provide an NSF Standard 61-approved coating for drinking water contact and was known to prevent the attachment of marine life on hydraulic structures. V&A identified the following foul release coating system for the stainless steel samples from the literature review and discussions with manufacturers:

A. 1st coat - Sherwin Williams Macropoxy 646 PW immersion grade epoxy primer at 6 mils dry film thickness (dft.)
B. 2nd coat - Sherwin Williams Seaguard Sher-Release beige silicone Tie Coat at 6 mils dft.
C. 3rd coat - Sherwin Williams Seaguard Sher-Release white silicone Surface Coat at 6 mils dft.

The coating was applied by Fuji Hunt Smart Surfaces in Davidsonville, Maryland.

2.3 Lab Analysis

2.3.1 Chemical Analysis by EDS

Anamet, Inc. of Hayward, California, performed a quantitative chemical analysis by Energy Dispersive x-ray Spectra (EDS) on a baseline control sample and on the samples after they were immersed in seawater. Anamet's report contains images of the spectra and is included as Appendix A.

2.3.2 Scanning Electron Microscopy

Anamet, Inc. of Hayward, California, performed Scanning Electron Microscopy (SEM) on the samples. The SEM uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. The signals that derive from electron-sample interactions reveal information about the sample including texture, chemical composition, and crystalline structure.

2.3.3 Metallography

Optical macrographs of the samples were also recorded by Anamet, Inc. before and after cleaning of the samples and are attached in Anamet's reports. A metallographic examination of a cross section of each sample was recorded.

2.3.4 Corrosion Rate Analysis

Samples were weighed by Anamet, Inc. Laboratories in Hayward, CA before they were installed. The samples were analyzed by the lab after they were exposed to the seawater environment per ASTM G1 *Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens* and ASTM D2688 *Standard Test Method for Corrosivity of Water in the Absence of Heat Transfer (Weight Loss Method)*. The samples were cleaned with either nitric acid or hydrochloric acid. Plots of mass loss versus cleaning cycles for each sample are attached in Anamet's report. The corrosion rate for each exposure duration was calculated using the equation below as given in ASTM G1. Pitting examination was performed per ASTM G46 *Standard Guide for Examination and Evaluation of Pitting Corrosion*.

ASTM G1 Paragraph 8.1:

$$Corrosion\ Rate = \frac{K \times W}{A \times T \times D}$$

where K = a constant provided by ASTM G1 (8.76×10^4 mm/yr)
T = time of exposure in hours
A = area in cm^2
W = mass loss in grams
D = density in g/cm^3

2.4 Procedures

After the initial baseline parameters were obtained, the samples were shipped to Tenera Environmental for installation at the project site. Tenera Environmental assembled the testing rack and affixed the coupons and wedge wire screens prior to immersion in the ocean source water. The wedge wire screens were secured to the testing rack with plastic zip ties. There was one test rack for each set of samples to be removed at each specified interval.

The testing samples consisted of metal coupons, wedge wire screens and flat plates (coated and uncoated) for installation on the in-situ testing apparatus installed by Tenera Environmental divers.
Samples and cleaning were performed per ASTM G-1 *Preparing, Cleaning, and Evaluating Corrosion Test Specimens* and ASTM D2688 *Standard Test Method for Corrosivity of Water in the Absence of Heat Transfer (Weight Loss Method)*. ASTM G-1 includes procedures in Sections 14.10 through 14.14 that involve weighing and classifying the types of pits, and pit measurements were made per ASTM G46. This test method covers the determination of the corrosivity of water by evaluating pitting and by measuring the weight loss of metal specimens. Pitting is a form of localized corrosion: weight loss is a measure of the average corrosion rate.

A metallographic examination was performed per ASTM E3 *Standard Guide for Preparation of Metallographic Specimens*. The primary objective of metallographic examinations is to reveal the constituents and structure of metals and their alloys by means of a light optical or scanning electron microscope.

Before installation the samples were examined for the following baseline parameters:

1. Weigh all samples per ASTM G1. Samples to be coated will be weighed before and after coating application.
2. Examine samples visually to 40X
3. Color photograph, one of each material type
4. Photomicrograph @ 10X, one of each material type
5. Photomicrograph @ 50X, one of each material type
6. Scanning Electron Micrograph (SEM) @ 100X, one of each material type
7. Energy Dispersive Spectroscopy (EDS), one of each material type

Samples removed after 3, 6, 10, 12 and 36 months of exposure have been and will be examined for the following:

1. Sample cleaning and weighing per ASTM G1 and ASTM D2688
2. Pitting examination per ASTM G46
3. Dimensional inspection (micrometers or NOGO gauge): Wedge wire and gap dimensions.
4. Photomicrograph @ 10X, one of each material type After Cleaning (AC)
5. Photomicrograph @ 50X, one of each material type AC
6. Scanning Electron Micrograph @ 100X, one of each material type AC
7. Elemental analysis with EDS, one of each material type AC
8. Metallographic examination per ASTM E3, one of each material type

2.5 Corrosion Mechanisms

Corrosion is an electrochemical phenomenon that takes place at the interface of the metal and electrolyte, which in this case is seawater. When the metal is in contact with the electrolyte, a difference in potential develops at the electrolyte/metal interface. When corrosion reactions take place, they generate a current between two points on the metal surface with current flow through the electrolyte. Factors that may impact the corrosion rate include the following:

- Presence of inclusions in the metal or a Heat Affected Zone due to welding
- Mechanical stresses caused by welding, forming or temperature
- Water velocity and tidal fluctuations at the surface of the coupon (not possible to simulate in a lab)
- Alloy resistance to corrosion due to high chloride concentrations in seawater
- Water temperature, dissolved oxygen, sulfates, and chlorides. Water temperature data was collected at the intake to better understand and account for how temperature may impact the corrosion rate.

The following sections explain some possible corrosion mechanisms for the metals based on V&A's research.

2.5.1 Uniform Corrosion

If all metal surfaces are attacked via corrosion at an equal rate, the corrosion is termed uniform. As far as failure rate, the uniform corrosion rate is expressed in terms of metal penetrating rates (rate of metal loss) in thousandths of inches (mils) per year (mpy).

2.5.2 Localized and Pitting Corrosion

When corrosion of the metal surface is localized, the surface under the most aggressive attack becomes recessed with respect to the rest of the metal surface and visible pits are formed. In such instances, the attack is said to be non-uniform, localized, or pitting corrosion. Theoretically, corrosion pitting in metals is divided into two phases: pit initiation and propagation.

2.5.3 Stress Corrosion Cracking

The occurrence of stress corrosion cracking (SCC) depends on the simultaneous achievement of three requirements: 1) a susceptible material; 2) a chemical environment that causes SCC for that material and 3) sufficient tensile (mechanical) stress within the material. The mechanical stresses may be caused by welding, forming, applied loads, and temperature.

Photo 2-1 and Photo 2-2 show samples of the cracking that might occur for copper alloys and duplex stainless steel under mechanical and chemical stresses. These photos are not of the metal samples that are part of this study and are presented for demonstrative purposes only.

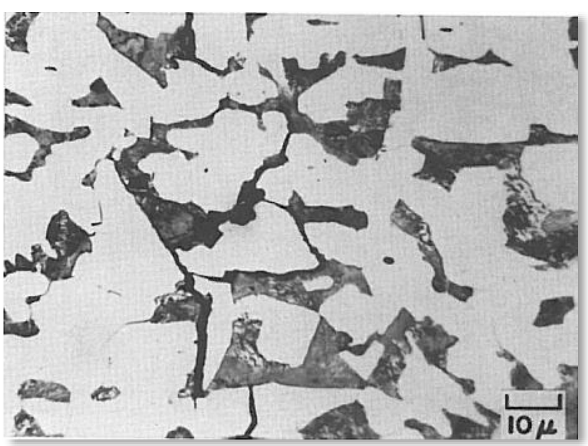

Photo 2-1. Intergranular Stress Corrosion Cracking in a Steel Pipe.[1]

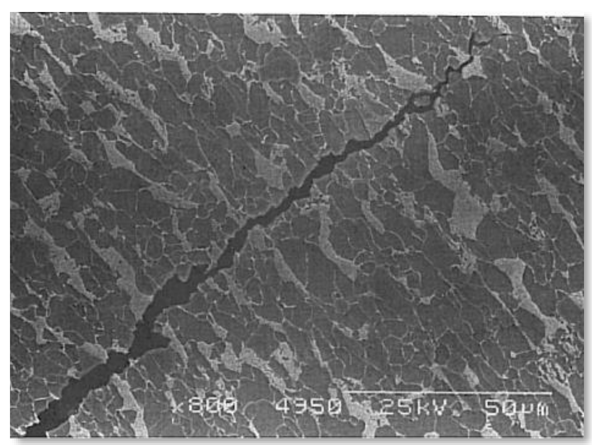

Photo 2-2. Transgranular Stress Corrosion Cracking in a Steel Pipe.[2]

2.6 Corrosion Rates from Studies Performed by Others

V&A researched seawater corrosion rates for some of the alloys in this study to compare the corrosion rate of the alloys with the results of this study. Table 2-2 summarizes the information found in corrosion control literature.

Table 2-2. Average Corrosion Rates from Literature Review for Alloys in Seawater

Material	UNS	1-year Average General Corrosion Rate (mil/yr)	3-year Average General Corrosion Rate (mil/yr)	Reference
2205 duplex stainless steel	S32205	0.03		McGuire, Stainless Steels for Design Engineers, p. 101, 2008
70-30 Cu-Ni	C71500	Flowing: 1.06 Quiet: 0.22	Flowing: 1.41 Quiet: 0.66	Efird & Anderson, Materials Performance Vol. 14 (No. 11), 1975
90-10 Cu-Ni	C70600	Flowing: 0.79 Quiet: 0.22	Flowing: 1.32 Quiet: 0.48	Efird & Anderson, Materials Performance, Vol. 14 (No. 11) 1975

Figure 2-1 shows a graph of the average corrosion rates for several metal alloys in seawater. As seen in the graph, 70-30 Cu-Ni and 90-10 Cu-Ni have a corrosion rate of 0.15 to 0.5 mils per year.

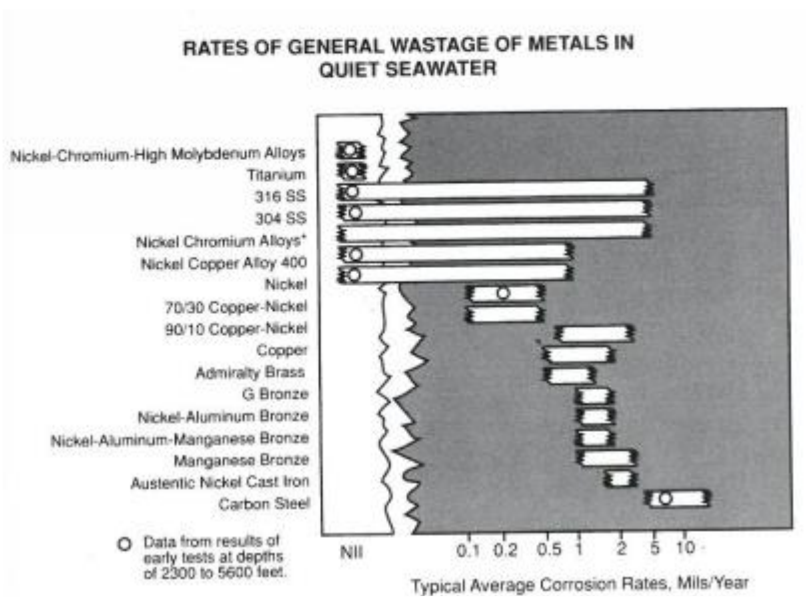

Figure 2-1. Graph of Average Corrosion Rates of Different Alloys in Seawater[1]

3.0 FINDINGS

The fifth set of wire screen samples was installed on Tuesday, June 17, 2014, and retrieved after nearly 3 years on Tuesday, May 23, 2017. Photographic documentation and lab results and analysis are presented below.

Two of the wire screen samples could not be retrieved since they detached from the test rack. It is suspected that the samples suffered a severe loss of material at the cable tie attachment points and fell. The bottom of the intake riser is filled with very fine silt which reduces visibility to zero when disturbed making retrieval very difficult. The material loss may have been caused by the turbulence in the water and the abrasion by the zip ties that prevented the passivation of the metal at those locations. The 70-30 Cu-Ni wire screen (see Photo 3-11 to Photo 3-14) and the immersed 1-year wire screens (see previous report) show signs of wear at the cable tie attachment points. This was identified in the previous report and Tenera Environmental wove the cable ties through the second slot at each point as a precautionary measure. Inspection of the PVC rack found that the cable ties from the missing samples (that could be seen through the biofouling) were still fully intact with closed loops.

3.1 Photos of Samples after 3 years of Exposure

Photo 3-1 through Photo 3-14 show the samples after 3 years of exposure. These photos are courtesy of Anamet, Inc. and are included in the reports in Appendix A.

Photo 3-1. Uncoated 2205 Duplex SS wedge wire screen, before cleaning.

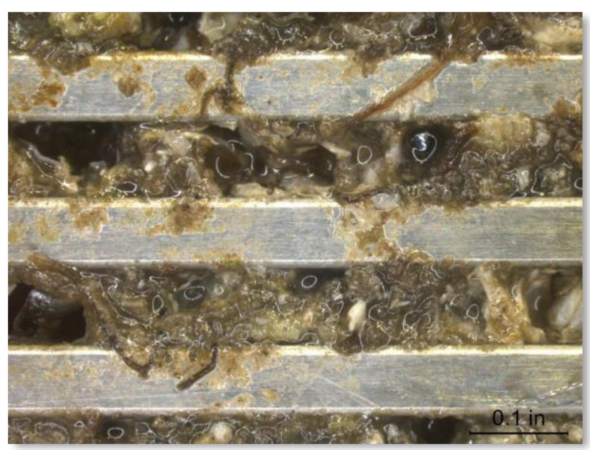

Photo 3-2. Detail view (10x) of uncoated 2205 Duplex stainless steel before cleaning.

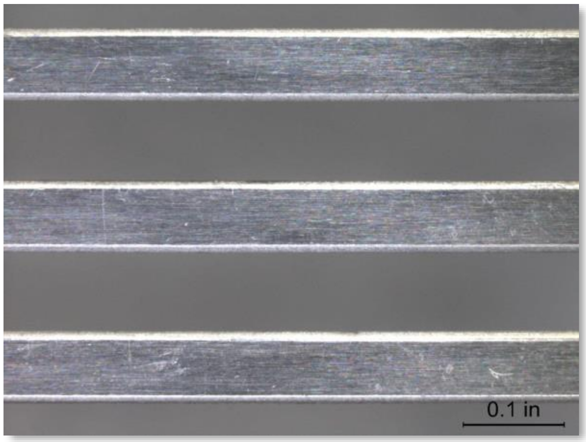

Photo 3-3. 2205 Duplex stainless steel wire screen, after cleaning (10x)

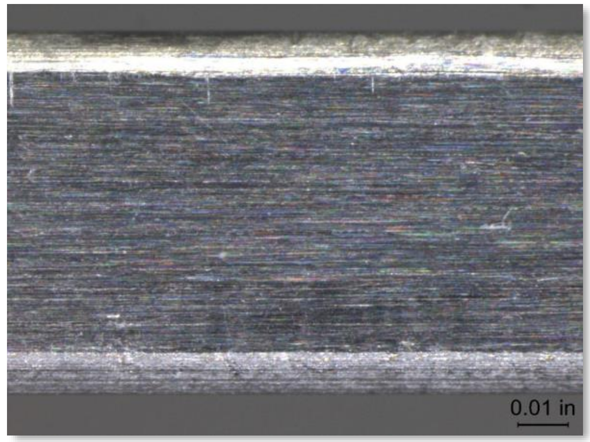

Photo 3-4. Detail view (50x) of uncoated 2205 Duplex stainless steel, after cleaning.

Photo 3-5. Coated 2205 Duplex SS wire screen, before cleaning.

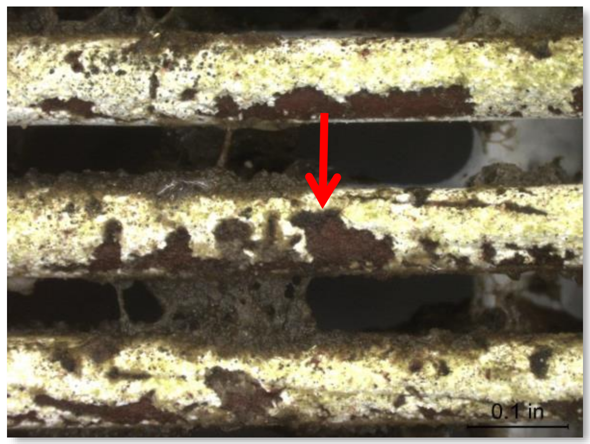

Photo 3-6. Detail view (10x) of coating damage on 2205 Duplex SS, before cleaning.

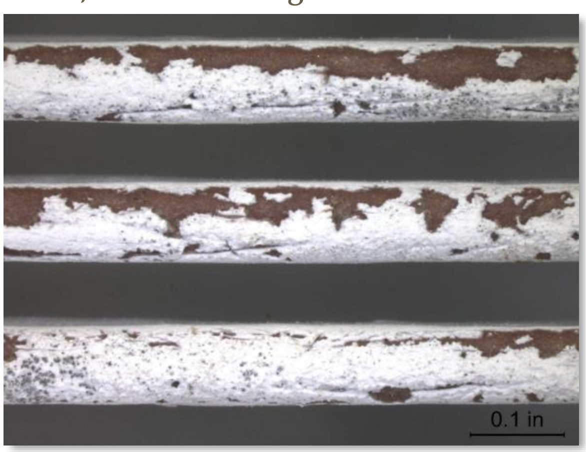

Photo 3-7. Coated 2205 Duplex stainless steel wire screen, after cleaning (10x).

Photo 3-8. Detail view (50x) of coating damage, after cleaning.

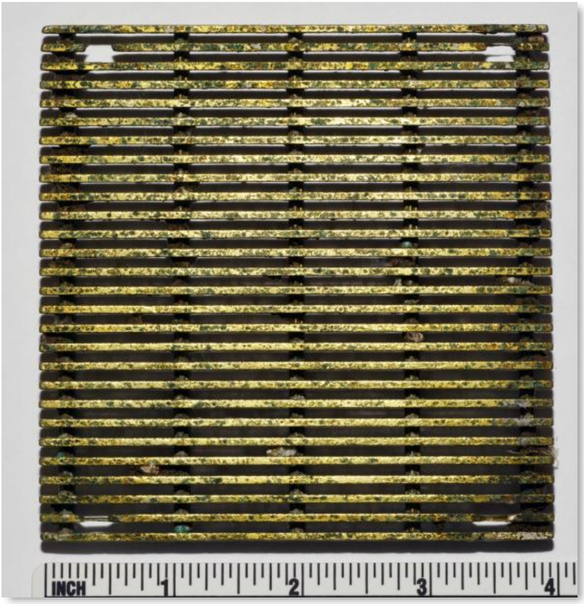

Photo 3-9. 70-30 Cu-Ni wedge wire screen, before cleaning.

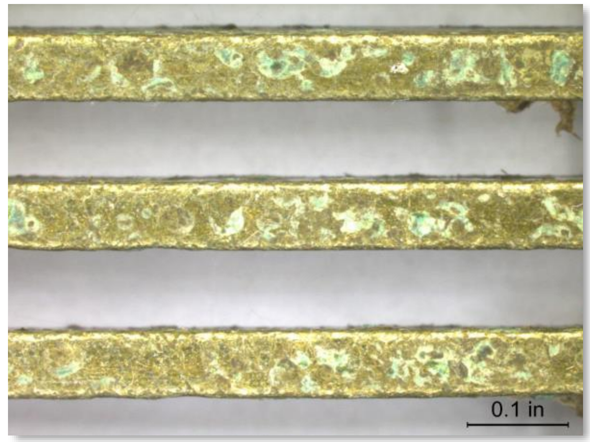

Photo 3-10. Detail view (10x) of 70-30 Cu-Ni wedge wire screen.

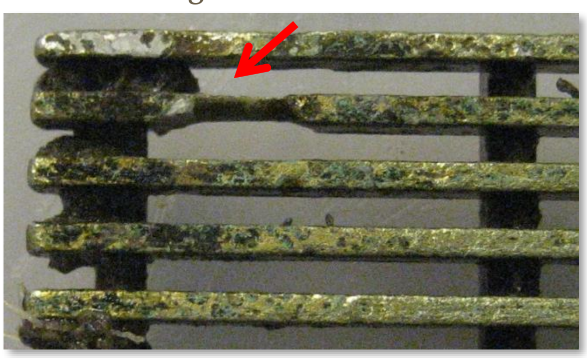

Photo 3-11. Mechanical damage to 70-30 Cu-Ni wedge wire screen at top left corner

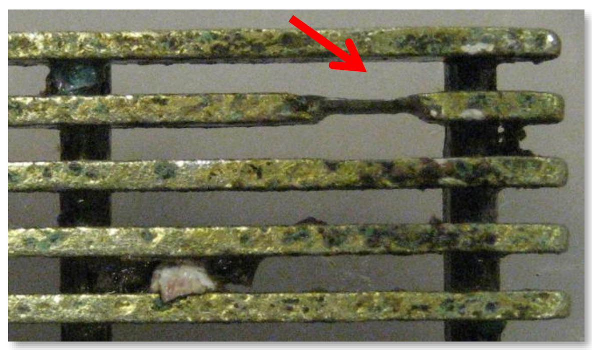

Photo 3-12. Mechanical damage to 70-30 Cu-Ni wedge wire screen top right corner

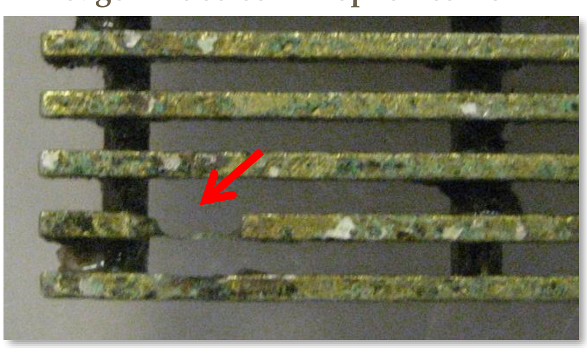

Photo 3-13. Mechanical damage to 70-30 Cu-Ni wedge wire screen at bottom left corner

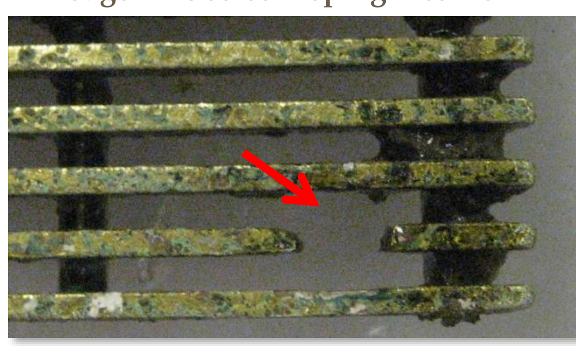

Photo 3-14. Mechanical damage to 70-30 Cu-Ni wedge wire screen at bottom right corner

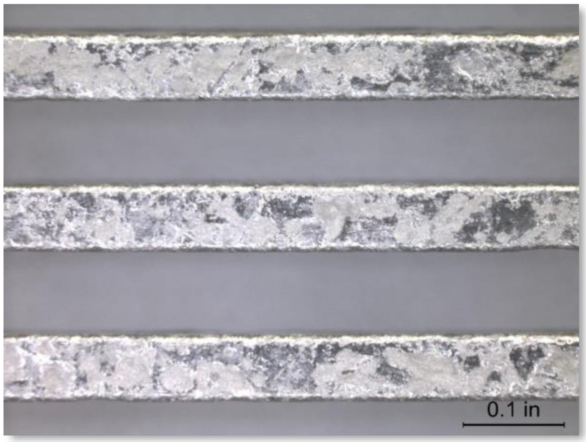

Photo 3-15. 70-30 Cu-Ni wire screen, after cleaning.

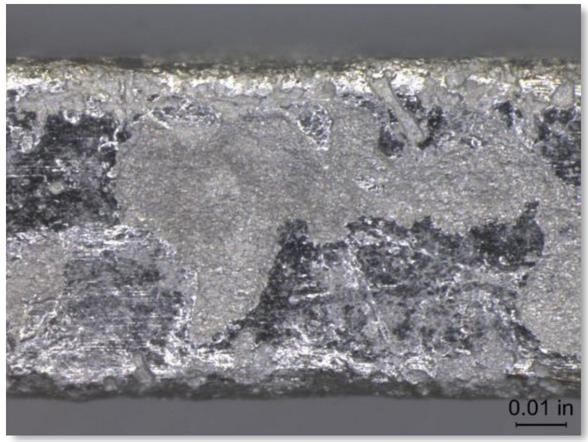

Photo 3-16. Detail view (50x) of 70-30 Cu-Ni wire screen, after cleaning.

3.2 Corrosion Rates after 3 years

Table 3-1 summarizes the results of the average general corrosion rate analysis conducted by Anamet, Inc. after the samples were exposed to seawater for nearly 3 years starting on June 17, 2014.

Pitting depths were not previously performed on the wedge wire screens due to the difficulty of mounting a pit depth gauge on the surface and were estimated to be less than 20 mils. Instead, pit depths were measured on the flat plate samples of the same alloy. In this report, the pit depths were estimated by metallographically mounting the screen and measuring the pits visually. After the 3 years of exposure, the foul release-coated 2205 Duplex SS screen pitting depth of 0.9 mils is less than the depth that was measured after 1 year of exposure (1.38 mils) on an uncoated 2205 Duplex SS sample. The smaller pitting depth on the foul-release-coated sample is likely due to the shorter time of exposure of the metal since it was protected by the coating. The 70-30 Cu-Ni screen pitting depth of 2.8 mils is greater than the depth measured after 1 year of exposure (1.57 mils).

Table 3-1. Average General Corrosion Rates of Alloys in Seawater Exposure

Alloy	Sample Type	Surface Area (sq. in.)	Maximum Pitting Depth after 1 and 3 Years (mils)	1 Year Average General Corrosion Rate (mils/year)	3 Year Average General Corrosion Rate (mils/year)
2205 Duplex SS Uncoated	1-inch by 3-inch coupon	8.2	1.38	0.0004	-
	Wedge Wire Screen	96.7	< 20 [A] (1 yr), <20 [A] (3 yr)	0.001	0.004
	4-inch by 4-inch plate	33.9	< 20 [A]	0.002	-
2205 Duplex SS with Foul Release Coating	1-inch by 3-inch coupon	8.2	1.30 [B]	0.039 [B]	-
	Wedge Wire Screen	96.7	< 20 [A] (1 yr), 0.9 (3 yr)	0.039 [B]	0.079
	4-inch by 4-inch plate	34.6	< 20 [A]	0.039	-
CDA 715 70-30 Cu-Ni	1-inch by 3-inch coupon	8.2	1.6	0.472	-
	Wedge Wire Screen	65.0	< 20 [A] (1 yr), 2.8 (3 yr)	0.709	0.394
	4-inch by 4-inch plate	34.4	< 20 [A]	0.315	-
CDA 706 90-10 Cu-Ni	1-inch by 3-inch coupon	8.2	11.5	0.669	-
	Wedge Wire Screen	79.1	< 20 [A]	1.732	-
	4-inch by 4-inch plate	34.1	< 20 [A]	1.142	-
Z Alloy	1-inch by 3-inch coupon	8.2	0.47	0.236	-
	Wedge Wire Screen	96.3	< 20 [A]	1.772	-
	4-inch by 4-inch plate	36.6	< 20 [A]	0.232	-

[A] Less than detectable/measurable. The screens were metallographically mounted and optical micrographs of the surface up to 200x, resolution of several micrometers, were examined.

[B] Mass loss and corrosion rate includes metal and coating material

3.2.1 Corrosion Rate over Time

The calculated average general corrosion rate value for each alloy and sample type is plotted on the graph below for each exposure time. Figure 3-1 visually summarizes the results of the corrosion rate analysis over nearly 3 years of testing. Please note that the corrosion rates were calculated per the procedures outlined in ASTM G1 and the graph below was not used to calculate the corrosion rate.

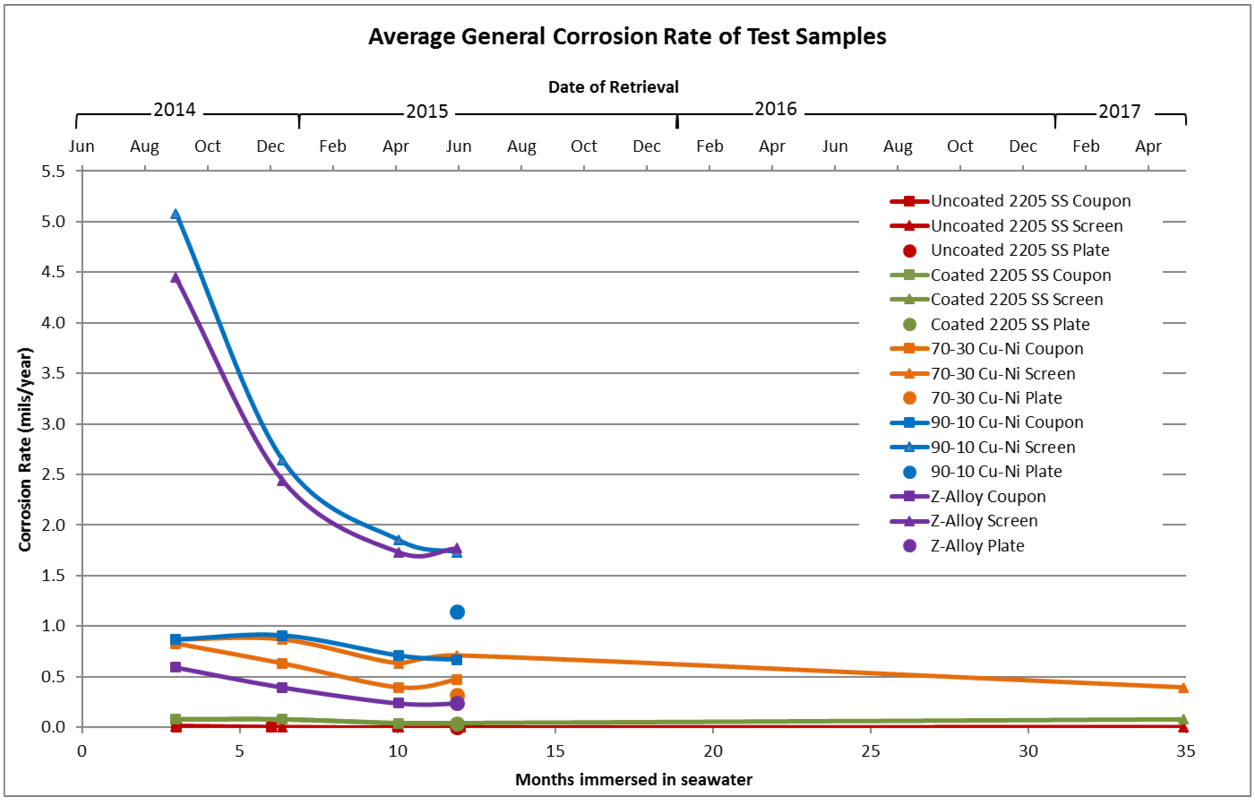

Figure 3-1. Corrosion Rates of Four Alloys over nearly 3 years in Seawater Exposure

The 2205 Duplex SS uncoated and coated screens showed minimal mass loss and pitting overall after 3, 6, 10, 12, and 36 months of corrosion testing. The average general corrosion rates of the 3-year stainless steel samples did increase slightly from the 12-month samples and were most similar to their respective materials' 6-month samples; however, the difference is minimal. The average general corrosion rate is higher for the coated 2205 Duplex SS sample due to the missing anti-fouling coating that was damaged over time and does not necessarily indicated more corrosion has occurred than the uncoated sample.

The 70-30 Cu-Ni wire screen showed a non-linear decrease in the average general corrosion rate from the 3-month to the 3-year samples. This is consistent with previous studies completed by others. The average general corrosion rate decreases after 3 months after a protective passive film layer is established. The passivation layer acts as a shield to keep corrosive ions like chlorides away from the metal surface. The trend of decreasing average general corrosion rate over time is similar over the 3-year study at an approximate loss of 0.176 mils/yr. The average general corrosion rate has likely reached a steady state and has built up a protective layer on the surface. It should be noted that the 70-30 Cu-NI wire screens had a lot less marine growth than the uncoated stainless steel screens.

Notably, the two wire screens that were not retrieved after 3 years previously had the highest corrosion rates. The average general corrosion rate for the 90-10 Cu-Ni and Z Alloy wedge wire screen samples quickly decreases after 3 months before a protective passive film is established and the corrosion rate equalizes after 9 to 12 months. At 12 months, the 90-10 Cu-Ni and Z Alloy wire screens had an average general corrosion rate of approximately 1.75 mils/yr and seemed to be reaching a steady state corrosion rate. Additionally, at 12 months, the 90-10 Cu-Ni and Z Alloy wire screens were showing surface discoloration and development of blue-green patina. The difference in the average general corrosion rates of the alloys is likely due to a difference in the metallurgy, abrasion resistance, and corrosion resistance of the materials.

In general, the wedge wire screens had a higher average general corrosion rate than the 1-inch by 3-inch flat coupons the 4-inch by 4-inch flat plates of the same alloy. This is likely due to the larger surface area of the wedge wire screens as compared to the flat coupons and plates.

3.2.2 Water Temperature

The corrosion rates may have also been affected by the seasonal water temperature changes. Figure 3-2 and Figure 3-3 graph the water temperature data collected at the intake throughout the course of the study. The temperature logger was able to log data until February 8, 2017 when the memory was filled or power was lost.

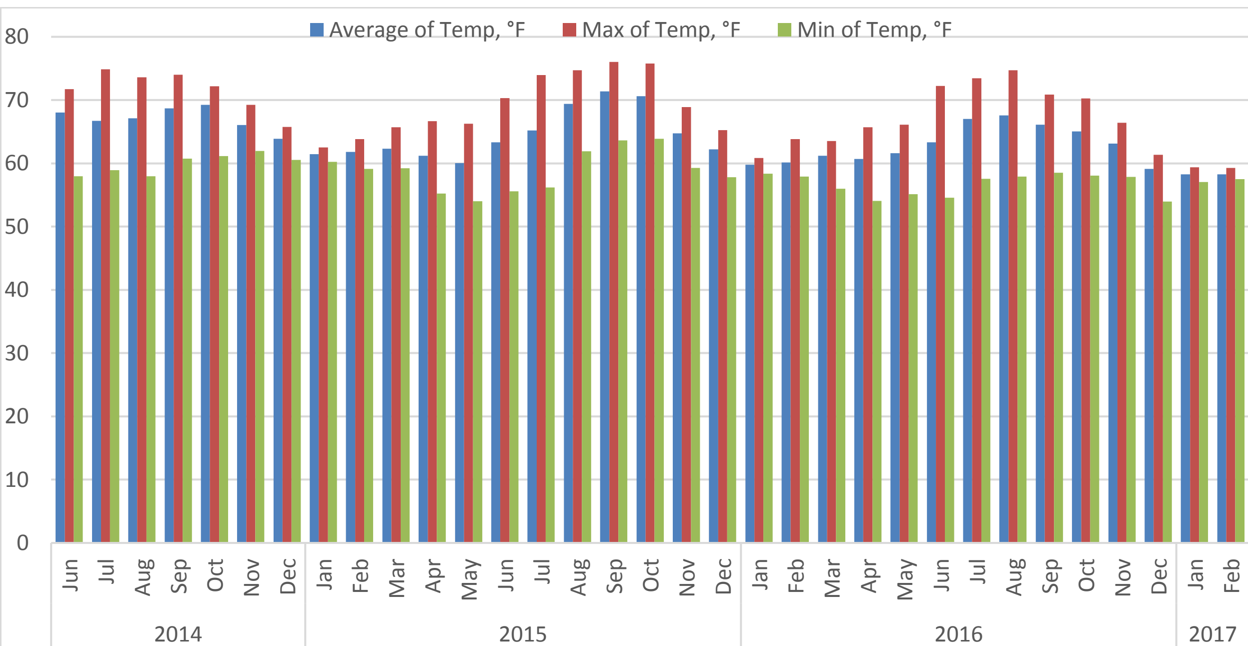

Figure 3-2. Summary of Temperature Data Per Month

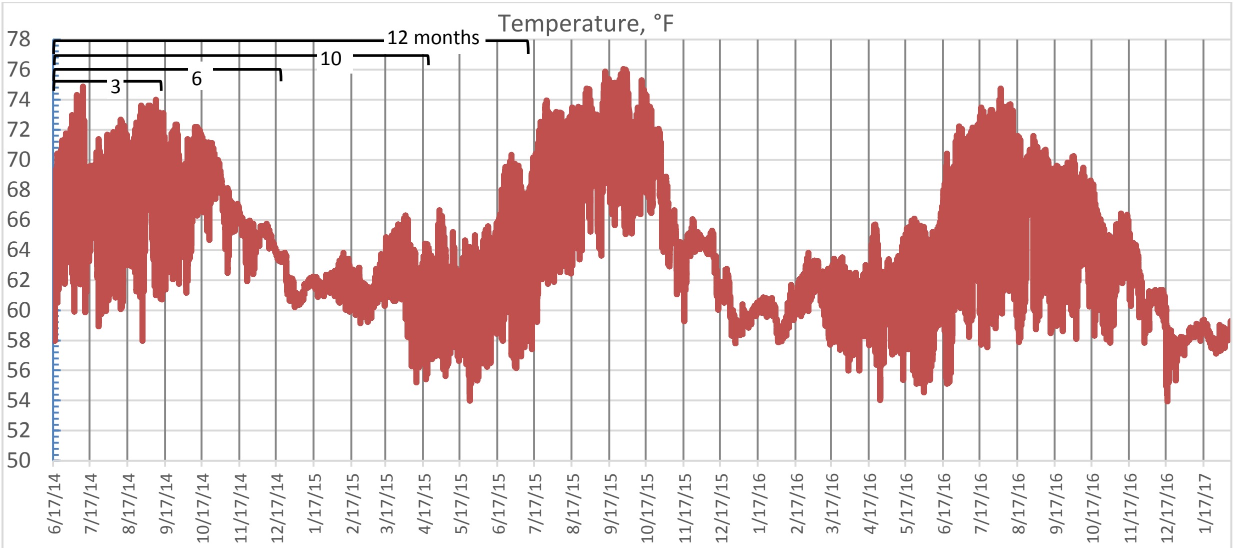

Figure 3-3. Raw Temperature Data Over Time at Intake Structure

The water temperature for all of the months was an average of 64 degrees Fahrenheit, minimum 54 degrees Fahrenheit and maximum 76 degrees Fahrenheit.

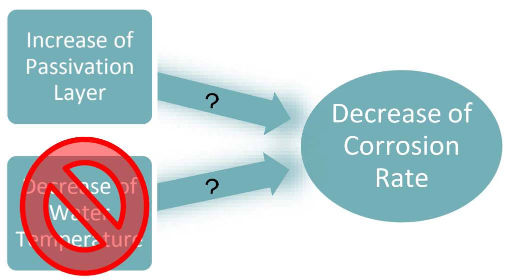

Figure 3-4. Potential Corrosion Rate Factors

The lower average corrosion rates of 10, 12 and 36 months appear to coincide with lower water temperatures, averaged over time. However, the lower average general corrosion rate also coincided with a more developed passivation layer. The causal influence of each factor cannot be separated in this study, but the decrease in temperature was minimal compared to the amount of passivation layer visible and the temperature effect should average out for the 3-years study. Therefore, the increase of passivation layer probably had a larger effect than the temperature change.

3.2.3 Comparison between the Different Material Types

Based on the data over 3 years, coated and uncoated 2205 Duplex Stainless Steel has the lowest average corrosion rates of the four metal alloy screens tested in this study. However, the uncoated 2205 Duplex Stainless Steel samples were the most heavily fouled by marine life.

Of the copper alloy wire screens, the 70-30 Cu-Ni sample exhibited only slight green marine life fouling; probably of the amount that may help reduce the corrosion rate by limiting the exposure of the metal to the seawater. After 3 years of immersion in seawater, the 70-30 Cu-Ni average general corrosion rate was 44% less than the average general corrosion rate after 1 year of the same alloy. This indicates that the corrosion rate has decreased over time and is likely due to the formation of the protective passivation layer over time that has shielded the metal from the corrosive seawater environment.

Of the three samples retrieved after 3-years, the highest pitting rate was observed on the 70-30 Cu-Ni wire screen. However, these were still shallow pits of less than or equal to 2.8 mils.

3.2.4 SEM and Energy X-ray Spectra Results

Baseline SEM and EDS scans were performed on the samples at the start of the study prior to deploying the samples into the seawater and can be viewed in V&A's November 2014 report. A summary of the EDS results and chemical composition requirements for 2205 Duplex SS and 70-30 Cu-Ni samples are presented in

Table 3-2.

The SEM scan (Anamet report Figure 5) of the 2205 Duplex SS indicated long narrow pits which was likely caused by corrosion. The EDS spectra after the cleaning of the sample indicated mostly chromium and iron at higher concentrations than minimum UNS standards; however, it is just estimated.

The SEM scan (Anamet report Figure 5) of the anti-fouling coated 2205 Duplex SS sample indicated degradation of the coating which was likely caused by erosion or abrasion. The EDS spectra (Anamet report Figure 6) of the coating after the cleaning of the sample indicated mostly carbon, oxygen, and silicon which fits the general description of Sherwin Williams Sher-Release Seaguard data sheet.

The SEM scan (Anamet report Figure 5 and 6) of the 70-30 Cu-Ni metal indicated pits which was likely caused by corrosion. The EDS spectra after the cleaning of the sample indicated mostly copper and nickel at lower concentrations than minimum UNS standards. This is likely because more carbon was on the samples during the EDS measurements, which caused the percentage of the other elements to appear lower than they likely are away from carbon contamination. The concentration of chlorides of 1.3% by weight (13,000 ppm) high due to the seawater exposure. For reference, the material certificates from the sample material manufacturers are included in the Appendix

Table 3-2. EDS Results for Baseline and 3-Year Exposure Samples

Element	Chemical Composition (Percent by Weight)							
	2205 Duplex SS (UNS S32205)				CDA 715 70-30 Cu-Ni			
	Spec	Cert	Baseline	3 Years	Spec	Cert	Baseline	3 Years
Carbon, C	≤ 0.30	0.019	5.35	4.11	≤ 0.050	0.004	19.58	6.46
Oxygen, O	-	-	1.70	-	-	-	1.24	-
Aluminum, Al	-	-	0.71	-	-	-	-	-
Silicon, Si	≤ 1.00	0.430	0.32	0.38	-	-	0.12	0.23
Chromium, Cr	22.0-23.0	22.500	21.48	22.71	-	-	-	-
Titanium, Ti	-	-	-	-	-	-	-	0.28
Manganese, Mn	≤ 2.00	1.390	1.16	-	≤ 1.0	0.68	0.53	0.74
Iron, Fe	Remainder	Remainder	61.16	64.46	0.40-1.00	0.50	0.47	0.67
Nickel, Ni	4.50-6.50	5.600	4.84	4.98	29-33	29.7	23.69	29.47
Zirconium, Zr	-	-	0.49	-	-	-	-	-
Molybdenum, Mo	3.00-3.50	3.100	2.80	3.36	-	-	-	-
Copper, Cu	-	-	-	-	≥ 65	69.16	54.37	62.13
Nitrogen, N	0.14-0.20	0.180	-	-	-	-	-	-
Phosphorus, P	≤ 0.030	0.023	-	-	≤ 0.003	< 0.01	-	-
Sulfur, S	≤ 0.020	0.001	-	-	≤ 0.020	0.001	-	-
Lead, Pb	-	-	-	-	≤ 0.020	< 0.01	-	-
Zinc, Zn	-	-	-	-	≤ 0.010	< 0.01	-	-

3.2.5 Sources of Variation

Corrosion rate variation for duplicate samples may be attributed to numerous factors, including differences in chemistry, surface condition, condition of exposure, location of test samples, and geometry and resultant biofouling. Also, environmental conditions may influence the degree of biofouling and integrity of the passive film, such as turbulence or mechanical damage. The thin passive oxide film is sensitive to the environment in which it is formed. The corrosion rate is directly influenced by the passive film because it acts as a barrier to the corrosion reaction on the metal surface.

4.0 CONCLUSIONS

Only the wire screens that were immersed for 3 years and recovered are included in the following section. Pitting, erosion corrosion, and general corrosion were the primary modes of corrosion on the screens.

1. 2205 Duplex Stainless Steel Uncoated: lowest and steady average general corrosion rate of less than 0.004 mils/yr after the first 3 months (initially 0.013 mils/yr rate). The average general corrosion rate is 7.5 times less than the data found in the literature (0.03 mils/yr). Minimal to non-detectable pitting was observed. However, this alloy had the most marine life attached to the surfaces of all the samples. The SEM scan (Anamet report Figure 5) of the sample indicated long narrow pits which was likely caused by corrosion. The EDS spectra after the cleaning of the sample indicated mostly chromium and iron at higher concentrations than minimum UNS standards.

2. 2205 Duplex Stainless Steel with 18 mils of Foul-Release Coating: steady and minimal average general corrosion rate of 0.04 to 0.08 mils/yr. Minimal to non-detectable pitting was observed. Note that the total mass loss and corrosion rate includes coating material and does not necessarily represent the metal loss only. Marine life/ bio-fouling mostly occurred after 12 months in concentrated locations; probably at areas of coating failure. The SEM scan (Anamet report Figure 5) of the sample indicated degradation of the coating which was likely caused by erosion or abrasion. The EDS spectra of the coating after the cleaning of the sample indicated mostly carbon, oxygen, and silicon which fits the general description of the Sherwin-Williams Sher-Release Seaguard data sheet.

3. CDA715 (70–30 Cu-Ni): moderate average general corrosion rate ranging between 0.32 mil/yr (plate sample exposed for 364 days) and 0.87 mils/yr (screen sample exposed for 91 days) during the 3-year study, with a steady decreasing trend over time. This study had a lower average general corrosion rate than found in the literature (1.06 mils/yr after 1 year and 1.41 mil/yr after 3 years). Shallow pitting of up to 2.8 mils in 3 years. The 70-30 Cu-Ni samples had less biofouling than other copper alloys after being immersed for 3 years; The biofouling on the surface is more prominent than surface discoloration. The SEM scan (Anamet report Figure 5 and 6) of the metal indicated pits which was likely caused by corrosion. The EDS spectra after the cleaning of the sample indicated mostly copper and nickel at lower concentrations than industry standards which may be due to deposits on the surface. The concentration of chlorides were high due to the seawater exposure.

4. CDA 706 (90-10 Cu–Ni): highest average general corrosion rate of the 5 materials, ranging between 0.67 mil/yr (coupon sample exposed for 364 days) to 5.08 mils/yr (screen sample exposed for 91 days) during the 12 month study. The sample was secured to the test rack with a plastic zip tie which may have eroded the metal over time and indicates that the alloy has a lower abrasion resistance than the 70-30 Cu-Ni alloy. The material loss especially at the attachment points is probably why this sample was not able to be retrieved after 3 years of immersion.

5. Z Alloy: high average general corrosion rate ranging between 0.24 mil/yr (coupon and plate samples exposed for 364 days) to 4.5 mils/yr (screen sample exposed for 91 days) during the 12 month study. A sample could not be retrieved after 3 years. The sample was secured to the test rack with a plastic zip tie which may have eroded the metal over time and indicates that the alloy has a lower abrasion resistance than the 70-30 Cu-Ni alloy. The material loss especially at the attachment points is probably why this sample was not able to be retrieved after 3 years immersion.

6. Pitting and general corrosion were the primary modes of corrosion on the coupons. In addition to pitting and general corrosion, the wedge wire screens experienced erosion corrosion. Pitting may occur under conditions that starve the metal surface of oxygen in short-term exposure periods.

7. The average general corrosion rate of the 70-30 Cu-Ni samples in this study were lower than the literature summarized in Table 2-2 after 1-year and 3-year exposures.

8. The average general corrosion rate of the 90-10 Cu-Ni samples in this study were higher than the literature summarized in Table 2-2 after 1 year of seawater exposure.

5.0 RECOMMENDATIONS

Based on the conclusions and V&A's experience with similar corrosion studies, the following recommendations are presented for WBMWD to consider for seawater exposures:

1. Intake screens should be manufactured with 70-30 Cu-Ni as it would provide a low average general corrosion rate over a long term service life, would not require a foul release coating and will not experience heavy biofouling. The 70-30 Cu-Ni screens would provide the less maintenance than the 2205 Duplex SS screens and would be recommended for long term service.
2. The foul-release-coated 2205 Duplex Stainless Steel screens would also provide a long term service based on the results of the study. The coating system provided the best protection against biofouling however the screen would have to be removed and the coating system would need to be touched up every 2 to 5 years as it is not abrasion resistant.
3. If intake screens are manufactured by 2205 Duplex Stainless Steel the following coating should be applied to the screens:
    a. 1st coat - Sherwin Williams Macropoxy 646 PW immersion grade epoxy primer at 6 mils dry film thickness (dft.)
    b. 2nd coat - Sherwin Williams Seaguard Sher-Release beige silicone Tie Coat at 6 mils dft.
    c. 3rd coat - Sherwin Williams Seaguard Sher-Release white silicone Surface Coat at 6 mils dft.
4. Foul-release coated screens should be inspected every 2 to 5 years to determine if repairs are required. The foul release coating will need to be removed from immersion service and repaired while the surfaces are dry.

APPENDIX A. LAB ANALYSIS REPORTS

Anamet, inc Materials Engineering & Laboratory Testing
26102 EDEN LANDING ROAD, SUITE 3 • HAYWARD, CALIFORNIA 94545 • (510) 887-8811 • FAX (510) 887-8427

Report No. 5005.4623B Rev.1 **July 7, 2017**

CORROSION EVALUATION OF A 2205 DUPLEX STAINLESS STEEL SCREEN

Customer Authorization: V&A Job Number 13-0376A

Report To: V & A Engineering
Attn: Manuel Najar
155 Grand Avenue, Suite 700
Oakland, CA 94612

1.0 INTRODUCTION

One wedge wire screen made from a 2205 duplex stainless steel alloy was submitted by V&A Engineering for corrosion evaluation. The wedge wire screen was 4-inches by 4-inches by 1-inch tall with 4 mm spacing. This evaluation was a continuation of a corrosion evaluation on 5 coupons, 5 wedge wire screens, and one plate as detailed in Anamet report 5005.0361.[1]

In the previous corrosion evaluation, the coupons, screens, and plate were to be placed in seawater for a period up to one year. After every 3 month interval, one coupon and one screen were to be removed from the test system and examined for corrosion. After 12 months, the plate was removed from the test system and examined for corrosion. The purpose of this evaluation was to document the samples in the baseline as-received condition, then again after 3, 6, 10, and 12 months of water exposure, record any loss in mass, examine for any pitting corrosion, and estimate the corrosion rate.

This screen was left in seawater for 3 years (36 months), then removed from the test system, and examined for corrosion. The purpose of this evaluation was to document the condition of the screen after 36 months of water exposure, record any loss in mass, examine for any pitting corrosion, and estimate the corrosion rate.

The screen was evaluated by the following laboratory procedures:

1) Visual examination and weighing
2) Cleaning per ASTM G1[2]
3) Scanning electron microscopy and energy dispersive x-ray spectroscopy
4) Metallography

The results of the evaluation showed minimal mass loss and corrosion for screen after 36 months of corrosion testing. The screen, after 36 months of corrosion testing, had a corrosion rate of less

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[1] Anamet Report 5005.0361: Corrosion Evaluation of 2205 Duplex Stainless Steel Coupons and Screens. July 17, 2015.
[2] G1: Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

than 0.0005 millimeters per year. When compared to the screens from the previous corrosion evaluation, the screens had lost less material over time from 3 to 12 months, but lost more material during the 36 month immersion period. The screens had a consistent corrosion rate of less than 0.0005 millimeters per year over the duration of the corrosion test.

2.0 EVALUATION[3]

2.1 Visual Examination

The sample identification for the wedge wire screen and the corresponding immersion time is shown in Table 1. A number of notches, corresponding to the sample number, were sawed at the edge of the screen for identification after the corrosion test. The weight of the screen was recorded and is presented in Table 2. A photograph of the screen after 36 months of corrosion testing is shown in Figure 1.

2.2 Cleaning

The screen was cleaned with solution C.7.1 per ASTM G1.[4] One cleaning cycle was approximately 10 minutes. After each cleaning cycle, the screen was rinsed in water, dried, and weighed. The cleaning and weighing cycle was completed five times. The weights of the screen as-received, after corrosion testing but before cleaning, and after each cleaning cycle are presented in Table 2. Optical macrographs of the screen, before and after cleaning, are shown in Figures 2 – 3.

The mass loss versus the number of cleaning cycles were plotted to determine the mass loss of the samples due to corrosion, shown in Figure 4. The equations for best fit lines AB and BC, calculated using IGOR Pro, are listed in Table 3. Point B, indicated by the red circle in the plot, corresponds to the mass loss due to corrosion during the cleaning process for the screen. This mass loss was subtracted from the weight of the screen before cleaning and from the weight of the screen as-received to determine the total mass loss from corrosion. The corrosion rate of the screen was determined by the formula specified in Section 8.1 of ASTM G1:

$$Corrosion\ Rate = \frac{K\ x\ W}{A\ x\ T\ x\ D}$$

where K = 8.76×10^4, T = time of exposure in hours, A = area in cm^2, W = mass loss in grams, and D = density in g/cm^3. The total mass loss from corrosion and the calculated corrosion rate of the screen is shown in Table 4. The results from the previous corrosion evaluation are presented for comparison.

2.3 Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy

The screen was examined with a scanning electron microscope. Representative scanning electron micrographs of the screen after cleaning is shown in Figure 5. Material loss was

[3] The magnifications of the optical and scanning electron micrographs in this report are approximate and should not be used as a basis for dimensional analyses unless otherwise indicated.
[4] 100 mL nitric acid + 900 ml reagent water.

observed on the surface of the screen and this material loss was likely due to corrosion of the metal. An energy dispersive x-ray spectrum of the screen after cleaning is shown in Figure 6. The screen was not analyzed by scanning electron microscopy or energy dispersive x-ray spectroscopy before cleaning due to the amount of biological products on it.

2.4 Metallography

A cross section was taken from the screen and prepared for a metallographic examination. Optical micrographs of the surface are shown in Figure 7. No pits were observed on the screen.

3.0 DISCUSSION

The screens showed minimal mass loss and pitting overall after 3, 6, 10, 12, and 36 months of corrosion testing. The screens had lost less material over time between 3 to 12 months, but lost more material during the 36 month immersion period. The calculated corrosion rate was consistent over the duration of the corrosion test.

4.0 CONCLUSIONS[5]

The following conclusions are based upon the submitted sample and the evidence gathered:

1. The screen, after 36 months of corrosion testing, had a mass loss of 0.16 grams. When compared to the screens from the previous corrosion evaluation, the screens had less mass loss over the duration of the corrosion test between 3 to 12 months, but had more material loss after 36 months of corrosion testing.

2. The screen, after 36 months of corrosion testing, had a corrosion rate less than 0.0005 mm / year. When compared to the screens from the previous corrosion evaluation, the screens had a consistent corrosion rate over the duration of the corrosion test.

Prepared by:	Reviewed by:
Norman Yuen Materials Engineer	Audrey A. Fasching, Ph.D., P.E. Senior Materials Engineer

[5] The conclusions in this report are based upon the available information and evidence provided by the client and gathered by Anamet, within the scope of work authorized by the client, and they are hereby presented by Anamet to a reasonable degree of engineering and scientific certainty. Anamet reserves the right to amend or supplement its conclusions or opinions presented in this report should additional data or information become available, or further work be approved by the client.

Table 1
Sample Identifications

Description		V&A Engineering Identification (As-Received)	Anamet Identification (in report)	Notes
Alloy	Part			
2205 Duplex Stainless Steel	**Wedge Wire Screen** 4-inch x 4-inch x 1-inch with 2 mm spacing	None	Screen 5	36 Month Immersion

Table 2
Sample Weights

Sample	Baseline Measurement	Measurements after 36 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Screen 5	311.97	311.91	311.89	311.80	311.82	311.80	311.81

Table 3
Equations of Lines AB and BC for Corrosion Testing Samples

Sample	Line AB	Line BC	Point B (Approximate Mass Loss from Corrosion)
Screen 5	y = 0.055x – 0.012	y = -0.001x + 0.106	0.104 grams

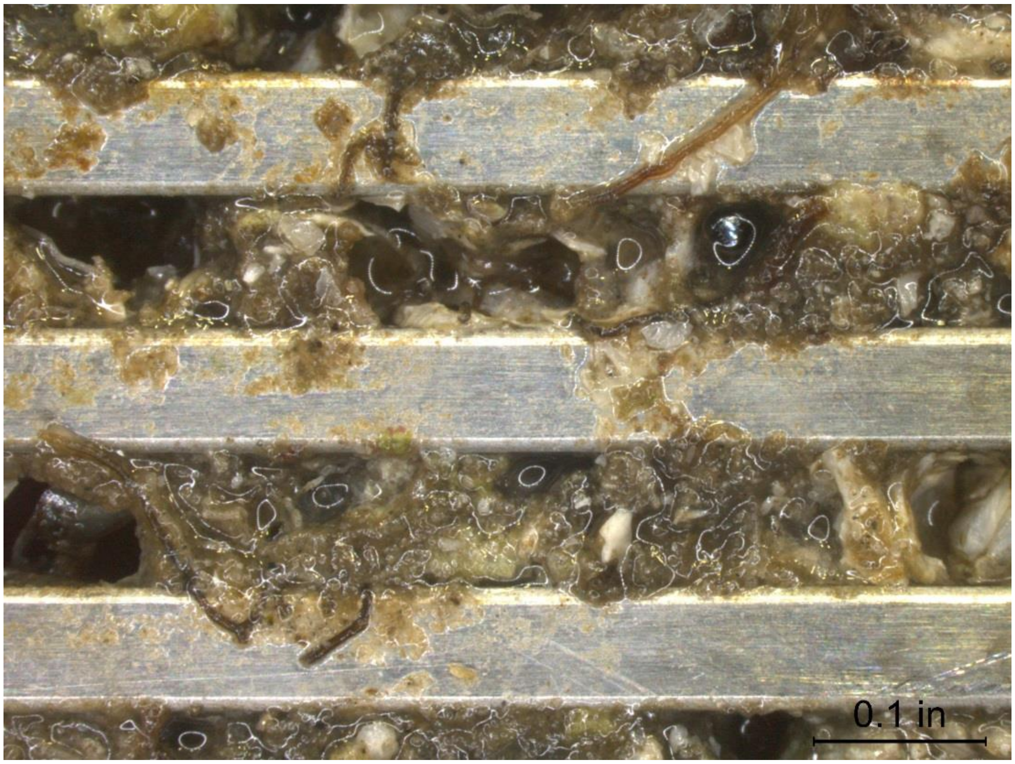
Table 4
Total Mass Loss from Corrosion and Corrosion Rate

Sample	Total Mass Loss from Corrosion*	Corrosion Rate
Screen 1	0.04 grams	< 0.0005 mm / year
Screen 2	0.02 grams	< 0.0005 mm / year
Screen 3	0.00 grams	< 0.0005 mm / year
Screen 4	0.01 grams	< 0.0005 mm / year
Screen 5	0.16 grams	< 0.0005 mm / year

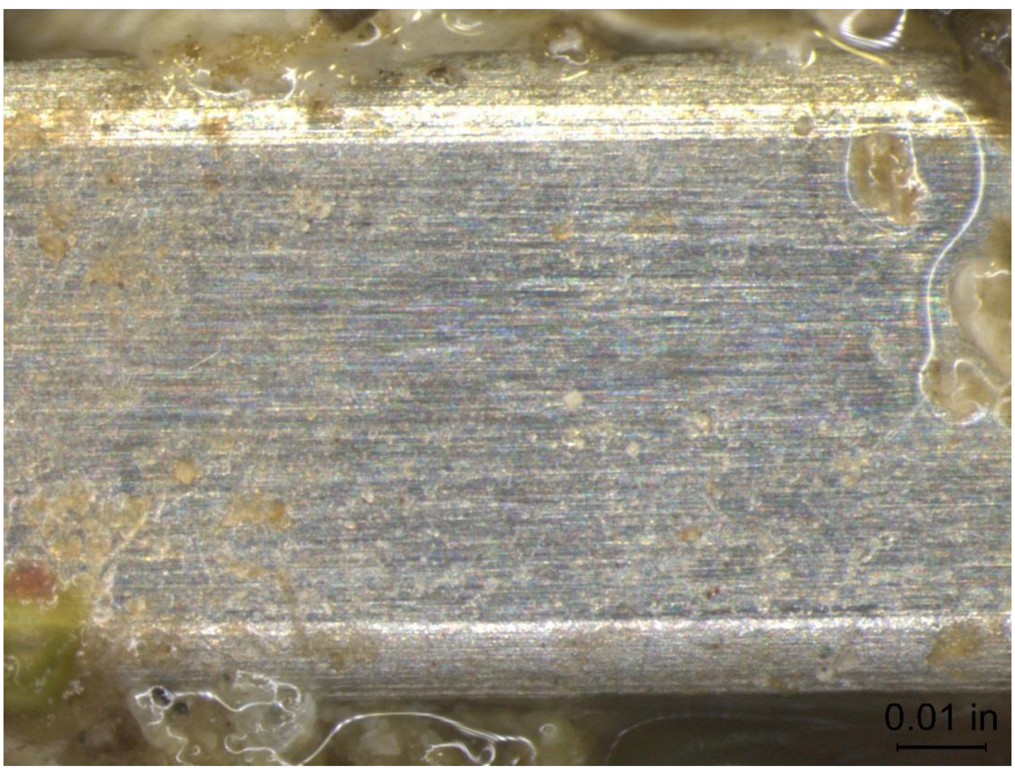
* Weight As-Received – (Weight Before Cleaning – Mass Loss from Corrosion During Cleaning)

(a) Duplex 2205 Stainless Steel Screen 5

Figure 1 Photograph of duplex 2205 stainless steel screen 5 after a 36 month corrosion test.

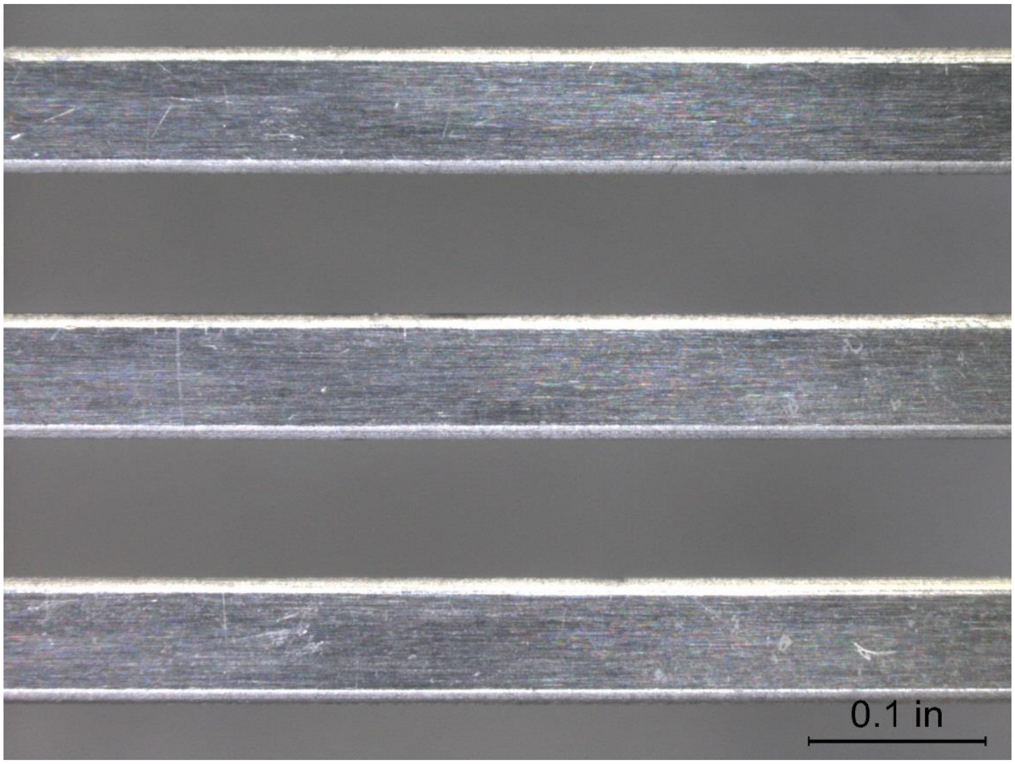


(a) Duplex 2205 Stainless Steel Screen 5, Before Cleaning 10X

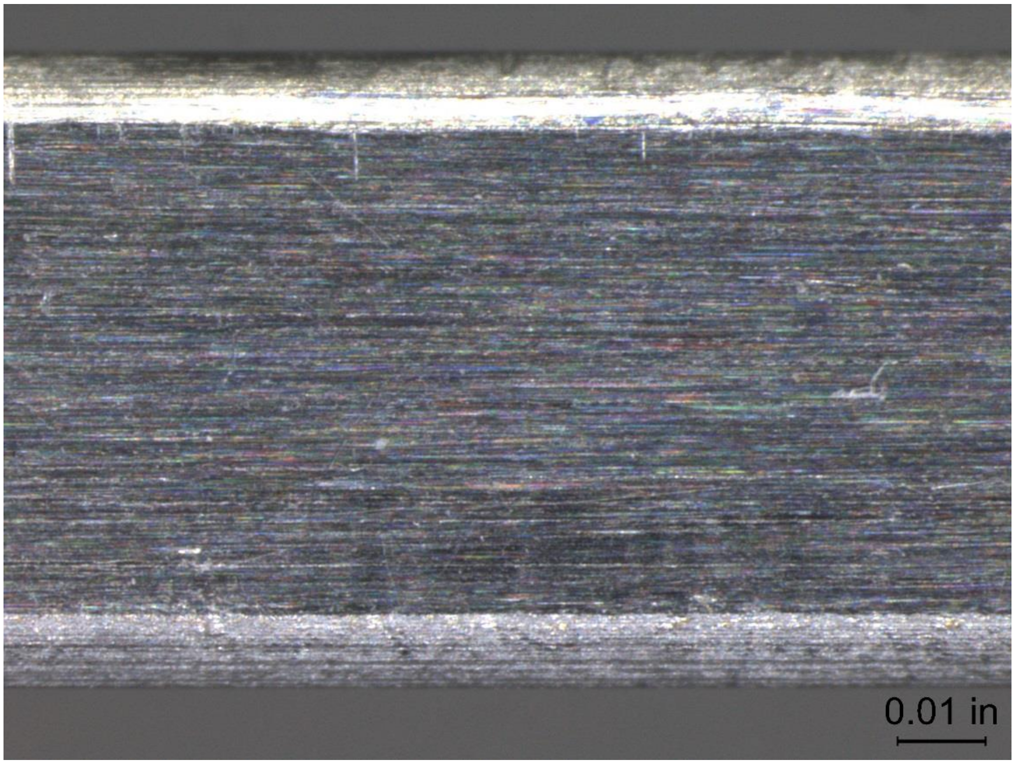


(b) Duplex 2205 Stainless Steel Screen 5, Before Cleaning 50X

Figure 2 Optical macrographs of duplex 2205 stainless steel screen 5 after a 36 month corrosion test, before cleaning.



(a) Duplex 2205 Stainless Steel Screen 5, After Cleaning 10X



(b) Duplex 2205 Stainless Steel Screen 5, After Cleaning 50X

Figure 3 Optical macrographs of duplex 2205 stainless steel screen 5 after a 36 month corrosion test, after cleaning.

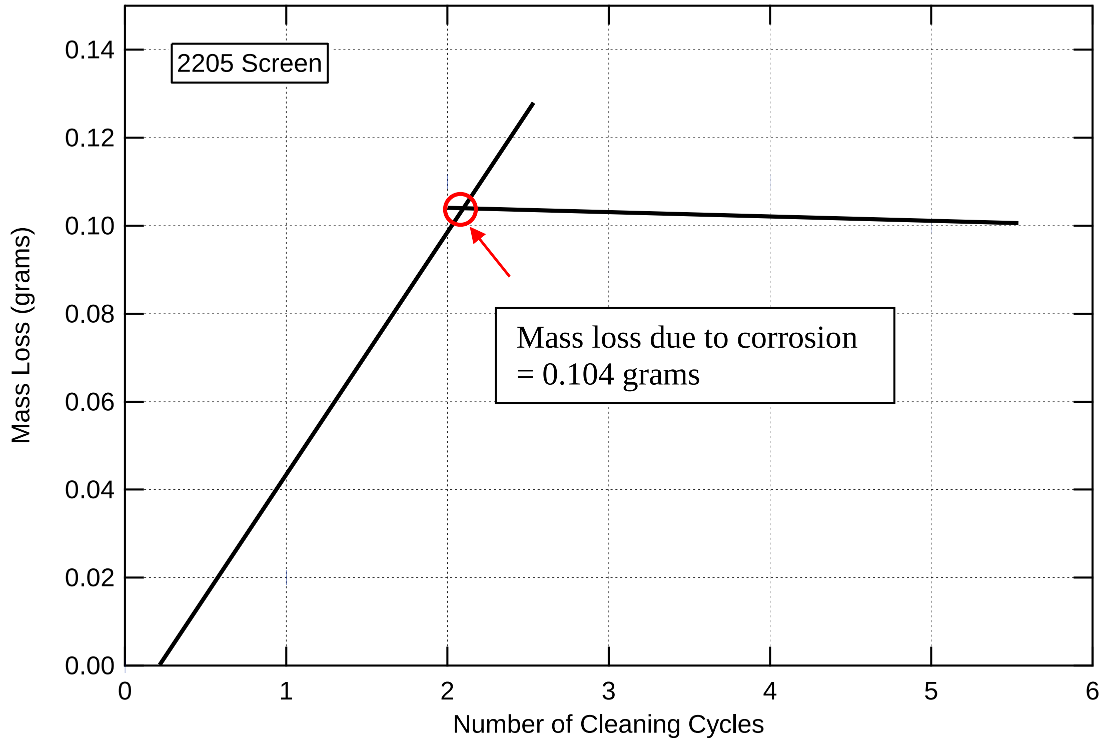
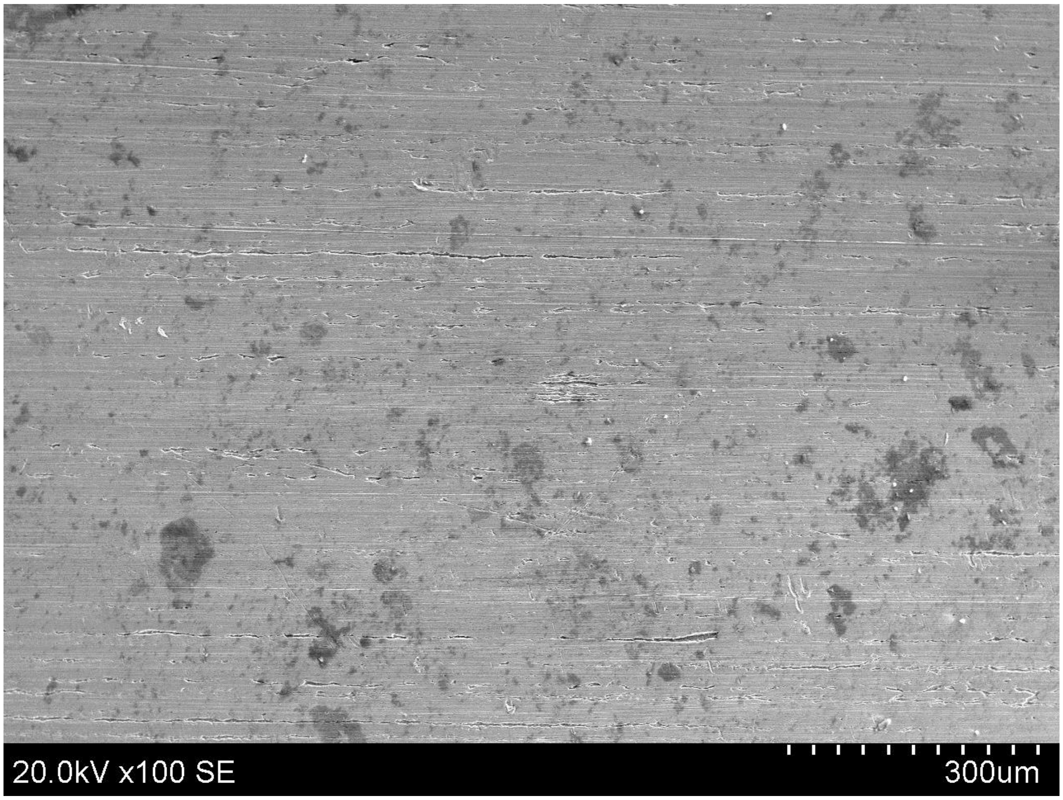
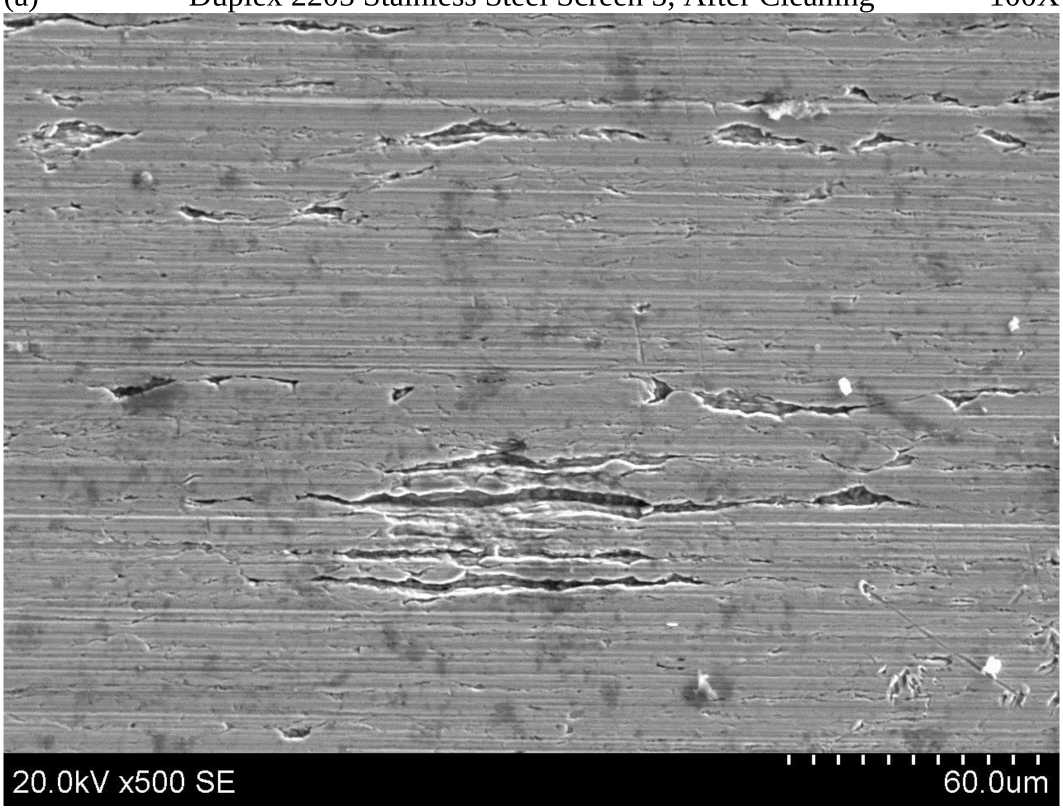


Figure 4 Mass loss of the duplex 2205 stainless steel screen 5 during cleaning.

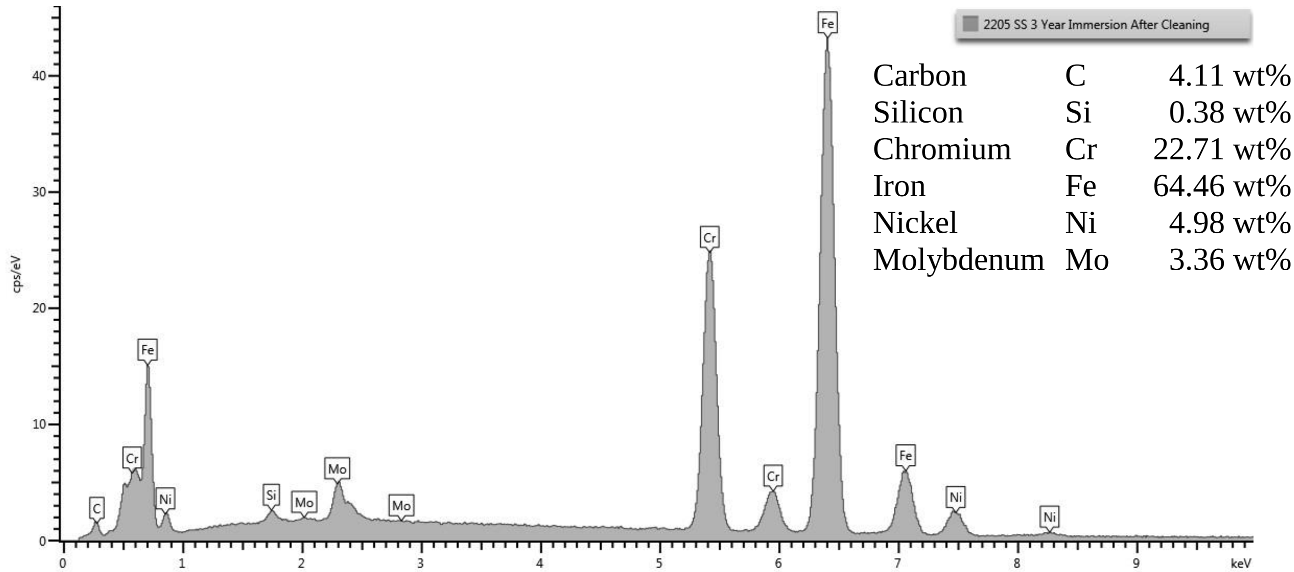


(a) Duplex 2205 Stainless Steel Screen 5, After Cleaning 100X



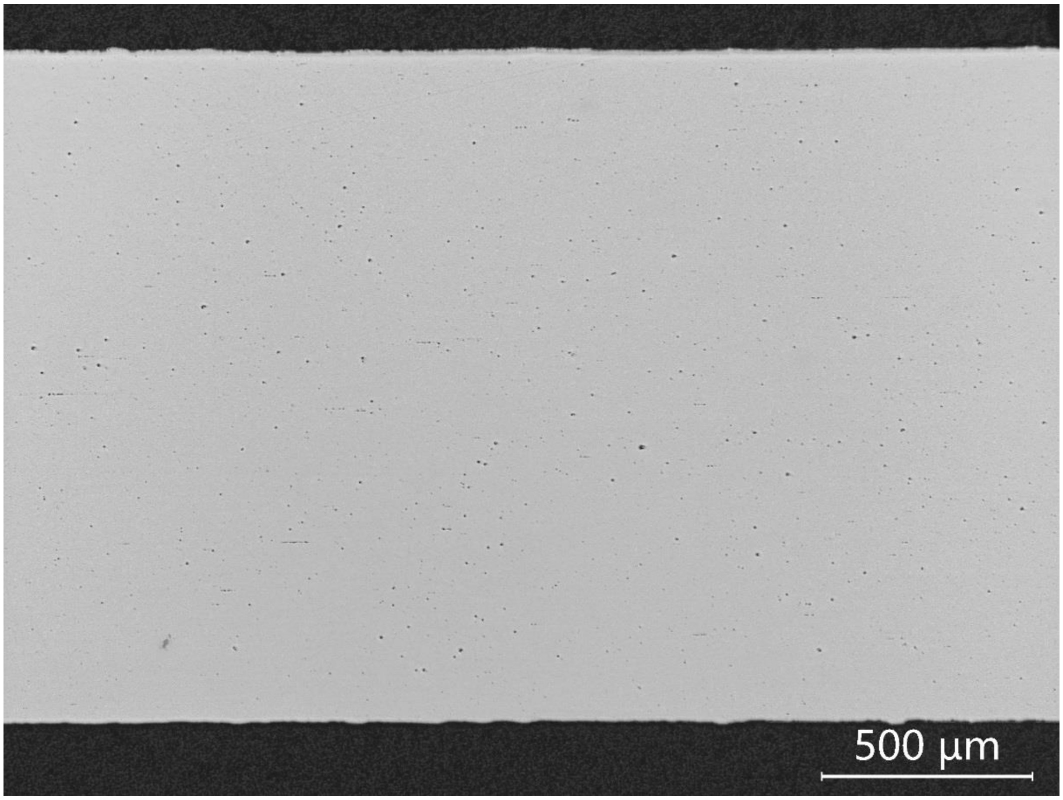
(b) Duplex 2205 Stainless Steel Screen 5, After Cleaning 500X

Figure 5 Scanning electron micrographs of duplex stainless steel screen 5 after a 36 month corrosion test, after cleaning.

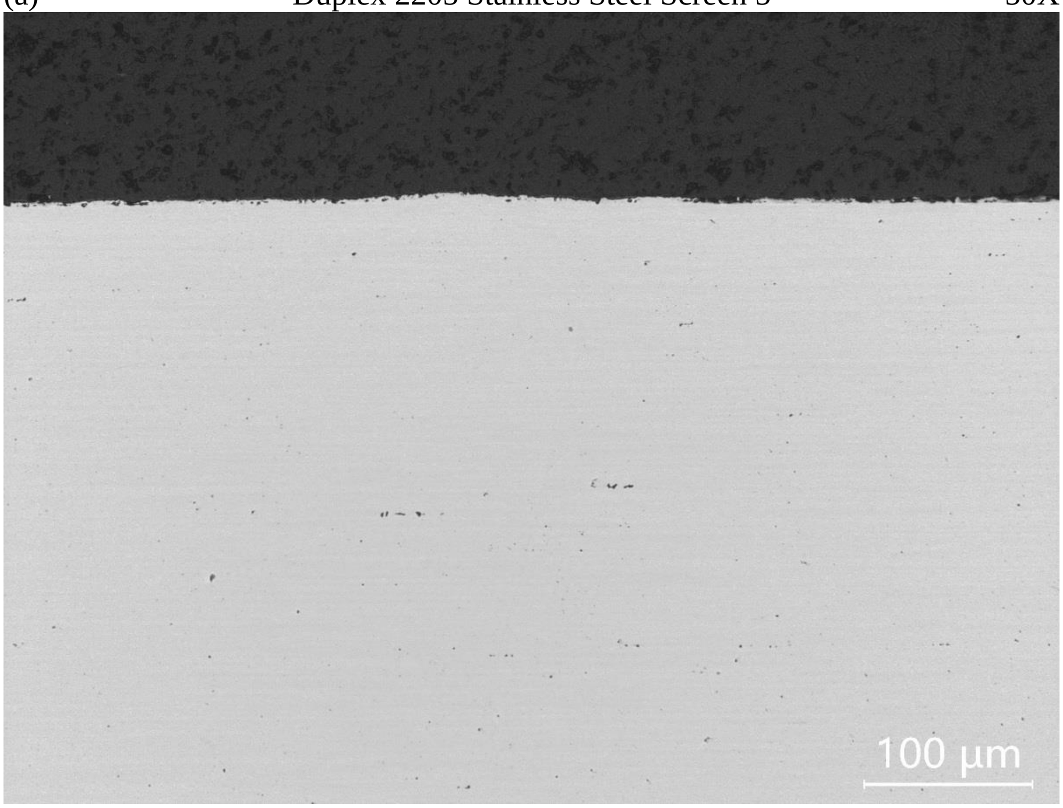


(a) Duplex 2205 Stainless Steel Screen 5, After Cleaning

Figure 6 Energy dispersive x-ray spectra of duplex stainless steel screen 5 after a 36 month corrosion test, after cleaning. The screen was not analyzed by energy dispersive x-ray spectroscopy before cleaning due to the marine life on the surface of the screen.



(a) Duplex 2205 Stainless Steel Screen 5 50X



(b) Duplex 2205 Stainless Steel Screen 5 200X

Figure 7 Optical micrographs of duplex stainless steel screen 5.

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Report No. 5005.4623A Rev.1 **July 7, 2017**

CORROSION EVALUATION OF A 2205 DUPLEX STAINLESS STEEL SCREEN WITH ANTI-BIOFOULING COATING

Customer Authorization: V&A Job Number 13-0376A

Report To: V & A Engineering
Attn: Manuel Najar
155 Grand Avenue, Suite 700
Oakland, CA 94612

1.0 INTRODUCTION

One wedge wire screen made from a 2205 duplex stainless steel with a bio-fouling coating was submitted by V&A Engineering for corrosion evaluation. The wedge wire screen was 4-inches by 4-inches by 1-inch tall with 4 mm spacing. This evaluation was a continuation of a corrosion evaluation on 5 coupons, 5 wedge wire screens, and one plate as detailed in Anamet report 5005.0361. [1]

In the previous corrosion evaluation, the coupons, screens, and plate were to be placed in seawater for a period up to one year. After every 3 month interval, one coupon and one screen were to be removed from the test system and examined for corrosion. After 12 months, the plate was removed from the test system and examined for corrosion. The purpose of this evaluation was to document the samples in the baseline as-received condition, then again after 3, 6, 10, and 12 months of water exposure, record any loss in mass, examine for any pitting corrosion, and estimate the corrosion rate.

This screen was left in seawater for 3 years (36 months), then removed from the test system, and examined for corrosion. The purpose of this evaluation was to document the condition of the screen after 36 months of water exposure, record any loss in mass, examine for any pitting corrosion, and estimate the corrosion rate.

The screen was evaluated by the following laboratory procedures:

1) Visual examination and weighing
2) Cleaning per ASTM G1[2]
3) Scanning electron microscopy
4) Metallography

[1] Anamet Report 5005.0361: Corrosion Evaluation of 2205 Duplex Stainless Steel Coupons and Screens with Anti-Biofouling Coating. July 17, 2015.
[2] G1: Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

The results of the evaluation showed minimal mass loss and corrosion for screen after 36 months of corrosion testing. The screen, after 36 months of corrosion testing, had a corrosion rate of 0.002 millimeters per year. When compared to the screens from the previous corrosion evaluation, the screens lost more material over time, but had a consistent corrosion rate over the duration of the corrosion test.

2.0 EVALUATION[3]

2.1 Visual Examination

The sample identification for the wedge wire screen and the corresponding immersion time is shown in Table 1. A number of notches, corresponding to the sample number, were sawed at the edge of the screen for identification after the corrosion test. The weight of the screen was recorded and is presented in Table 2. A photograph of the screen after 36 months of corrosion testing is shown in Figure 1.

2.2 Cleaning

The screen was cleaned with solution C.7.1 per ASTM G1.[4] One cleaning cycle was approximately 10 minutes. After each cleaning cycle, the screen was rinsed in water, dried, and weighed. The cleaning and weighing cycle was completed six times. The weights of the screen as-received, after corrosion testing but before cleaning, and after each cleaning cycle are presented in Table 2. Optical macrographs of the screen, before and after cleaning, are shown in Figures 2 – 3.

The mass loss versus the number of cleaning cycles were plotted to determine the mass loss of the samples due to corrosion, shown in Figure 4. The equations for best fit lines AB and BC, calculated using IGOR Pro, are listed in Table 3. Point B, indicated by the red circle in the plot, corresponds to the mass loss due to corrosion during the cleaning process for the screen. This mass loss was subtracted from the weight of the screen before cleaning and from the weight of the screen as-received to determine the total mass loss from corrosion. The corrosion rate of the screen was determined by the formula specified in Section 8.1 of ASTM G1:

$$Corrosion\ Rate = \frac{K\ x\ W}{A\ x\ T\ x\ D}$$

where K = 8.76×10^4, T = time of exposure in hours, A = area in cm^2, W = mass loss in grams, and D = density in g/cm^3. The total mass loss from corrosion and the calculated corrosion rate of the screen is shown in Table 4. The results from the previous corrosion evaluation is presented for comparison.

2.3 Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy

The screen was examined with a scanning electron microscope. Representative scanning electron micrographs of the anti-biofouling coating on the screen after cleaning is shown in

[3] The magnifications of the optical and scanning electron micrographs in this report are approximate and should not be used as a basis for dimensional analyses unless otherwise indicated.
[4] 100 mL nitric acid + 900 ml reagent water.

Figure 5. An energy dispersive x-ray spectrum of the anti-biofouling coating on the screen after cleaning is shown in Figure 6. The screen was not analyzed by scanning electron microscopy or energy dispersive x-ray spectroscopy before cleaning due to the amount of biological products on it.

2.4 Metallography

A cross section was taken from the screen and prepared for a metallographic examination. Optical micrographs of the surface are shown in Figure 7. Small, narrow pits were observed on the surface, the deepest of which measured 23 µm.

3.0 DISCUSSION

The screens showed minimal mass loss and pitting overall after 3, 6, 10, 12, and 36 months of corrosion testing. The screens had more material loss over time but had a consistent corrosion rate over the duration of the corrosion test.

4.0 CONCLUSIONS[5]

The following conclusions are based upon the submitted sample and the evidence gathered:

1. The screen, after 36 months of corrosion testing, had a mass loss of 2.26 grams. When compared to the screens from the previous corrosion evaluation, the screens had more mass loss over the duration of the corrosion test.

2. The screens, after 36 months of corrosion testing, had a corrosion rate of 0.002 mm / year. When compared to the screens from the previous corrosion evaluation, the screens had a consistent corrosion rate over the duration of the corrosion test.

Prepared by:	Reviewed by:
Norman Yuen Materials Engineer	Audrey A. Fasching, Ph.D., P.E. Senior Materials Engineer

[5] The conclusions in this report are based upon the available information and evidence provided by the client and gathered by Anamet, within the scope of work authorized by the client, and they are hereby presented by Anamet to a reasonable degree of engineering and scientific certainty. Anamet reserves the right to amend or supplement its conclusions or opinions presented in this report should additional data or information become available, or further work be approved by the client.

Table 1
Sample Identifications

Description		V&A Engineering Identification (As-Received)	Anamet Identification (in report)	Notes
Alloy	Part			
2205 Duplex Stainless Steel with anti-biofouling coating	**Wedge Wire Screen** 4-inch x 4-inch x 1-inch with 2 mm spacing	None	Screen 5	36 Month Immersion

Table 2
Sample Weights

Sample	Baseline Measurement	Measurements after 12 Months Corrosion Testing						
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)	Weight After 6th Cleaning (grams)
Screen 5	339.83	338.35	338.01	338.03	338.05	337.59	337.55	337.54

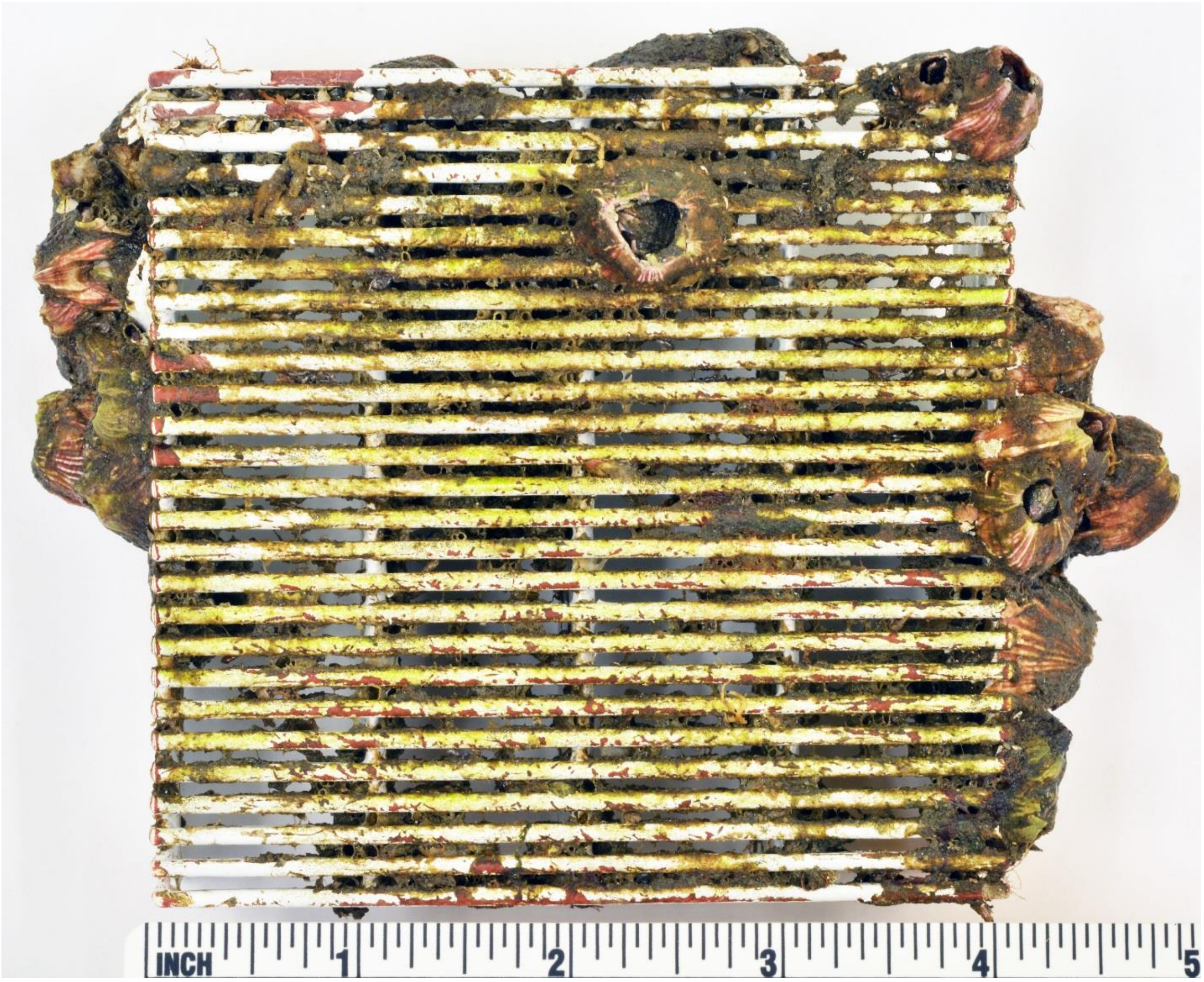
Table 3
Equations of Lines AB and BC for Corrosion Testing Samples

Sample	Line AB	Line BC	Point B (Approximate Mass Loss from Corrosion During Cleaning)
Screen 5	$y = 0.160x + 0.060$	$y = 0.025x + 0.665$	0.777 grams

Table 4
Total Mass Loss from Corrosion and Corrosion Rate

Sample	Total Mass Loss from Corrosion*	Corrosion Rate
Screen 1	0.25 grams	0.002 mm / year
Screen 2	0.43 grams	0.002 mm / year
Screen 3	0.60 grams	0.001 mm / year
Screen 4	0.60 grams	0.001 mm / year
Screen 5	2.26 grams	0.002 mm / year

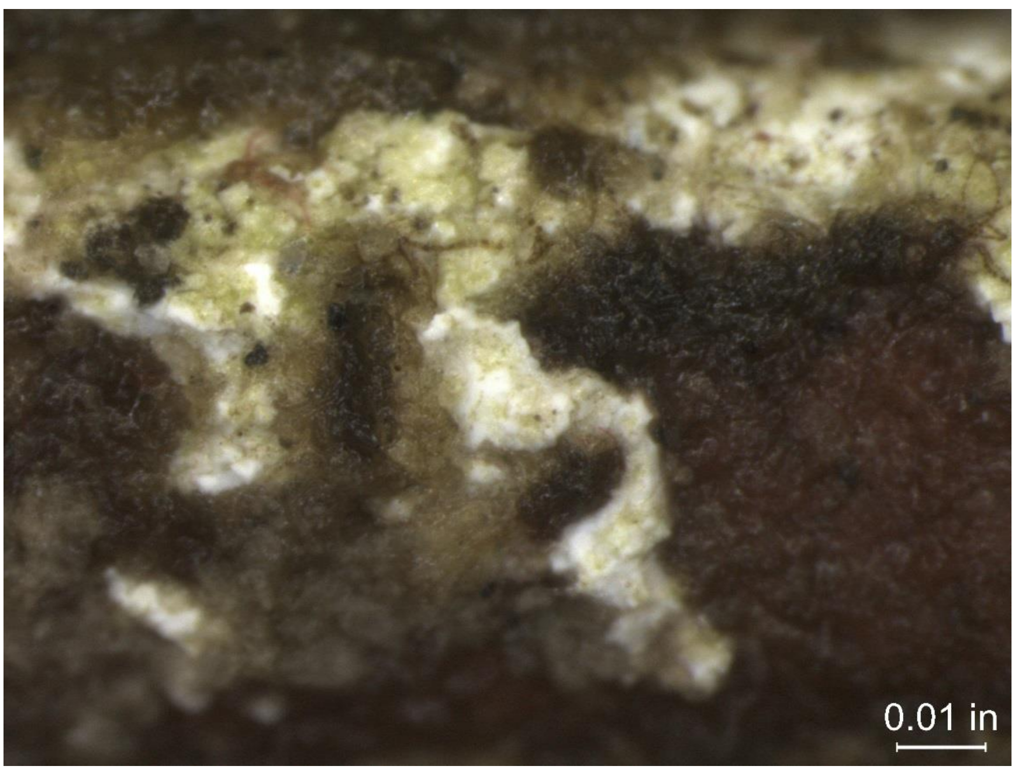
* Weight As-Received – (Weight Before Cleaning – Mass Loss from Corrosion During Cleaning)



(a) Coated Duplex 2205 Stainless Steel Screen 5

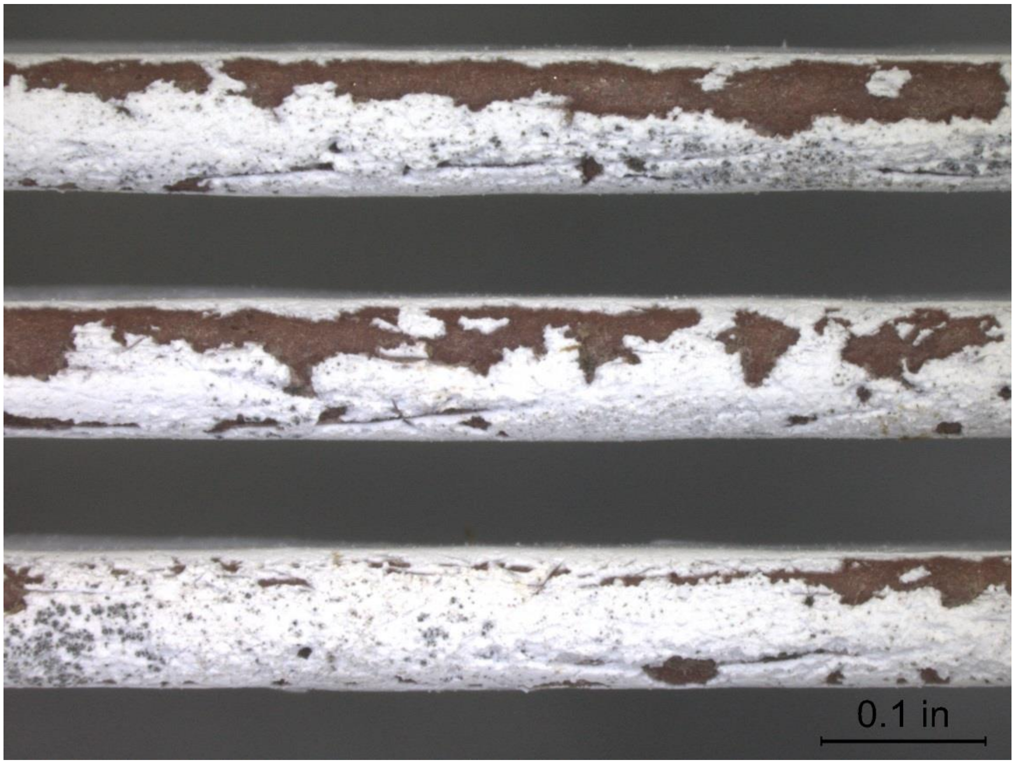
Figure 1 Photograph of duplex 2205 stainless steel with anti-biofouling coating screen 5 after a 36 month corrosion test.

(a) Coated Duplex 2205 Stainless Steel Screen 5, Before Cleaning 10X



(b) Coated Duplex 2205 Stainless Steel Screen 5, Before Cleaning 50X

Figure 2 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating screen 5 after a 36 month corrosion test, before cleaning.



(a) Coated Duplex 2205 Stainless Steel Screen 5, After Cleaning 10X

(b) Coated Duplex 2205 Stainless Steel Screen 5, After Cleaning 50X

Figure 3 Optical macrographs of duplex 2205 stainless steel with anti-biofouling coating screen 5 after a 36 month corrosion test, after cleaning.

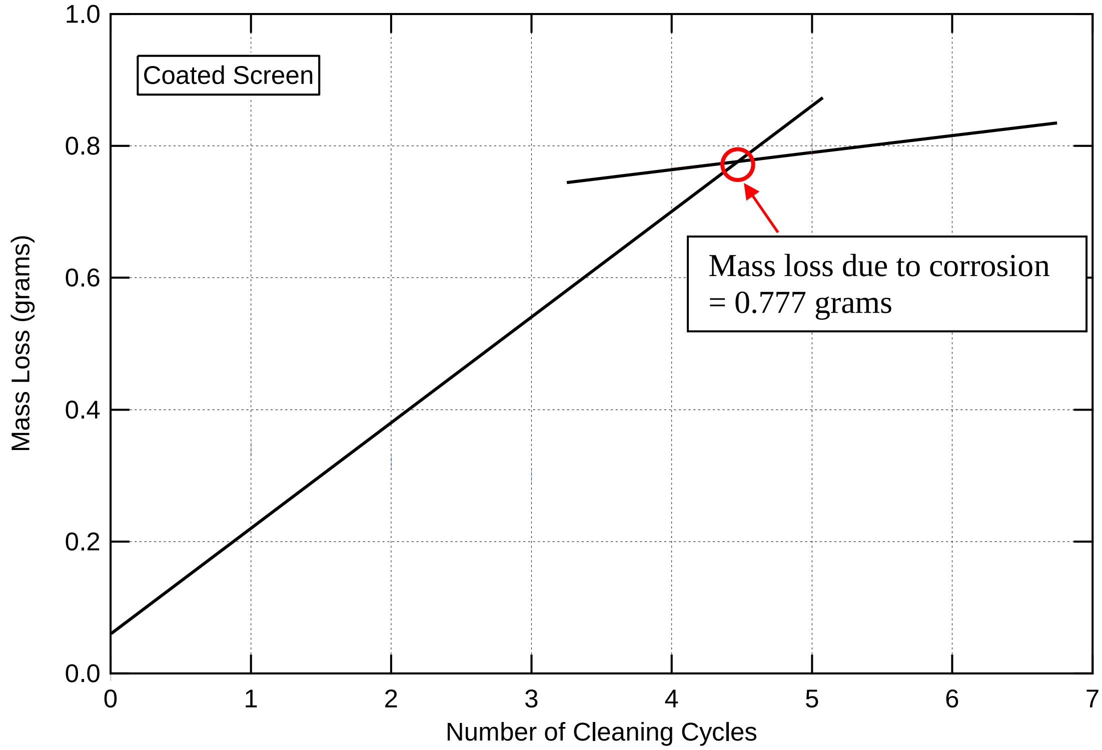
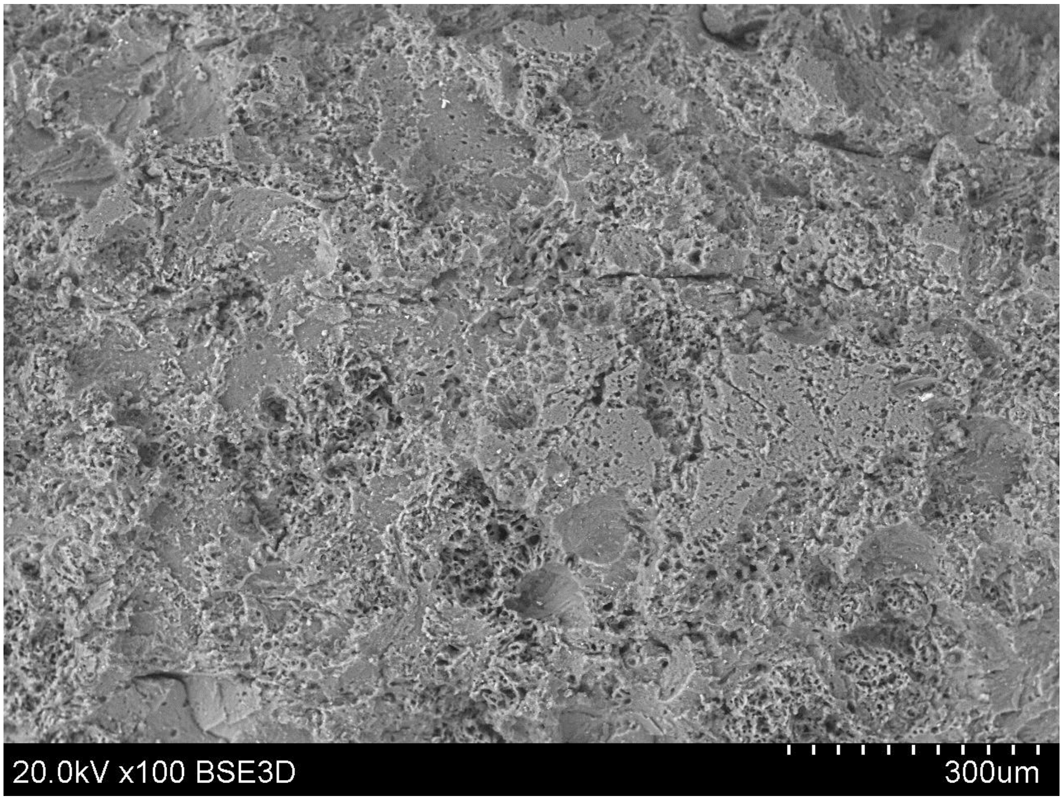
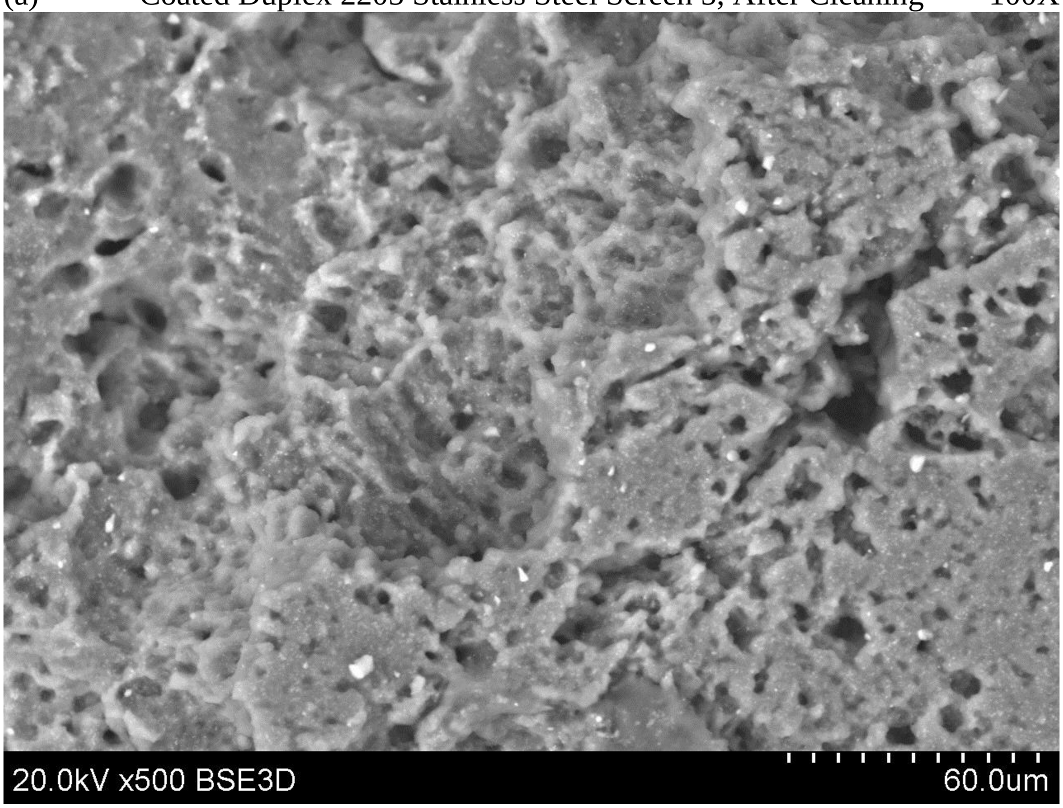


Figure 4 Mass loss of the duplex 2205 stainless steel with anti-biofouling coating screen 5 during cleaning.

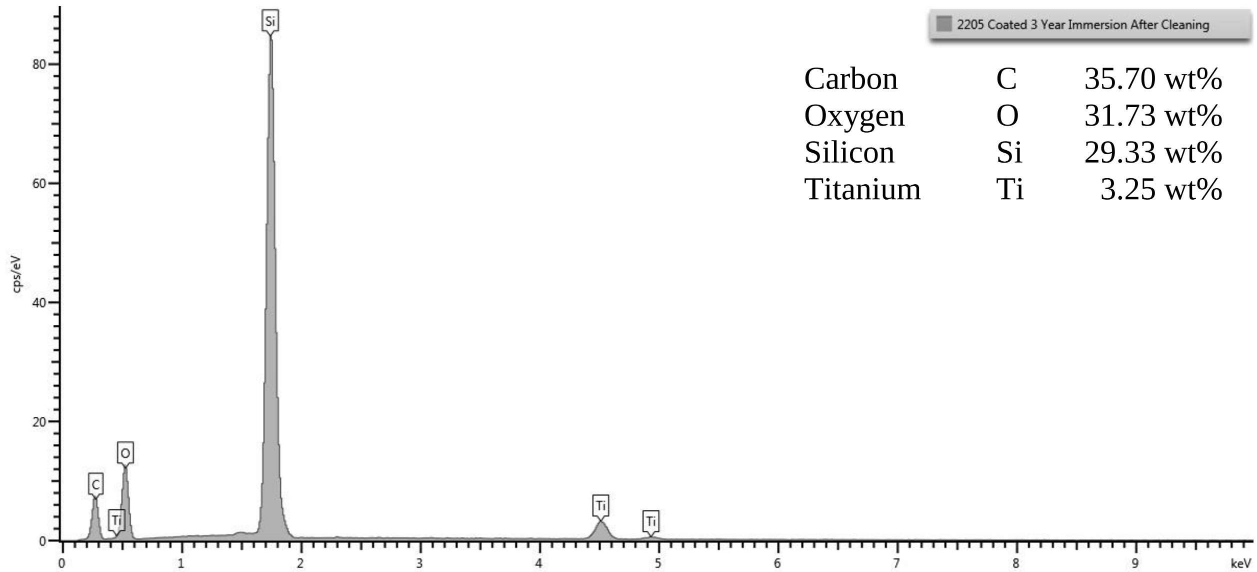


(a) Coated Duplex 2205 Stainless Steel Screen 5, After Cleaning 100X



(b) Coated Duplex 2205 Stainless Steel Screen 5, After Cleaning 500X

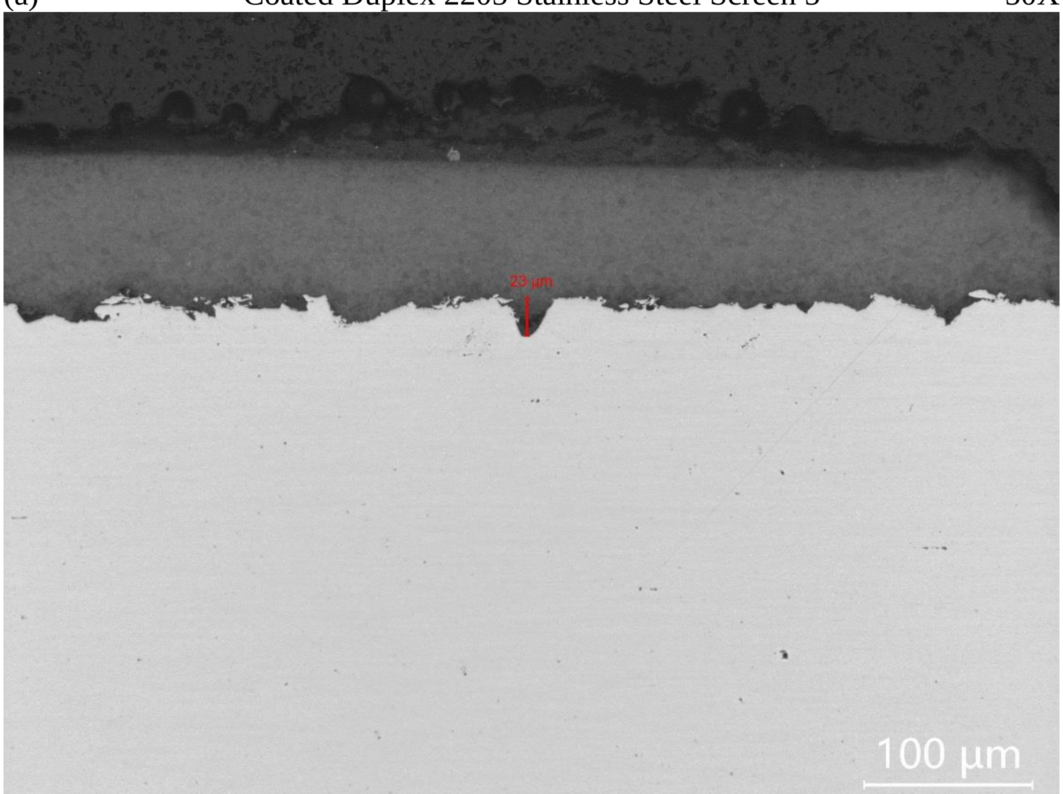
Figure 5 Scanning electron micrographs of duplex 2205 stainless steel with anti-biofouling coating screen 5 after a 36 month corrosion test, after cleaning.



(a) Coated Duplex 2205 Stainless Steel Coupon 4, After Cleaning

Figure 6 Energy dispersive x-ray spectrum of duplex 2205 stainless steel with anti-biofouling coating screen 5 after a 36 month corrosion test, after cleaning. The screen was not analyzed by energy dispersive x-ray spectroscopy before cleaning due to the marine life on the surface of the screen.

(a) Coated Duplex 2205 Stainless Steel Screen 5 50X



(b) Coated Duplex 2205 Stainless Steel Screen 5 200X

Figure 7 Optical micrographs of duplex 2205 stainless steel with anti-biofouling coating screen 5.

Anamet, inc Materials Engineering & Laboratory Testing
26102 EDEN LANDING ROAD, SUITE 3 • HAYWARD, CALIFORNIA 94545 • (510) 887-8811 • FAX (510) 887-8427

Report No. 5005.4623C Rev.1 **July 7, 2017**

CORROSION EVALUATION OF A CDA 715 SCREEN

Customer Authorization: V&A Job Number 13-0376A

Report To: V & A Engineering
Attn: Manuel Najar
155 Grand Avenue, Suite 700
Oakland, CA 94612

1.0 INTRODUCTION

One wedge wire screen made from CDA 715, a 70-Copper, 30-Nickel alloy, was submitted by V&A Engineering for corrosion evaluation. The wedge wire screen was 4-inches by 4-inches by 1/4-inch tall with 2 mm spacing. This evaluation was a continuation of a corrosion evaluation on 5 coupons, 5 wedge wire screens, and one plate as detailed in Anamet report 5005.0361.[1]

In the previous corrosion evaluation, the coupons, screens, and plate were to be placed in seawater for a period up to one year. After every 3 month interval, one coupon and one screen were to be removed from the test system and examined for corrosion. After 12 months, the plate was removed from the test system and examined for corrosion. The purpose of this evaluation was to document the samples in the baseline as-received condition, then again after 3, 6, 10, and 12 months of water exposure, record any loss in mass, examine for any pitting corrosion, and estimate the corrosion rate.

This screen was left in seawater for 3 years (36 months), then removed from the test system, and examined for corrosion. The purpose of this evaluation was to document the condition of the screen after 36 months of water exposure, record any loss in mass, examine for any pitting corrosion, and estimate the corrosion rate.

The screen was evaluated by the following laboratory procedures:

1) Visual examination and weighing
2) Cleaning per ASTM G1[2]
3) Scanning electron microscopy and energy dispersive x-ray spectroscopy
4) Metallography

The results of the evaluation showed minimal mass loss and corrosion for screen after 36 months of corrosion testing. The screen, after 36 months of corrosion testing, had a corrosion rate of 0.010 millimeters per year. When compared to the screens from the previous corrosion

[1] Anamet Report 5005.0361: Corrosion Evaluation of CDA Coupons and Screens. July 15, 2015.
[2] G1: Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

evaluation, the screens had loss more material over time but had a decreasing corrosion rate over the duration of the corrosion test.

2.0 EVALUATION[3]

2.1 Visual Examination

The sample identification for the wedge wire screen and the corresponding immersion time is shown in Table 1. A number of notches, corresponding to the sample number, were sawed at the edge of the screen for identification after the corrosion test. The weight of the screen was recorded and is presented in Table 2. A photograph of the screen after 36 months of corrosion testing is shown in Figure 1.

2.2 Cleaning

The screen was cleaned with solution C.2.1 per ASTM G1.[4] One cleaning cycle was approximately 1 minute. After each cleaning cycle, the screen was rinsed in water, dried, and weighed. The cleaning and weighing cycle was completed five times. The weights of the screen as-received, after corrosion testing but before cleaning, and after each cleaning cycle are presented in Table 2. Optical macrographs of the screen, before and after cleaning, are shown in Figures 2 – 3.

The mass loss versus the number of cleaning cycles was plotted to determine the mass loss of the samples due to corrosion, shown in Figure 4. The equations for best fit lines AB and BC, calculated using IGOR Pro, are listed in Table 3. Point B, indicated by the red circle in the plot, corresponds to the mass loss due to corrosion during the cleaning process for the screen. This mass loss was subtracted from the weight of the screen before cleaning and from the weight of the screen as-received to determine the total mass loss from corrosion. The corrosion rate of the screen was determined by the formula specified in Section 8.1 of ASTM G1:

$$Corrosion\ Rate = \frac{K\ x\ W}{A\ x\ T\ x\ D}$$

where K = 8.76×10^4, T = time of exposure in hours, A = area in cm^2, W = mass loss in grams, and D = density in g/cm^3. The total mass loss from corrosion and the calculated corrosion rate of the screen is shown in Table 4. The results from the previous corrosion evaluation is presented for comparison.

2.3 Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy

The screen was examined with a scanning electron microscope. Representative scanning electron micrographs of the screen, before and after cleaning, are shown in Figures 5 – 6. An examination by scanning electron microscopy showed that the surface of the screen, prior to cleaning, likely had a combination of corrosion products, biological agents, and compounds

[3] The magnifications of the optical and scanning electron micrographs in this report are approximate and should not be used as a basis for dimensional analyses unless otherwise indicated.
[4] 500 mL hydrochloric acid + 500 ml reagent water.

found in seawater. General corrosion with some pitting was observed in Figure 6. Energy dispersive x-ray spectra of the screen, before and after cleaning, are shown in Figure 7.

2.4 Metallography

A cross section was taken from the screen and prepared for a metallographic examination. Optical micrographs of the surface are shown in Figure 8. A shallow pit was observed on the screen, which measured 71 μm deep.

3.0 DISCUSSION

The screen showed minimal mass loss and pitting overall after 3, 6, 10, 12, and 36 months of corrosion testing. The screens had an increasing amount of material loss over time, but had a decreasing corrosion rate over the duration of the corrosion test.

4.0 CONCLUSIONS[5]

The following conclusions are based upon the submitted samples and the evidence gathered:

1. The screen, after 36 months of corrosion testing, had a mass loss of 10.75 grams. When compared to the screens from the previous corrosion evaluation, the screens had an increasing amount of mass loss over the duration of the corrosion test.

2. The screen, after 36 months of corrosion testing, had a corrosion rate of 0.010 mm / year. When compared to the screens from the previous corrosion evaluation, the screens had a decreasing corrosion rate over the duration of the corrosion test.

Prepared by:	Reviewed by:
Norman Yuen Materials Engineer	Audrey A. Fasching, Ph.D., P.E. Senior Materials Engineer

[5] The conclusions in this report are based upon the available information and evidence provided by the client and gathered by Anamet, within the scope of work authorized by the client, and they are hereby presented by Anamet to a reasonable degree of engineering and scientific certainty. Anamet reserves the right to amend or supplement its conclusions or opinions presented in this report should additional data or information become available, or further work be approved by the client.

Table 1
Sample Identifications

Description		V&A Engineering Identification (As-Received)	Anamet Identification (in report)	Notes
Alloy	Part			
CDA 715 (Cu 70 – Ni 30)	**Wedge Wire Screen** 4-inch x 4-inch x 1-inch with 2 mm spacing	None	Screen 5	36 Month Immersion

Table 2
Sample Weights

Sample	Baseline Measurement	Measurements after 36 Months Corrosion Testing					
	Weight As-Received (grams)	Weight Before Cleaning (grams)	Weight After 1st Cleaning (grams)	Weight After 2nd Cleaning (grams)	Weight After 3rd Cleaning (grams)	Weight After 4th Cleaning (grams)	Weight After 5th Cleaning (grams)
Screen 5	212.09	204.13	201.50	201.34	201.20	201.22	201.19

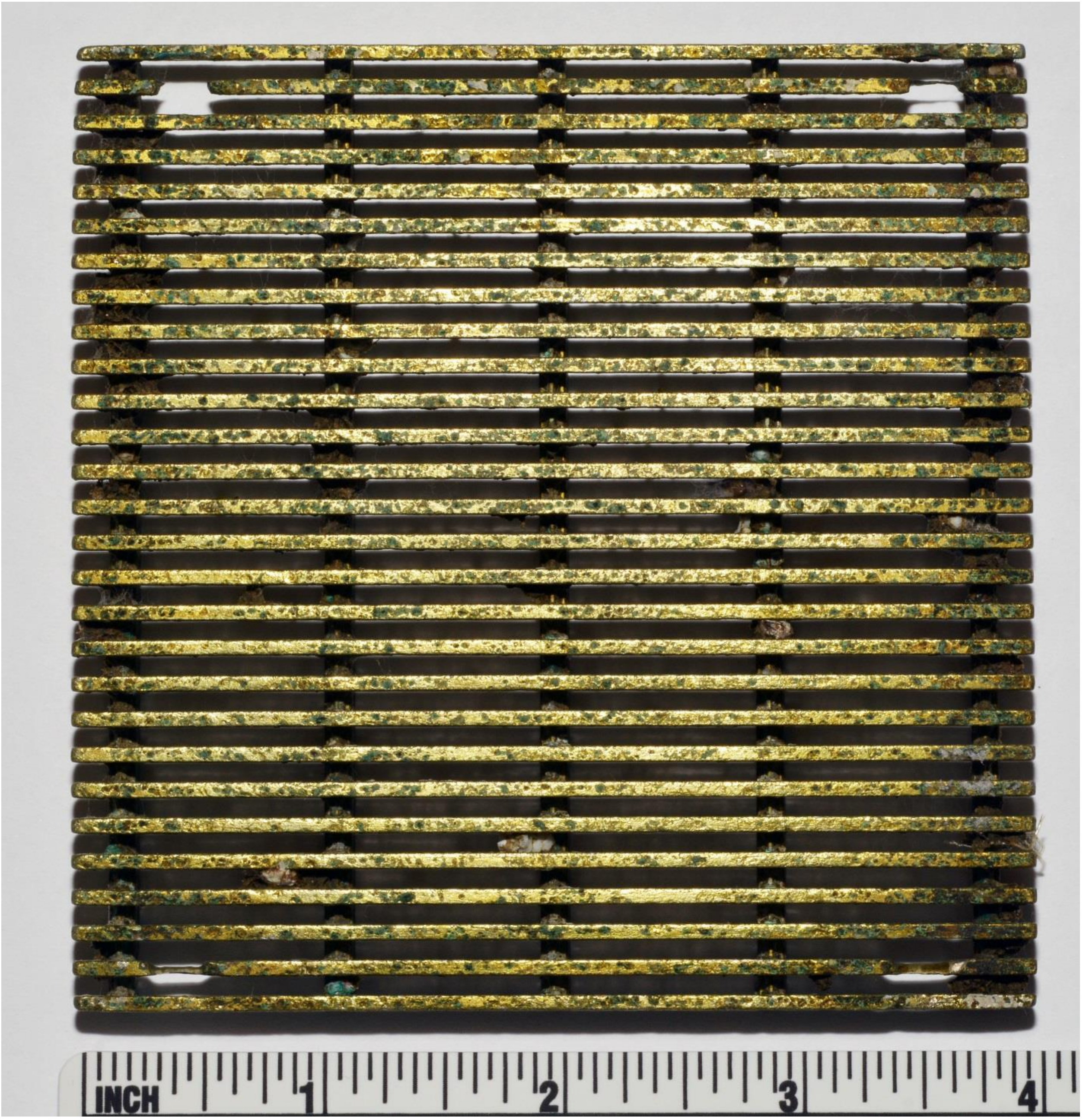
Table 3
Equations of Lines AB and BC for Corrosion Testing Samples

Sample	Line AB	Line BC	Point B (Approximate Mass Loss from Corrosion During Cleaning)
Screen 5	y = 2.630x	y = 0.043x + 2.742	2.788 grams

Table 4
Total Mass Loss from Corrosion and Corrosion Rates

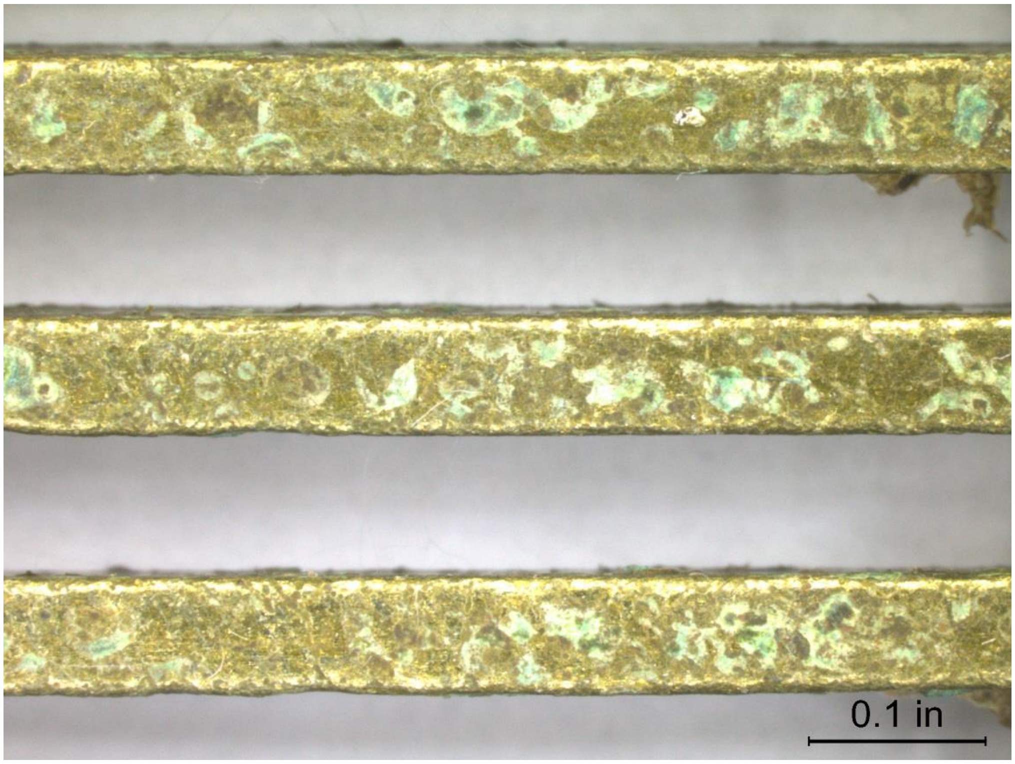
Sample	Total Mass Loss from Corrosion*	Corrosion Rate
Screen 1	2.04 grams	0.022 mm / year
Screen 2	4.05 grams	0.022 mm / year
Screen 3	4.94 grams	0.016 mm / year
Screen 4	6.79 grams	0.018 mm / year
Screen 5	10.75 grams	0.010 mm / year

* Weight As-Received – (Weight Before Cleaning – Mass Loss from Corrosion During Cleaning)

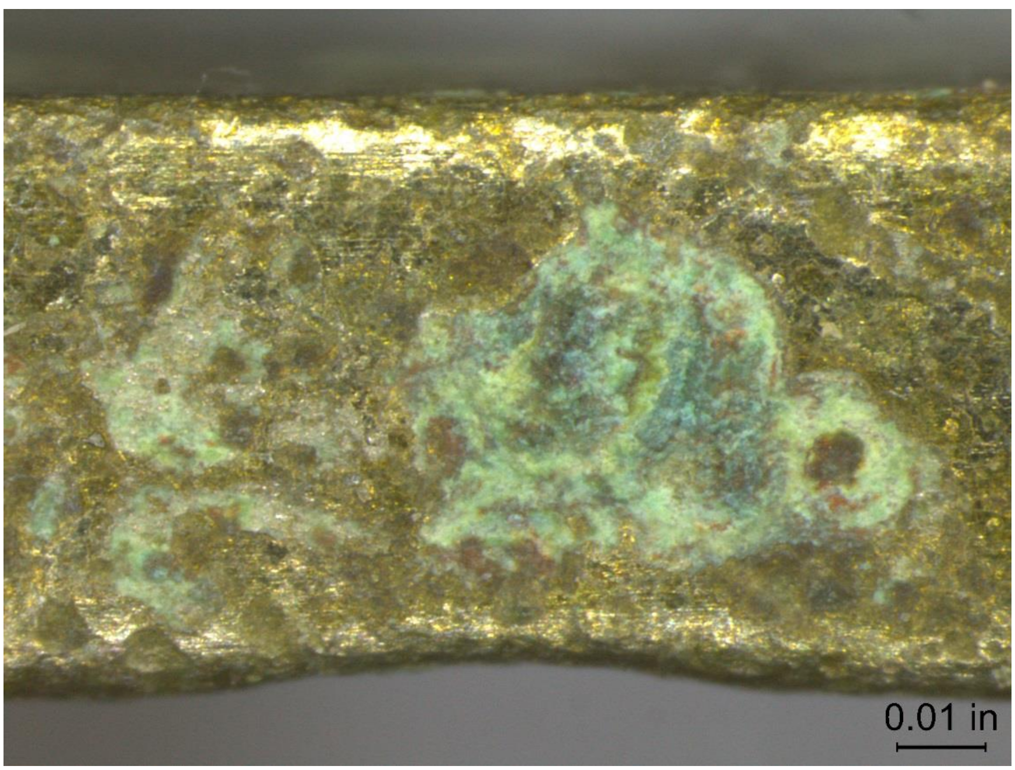


(a) CDA 715 Screen 5

Figure 1 Photograph of CDA 715 screen 5 after a 36 month corrosion test.

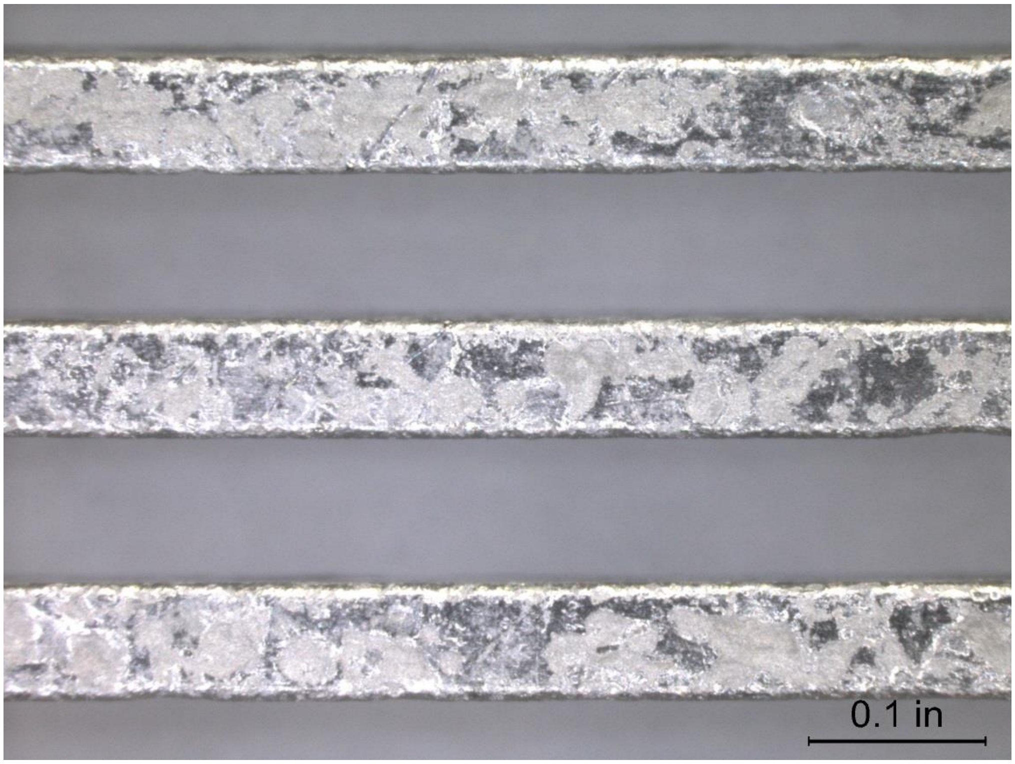


(a) CDA 715 Screen 5, Before Cleaning 10X

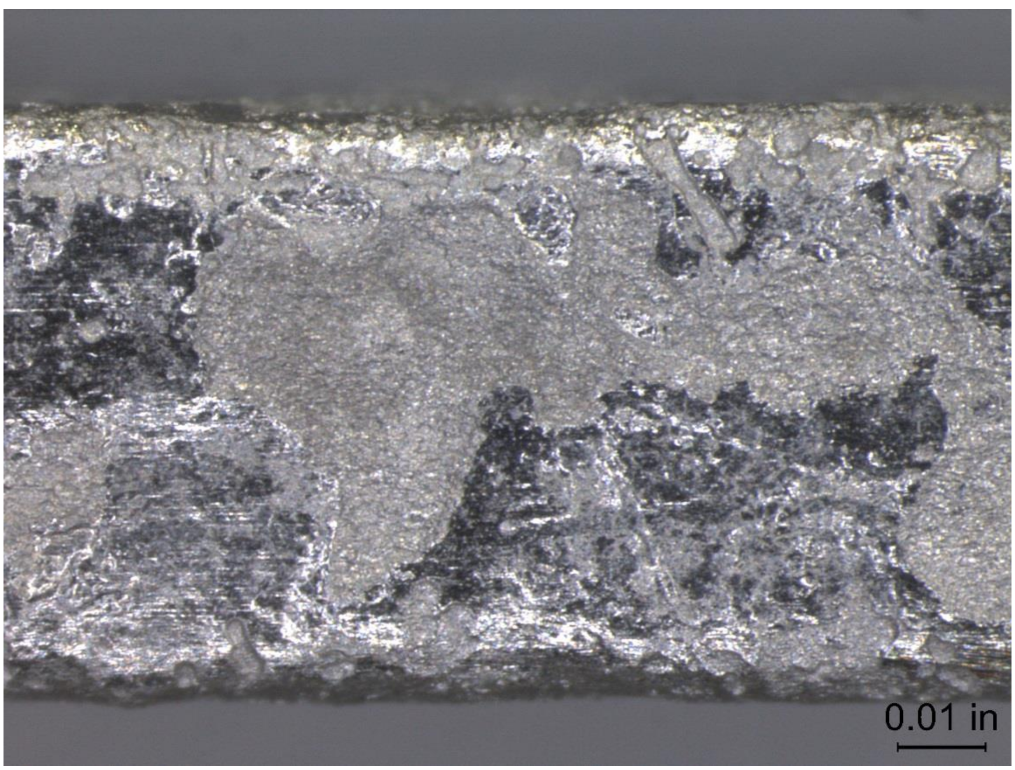


(b) CDA 715 Screen 5, Before Cleaning 50X

Figure 2 Optical macrographs of CDA 715 screen 5 after a 36 month corrosion test, before cleaning.



(a) CDA 715 Screen 5, After Cleaning 10X



(b) CDA 715 Screen 5, After Cleaning 50X

Figure 3 Optical macrographs of CDA 715 screen 5 after a 36 month corrosion test, after cleaning.

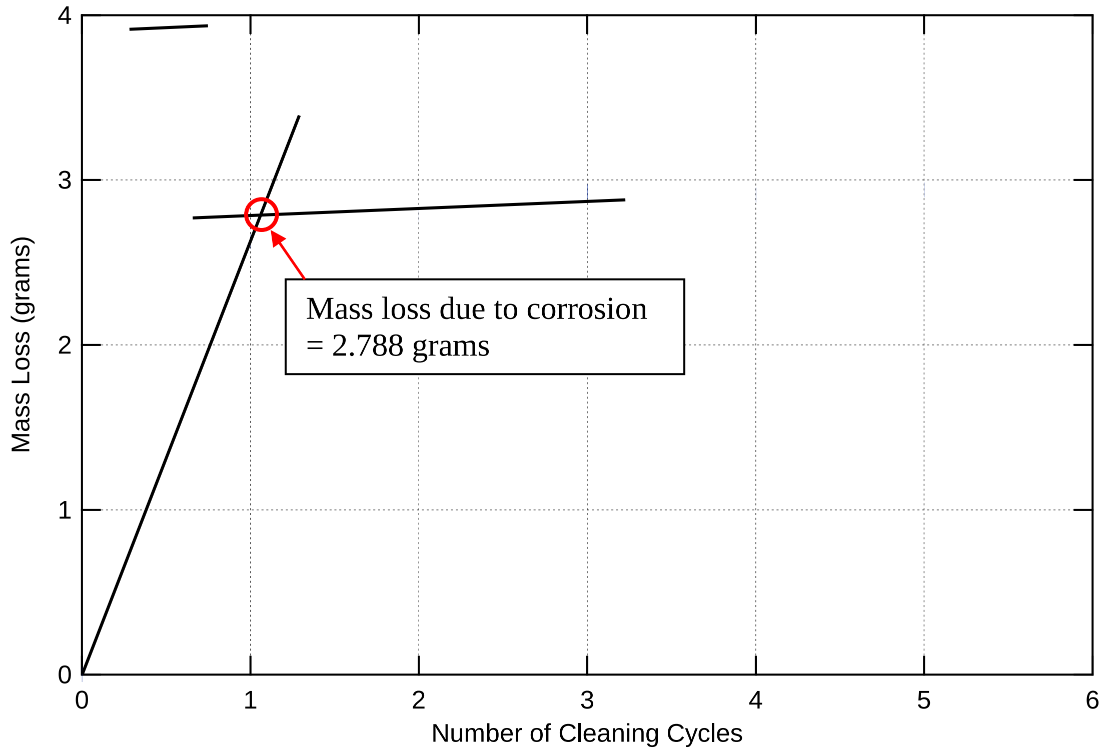
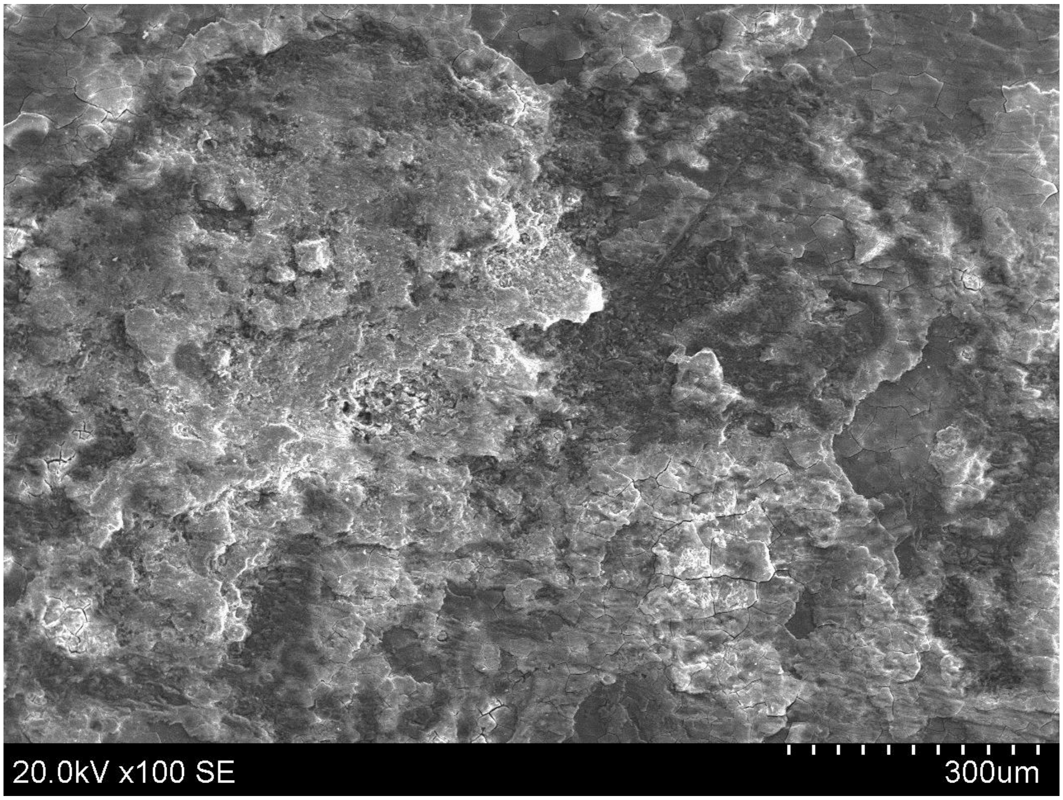
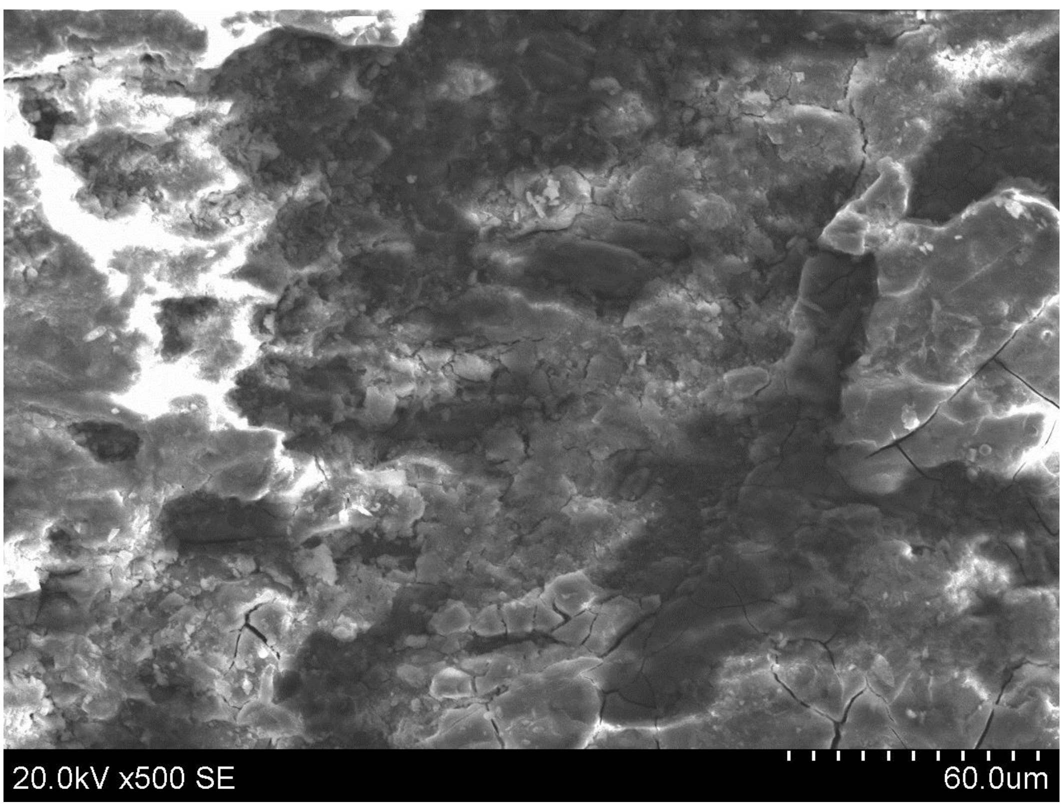


Figure 4 Mass loss of CDA 715 screen 5 during cleaning.

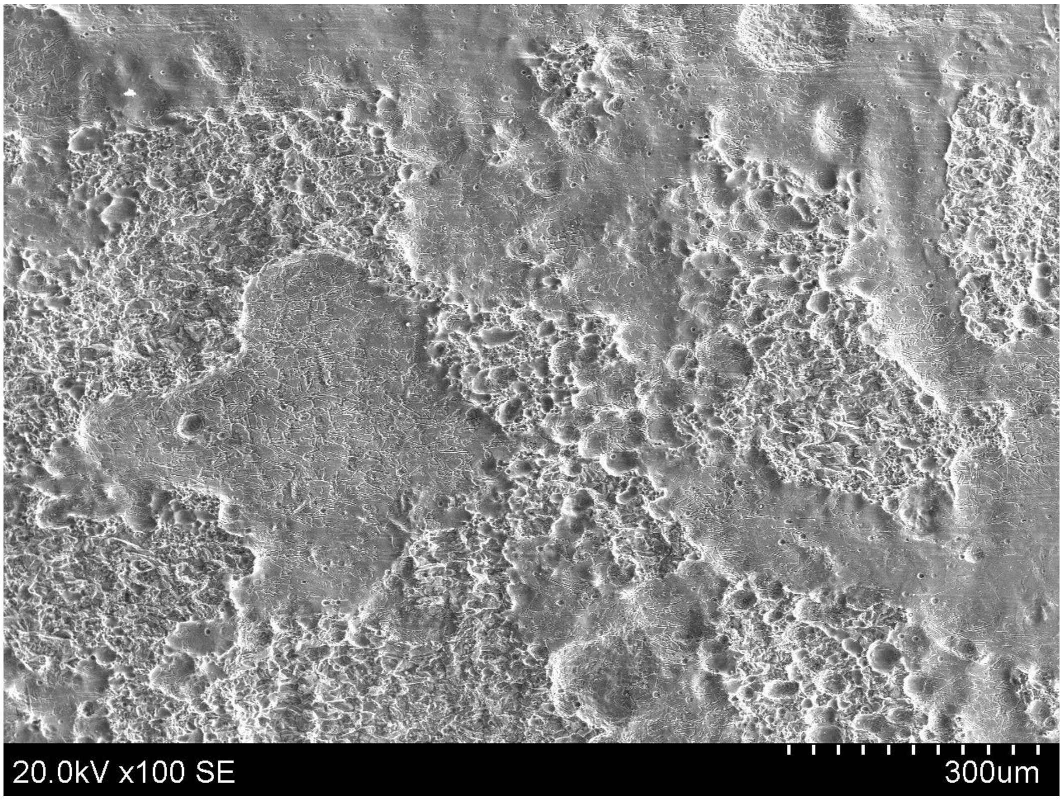


(a) CDA 715 Screen 5, Before Cleaning 100X

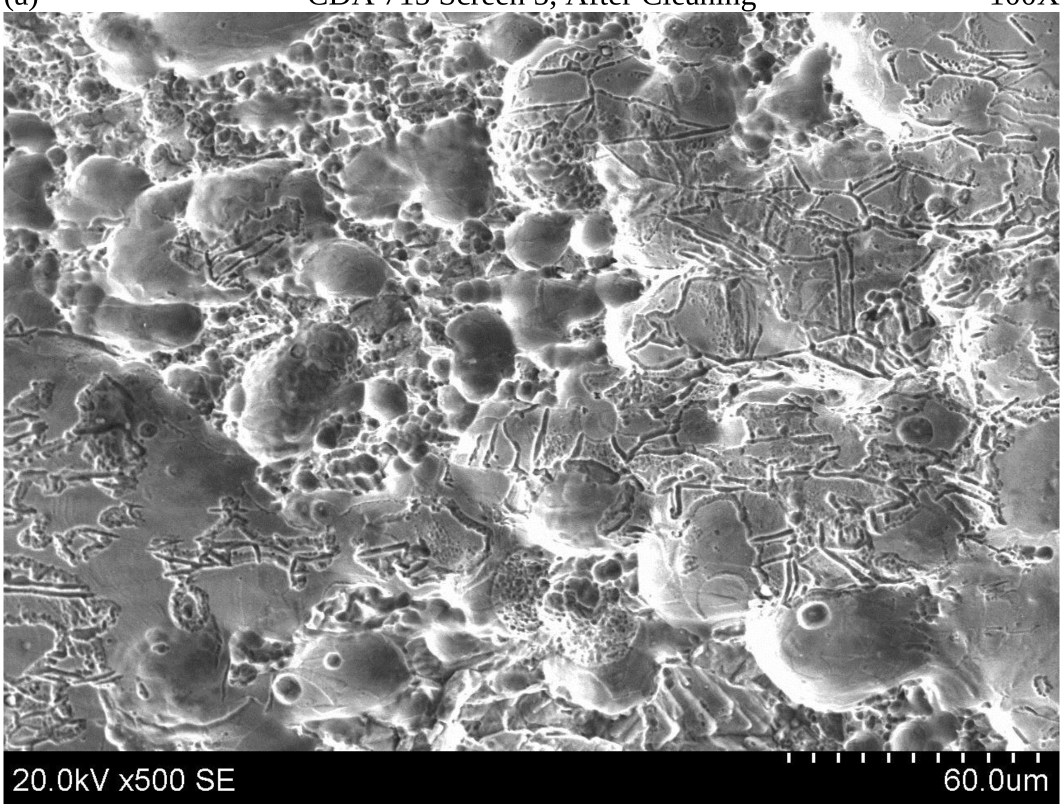


(b) CDA 715 Screen 5, Before Cleaning 500X

Figure 5 Scanning electron micrographs of CDA 715 screen 5 after a 36 month immersion test, before cleaning.

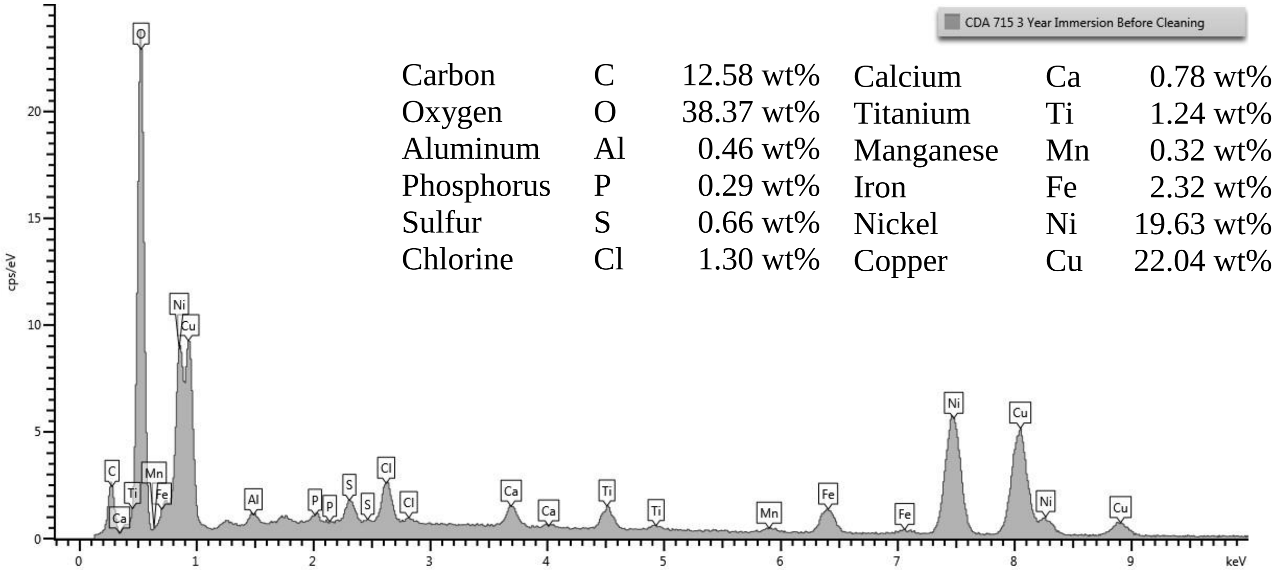


(a) CDA 715 Screen 5, After Cleaning 100X

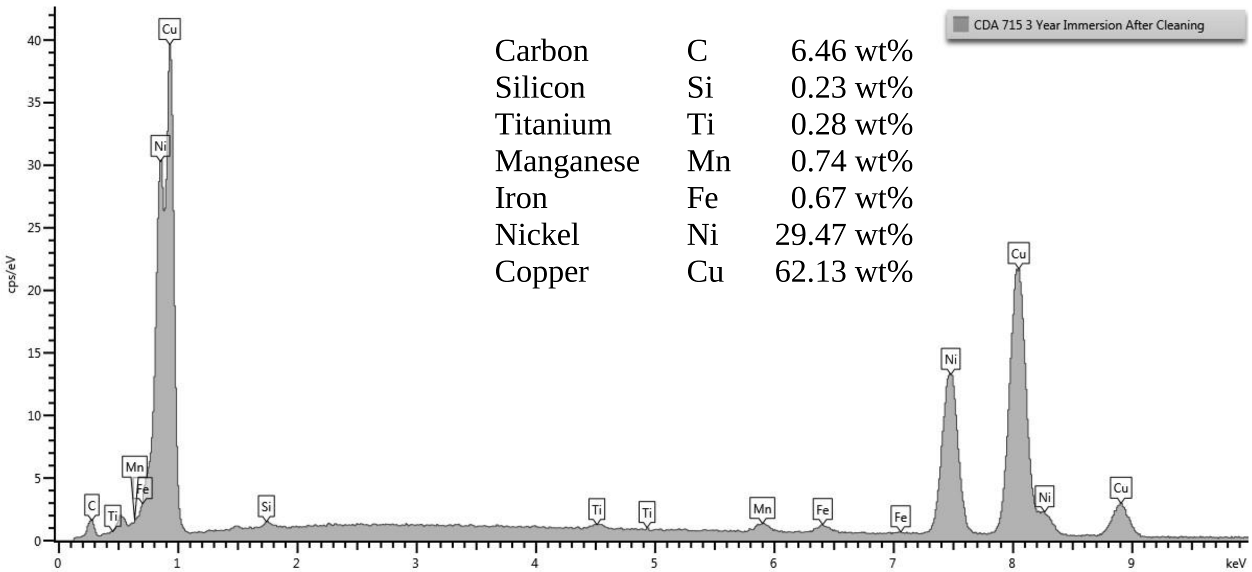


(b) CDA 715 Screen 5, After Cleaning 500X

Figure 6 Scanning electron micrographs of CDA 715 screen 5 after a 36 month immersion test, after cleaning.

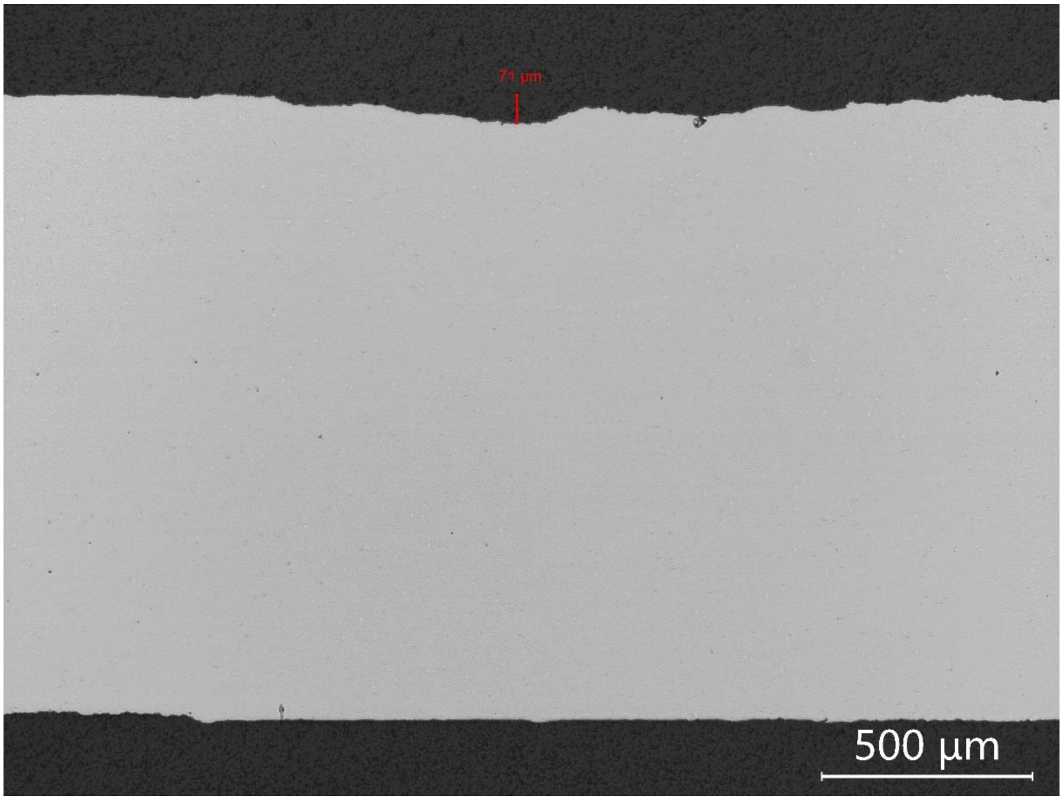


(a) CDA 715 Screen 5, Before Cleaning

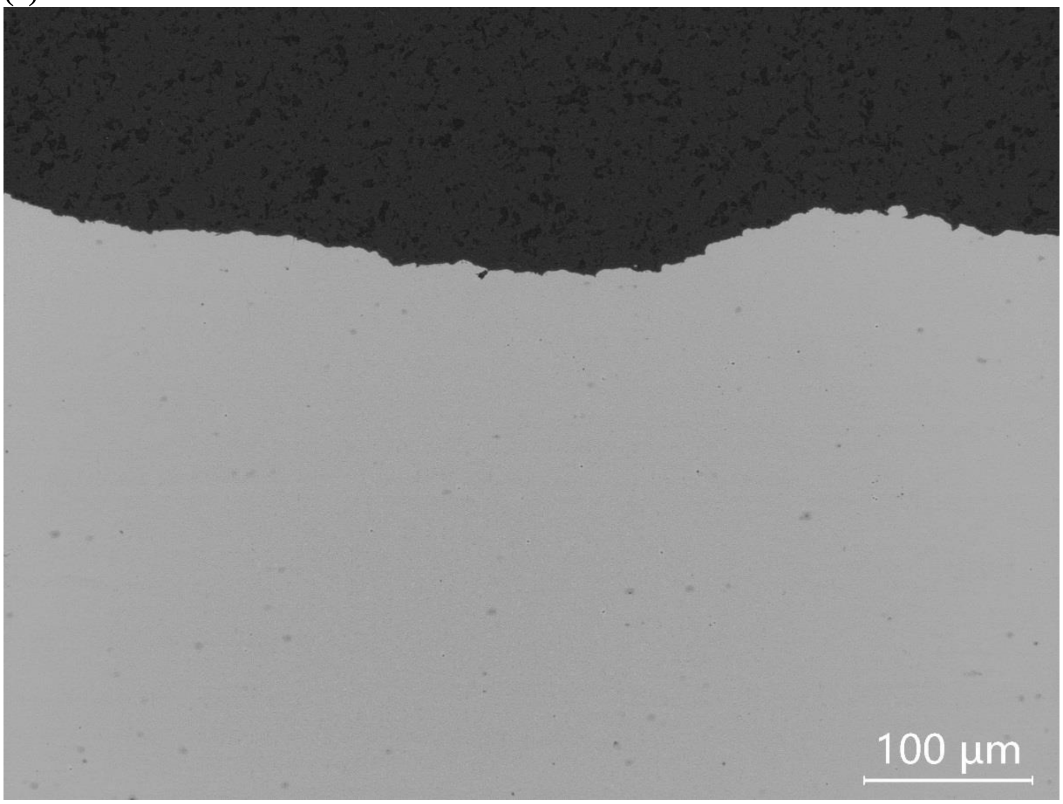


(b) CDA 715 Screen 5, After Cleaning

Figure 7 Energy dispersive x-ray spectra of CDA 715 screen 5 after a 36 month corrosion test (a) before cleaning and (b) after cleaning.



(a) CDA 715 Screen 5 50X



(b) CDA 715 Screen 5 200X

Figure 8 Optical micrographs of CDA 715 screen 5.

Appendix B. Material Certifications

RA TRACER # 251557

ROLLED ALLOYS QUALITY ASSURANCE
APPROVED [illegible]
DATE 12/13/11

OUTOKUMPU

Outokumpu Stainless Coil, Inc.

500 Park Boulevard, Suite 4C
Itasca, IL 60143
Tel (847) 517-4050
Tel (800) 833-8703
Fax (847) 517-2950
Fax (800) 545-8617

www.outokumpu.com/stainless/nad

****
*   CERTIFICATION   *
****

TO:
ROLLED ALLOYS
P.O. Box 310
125 W. Sterns Road
Temperance MI 48182

HEAT E111568-5 ORDER 0613803/003 SON N78831A B00000000 TAG 0063239 11/30/11

---------- YOUR ORDER & DATE ----------
T81872 0/00/00 CUST# ROLALL01 CUST TAG# 1-3901-1399-03

---------- ITEM DESCRIPTION ----------
GRADE 2205+2
Size 2205 CODE+2 16GA (.0585) X 48 X COIL
Ship Condition A
Country of Melt : SWE
Country of Mfg. : SWE

Total PCS   Total Weight 7037

---------- SPECIFICATIONS ----------
ASME SA240 2010 ED
EN10204-3.1
ASTM A480-11
ASTM E562- POINT COINT FERRITE
NACE MR0175-2003/ISO15156
REFINED A.O.D. PROCESS
UNS S31803
ASTM A923-06 PRACTICE A, B & C
ASME SA480-2010 ED
ASTM A240-11A
FREE FROM CONTINUOUS CARBIDE
(40-50%)
NACE MRO 103-2005
[illegible] ARC METHOD
UNS S2205

---------- MECHANICAL & OTHER TESTS ----------
Test Condition A

Micro	NA	Hardness as tested	HB 264
Intergranular corrosion	OK	Hardness as tested	HB 264
Macro	OK	Tensile strength,KSI (MPa)	127.0 (876)
Corrosion Rate (mdd)	.0	Yield strength,KSI (MPa)	96.0 (662)
		Elongation %	28.0
		Reduction of area %	.0

---------- CHEMICAL COMPOSITION ----------

Carbon	(C)	.019	Manganese	(Mn)	1.390
Phosphorus	(P)	.023	Sulphur	(S)	.001
Silicon	(Si)	.430	Chromium	(Cr)	22.500
Nickel	(Ni)	5.600	Moly	(Mo)	3.100
Nitrogen	(N)	.180			
Iron	(Fe)	Balance			

Melt Practice
Refining Practice

We hereby certify that the material herein has been made and tested in accordance with the listed specification(s) and that the results of all tests are acceptable.

Free of known mercury contamination

For Material Safety Data Sheets go to the following link:
http://www.outokumpu.com/ABOUT-US/NORTH-AMERICA/MATERIAL-SAFETY-DATA-SHEETS/ REVISED 09/09

Line 2

Quality Manager
Authorized Signature Chuck Turack

MAT'D I.D. NO. AP058 P.O. NO. 108124

RA TRACER # 251557

SPEC. 2205 INITIAL SF

OUTO KUMPU

Outokumpu Stainless Coil, Inc.
500 Park Boulevard, Suite 40
Itasca, IL 60143
Tel (847) 517-4050
Tel (800) 833-8703
Fax (847) 517-2950
Fax (800) 545-8617
www.outokumpu.com/stainless/nad

****
* CERTIFICATION *
****

TO:
ROLLED ALLOYS
P.O. Box 310
125 W. Sterns Road
Temperance MI 48182

HEAT 430100-2 ORDER 0615791/001 SON N73600A BOO000000 TAG 0066934 4/15/13

---------- YOUR ORDER & DATE ----------

T88123 0/00/00 CUST# ROLALL01 CUST TAG# 1-3902-1990-03-

---------- ITEM DESCRIPTION ----------

GRADE 2205
Size 2205 CODE+2 11GA (.118) X 48 X COIL — Country of Melt : SWE
Ship Condition A — Country of Mfg. : SWE

Total PCS Total Weight 12668

---------- SPECIFICATIONS ----------

ASME SA240 2011A ED	ASME SA480-2011 A ED
EN10204-3.1	ASTM A240-11A
ASTM A480-11	FREE FROM CONTINUOUS CARBIDE
ASTM E562- POINT COINT FERRITE	(40-50%)
ISO 15156	NACE MRO 103-2005
REFINED A.O.D. PROCESS	MELTED ELECTRIC ARC METHOD
UNS S31803	UNS 32205
ASTM A923-06 PRACTICE A	

HEAT# 430100-2
TRACER# 287258

Revised

---------- MECHANICAL & OTHER TESTS ----------

Test Condition A

		Hardness as tested	HB 272
		Hardness as tested	HB 261
		Tensile strength,KSI (MPa)	124.0 (855)
Micro	NA	Yield strength,KSI (MPa)	100.0 (690)
Intergranular corrosion	OK	Elongation %	27.0
Macro	OK	Reduction of area %	.0
Corrosion Rate (mdd)	.0		

---------- CHEMICAL COMPOSITION ----------

Carbon	(C)	.017	Manganese	(Mn)	1.470
Phosphorus	(P)	.024	Sulphur	(S)	.001
Silicon	(Si)	.420	Chromium	(Cr)	22.400
Nickel	(Ni)	5.790	Moly	(Mo)	3.130
Nitrogen	(N)	.170			
Iron	(Fe)	Balance			

Melt Practice
Refining Practice

We hereby certify that the material herein has been made and tested in accordance with the listed specification(s) and that the results of all tests are acceptable.

Free of known mercury contamination

MATERIAL SAFETY DATA SHEETS:
WWW.NAD.OUTOKUMPU.COM/NA.HTML
REVISED 03/10/13

PMI VERIFIED BY: [signature]

Quality Manager
Authorized Signature Chuck Turack

[signature] Charles A. Turack

ROLLED ALLOYS QUALITY ASSURANCE
APPROVED [signature]
DATE 4-22-13

P.O. NO. 1/2/18
INITIAL P.S.
MAT'L. I.D. NO. AQ334
SPEC. 2205 .125"

element

Element Materials Technology
5405 E Schaaf Road
Cleveland, OH
44131-1337 USA

P 216 524 1450
F 216 524 1459
T 888 786 7555
info.cleveland@element.com
element.com

Contact: Chris Wonders
Rolled Alloys
125 W. Sterns Road
Post Office
TEMPERANCE, MI 48182-9546

TEST REPORT — EAR-CONTROLLED DATA

Date:	6/7/2013
P.O. No.:	287258W28405 TKCW
W/O No.: REVISED	ROL008-13-06-78077-1
Date Received:	6/5/2013

øSample Description: One (1) 1/8" Plate, Alloy: Alloy 2205, Spec.: ASTM A923 Practice C, Heat# 430100-2, Tracer: 287258

FERRIC CHLORIDE CORROSION TEST PER ASTM A923, METHOD C

The test sample was immersed in a solution containing 100 g $FeCl_3 \cdot H_2O$, 900 ml H_2O and adjusted to a pH of approximately 1.3 at 25°± 1°C for a duration of 1 day. The corrosion rate is calculated to be:

Surface Area, dm^2	Mass Loss, mg	Corrosion Rate, mdd
0.33	0.2	0.6

Requirement: 10 mdd, maximum

CONFORMANCE

The sample is acceptable per ASTM A923-08, Method C.

This document contains technical data whose export and re-export/retransfer is subject to control by the U.S. Department of Commerce under the Export Administration Act and the Export Administration Regulations. The Department of Commerce's prior written approval may be required for the export or re-export/retransfer of such technical data to any foreign person, foreign entity or foreign organization whether in the United States or abroad.
øREVISED (12/2/13): Sample description

Paula Tesar
Paula Tesar
Quality Administrator

ABNAHMEPRUFZEUGNIS EN 10204/2005-3.1
INSPECTION CERTIFICATE

MKM Kazakhmys

Besteller / Purchaser: Hillman Brass & Copper, Inc.
P.O. Box "R"

2345 Maryland Road
19090 Willow Grove PA

USA

QA APPROVED by
QJM
3/3/10
H M Hillman
Brass & Copper

Mansfelder Kupfer und Messing GmbH
Produktbereiche Bleche / Bänder
Überprüft nach AD 2000-Merkblatt W0/TRD100 durch den TÜV Hannover/Sachsen-Anhalt e.V.
Zertifiziert nach Richtlinie 97/23/EG durch die TÜV CERT-Zertifizierungsstelle für Druckgeräte der TÜV Nord Gruppe, Benennte Stelle, Kenn-Nr.: 0045

Lichtlöcherberg 40
06333 Hettstedt / Germany
Telefon +49 (0)3476 89 3023 / 2475
Fax: +49 (0)3476 89 2919 / 3043

Auftragsnr./Pos. / Contract-No./Item	Bestellnr. / Order no.	Kundenmat.-Nr.	Datum / date	Lieferschein-Nr. / Delivery note No.
0000824974/000001	1-20465		03.03.2010	0000106940

Erzeugnis / Product	Werkstoff / Material
Sheet C71500 0,125 x 36 x 96"	C71500 ASMESB171/SB171M/2007
Abmessung / Dimension	**Lieferzustand / Temper**
3,17 * 914,4 * 2.438,4 mm	H01 MILC15726FAM1/1991
Lieferbedingungen / Terms of delivery	
MILC15726FAM1/1991	

Verpackung / shipping units

Charge / Batch	1708
Colli	001
Stück / Pieces	15
Masse / Weight	1007

1-

Gesamtgewicht: / Weight total: 1007 kg

Mechanische Anforderungen / mechanical properties

Charge / Batch Probendatum / Date Probe / Sample		1708 20100217 0098	1708 20100217 0097
Rm	min. 380 N/mm²	426	416
Rp 0,2	min. 173 N/mm²	380	372
Rt0,5	min. 173 N/mm²	381	375
A50	min. 10 %	31	32
Rm (Tensile Strength)	min. 55,0 ksi	61,8	60,3
Rp0,2 (Yield at 0,2% Offset)	min. 25,0 ksi	55,1	54,0
Rt0,5 (Yield strength)	min. 25,0 ksi	55,3	54,4

Chemische Anforderungen / chemical properties

Charge / Batch		1708
Zn	max. 0,500 %	0,010
Cu (incl. Ag)	min. 65,0 %	68,15
P	max. 0,020 %	0,003
Ni (incl. Co)	29,00 - 33,00 %	30,36
S	max. 0,020 %	0,003
Mn	max. 1,00 %	0,72
C	max. 0,050 %	0,020
Fe	0,40 - 1,00 %	0,63
Pb	max. 0,020 %	0,003

MAT'L. I.D. NO. AK273 P.O. NO. 95010
SPEC ____________ INITIAL JR
CDA 715

H M Hillman Brass & Copper Inc
ALABAMA SPECIALTY PRODUCTS
P.O. NO. 95010
ITEM NO. 1
P/N 014530125
QTY. 1 PC 24" x 48"

Die Maß- und Formtoleranzen entsprechen den Bestellvorgaben. Es wird bestätigt, daß die Lieferung geprüft wurde und den Vereinbarungen bei der Bestellannahme entspricht.

The dimensional- and shapetolerances conform to the requirements. We hereby certify, that the material described above has been tested and complies with the terms of the order contract.

MKM Mansfelder Kupfer und Messing GmbH Hettstedt

Abnahmebeauftragter / Acceptance representative

HUSSEY COPPER LTD.

9001 ISO CERTIFIED

LEETSDALE, PA 15056-1899 PHONE: (724) 251-4200

12-21-2005 004015

Material Certification

Alaskan Copper & Brass Co.

3223 Sixth Ave. S.
Seattle WA 98134-2109

Hussey Order Number: 230722-3
Cert. Date: 12/14/05
Ship Date: 12/20/05
Weight: 4570

Customer P.O: 06025561
Description: 71500 SHEET
Size: .063 x 32 x COIL
Specification: MILC 15726F-AM1 PARA 6.2(f)

Temper: O60 SOFT
Lot Number: 165519
Heat Number: F7A-05-5995-2

NO WELD REPAIRS ARE PERFORMED ON THIS MATERIAL AS SUPPLIED BY HUSSEY COPPER LTD.

Chemical Properties %

Copper+Sum:	100.00/100.00
Copper:	69.16/69.11
Lead:	<0.01/<0.01
Iron:	0.50/0.50
Zinc:	<0.01/<0.01
Silver:	
Oxygen:	
Phosphorous:	<0.01/<0.01
Magnesium:	
Nickel:	29.7/29.8
Manganese:	0.68/0.67
Carbon:	0.004/0.005
Sulfur:	0.001/0.001

Mechanical Properties

Tensile Strength (PSI):	57,000	56,000
0.5% Extension Yield(PSI):	21,000	20,000
Elongation in 2"(%):	32.0%	37.5%
Rockwell Hardness:	BW- 39/40	
Grain Size (mm):		
Conductivity(%IACS):		
Bend Test (o w/o Fracture):	180	

ALASKAN COPPER & BRASS
DEC 19 2005

Hussey Copper, Ltd hereby certifies that in all it's manufacturing operations, no free Mercury came in contact with the above material. No electrical devices containing Mercury were damaged to the point of contaminating the said metal anywhere in it's process. Hussey Copper, Ltd. testing equipment meets Mil-Std-45662. Material marking meets federal standard 185, when specified. We hereby certify the foregoing results correct and that the material complies with the above specifications.

Issuing Agent: [signature]
Mark J. Ciccarelli
Certification Technician

165519A

MAT'L. I.D. NO. AA055 P.O. NO. 111152
SPEC. C0A 715.062" INITIAL JB

ALASKAN COPPER & BRASS CO.
TO Alabama Specialty
ATTN Jean H.
P.O. NO.
LINE NO. 1
SALES NO. 971033-1
COMPLETED BY CDW

HUSSEY COPPER LTD.
LEETSDALE, PA 15056-1099 PHONE: (724) 251-4200

9001 ISO CERTIFIED

Material Certification

Alaskan Copper & Brass Co.

3223 Sixth Ave. S.
Seattle WA 98134-2109

Hussey Order Number: 230722-3
Cert. Date: 12/14/05
Ship Date: 12/20/05
Weight: 4570

Customer P.O: 08025561
Description: 71500 SHEET
Size: .083 x 32 x COIL
Specification: ASME SB171-01

Temper: HOT ROLLED & ANNEALED O25
Lot Number: 165519
Heat Number: F7A-05-5995-2

"NO WELD REPAIRS ARE PERFORMED ON THIS MATERIAL AS SUPPLIED BY HUSSEY COPPER LTD.

Chemical Properties %

Copper+Sum:	100.00/100.00
Copper+Silver:	69.16/69.11
Lead:	<0.01/<0.01
Iron:	0.50/0.50
Zinc:	<0.01/<0.01
Silver:	
Oxygen:	
Phosphorous:	<0.01/<0.01
Magnesium:	
Nickel+Cobalt:	29.7/29.8
Manganese:	0.68/0.67
Carbon:	0.004/0.005
Sulfur:	0.001/0.001

Mechanical Properties

Tensile Strength (PSI):	57,000	56,000
0.5% Extension Yield(PSI):	21,000	20,000
Elongation in 2"(%):	32.0%	37.5%
Rockwell Hardness:	BW- 39/40	
Grain Size (mm):		
Conductivity(%IACS):		
Bend Test (o w/o Fracture):	180	

Hussey Copper, Ltd hereby certifies that in all it's manufacturing operations, no free Mercury came in contact with the above material. No electrical devices containing Mercury were damaged to the point of contaminating the said metal anywhere in it's process. Hussey Copper, Ltd. testing equipment meets Mil-Std-45662. Material marking meets federal standard 185, when specified. We hereby certify the foregoing results correct and that the material complies with the above specifications.

Issuing Agent: [signature]
Mark J. Ciccarelli
Certification Technician

165519B

HUSSEY COPPER LTD.
LEETSDALE, PA 15056-1899 PHONE: (724) 251-4200

9001 ISO CERTIFIED

Material Certification

QA APPROVED by
3/25/11
H M Hillman
Brass & Copper

HILLMAN HM BRASS & COPPER
PO BOX R
2345 MARYLAND AVE.
WILLOW GROVE PA 19090

Hussey Order #: 354309-1
Cert. Date: 03/24/11
Ship Date: 03/23/11
Weight: 4946

Temper: O60 SOFT

Customer P.O: 20928
Description: 70600 SHEET
Size: 0.063 X 36 X 96
Specification: MILC 15726F AM1

Lot Number: 224534
Heat Number: F7B-11-8279

NO WELD REPAIRS ARE PERFORMED ON THIS MATERIAL AS SUPPLIED BY HUSSEY COPPER LTD.

Chemical Properties %

Copper+Sum:	100.00	100.00
Copper:	87.63	87.51
Lead:	<0.01	<0.01
Iron:	1.41	1.43
Zinc.	0.02	0.02
Silver:		
Oxygen:		
Phosphorous:	<0.01	<0.01
Magnesium:		
Nickel:	10.4	10.5
Manganese:	0.52	0.52
Carbon:	0.003	0.006
Sulfur:	0.003	0.003

Mechanical Properties

Tensile Strength (PSI):	45,800	46,000
0.5% Extension Yield(PSI):	21,900	21,300
Elongation in 2"(%):	35.5%	35.5%
Rockwell Hardness:	BW- 29/30	
Grain Size (mm):	0.025	0.035
Conductivity(%IACS):		
Bend Test (o w/o Fracture):	180	

SPEC. CDA 706 AQ072 NO. 11194 INITIAL TR

Hussey Copper, Ltd hereby certifies that in all it's manufacturing operations, no free Mercury came in contact with the above material. No electrical devices containing Mercury were damaged to the point of contaminating the said metal anywhere in its process. Hussey Copper, Ltd. testing equipment meets Mil-Std-45662. Material marking meets federal standard 185, when specified. We hereby certify the foregoing results correct and that the material complies with the above specifications.

Hussey Copper, Ltd. recognizes that the European Union issued Directive 2002/95/EC (RoHS) restricts the use of certain hazardous substances in electrical and electronic equipment. Hussey Copper, Ltd. does not add any of the restricted substances to our products.

The results reported on this test report represent the actual attributes of the materail furnished and indicate full compliance with all applicable specifications and contract requirements.

Hussey Copper, Ltd. products are Made in the USA.

Issuing Agent: Chad R Baird

Certified by Chad Baird 3/21/11
General Supervisor of QC and ISO Certification

H M Hillman Brass & Copper Inc
Alabama Specialty Products
P.O. NO. 11194
ITEM NO. 1
P/N 014510062
QTY. 4pcs - 36" x 48"

FRAUD AND FALSIFICATION NOTICE: The recording of false, fictitious or fraudulent statements or entries on this document may be punishable as a felony under federal statutes, including federal law, title 18, chapter 47. All orders and contracts are accepted subject to standard terms of sale, which are printed on acknowledgements of orders

- 2 pages -

1/8" 706 Sheet

HUSSEY COPPER LTD.

100 WASHINGTON STREET • LEETSDALE, PA 15056-1000
PHONE: (724) 251-4200

Material Certification

FARMERS COPPER LTD.
Cust. ALABAMA SPECIALTY PRODS
P.O.# 86672
Line 770352-1
Item S7061250HR---
Desc 1/8" 706 HR 90/10 SHT
Qty 47
Doc. F7C061658
Req 1
Carr. UPS GROUND

FARMERS COPPER IND SUPPLY
BOX 2649

GALVESTON TX 77553

Hussey Order Number: 278345-5
Cert. Date: 08/29/07
Ship Date:
Weight: 1710

Temper: HOT ROLLED & ANNEALED O25
Lot Number: 185020
Heat Number: F7C-06-1658

Customer P.O: 717329-FC
Description: C70600 SHEET
Size: 0.125 x 48 x 120
Specification: ASTM B171-04, ASME SB171-01
NO WELD REPAIRS ARE PERFORMED ON THIS MATERIAL AS SUPPLIED BY HUSSEY COPPER LTD.

Chemical Properties %

Copper+Sum:	100.00/100.00
Copper+Silver:	88.17/88.10
Lead:	<0.01/<0.01
Iron:	1.35/1.36
Zinc:	0.01/0.01
Silver:	
Oxygen:	
Phosphorous:	<0.01/<0.01
Magnesium:	
Nickel+Cobalt:	9.8/9.9
Manganese:	0.52/0.51
Carbon:	0.006/0.008
Sulfur:	0.002/0.002

Mechanical Properties

Tensile Strength (PSI):	47,000	46,000
0.5% Extension Yield(PSI):	27,000	24,000
Elongation in 2"(%):	34.0%	31.0%
Rockwell Hardness:	BW- 33/35	
Grain Size (mm):		
Conductivity(%IACS):		
Bend Test (o w/o Fracture):	180	

Hussey Copper, Ltd hereby certifies that in all it's manufacturing operations, no free Mercury came in contact with the above material. No electrical devices containing Mercury were damaged to the point of contaminating the said metal anywhere in its process. Hussey Copper, Ltd. testing equipment meets Mil-Std-45662. Material marking meets federal standard 185, when specified. We hereby certify the foregoing results correct and that the material complies with the above specifications.

Hussey Copper, Ltd. recognizes that the European Union issued Directive 2002/95/EC (RoHS) restricts the use of certain hazardous substances in electrical and electronic equipment. Hussey Copper, Ltd. does not add any of the restricted substances to our products.

Issuing Agent: [signature]
Mark J. Ciccarelli
Certification Technician

MAT'L. I.D. NO. At209 P.O. NO. 86672
SPEC. __________ INITIAL JB
CDA 706 .125"