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Demonstration and Validation of Materials for Corrosion-Resistant Fencing and Guard Railings in Aggressive Climates

Final Report on Project F09-AR02

Christopher Olaes, Richard G. Lampo, and Lawrence Clark

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Construction Engineering Research Laboratory

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Final report

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Abstract

Standard galvanized steel chain-link fencing, including products coated with polyvinyl chloride (PVC), can severely corrode in as little as 5 years in coastal locations where the atmosphere is warm, humid, and infused with chlorides. This problem affects fencing needed to secure military equipment, supplies, and buildings. Painted and galvanized-steel safety railings also can severely corrode in those environments, creating personal-safety hazards. This report describes a study that assessed several alternative corrosion-resistant materials for fencing and railings using atmospheric exposure coupons and full-scale installations. The research design compares the performance of the alternative and conventional materials to identify those that may reduce the Army's corrosion prevention and control costs. Tested materials included fuse-bonded PVC, galvanized steel, stainless steel, aluminized steel, a proprietary material called Galfan®, aluminum alloys, and fiber-reinforced polymer (FRP) composites. The test exposure sites were Kahuku, HI; Duck, NC; and Treat Island, ME.

The report provides cost justification for using specified corrosion-resistant fencing and railing materials that have a higher first cost than standard materials. The project return on investment using fuse-bonded fencing and anodized aluminum railings was calculated at 6.13; using fuse-bonded fencing and FRP composite railings instead of anodized aluminum railings, the calculated project ROI is 5.75.

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Preface

This investigation was performed for the Office of the Secretary of Defense under the Department of Defense Corrosion Prevention and Control Program; Project F09-AR02, "Corrosion-Resistant Fencing and Guard Railings." The proponent was the U.S. Army Office of the Assistant Chief of Staff for Installation Management (ACSIM) and the stakeholder was the U.S. Army Installation Management Command (IMCOM). The technical monitors were Daniel J. Dunmire (OUSD(AT&L)), Bernie Rodriguez (IMPW-FM), and Valerie D. Hines (DAIM-ODF).

The work was performed by the Materials and Structures Branch of the Facilities Division (CEERD-CFM), Construction Engineering Research Laboratory, Engineer Research and Development Center (ERDC-CERL). The ERDC-CERL Project Manager was Richard G. Lampo. Significant portions of this work were performed by Mandaree Enterprise Corporation (MEC), Warner Robins, GA. At the time this report was prepared, Vicki L. Van Blaricum was Chief, CEERD-CFM; Donald K. Hicks was Chief, CEERD-CF; and Kurt Kinnevan, CEERD-CZT, was the Technical Director for Adaptive and Resilient Installations. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti, and the Director was Dr. Ilker Adiguzel.

The following personnel are gratefully acknowledged for their support and assistance in this project:

- Dean Kissinger, Deputy Director of Public Works, Kahuku Training Area, HI
- Brian Scarborough, Field Research Facility, Duck, NC
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- Butch Harris, Treat Island Maintenance, Treat Island, ME
- Heather Johnson, Research Assistant, ERDC-CERL, Champaign, IL

The Commander of ERDC was COL Bryan S. Greene and the Director was Dr. Jeffery P. Holland.

Executive Summary

Military installations use large quantities of fencing and safety railing to provide physical security. Many installations are located in severely corrosive environments where metals may approach failure in as little as 5 years. Even metals coated with polyvinyl chloride (PVC) can corrode in severe environments, especially where exposure to ultraviolet (UV) rays in sunlight is intensive. Both security fencing and safety railings must be replaced as soon as functionality is compromised by corrosion.

Five types of advanced corrosion-resistant security fencing were demonstrated and evaluated in this project: fuse-bonded PVC galvanized steel, aluminized steel, Galfan®, stainless steel, and aluminum for use in severely corrosive environments. Standard galvanized steel and standard PVC-coated steel fence specimens were used a control materials. Three types of advanced corrosion-resistant railing materials also were evaluated: stainless steel, fiber-reinforced polymer (FRP), and aluminum. Traditional coated steel railing was used for experimental control. The test exposure sites were Kahuku, HI; Treat Island, ME; and Duck, NC.

Over 12 months of exposure, the standard PVC and fuse-bonded PVC coated fencing materials showed the least amount of corrosion. The aluminized steel and aluminum fencing also showed little sign of corrosion. Aluminum and aluminized steel fencing began to show signs of pitting and buildup of corrosion products. The stainless steel fencing began to discolor as the outside surface oxidized. Of the four railing materials, aluminum performed the best. The coated steel railing corroded within months; the stainless steel railing, like the fencing, became discolored; and the FRP railing showed signs of UV-related degradation.

Results indicate that using corrosion-resistant materials could reduce the life-cycle costs of fences and railings by 62–80%. A follow-on study over an extended time could more accurately identify the realistic life cycles of each material because specimens of the demonstrated fencing and railing materials remain on the test racks and exposure sections. The return on investment (ROI) ratio for using fuse-bonded fencing and anodized aluminum railings was calculated at 6.13; and the ROI for using FRP composite railings instead of anodized aluminum was 5.75.

Unit Conversion Factors

Multiply	By	To Obtain
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
inches	0.0254	meters
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals

1 Introduction

1.1 Problem statement

Conventional metallic security fencing and safety railing materials[1] used on military installations degrade rapidly in highly corrosive environments, especially coastal regions with high atmospheric humidity and chloride content. Short life cycles lead to high repair and replacement costs, and potential security and safety risks due to corrosion-related failure. Long-lasting materials are needed for effectively controlling access to military vehicles, equipment, supplies, and buildings, and for physical barriers that protect personnel and equipment from hazardous boundaries such as staircases and piers. Maintenance and repair costs for corroded critical infrastructure can be excessive.

Fencing and railings damaged by corrosion are usually replaced with the same systems previously procured, thus repeating the cycle of reduced service life and premature replacement costs. Corrosion-resistant fencing and railing is an alternative that may greatly reduce maintenance costs while providing better and more cost-effective physical security.

The Corrosion Prevention and Control Program project documented in this report was undertaken to demonstrate and evaluate durable, cost-effective fencing and security railing materials for use in locations subject to corrosive conditions and high exposure to solar ultraviolet radiation.

1.2 Objective

The objective of this project was to demonstrate and validate the performance and cost of a variety of corrosion-resistant security fencing and corrosion-resistant railing materials at military facilities in severely corrosive locations.

[1] As specified in Unified Facilities Guide Specification (UFGS) 32-31-13, *Chain Link Fences and Gates*; and UFGS 05-52-00, *Metal Railings*, respectively.

1.3 Approach

The primary demonstration sites were the Kahuku Training Area (KTA), Kahuku, HI; and the Field Research Facility (FRF), Duck, NC. Treat Island, ME, was selected as an additional location for material coupon exposure testing to collect data in a cold marine climate. Researchers coordinated with Department of Public Works (DPW) and engineering office personnel to select the specific locations and materials to be used.

Five types of corrosion-resistant chain-link security fencing and four types of corrosion-resistant handrail materials were selected for demonstration. Two additional materials, standard galvanized steel wire and galvanized steel coated in polyvinyl chloride (PVC), were installed as controls for the fencing exposure tests.

This project provides material performance data to support proper material selection based on facility-specific locations and severe climate considerations. As a result, updates to guidance for use of these materials in a severely corrosive environment can be recommended.

The perimeter of the Kahuku Range Control Compound at KTA included 1,000 ft of chain-link security fencing and gates. Five different types of commercial-grade security fencing were installed and monitored over the course of a year to determine their durability and effectiveness at the selected location. Each fencing section was mounted in concrete for stability. Also, four different types of commercial-grade guard rails (48 ft in total length) were installed as test exposure sections.

The perimeter of the selected location at the FRF included 450 ft of chain-link security fencing and gates. A single material type of commercial-grade security fencing was installed and monitored over the course of a year to determine to determine durability and effectiveness for the selected site. Each fencing section was mounted in concrete for stability. Additionally, four different material types of commercial-grade guard rails (48 ft in total length) were installed as test exposure sections.

A coupon rack was installed at both demonstration locations and also Treat Island. Twenty coupons of each of the seven fencing materials (five test materials and two controls) and the four railing materials were mounted on the rack to be evaluated over 1 year. An atmospheric corrosion rack with six different materials was also installed at each site. These coupons were inspected over the course of 1 year to establish relative corrosivity of each of the locations. A weather station was also erected near each test site to record environmental data for correlation with the corrosion findings after 1 year.

Shortly after the start of this project, the Hawaii Garrison offered to supplement this work by installing the same fencing materials for the security fencing at the Bradshaw Army Airfield (BAA), Pohakuloa Training Area (PTA), on the big island of Hawaii. This supplemental effort was executed as part of the official work requirement for this project. Control specimens and test sections of the railing materials were installed in the same manner as at the other sites. The results of the demonstration at the BAA generally support the conclusions drawn for the main test sites. The results of the BAA testing are included as Appendix A of this report.

2 Technical Investigation

2.1 Project overview

Table 1 lists the exposure sites and installation dates. Each site is classified as a marine-type atmosphere, with sea mist particles are carried by the wind. Various degrees of salt deposition can be expected depending on weather conditions. A brief description of each site follows.

Table 1. Exposure sites.

Exposure Site	Type of Atmosphere	Initial Exposure Date
Kahuku Training Area (KTA), HI	Marine	13 Jan 2010
Field Research Facility (FRF), Duck, NC	Marine	19 Feb 2010
Treat Island, ME	Marine	20-Apr 2010

2.1.1 Kahuku, HI

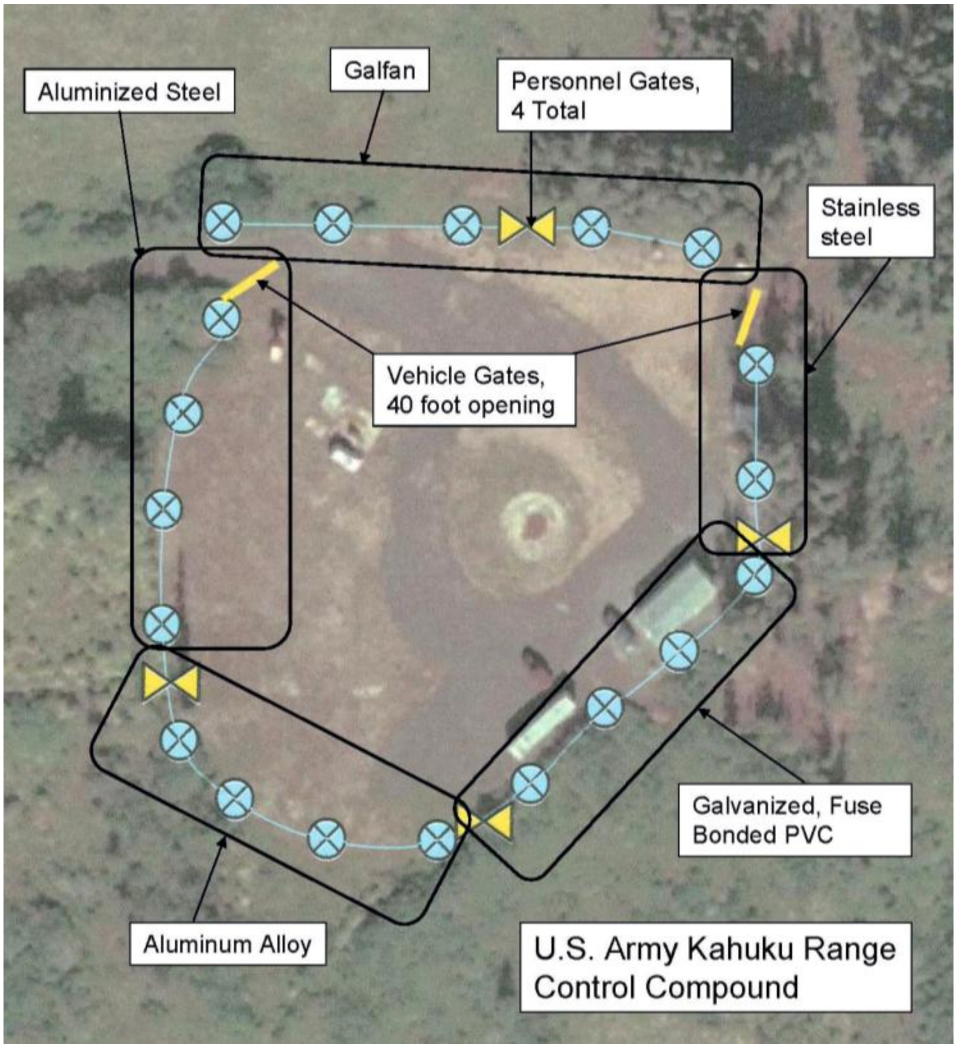
The KTA site serves as a training area for Hawaii military units to maintain combat readiness. It encompasses more than 8,000 acres of land located on the northern side of the Island of Oahu. Elevations vary from 400 ft to 1,700 ft above sea level. The specific exposure site is approximately 2.5 miles from the northern coast of Kahuku, HI. A total of 1,000 ft of fencing was installed at KTA, including four personnel gates and two vehicle gates. The following five corrosion-resistant chain-link fence materials were installed:

- Aluminized steel
- Galfan® brand galvanized steel[2]
- Stainless steel
- Fuse-bonded PVC
- Aluminum

The layout of the fence material is shown in Figure 1.

[2] Galfan is a registered trademark of the Galfan Technology Center, Inc., at the University of Pittsburgh.

Figure 1. General layout of fencing at Kahuku Range Control Compound.



The following four railing materials were installed in 12 ft sections for exposure testing:

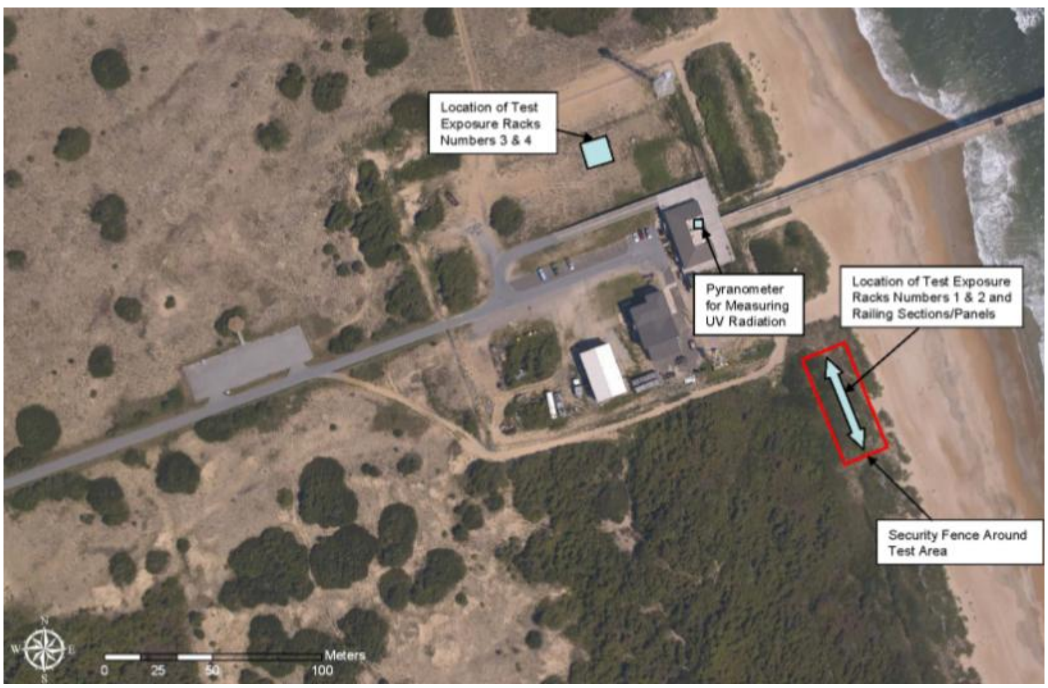
- Fiber-reinforced polymer (FRP)
- Aluminum
- Stainless steel
- Coated steel

A coupon rack was also installed with 20 coupons of each of the five corrosion-resistant wire materials, two control wire materials (standard PVC and galvanized steel), and the four railing materials.

2.1.2 Duck, NC

The exposure site was the FRF established at Duck, NC, by the Corps of Engineers in 1977. A total of 450 ft of fencing was installed at the FRF, including one vehicle gate. Only one corrosion-resistant fence material, fuse-bonded PVC, was installed. Four other corrosion-resistant materials, aluminized steel, Galfan, stainless steel, and aluminum were installed at four separate 8 ft long test sections. The layout of the fence material is shown in Figure 2. Four railing materials—FRP, aluminum, stainless steel, and coated steel—were installed in 12 ft sections for exposure testing. A coupon rack was also installed the same as at KTA.

Figure 2. FRF fencing layout (not to scale).



2.1.3 Treat Island, ME

Treat Island is located at the entrance of Fundy Bay within a few miles of the Canadian border. An exposure site was established there in 1936 by the Concrete Laboratory of the Passamaquoddy Tidal Power Project. This site was not part of the original project scope, but it was added to test additional coupons in a northern marine environment. A coupon rack like the one set up at was installed on a wooden wharf shown in Figure 3.

Figure 3. Treat Island weathering station wharf, view toward location of exposure racks and weather station (left) and end of wharf showing access stairway (right).

2.2 Test setup

2.2.1 Perimeter fencing installation

Perimeter fencing was installed at the KTA and FRF test sites. Before installation, each area was surveyed and graded to provide a suitable terrain for installation. The fencing was installed as prescribed by Field Manual FM 3-19.30, *Physical Security*. All chain-link fabric was a commercial nine gage wire and had a mesh opening no larger than 2 in. per side and measured at least 6 ft in height. Three rows of double-stranded barbed wire were mounted on top of the fencing using 45 degree outriggers pointing away from the fenced area as shown in Figure 4. All supporting poles were mounted in concrete as shown in Figure 5. The following materials were used:

- Galvanized steel coated with fuse-bonded PVC powder coating (green) (ASTM F668, Class 2b)
- Stainless steel with 18% chromium and 8% nickel by weight (AISI 304 alloy)
- Galfan, a proprietary 5% aluminum/95% zinc (by weight) coating metallurgically bonded to a core of ASTM A-817, Type III steel
- Aluminum alloy 6061-T94
- Aluminized steel (ASTM A-817, Type I)
- Standard galvanized steel fencing meeting Unified Facilities Guide Specification (UFGS) 32-31-13, *Chain Link Fences and Gates*, as a control
- Standard PVC-coated fencing meeting UFGS 32-31-13 as a control

Two hundred feet each of corrosion-resistant fence material was installed around the perimeter of KTA, for a total of 1,000 feet of fencing. Matching hardware was used throughout each section of fencing. Included with the total fence perimeter were two vehicle gates and four personnel gates. The opening for each vehicle access gate was 44 ft wide, with two 24 ft wide swing gates. The four personnel gates were constructed 42 in. wide with latches that may be locked. Hardware was included to make sure the gates were securely fixed in open position and locked when in the closed position as shown in Figure 6.

A total of 450 ft of the fuse-bonded PVC fencing was installed around a perimeter at the FRF. The fencing area measured 150 x 75 ft. Matching hardware was used throughout each installation of fencing. A 10 ft wide opening, with two 5 ft swinging gates, was installed at the northwest corner of the perimeter. Hardware was included to make sure the gates were securely fixed in open position and locked when in the closed position. Five separate fence sections were installed within the 450 ft of fencing. Each section was 8 ft long and was constructed the same as the perimeter fence. Four sections were constructed with the other four corrosion-resistant fence materials not included in the perimeter fencing: aluminized steel, Galfan, stainless steel, and aluminum. The fifth section was constructed with standard galvanized steel as a control material.

Figure 4. Barbed wire at top of security fencing at KTA (left) and the FRF (right).

Figure 5. Fencing pole anchored in concrete.

Figure 6. Position-locking hardware for vehicle gates.

2.2.2 Railing installation

Railing test sections were installed at KTA and the FRF. Before installing the railing, a level concrete surface was prepared to provide a suitable surface for installation. Four types of railing materials were used:

- 1-1/4 in. Schedule 10 (1.66 in. outside diameter (OD), 0.109 in. wall) Type 304 stainless steel pipe #6 finish
- 1-1/4 in. pipe (1.66 in. OD) painted carbon steel railings meeting UFGS 05-52-00, *Metal Railings*
- 1-1/2 in. Schedule 40 (1.90 in. OD, 0.145 in. wall) alloy 6063 aluminum mill finish and clear anodize pipe
- 2 in. square tube (0.25 in. wall) FRP

Each material was installed in 8 ft test sections at KTA. The ground was first leveled, then three 12 x 12 x 6 in. concrete blocks were placed for each railing section. Each block was positioned 4 ft apart to support each leg of the railing. The railings were assembled using the manufacturer-supplied hardware (i.e., fittings and fasteners). The railing assemblies (Figure 7) were attached to the concrete pads with 3 in. Tapcon concrete hex-head anchors. At the FRF, 12 ft test sections of each railing material were installed in a similar way; four parallel concrete pads were poured to attach one leg of each railing section and allowed to cure for 24 hours. The railing assemblies were anchored perpendicular to the pads as shown in Figure 8.

Figure 7. Railing test sections installed at KTA.

Figure 8. Railing test sections installed at the FRF.

2.2.3 ASTM G7 Exposure rack and coupon installation

ASTM G7 exposure racks were installed at each test site to determine the relative corrosivity of each location. A 42 in. deep hole was dug for each support post of the exposure rack at KTA and the FRF. The posts were placed in the hole and backfilled with concrete. This was allowed to cure for 24 hours before completing the rack assembly. The exposure rack at Treat Island was modified to attach to the wooden wharf. The legs were shortened by 42 in.. Prefabricated stainless steel feet were attached to the legs and bolted to the wooden wharf with stainless steel bolts. Each face of the rack measured 60 in. tall and 144 in. long. In order to fit all of the desired coupons on each rack, an aluminum U-channel was fastened to the rack with stainless steel bolts. This modification extended the rack by 36 in. in length on both sides. After installation of the exposure coupons, the ASTM G7 exposure rack was set at a 45 degree angle facing the coast, shown in Figure 12–Figure 14.

Seven wire materials were selected for exposure testing at each site. Twenty specimens of each material were cut to 39 in. long. The following materials were selected:

- 9 gage galvanized steel coated core with a 6 gage extruded/adhered PVC finish green ASTM F668 Class 2a coating
- 9 gage galvanized steel coated core with an 8 gage fuse-bonded PVC finish green ASTM F668 Class 2b coating
- 9 gage AIS 304 stainless steel alloy with 18% chromium and 8% nickel by weight
- 9 gage Galfan-coated (5% aluminum/95% zinc by weight) ASTM A-817, Type III
- 9 gage aluminum alloy 6061-T94
- 9 gage aluminized steel, ASTM A-817, Type I
- 9 gage standard galvanized steel, UFGS 32-31-13

The non-fabricated wire coupons (i.e., wire specimens not twisted into chain link) were installed on the exposure rack similar to the method described in ASTM STP 585A, *Atmospheric Corrosion Investigation of Aluminum-Coated, Zinc-Coated, and Copper-Dearing Steel Wire and Wire Product*. In Figure 9, the un-fabricated wire coupons were inserted into a predrilled 1.5 in. diameter aluminum round tubing. The round tubing with one end of the wire coupon was fastened to top of the ASTM G7 exposure rack and the other end 36 in. below the top. Each wire coupon was dipped in EC 1099 plastic adhesive and installed approximately 1 in. apart on center. A continuous plastic-coated wire was wrapped around each wire specimen as shown in Figure 9 to prevent contact between dissimilar metals. After installation, the exposure rack was set at a 45 degree angle facing the coast.

Figure 9. Profile of wire coupons on ASTM G7 rack (left) and method of separating specimens using a plastic-coated wire (right).

Four railing materials were selected for exposure testing at each site. Twenty specimens of each material were to cut to 36 in. long. The following materials were selected:

- 1.5 in. pipe (1.90 in. OD, 0.145 in. wall), carbon steel mill finish ASTM A513 coated with a long oil primer (Sherwin Williams KROMIK Metal primer, with performance comparable to the Society for Protective Coatings Paint Specification SSPC 25) and top-coated with a medium oil alkyd enamel (Sherwin Williams Industrial Enamel, with performance comparable to Federal Specification Mil-E-15090) followed by an alkyd enamel top coat
- 1.5 in. pipe (1.90 in. OD, 0.145 in. wall), alloy 6063 aluminum mill finish and clear anodize pipe 30 minute anodized (Aluminum Association specification for anodized finishes AAM12C22A31)
- 1.5 in. pipe size (1.90 in. OD, .145 in. wall) Type 304 stainless steel pipe and #4 satin finish
- 1.5 in. square tube (0.125 in. wall) FRP

A 3/8 in. hole was drilled at 1 and 22 in. from one end of each railing coupon. The coupons were fastened to the U-channel attached to the ASTM G7 rack using nylon bolts and wing nuts. Nylon washers were placed in between the coupon the rack to prevent dissimilar-metal contact. Typical installation of the railing coupons is shown in Figure 10–Figure 13.

Figure 10. Railing and wire coupons installed on an ASTM G7 exposure rack placed at 45 degree angle at the FRF.

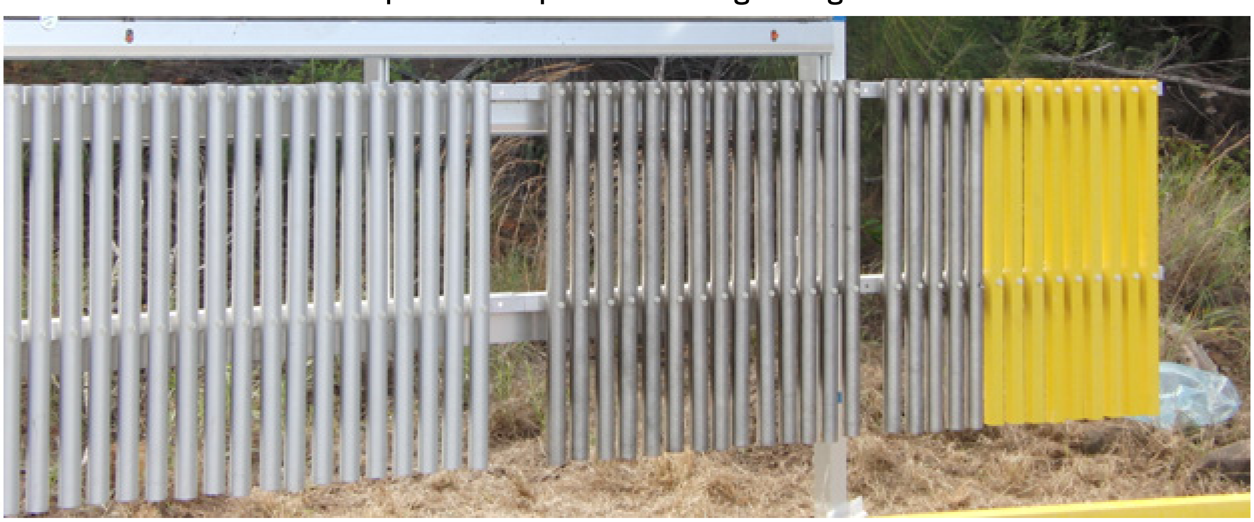


Figure 11. Railing and wire coupons installed on ASTM G7 exposure rack placed a 45 degree angle at KTA.

Figure 12. Railing and wire coupons on exposure rack placed at 45 degree angle at the FRF.

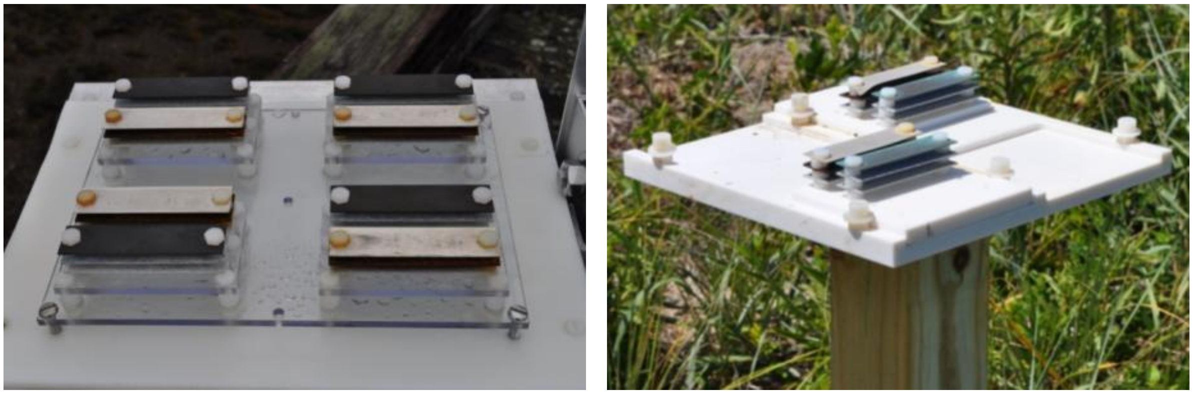
Figure 13. Railing and wire coupons installed on exposure rack placed at 45 degree angle at Treat Island.

2.2.4 Atmospheric coupon racks

An atmospheric coupon rack to determine the relative corrosivity of the site was installed facing 90 degrees from vertical[3] at the FRF and Treat Island as shown in Figure 14. Relative corrosivity data for KTA had been previously collected and was used for comparison in Chapter 3. The corrosion coupons included silver, copper, 1010 steel, and three aluminum alloys: 2024 T3, 6061 T6 and 7075 T6. They measured 1 in. wide by 4 in. long by 1/16 in. thick. These coupons were collected after 3, 6, 9, and 12 months of exposure. The mass of each coupon was recorded before being exposed to the test environment. The silver coupon was tested for chlorides in accordance with ASTM B825. The remaining coupons were analyzed for mass loss in accordance with ASTM G1.

[3] In order to minimize cross contamination from water runoff from upper to lower coupons, the preferred orientation is to have the racks installed 90 degrees vertical instead of 90 degrees from vertical and with each group of specimens positioned so no other group of specimens is below it. Data from previous exposure testing at KTA were taken from coupons positioned in the preferred orientation.

Figure 14. Atmospheric coupon racks at Treat Island, ME (left), and the FRF (right).



2.2.5 Weather stations

A weather station was installed at each site to measure and record environmental characteristics throughout the exposure period (Figure 15). The station measured temperature, relative humidity, solar irradiance, wind speed and direction, and rainfall.

Figure 15. Weather stations at KTA (left), FRF (center), and Treat Island (right).

Weather stations were powered by a solar panel and a rechargeable battery. A data logger was used to store the measurements, which were at 15 minute intervals. Data were downloaded manually during each quarterly inspection through the use of a laptop computer. The data logger and sensors were each powered by a rechargeable battery connected to a solar panel. The data logger has a storage capacity to continue storing data at 15 minute intervals for approximately 2.5 years. When the amount of data reaches full storage capacity, the device deletes the oldest data point to create room for new data.

2.3 Coupon monitoring and post-exposure lab testing

Visual inspections were performed after 3, 6, 9, and 12 months of exposure. Table 2 lists the dates of installation and inspections of the fencing and railings. The approximate percentage of the areas of corrosion observed was documented. Weather data recorded on the data logger was downloaded from the logger during each inspection via a laptop. A set of atmospheric coupons were collected and sent to a laboratory for mass loss and chloride content analysis. This report summarizes the observation made over a period of one year.

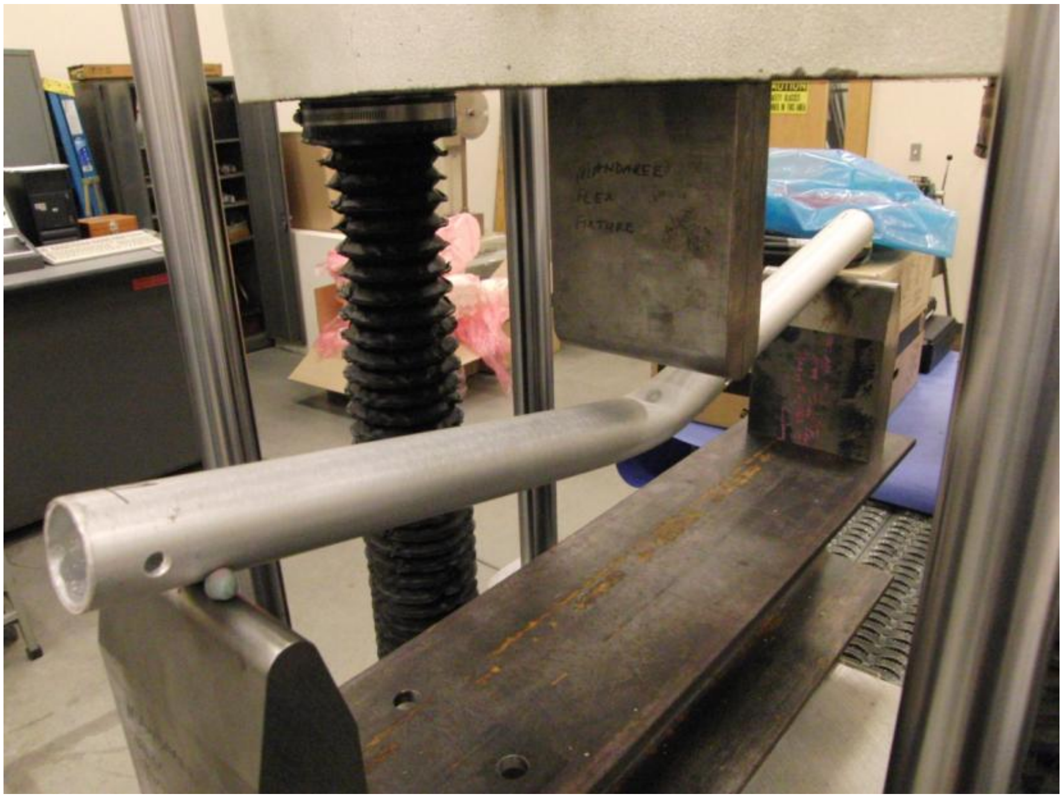
During the 6- and 12-month inspections, five coupons of each wire material and railing material were collected and sent to a laboratory for testing. The wire coupons were subjected to a tensile break test per ASTM A931, "Standard Test Method for Tension Testing of Wire Ropes and Strands" as shown in Figure 16. Applied loads and deflection were measured and recorded. Railing coupons were subjected to a flexure testing per ASTM D-790, Procedure A as shown in Figure 17.

Table 2. Visual inspection intervals.

Exposure Location	Initial Exposure	First Quarterly	Second Quarterly	Third Quarterly	Fourth Quarterly
Kahuku, HI	13-Jan-10	26-Apr-10	14-July-10	04-Oct-10	25-Jan-11
Cumulative Days	0	103	183	264	377
Duck, NC	19-Feb-10	18-May-10	17-Aug-10	08- Nov-10	23-Feb-11
Cumulative Days	0	88	184	267	372
Treat Island, ME	20-Apr-10	29-Jul-10	02-Nov-10	24-Feb-11	24-May-11
Cumulative Days	0	100	196	310	399

Figure 16. ASTM A931 tensile test of wire coupons after exposure.

Figure 17. ASTM D790 flexure test of railing coupons after exposure.



3 Discussion

3.1 Metrics

The installed fencing sections met the requirements as described in Field Manual, FM 3-19.30, *Physical Security*, Chapter 4, section on fencing, dated January 2001. The vehicle and personnel gates met the security requirements in Section 3 of FM 3-19.30 and Military Handbook MIL-HDBK 1013.

The exposure racks were built in accordance with ASTM G7 and the atmospheric coupon rack was built and tested in accordance with ASTM G1, with the exception of the silver coupons. The silver coupons were tested in accordance with ASTM B825. Wire specimens on the ASTM G7 rack were mounted as described in ASTM Special Technical Publication STP 585A, *Atmospheric Corrosion Investigation of Aluminum-Coated, Zinc-Coated, and Copper-Bearing Steel Wire and Wire Product–a Twenty Year Study*.

3.2 Results

3.2.1 Visual inspections of fencing

Figure 18 – Figure 28 illustrate the progression of corrosion on each material over the 12 month exposure period, and the results of the visual inspections are summarized in Table 3 – Table 5. See Appendix B for more details and photos from each of the quarterly site inspections.

Based on the 12 month evaluation of the materials, the fuse-bonded PVC appeared to perform the best against corrosion at each site. The non-conductive characteristic of the PVC coating provides a long-lasting protection against electrochemical corrosion. However, corrosion formation was observed wherever the PVC coating was damaged or cut ends were not protected. This could be a potential problem over the service life of the materials. Corrosion will eventually propagate further along the material and cause the PVC coating to separate from the core material, which can become aesthetically unacceptable and degrade substrate material performance. The evaluation period was not long enough to differentiate performance between the standard PVC-coated and the fuse-bonded PVC-coated fabrics.

At KTA, the aluminized steel and aluminum fencing were the only other two materials that performed well, each showing little indication of corrosion. The zinc-coated materials oxidized over the 12 month observation period. At the FRF, some areas the zinc coating on Galfan and the galvanized fencing were depleted. The stainless steel did not severely corrode, but the outer surface was quick to oxidize at the FRF and became discolored at KTA.

Figure 18. Standard PVC coated galvanized wire coupon at FRF (left) and KTA (right) after 6 months of exposure.

Figure 19. Aluminum wire coupon at FRF (left) and KTA (right) after 6 months of exposure.

Figure 20. Stainless steel wire coupon at FRF (left) and KTA (right) after 6 months of exposure.

Figure 21. Galfan wire coupon at FRF (left) and KTA (right) after 6 months of exposure

Figure 22. Standard PVC coated galvanized steel wire coupon at FRF (left) and KTA (right) after 12 months of exposure.

Figure 23. Standard galvanized steel wire coupon at FRF (left) and KTA (right) after 12 months of exposure.

Figure 24. Aluminized steel wire coupon at FRF (left) and KTA (right) after 12 months of exposure.

Figure 25. Fuse bonded PVC coated wire coupon at FRF (left) and KTA (right) after 12 months of exposure.

Figure 26. Aluminum wire coupon at the FRF (left)
and KTA (right) after 12 months of exposure.

Figure 27. Stainless Steel wire coupon at FRF (left)
and KTA (right) after 12 months of exposure.

Figure 28. Galfan wire coupon at FRF (left)
and KTA (right) after 12 months of exposure.

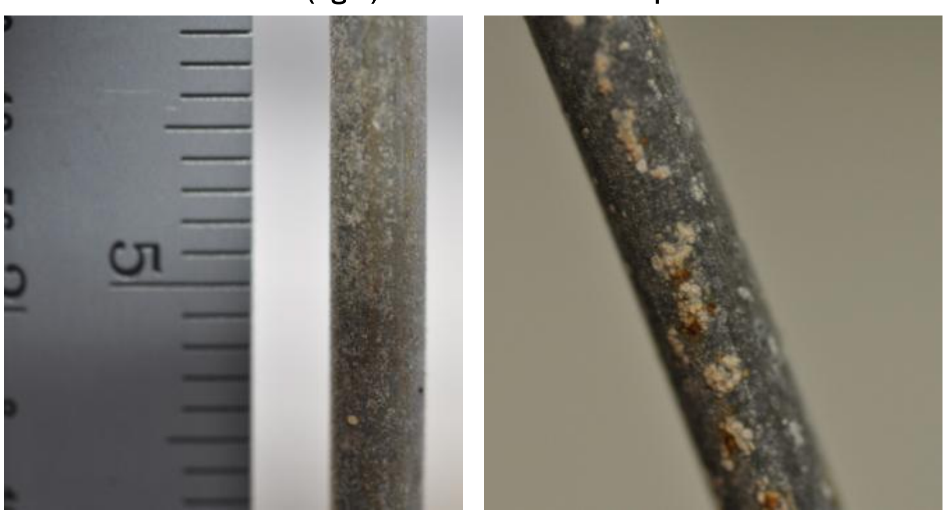


Table 3. Visual inspection summary for fencing materials after 12 months of exposure at KTA.

Fencing Material Type	% of Surface Corroded	Type	Comments
Standard PVC coated galvanized	0%	N/A	No visible corrosion
Fuse bonded PVC coated galvanized	0%	N/A	No visible corrosion
Standard galvanized	50%	Oxidation / Rust	50% of the corrosion areas have degraded past the sacrificial zinc coating and have begun to rust.
Stainless steel	100%	Oxidation	Surface oxidation
Aluminum	5%	Pitting	Minor pitting
Galfan	75%	Oxidation / Rust	50% of the corrosion areas have degraded past the sacrificial zinc coating and have begun to rust.
Aluminized steel	<5%	Oxidation	White oxidation of the zinc/AL coating

Table 4. Visual inspection summary for fencing materials after 12 months of exposure at the FRF.

Fencing Material Type	% of Surface Corroded	Type	Comments
Standard PVC coated galvanized	0%	N/A	No visible corrosion. Covered in chloride residues.
Fuse bonded PVC coated galvanized	0%	N/A	No visible corrosion. Covered in chloride residues.
Standard galvanized	100%	Oxidation	White oxidation of the zinc/AL coating
Stainless steel	100%	Oxidation	Surface oxidation
Aluminum	50%	Oxidation / Pitting	Pitting and White corrosion product
Galfan	100%	Oxidation	White oxidation of the zinc/AL coating
Aluminized steel	100%	Oxidation	White oxidation of the AL coating

Table 5. Visual inspection summary for fencing materials after 12 months of exposure at Treat Island.

Fencing Material Type	% of Surface Corroded	Type	Comments
Standard PVC coated galvanized	0%	N/A	No visible corrosion
Fuse bonded PVC coated galvanized	0%	N/A	No visible corrosion
Standard galvanized	5%	Oxidation / Rust	50% of the corrosion areas have degraded past the sacrificial zinc coating and have begun to rust.
Stainless steel	10%	Oxidation	Surface oxidation
Aluminum	0%	N/A	No visible corrosion
Galfan	5%	Oxidation / Rust	50% of the corrosion areas have degraded past the sacrificial zinc coating and have begun to rust.
Aluminized steel	5%	Oxidation	White oxidation of the zinc/AL coating

3.2.2 Visual inspections of railings

Figure 29 – Figure 36 illustrate the progression of corrosion on each material over the 12 month exposure period, and the results of the visual inspections are summarized in Table 6 – Table 8. See Appendix B for additional details and photos for each of the quarterly site inspections.

The FRF was the most corrosive site for the metallic materials after 12 months of exposure. Due to the tropical climate and high solar radiation levels, the KTA site was the most damaging to the FRP railing materials. Based on the 12 month evaluation of the materials, the anodized railing appears to perform the best against corrosion at each site. Additionally the aluminum also retains its aesthetic appeal longer in comparison to the other materials. The only signs of corrosion found on the aluminum railings were at locations where the material was scratched or damaged through the anodized layer.

The traditional painted carbon steel railing began showing signs of corrosion after 3 months of exposure and severe corrosion after 12 months of exposure at the FRF and KTA. The stainless steel did not severely degrade, but the outer surface was quick to oxidize and turn a rust color at each site. The aesthetic appeal of the stainless steel was largely compromised after 3 months of exposure. The FRP railings did not show signs of degradation until 6 months of exposure. The sides of railing specimens that face the sun the longest during the day were affected by color fading.

Figure 29. FRP railing coupon at FRF (left) and KTA (right) after 6 months of exposure.

Figure 30. Coated steel railing coupon at FRF (left) and KTA (right) after 6 months of exposure.

Figure 31. Stainless steel railing coupon at FRF (left) and KTA (right) after 6 months of exposure.

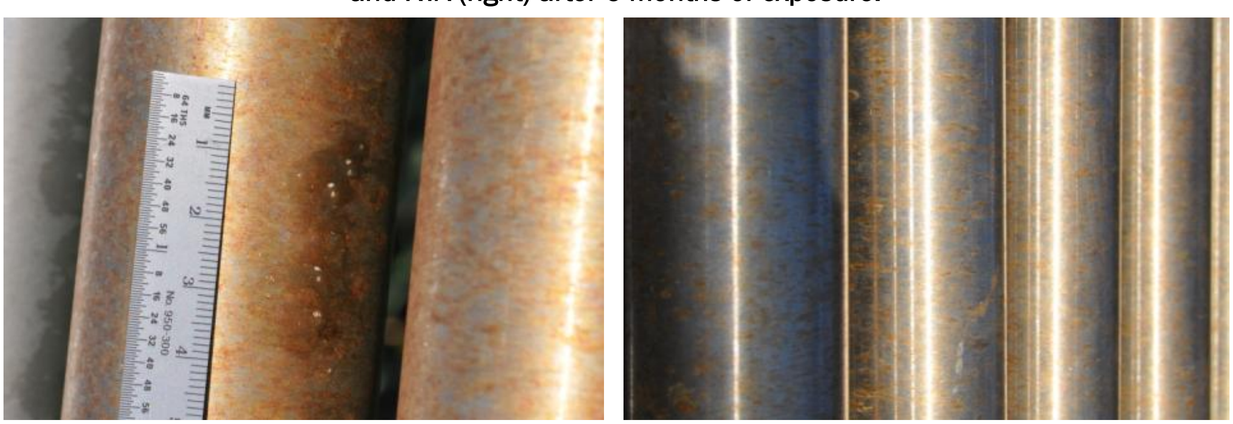


Figure 32. Aluminum railing coupon at FRF (left) and KTA (right) after 6 months of exposure.

Figure 33. FRP railing coupon at FRF (left) and KTA (right) after 12 months of exposure.

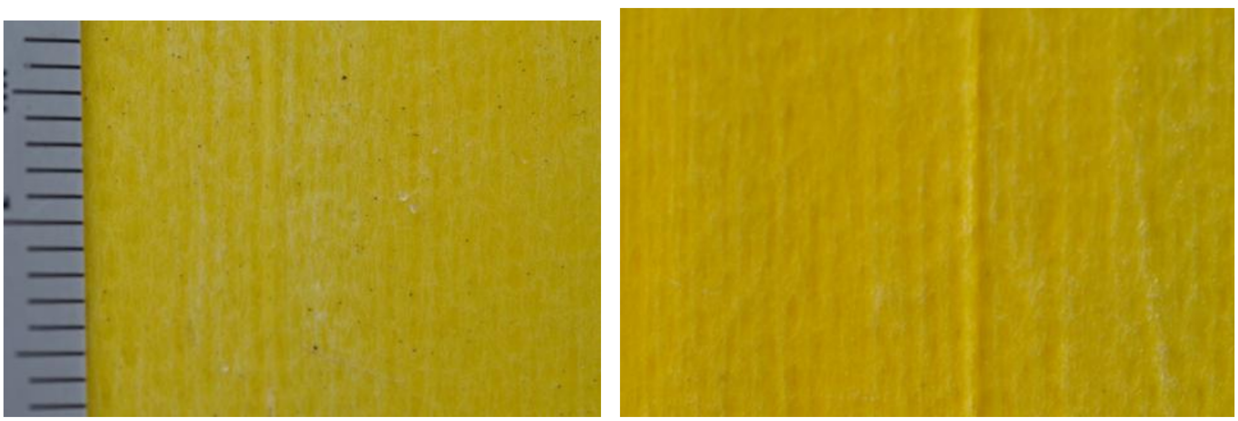


Figure 34. Coated steel railing coupon at FRF (left) and KTA (right) after 12 months of exposure.

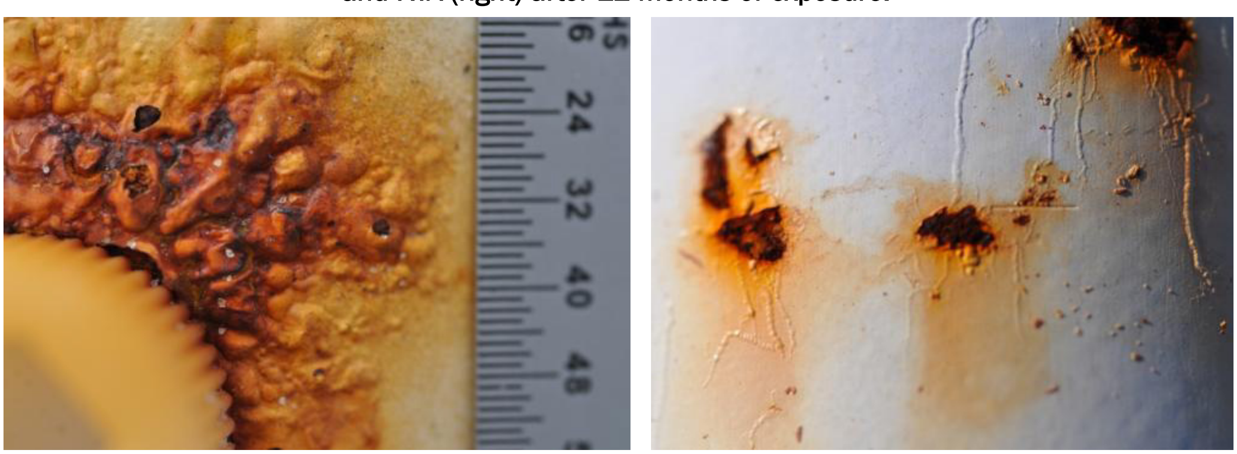


Figure 35. Stainless steel railing coupon at FRF (left) and KTA (right) after 12 months of exposure.

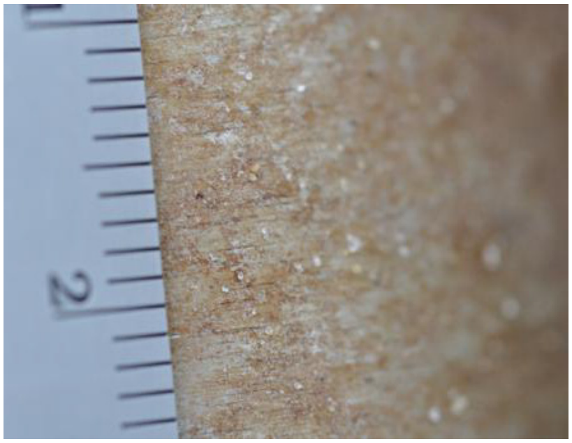


Figure 36. Aluminum railing coupon at FRF (left) and KTA (right) after 12 months of exposure.

Table 6. Visual inspection summary for railing materials after 12 months of exposure at KTA.

Railing Material Type	Corrosion	Staining	Comments
Stainless steel	80%	Oxidation	Surface oxidation has discolored the material.
Aluminum	<5%	Pitting	Pitting has begun in areas where the anodize may have been damaged
Coated steel	20%	Rust	Rust has begun to form where the coating has failed. Discoloring of the coating due to the rust.
FRP	25%	UV	Discoloring due to UV exposure on the face of the railing that faces the sun

Table 7. Visual inspection summary for railing materials after 12 months of exposure at FRF.

Railing Material Type	Corrosion	Staining	Comments
Stainless steel	100%	Oxidation	Surface oxidation has discolored the material.
Aluminum	<5%	Pitting	Pitting has begun in areas where the anodize may have been damaged
Coated steel	50%	Rust	Rust has begun to form where the coating has failed. Discoloring of the coating due to the rust.
FRP	25%	UV	Discoloring due to UV exposure on the face of the railing that faces the sun

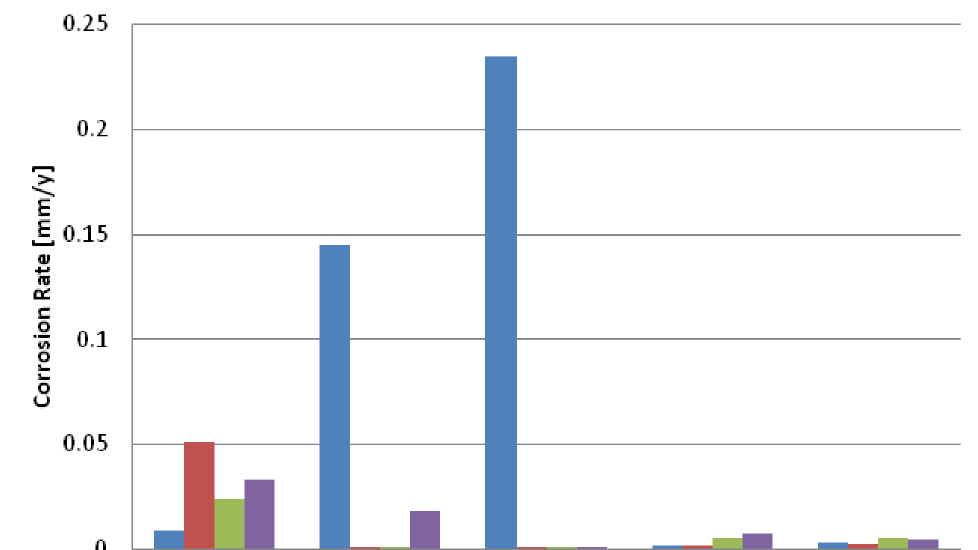
Table 8. Visual inspections of corrosion on railings after 12 months of exposure at Treat Island, ME.

Railing Material Type	Corrosion	Staining	Comments
Stainless steel	10%	Oxidation	Surface oxidation
Aluminum	0%	N/A	No visible corrosion
Coated steel	<5%	Rust	Rust has begun to form where the coating has failed. Discoloring of the coating due to the rust.
FRP	25%	UV	Discoloring due to UV exposure on the face of the railing that faces the sun

3.2.3 Atmospheric coupon laboratory results

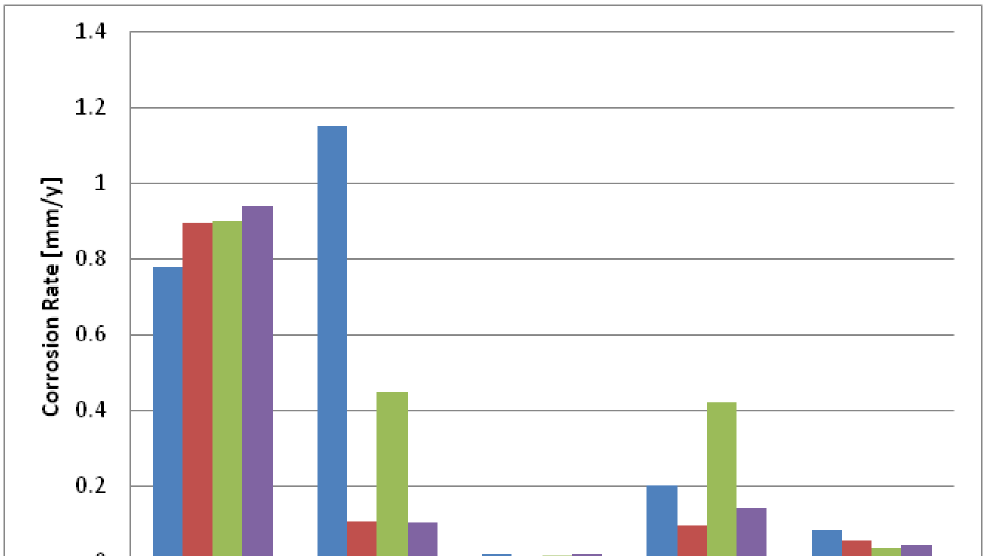
The corrosion rates calculated in accordance with ASTM G1 are listed and graphed in Figure 37 – Figure 39. Additional details and tabular data are presented in Appendix C. Results from the silver coupon coulometric reduction analysis, executed in accordance with ASTM B825, are shown in Table 9 – Table 11.

Figure 37.Corrosion rates of steel, copper and aluminum alloy atmospheric coupons after 3, 6, 9, and 12 months of exposure at Treat Island, ME.



	Steel	AL2024 T3	AL6061 T6	AL7075 T6	Copper
2520	0.008938006	0.145095955	0.234794747	0.00135648	0.003032116
4560	0.050919774	0.000349718	0.000810181	0.00196058	0.002039046
7272	0.02400559	0.000932005	0.000639747	0.005441933	0.005296286
9072	0.033376596	0.017812819	0.000422317	0.007449046	0.00470551

Figure 38. Corrosion rates of steel, copper and aluminum alloy atmospheric coupons after 3, 6, 9, and 12 months of exposure at the FRF.



	Steel	AL2024 T3	AL6061 T6	AL7075 T6	Copper
2520	0.778733081	1.150410424	0.020030476	0.199913849	0.084089963
4560	0.894219781	0.107301871	0.010186276	0.092835405	0.05645409
7272	0.898799297	0.44765254	0.016090262	0.419074063	0.036139954
9072	0.93966568	0.10100791	0.019099267	0.141179569	0.044725346

Figure 39. Corrosion rates of steel, copper and aluminum alloy atmospheric coupons after 3, 6, 9, and 12 months of exposure at Kahuku, HI.

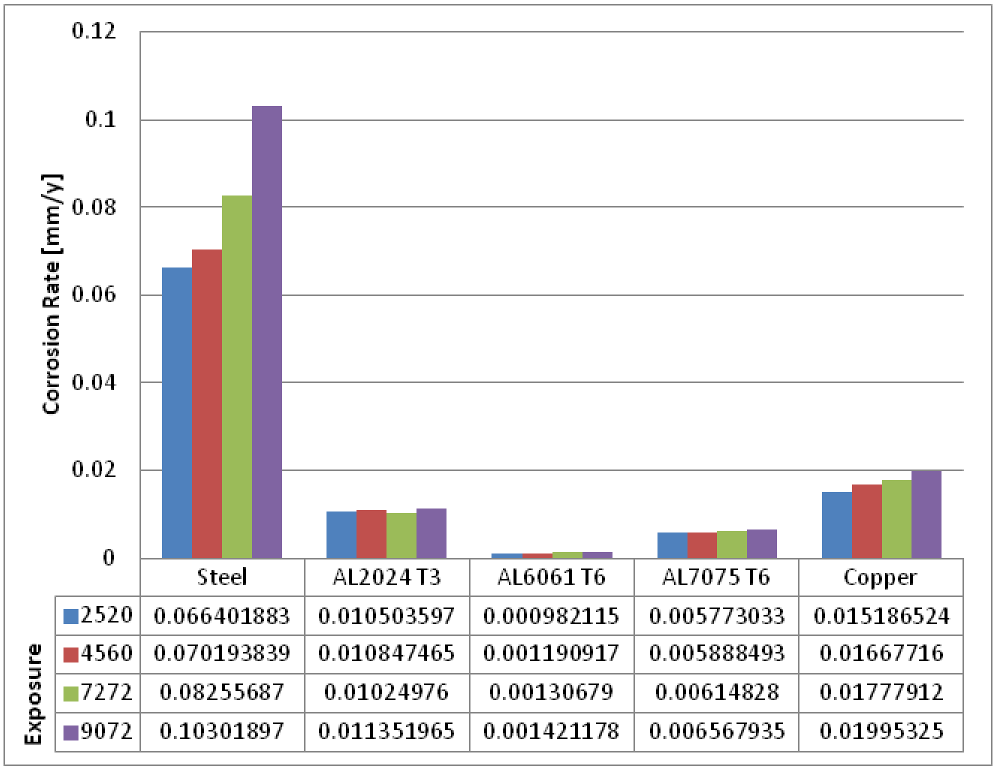


Table 9. Coulometric reduction time and film thickness of silver chloride present after environmental exposure at the FRF.

Approximate Exposure [months]	Reduction Time [seconds]	AgCl Film Thickness [ångströms]
3	6325	434.19
6	14090	967.23
9	19250	1321.45
12	28605	1963.64

Table 10. Coulometric reduction time and film thickness of silver chloride present after environmental exposure at Treat Island.

Approximate Exposure [months]	Reduction Time [seconds]	AgCl Film Thickness [ångströms]
3	1010	69.33
6	2025	139.01
9	6900	473.66
12	8050	552.60

Table 11. Coulometric reduction time and film thickness of silver chloride present after environmental exposure near KTA.

Approximate Exposure [months]	AgCl Film Thickness [ångströms]
3	11766.00
6	17416.00
9	23764.00
12	33244.00

The atmospheric data were collected by placing atmospheric coupons at the test sites for a 12 month exposure period. The data used for the KTA were produced by atmospheric coupons from a different project that was located closer to the coast than the subject test site. Consequently, the data reflect higher levels of chlorides than would be seen at KTA, which is approximately 1,700 ft above sea level and 2.5 miles from the closest coast. Although the results of the silver chloride film thickness do not accurately reflect the conditions at the test site KTA, they provide a realistic comparison with atmospheric data from the FRF and Treat Island, ME, costal test sites. The data suggests that the atmosphere at the Kahuku, HI, coast has chlorides up to 27 times greater than the FRF and up to 170 times greater than Treat Island.

Although the presence of chlorides was higher in the Kahuku data, the mass loss of five materials was greater at the FRF. Chlorides can promote rapid and severe corrosion of metals. Other environmental conditions, however, such as wind and moisture are also critical to the electrochemical corrosion process. The corrosion rates calculated at the FRF were up to 10 times the rates calculated at Kahuku, and up to 100 times the rates at Treat Island.

3.2.4 Weather data

The data presented in Table 12 were recorded at the FRF from 19 February 2010 through 28 February 2011. Individual data points were continuously logged at 10 minute intervals from an existing FRF weather station. Weather stations were placed at both the KTA and Treat Island test sites. The data represented in Table 13 and Table 14 were recorded at the KTA from 19 February 2010 through 28 February 2011, and at Treat Island from 20 April 2010 through 24 May 2011. Individual data points KTA and Treat Island were continuously logged in 15 minute intervals.

Table 12. Weather data recorded from Feb 2010 – Feb 2011 at the FRF.

	Rain [in./day]	Solar Radiation [W/m²]	Wind Speed [mph]	Gust Speed [mph]	Wind Direction [ø]	Temp [°F]	RH [%]
Average	0.421138	124.8527	6.014856	7.430096	179.4423	59.60083	76.78167

Table 13. Weather data recorded from Feb 2010 – Feb 2011 at the KTA.

	Rain [in./day]	Solar Radiation [W/m²]	Wind Speed [mph]	Gust Speed [mph]	Wind Direction [ø]	Temp [°F]	RH [%]
Average	0.112	215.0777	61.49623	70.23075	35.82344	40.93099	89.29874

Table 14. Weather data recorded from April 2010 – May 2011 at Treat Island.

	Rain [in./day]	Solar Radiation [W/m²]	Wind Speed [mph]	Gust Speed [mph]	Wind Direction [ø]	Temp [°F]	RH [%]
Average	0.1357	117.3637	9.230218	14.51839	88.55464	41.99848	82.44376

The anemometer on the contractor-installed weather station at KTA stopped logging data, then began reporting incorrect values. The location is subject to strong tropical trade winds, but the measured average speed of 61.5 miles per hour (mph) is not considered realistic. The average temperature is also suspect. According to the most pertinent available weather data for the location, obtained from the commercial business data service www.usa.com, (World Media Group LLC, Basking Ridge, NJ, accessed 15 October 2015), the average wind speed for Kahuku is 16.0 mph and the average temperature is 74.7 °F, not 61.5 mph and 40.9 °F as recorded by the contractor's weather station.

Each test site is located near a marine coastline with high atmospheric chloride content. Wind transports chlorides to be deposited onto materials. KTA had the largest average wind speed at 16.0 mph. The FRF received the most rain throughout the test period. Moisture acts as the electrolyte needed to initiate a corrosion process. This, in combination with chloride ions and warm temperatures result in a severely corrosive environment for metallic materials at the FRF. The benefit of the polymer based materials like the FRP composite railings is that they are electrically nonconductive, which eliminates an essential condition for electrochemical-type corrosion seen in metallic materials. However, polymers can deteriorate due to exposure solar radiation, becoming brittle and losing strength over time. The KTA test site recorded levels of solar radiation that were two times higher than at the FRF and Treat Island. A typical visual sign of solar deterioration is fading or discoloring of the polymer material.

3.2.5 Tensile testing of wire specimens

Five samples of each wire material were tensile tested without any environmental exposure, and five weathered samples of each material from each site were tested after 6 and 12 months of exposure. Table 15 – Table 21 summarize of the average breaking loads of each material and the percentage of strength loss compared with the original breaking load.

Table 15. Breaking loads of wires removed during the exposure period (9 gage aluminum alloy 6061-T94, original breaking load 912 lb.)

Location	Months Exposed	Breaking Load Exposed lb	Loss %
KTA	6	903	0.97%
	12	907	0.53%
FRF	6	912	-0.02%
	12	901	1.18%
Treat Island	6	920	-0.90%
	12	897	1.62%

Table 16. Breaking loads of wires removed during exposure period (9 gage aluminized steel, ASTM A-817, Type I, original breaking load 1525 lb).

Location	Months Exposed	Breaking Load Exposed lb	Loss %
KTA	6	1621	2.23%
	12	1632	1.57%
FRF	6	1620	2.29%
	12	1614	2.65%
Treat Island	6	1632	1.57%
	12	1601	3.44%

Table 17. Breaking loads of wires removed during the exposure period (9 gage standard galvanized steel, UFGS 32-31-13, original breaking load 840 lb).

Location	Months Exposed	Breaking Load Exposed lb	Loss %
KTA	6	846	-0.69%
	12	822	2.17%
FRF	6	847	-0.81%
	12	835	0.62%
Treat Island	6	862	-2.59%
	12	839	0.14%

Table 18. Breaking loads of wires removed during the exposure period (9 gage Galfan ASTM A-817, Type III, original breaking load 838 lb).

Location	Months Exposed	Breaking Load Exposed lb	Loss %
KTA	6	833	0.55%
	12	834	0.43%
FRF	6	862	-2.91%
	12	842	-0.53%
Treat Island	6	858	-2.44%
	12	843	-0.64%

Table 19. Breaking loads of wires removed during the exposure period (9 gage AIS 304 stainless steel alloy, original breaking load 1522 lb).

Location	Months Exposed	Breaking Load Exposed lb	Loss %
KTA	6	1523	-0.09%
	12	1545	-1.54%
FRF	6	1606	-5.55%
	12	1582	-3.97%
Treat Island	6	1541	-1.27%
	12	1553	-2.06%

Table 20. Breaking loads of wires removed during the exposure period (9 gage galvanized steel coated core with 8 gage extruded/adhered PVC finish green ASTM F668 Class 2b coating, original breaking load 1484 lb).

Location	Months Exposed	Breaking Load Exposed lb	Loss %
KTA	6	1512	-1.89%
	12	1485	-0.07%
FRF	6	1514	-2.03%
	12	1455	1.95%
Treat Island	6	1538	-3.65%
	12	1507	-1.56%

Table 21. Breaking loads of wires removed during the exposure period (9 gage galvanized steel coated core with a 6 gage extruded/adhered PVC finish green ASTM F668 Class 2a coating, original breaking load 1525 lb).

Location	Months Exposed	Breaking Load Exposed lb	Loss %
KTA	6	1506	1.28%
	12	1505	1.34%
FRF	6	1460	4.29%
	12	1516	0.62%
Treat Island	6	1527	-0.10%
	12	1525	0.03%

The percent of loss of load required for a tensile failure varied ± 5% from time zero through the 12 month test period. This amount of variation is too small to attribute to corrosion. Variations in strength expected from material processing also can account for ± 5% variation in strength properties. A 12 month test period is not long enough to validate material property reduction due to corrosion; a significantly longer test period appears to be required before a loss in strength due to corrosion could be recorded.

Long-term data relevant to this demonstration are available ASTM International Special Technical Publication STP 585A, "*Atmospheric Corrosion Investigation of Aluminum-Coated, Zinc-Coated, and Copper-Bearing Steel Wire and Wire Product*." This publication discusses observations and results of exposing wire products to corrosive environments over a 20 year test period. One of the test sites from that study, Kure Beach, NC, has characteristics similar to the FRF. The zinc and aluminum coated-wire materials tested at Kure Beach by ASTM did not lose a significant percentage of their strength even after 10-plus years of environmental exposure.

Plots of the calculated ultimate tensile strengths for the different wire specimens tested in this CPC project are shown in Figure 40 – Figure 42. These plots compare both the relative strength of each material and changes measured in each material over time. Additional data can be found in Appendix D.

Figure 40. Force calculated from tensile testing of wire coupons exposed at the FRF.

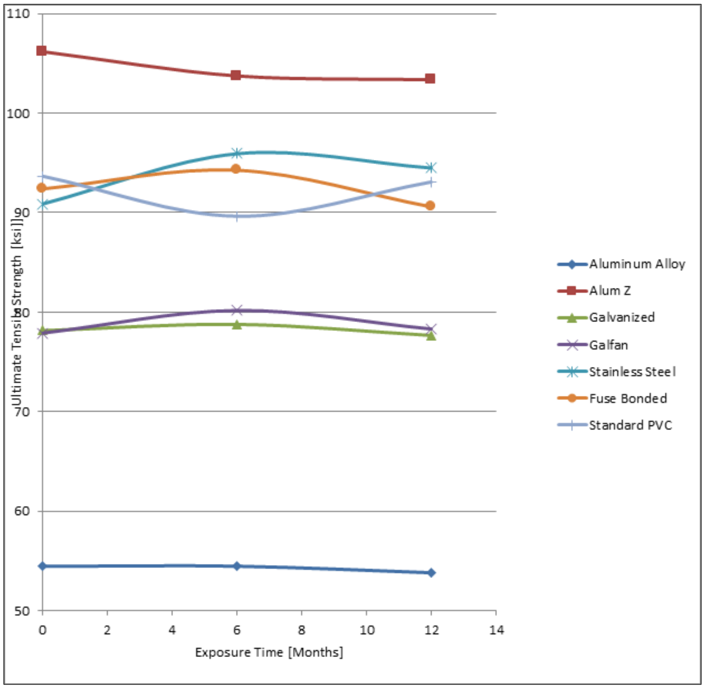


Figure 41. Force calculated from tensile testing of wire coupons exposed at KTA.

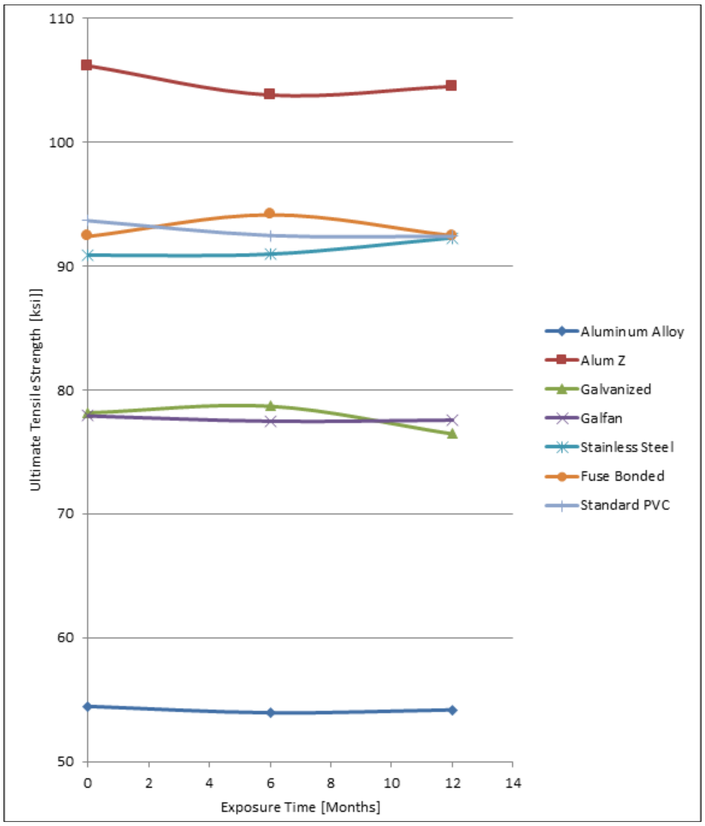
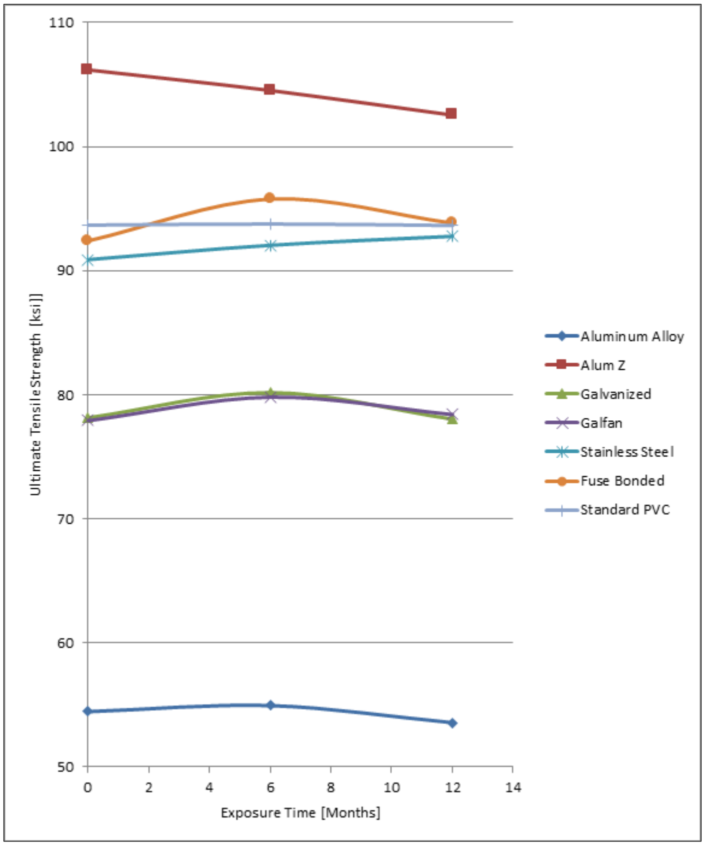


Figure 42. Force calculated from tensile testing of wire coupons exposed at Treat Island.



3.2.6 Flexure testing

Flexure testing did not reveal a significant change in mechanical properties of railing materials over the exposure period. Figure 43 – Figure 45 show the relative yield strength of each material, and changes measured in specimens after exposure. Yield stress describes the plasticity of a material. In a flexure test, the material deforms in compression and tension.

Figure 43. Yield stress calculated from flexure testing of railing coupons at the FRF.

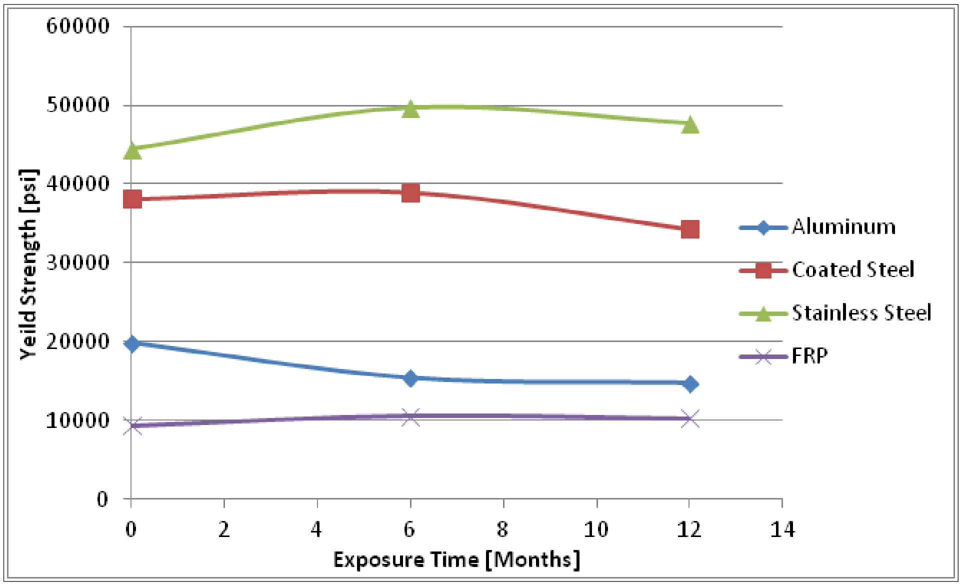


Figure 44. Yield stress calculated from flexure testing of railing coupons exposed at KTA.

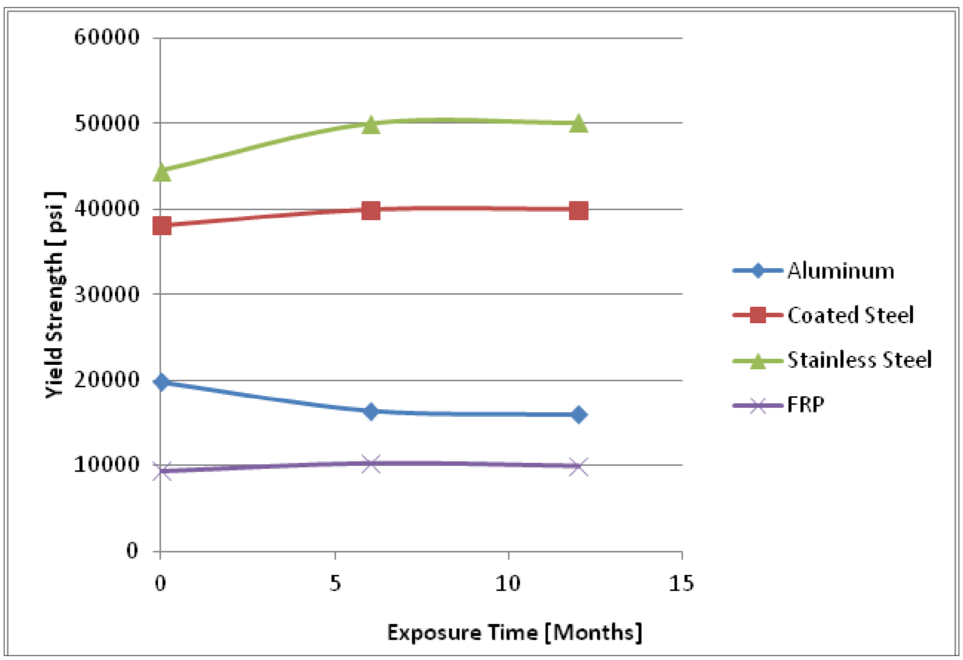


Figure 45. Yield stress calculated from flexure testing of railing coupons exposed in Treat Island.

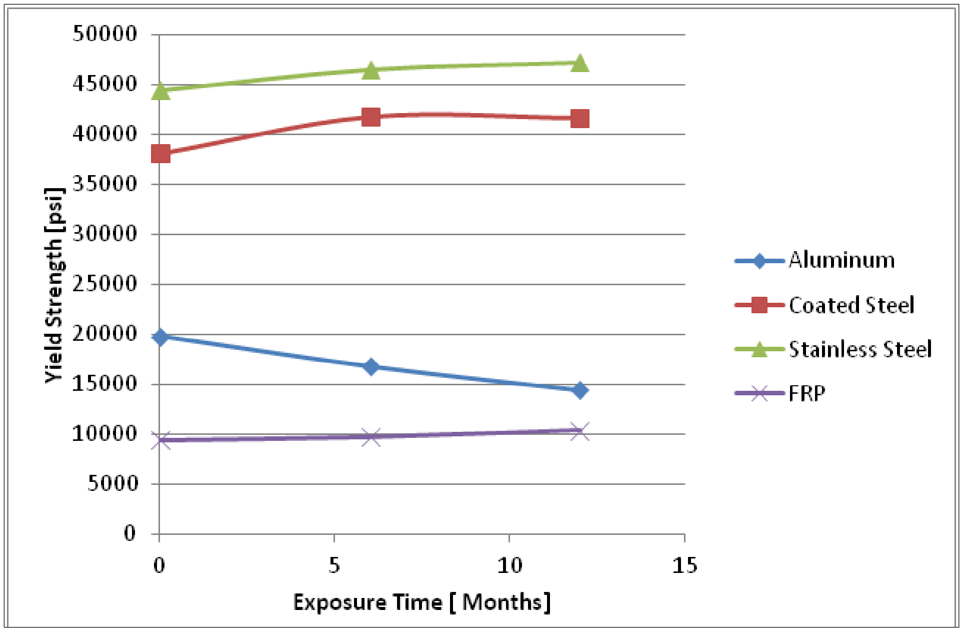


Figure 46 shows a typical graph of steel pipe deformation as a flexure load is applied. It was found that the longitudinal shape of the pipe remained rigid and the circular cross section collapsed before the pipe began to flex, as seen in Figure 47. This same behavior was not observed in the aluminum or FRP railing specimens. The aluminum specimens were relatively ductile in comparison with steel and stainless steel, and therefore began to deform in both the cross section and longitudinally at the same time. The FRP railing had a square cross section and is not very ductile compared to either steel or aluminum, so its failure was different than the metallic specimens. Figure 48 – Figure 50 represent the change in the tangent modulus throughout the exposure period for each test site. More data can be found in Appendix E.

Figure 46. Typical load-deflection plot of a steel pipe during flexure testing.

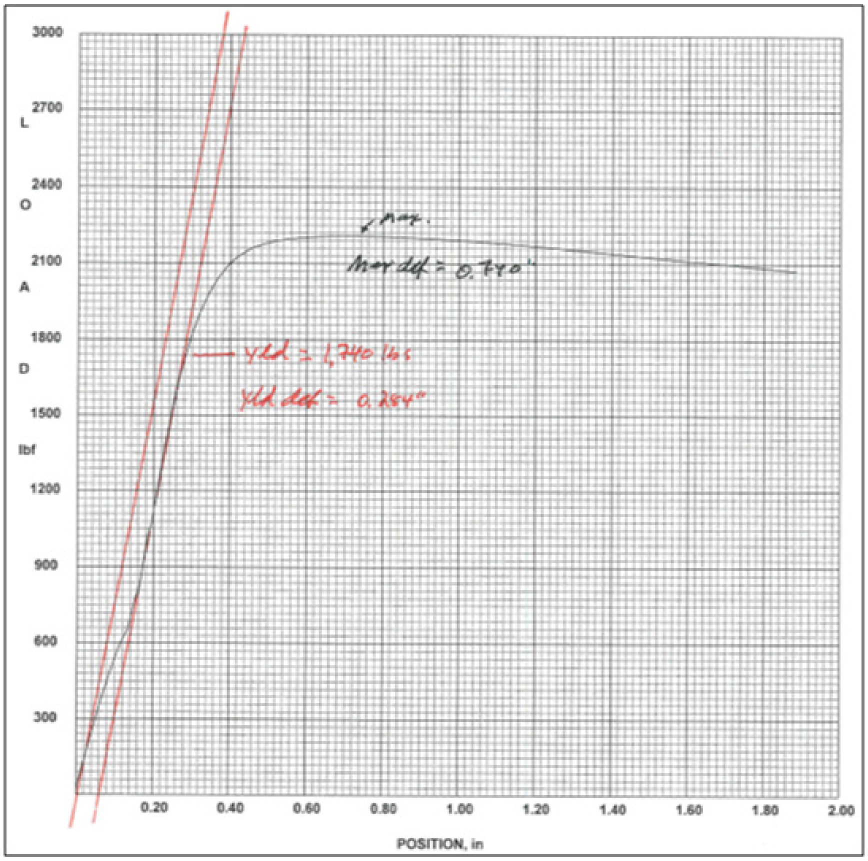


Figure 47. Cross sectional collapse of a stainless steel pipe under flexure testing.

Figure 48. Tangent modulus of elasticity calculated from flexure testing of railing coupons exposed at the FRF.

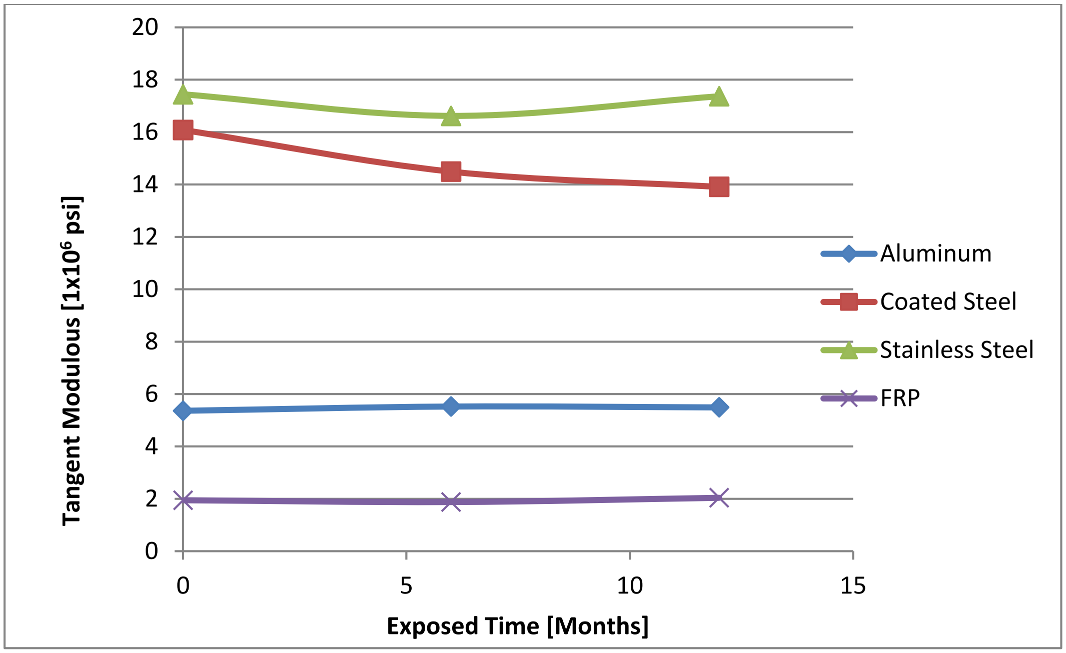


Figure 49. Tangent modulus of elasticity calculated from flexure testing of railing coupons exposed at KTA.

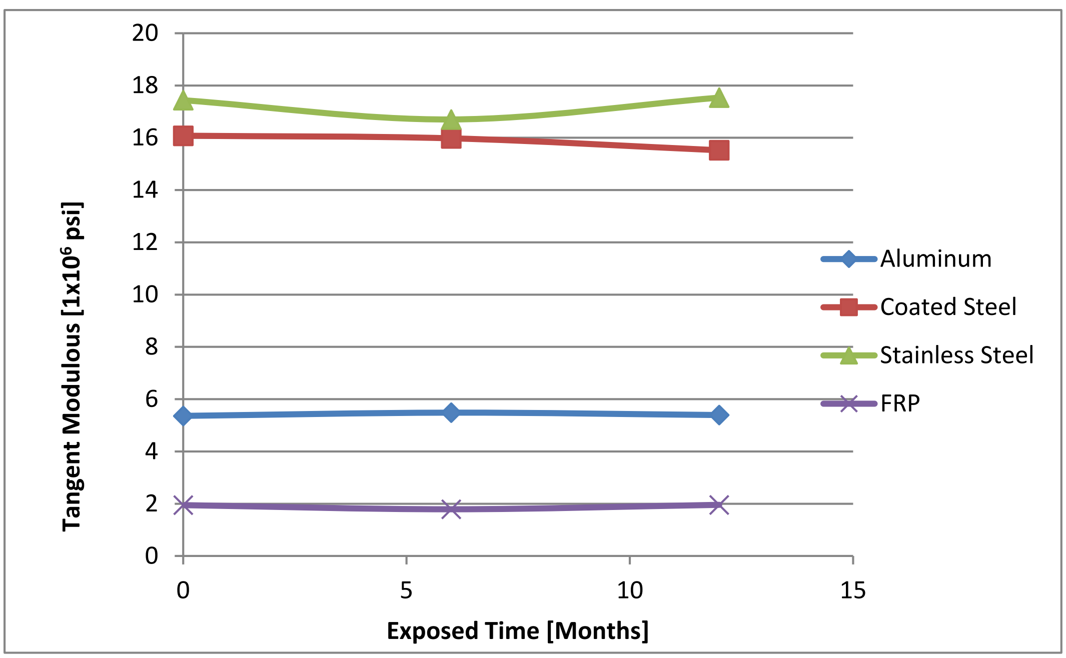
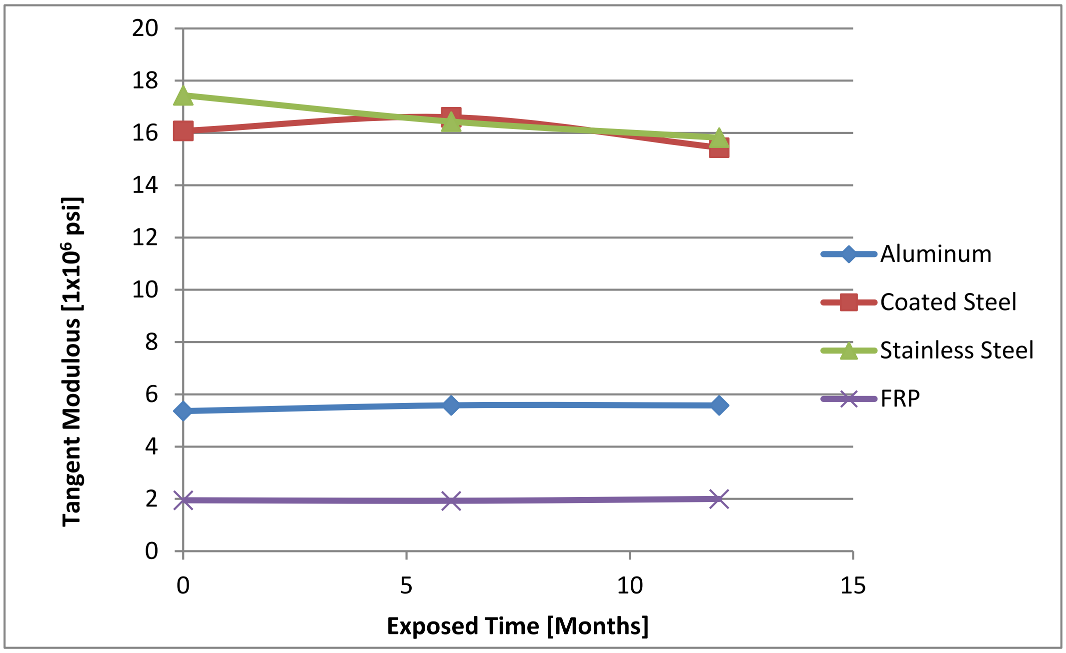


Figure 50. Tangent modulus of elasticity calculated from flexure testing of railing coupons exposed at Treat Island.



4 Economic Summary

4.1 Calculations and assumptions

Table 22 and Table 23 represent the cost for each type of fencing and railing material evaluated in this report. The installation procedure for each material is the same, so the installation cost for each type of material was assumed to be equal. The labor cost to erect 1,000 ft of fencing was $24,000. The equipment cost associated with erecting 1,000 ft was an additional $14,000. It was assumed that the total cost to erect fencing per linear foot was $38. The cost of labor and equipment associated to install 48 ft of railing was $2,600 and $1,350, respectively. It was assumed the total cost per foot to erect railing was $82.

Table 22. Cost per linear foot of fencing material.

Fencing material type	Size	Unit cost per foot	+ Installation $38/ft
Standard galvanized steel wire	9 gage	$5.28	$43.28
Fuse-bonded PVC coated galvanized	9 gage	$10.94	$48.94
PVC coated galvanized steel wire	9 gage	$19.66	$57.66
Galfan	9 gage	$25.19	$63.19
Aluminum alloy	9 gage	$25.97	$63.97
Aluminized steel	9 gage	$30.58	$68.58
Stainless steel	9 gage	$71.86	$109.86

Table 23. Cost per linear foot of railing material.

Railing material type	Size	Unit cost per foot	+ Installation $82/ft
Painted carbon steel	1.66 in. OD 0.109 in. wall	$12.84	$94.84
Aluminum (clear anodized)	1.66 in. OD 0.109 in. wall	$15.02	$97.02
FRP Composite	1.90 in. OD 0.145 in. wall	$24.79	$106.79
Stainless steel	2 in. square 0.25 in. wall	$49.60	$131.60

4.2 Life-cycle cost analysis

Based on the 12 month performance evaluation of the materials at KTA, the FRF, and Treat Island, an anticipated life cycle was determined. The total cost per year of installing and replacing fencing and railing materials over their life cycle was calculated and listed in Table 24 and Table 25. It was determined that the fuse-bonded PVC fence material cost 62% less than traditional galvanized fencing over their respective life cycles. Similarly, aluminum railing was calculated to cost 80% less than traditional painted steel railing over their respective life cycles.

Table 24. Life-cycle cost per foot per year of fencing material.

Fencing material type	Total cost per foot	Anticipated life cycle (years)	Life-cycle cost per foot per year
Standard galvanized	$43.28	5	$8.66
Fuse bonded galvanized PVC coated	$48.94	15	$3.26
Standard PVC coated galvanized	$57.66	15	$3.84
Galfan	$63.19	10	$6.32
Aluminum alloy	$63.97	15	$4.26
Aluminized steel	$68.58	15	$4.57
Stainless steel	$109.86	15	$7.32

Table 25. Life-cycle cost per foot per year of railing material.

Railing material type	Total cost per foot	Anticipated life cycle (years)	Life-cycle cost per foot per year
Painted Carbon Steel	$94.84	3	$31.61
Aluminum (clear anodized)	$97.02	15	$6.47
FRP Composite	$106.79	10	$10.68
Stainless Steel	$131.60	15	$8.77

4.3 Return-on-investment analysis

Originally, this work was proposed as two separate projects: (1) a fencing materials demonstration at Tori Station, Okinawa, and (2) a railing materials demonstration at the Military Ocean Terminal–Sunny Point (MOTSU), NC. Subsequently, the two projects were merged for execution, but at different demonstration sites. Final site selection for the installation of fencing was at the FRF and KTA. Only 8 ft long sample sections of railings were to be installed at these two sites. Treat Island, ME, was selected as a third site in order to include data from a cold marine coastal exposure. Only test wires and coupons were placed at Treat Island.

The ROI estimate in the original Project Management Plan was based on replacing part of an existing fence at Tori Station and part of an existing hand railing at MOTSU. The assumptions used to generate an ROI for those two sites, therefore, were not valid for the actual sites and conditions used in this demonstration. The ROI calculation based on the revised demonstration plan used the following conditions and assumptions:

1. In Year 1, 1,000 linear feet of fencing was installed at the KTA and 450 linear feet of fencing was installed at the FRF. The cost of fencing installation in Year 1 was covered by project costs for these two sites.
2. In Year 1, 20,410 linear feet of fencing was installed at the Bradshaw Army Airfield (BAA) at the PTA. The cost of this fencing was not included in the project costs.
3. Using values from Table 24, standard galvanized fencing at $45.28 per linear foot and fuse-bonded PVC fencing at $48.94 per linear foot were respectively used for *Baseline Costs* and *New System Costs* for the 1,000 linear feet of fencing at the KTA. The same costs and conditions were used for the 450 linear feet of fencing at the FRF and the 20,410 linear feet at the BAA.
4. Since only test sections of railing materials were installed as part of this project, the replacement of 3,000 linear feet of existing hand railing at the MOTSU was used as a hypothetical example.
5. Using values from Table 25, painted railing at $94.84 per linear foot and anodized aluminum at $97.02 per linear foot, respectively, were used for *Baseline Costs* and *New System Costs* for the 3,000 linear feet of railing at the MOTSU. As an additional comparison and calculated ROI, FRP composite railing was considered at $106.79 per linear foot instead of anodized aluminum railing.
6. The anticipated life of each material type was taken from Table 24 and Table 25 as follows:
   a. Standard galvanized fencing – 5 years
   b. Fuse-bonded galvanized PVC fencing – 15 years
   c. Painted carbon steel railing – 3 years
   d. Anodized aluminum railing – 15 years
   e. FRP composite railing – 10 years

7. Average annualized maintenance costs shown in the *Baseline Costs* for standard galvanized fencing is $5,000, and for painted steel railings is $2,000. The average annualized maintenance costs shown in the *New System Costs* for fuse-bonded PVC fencing is $3,000 and for anodized aluminum railing and for FRP composite railing is $1,000.
8. Costs for site vandalism enabled by deteriorated standard galvanized fencing are estimated at $300,000, and occur the year before replacement at Years 5, 10, 15, 20, 25, and 30. Personal injury costs due to failing standard painted railings are estimated at $100,000, and occur the year before replacement at Years 3, 6, 9, 12, 15, 18, 21, 24, 27, and 30. These values are shown under *New System Benefits/Savings*.

Based on the above assumptions and conditions, the ROI using fuse-bonded fencing and anodized aluminum railings calculates at 6.13, as shown in Table 26. If using FRP composite railings instead of anodized aluminum railings, the ROI calculates at 5.75, as shown in Table 27.

Table 26. ROI calculation fencing and railing project with anodized aluminum railing.

Return on Investment Calculation

Investment Required				531,482
Return on Investment Ratio	6.13		Percent	613%
Net Present Value of Costs and Benefits/Savings	1,736,911		4,993,006	3,256,095

A Future Year	B Baseline Costs	C Baseline Benefits/Savings	D New System Costs	E New System Benefits/Savings	F Present Value of Costs	G Present Value of Savings	H Total Present Value
1	1,187,341		1,317,608		1,231,436	1,109,689	-121,748
2	7,000		4,000		3,494	6,114	2,620
3	7,000		4,000	100,000	3,265	87,344	84,079
4	289,520		4,000		3,052	220,875	217,823
5	7,000		4,000	300,000	2,852	218,891	216,039
6	948,101		4,000	100,000	2,665	698,350	695,684
7	289,520		4,000		2,491	180,284	177,793
8	7,000		4,000		2,328	4,074	1,746
9	7,000		4,000	100,000	2,176	58,197	56,022
10	289,520		4,000	300,000	2,033	299,653	297,620
11	948,101		4,000		1,900	450,443	448,542
12	7,000		4,000	100,000	1,776	47,508	45,732
13	289,520		4,000		1,660	120,151	118,491
14	7,000		4,000		1,551	2,715	1,163
15	7,000		4,000	400,000	1,450	147,497	146,047
16	1,239,621		1,360,888		460,933	419,860	-41,073
17	7,000		4,000		1,266	2,216	950
18	7,000		4,000	100,000	1,184	31,661	30,478
19	289,520		4,000		1,106	80,052	78,946
20	7,000		4,000	300,000	1,034	79,329	78,295
21	948,101		4,000	100,000	966	253,116	252,150
22	289,520		4,000		903	65,345	64,442
23	7,000		4,000		844	1,476	633
24	7,000		4,000	100,000	788	21,090	20,301
25	289,520		4,000	300,000	737	108,590	107,853
26	948,101		4,000		689	163,263	162,574
27	7,000		4,000	100,000	644	17,216	16,573
28	289,520		4,000		602	43,544	42,942
29	7,000		4,000		562	984	422
30	7,000		4,000	400,000	526	53,480	52,954

Table 27. ROI calculation fencing and railing project with FRP composite railing.

Return on Investment Calculation

Investment Required			531,482
Return on Investment Ratio	5.75	Percent	575%
Net Present Value of Costs and Benefits/Savings	1,935,371	4,993,006	3,057,635

A Future Year	B Baseline Costs	C Baseline Benefits/Savings	D New System Costs	E New System Benefits/Savings	F Present Value of Costs	G Present Value of Savings	H Total Present Value
1	1,187,341		1,390,198		1,299,279	1,109,689	-189,590
2	7,000		4,000		3,494	6,114	2,620
3	7,000		4,000	100,000	3,265	87,344	84,079
4	289,520		4,000		3,052	220,875	217,823
5	7,000		4,000	300,000	2,852	218,891	216,039
6	948,101		4,000	100,000	2,665	698,350	695,684
7	289,520		4,000		2,491	180,284	177,793
8	7,000		4,000		2,328	4,074	1,746
9	7,000		4,000	100,000	2,176	58,197	56,022
10	289,520		4,000	300,000	2,033	299,653	297,620
11	948,101		323,370		153,633	450,443	296,810
12	7,000		4,000	100,000	1,776	47,508	45,732
13	289,520		4,000		1,660	120,151	118,491
14	7,000		4,000		1,551	2,715	1,163
15	7,000		4,000	400,000	1,450	147,497	146,047
16	1,239,621		1,070,828		362,689	419,860	57,170
17	7,000		4,000		1,266	2,216	950
18	7,000		4,000	100,000	1,184	31,661	30,478
19	289,520		4,000		1,106	80,052	78,946
20	7,000		4,000	300,000	1,034	79,329	78,295
21	948,101		323,370	100,000	78,094	253,116	175,023
22	289,520		4,000		903	65,345	64,442
23	7,000		4,000		844	1,476	633
24	7,000		4,000	100,000	788	21,090	20,301
25	289,520		4,000	300,000	737	108,590	107,853
26	948,101		4,000		689	163,263	162,574
27	7,000		4,000	100,000	644	17,216	16,573
28	289,520		4,000		602	43,544	42,942
29	7,000		4,000		562	984	422
30	7,000		4,000	400,000	526	53,480	52,954

5 Conclusions and Recommendations

5.1 Conclusions

The corrosion rates calculated from the atmospheric coupons suggest that the Field Research Facility (FRF) in Duck, NC, is more corrosive of metals than either Kahuku Training Area (KTA), in Kahuku, HI, or Treat Island, ME. However, the KTA is exposed to more intensive solar radiation than the FRF or Treat Island, ME, which can be corrosive to polymer-based materials. The collected weather data correlates with the corrosion-rate data from the atmospheric coupons. Moisture is a primary driver of corrosion. The relative humidity of each site averaged between 76% and 89%, which suggests that there is usually enough moisture in the air to act as the electrolyte for corrosion and oxidation reactions. Chlorides are transported by wind from the coastal salt water environment to be deposited on nearby infrastructure, accelerating the corrosion process.

5.1.1 Fencing

Based on the observations made during the 12 month field evaluations, fuse-bonded PVC, aluminum, and aluminized steel fencing fabrics all exhibited satisfactory performance. It was noted, however, that where the PVC coating is damaged, on either the fuse-bonded or standard PVC-coated fabrics, the exposed wire began to show signs of rust. The effect of this localized corrosion relative to the long-term integrity of fencing materials was beyond the scope of a one-year field-exposure demonstration. The zinc-coated fencing materials, like galvanized steel and Galfan, were quick to corrode in the corrosive field exposures. The stainless steel fencing fabric was not observed to have been mechanically affected by severe corrosion, but it was quick to discolor due to surface oxidation.

Based on life-cycle analyses, the fuse-bonded galvanized PVC coated fencing had the lowest life-cycle costs, followed closely by the standard PVC-coated galvanized fencing. Standard galvanized fencing had the highest life-cycle costs of all materials compared in the study, indicating that it should be the last choice for use in a corrosive environment. Table 28 shows the relative life-cycle cost rankings in ascending order of cost per year.

Table 28. Relative ranking for fencing based on life-cycle costs.

Fencing material type	Life-cycle cost per foot per year	Relative ranking
Fuse-bonded galvanized PVC coated	$3.26	1
Standard PVC coated galvanized	$3.84	2
Aluminum alloy	$4.26	3
Aluminized steel	$4.57	4
Galfan	$6.32	5
Stainless steel	$7.32	6
Standard galvanized	$8.66	7

5.1.2 Railings

Based on the observations made during the 12 month field evaluations, the aluminum railing material outperformed the other three materials, with minor corrosion present only on damaged areas. The coated steel was quick to fail and began to rust, resulting in continuous corrosion propagating throughout the entire material. Although the FRP railing is not subject to electrochemical corrosion like the metallic materials, the solar radiation at each site caused the FRP material to fade in color, suggesting the possible start of material degradation. Similar to the stainless steel fencing, the stainless steel railing materials were quick to discolor due to surface oxidation.

Based on life-cycle analyses, the anodized aluminum showed the lowest life-cycle costs, followed by stainless steel, and FRP composite railing. Due to its short life expectancy in a corrosive environment, painted carbon steel had, by far, the highest life-cycle costs. Painted carbon steel railings are not recommended for use in a corrosive environment. Table 29 shows the relative rankings in ascending order of annual life-cycle cost.

Table 29. Relative ranking for railings based on life-cycle costs.

Railing material type	Life-cycle cost per foot per year	Relative ranking
Aluminum (clear anodized)	$6.47	1
Stainless steel	$8.77	2
FRP composite	$10.68	3
Painted carbon steel	$31.61	4

5.2 Recommendations

5.2.1 Applicability

The DoD has a need to provide security through use of fencing around the perimeter of its installations and railing systems for personnel safety. Traditional fence and railing materials last 5–7 years in a corrosion-prone environment before replacement is required adding to maintenance costs. New coatings such as fuse bonded PVC, anodized aluminum, and aluminized steel can be used to more effectively protect fencing and railing assets from corrosion. The key to lowest cost is proper material selection.

Far too often, corrosion-damaged fencing is replaced with the same material that has already failed. Application of corrosion-resistant materials can reduce maintenance costs by increasing the service life of fencing. This report provides cost justification that warrants the use of materials that have a higher first cost in order to provide a more corrosion-resistant and secure fencing perimeter at a lower life cycle basis. The same is true for railings.

5.2.2 Implementation

Several Unified Facilities Guide Specifications (UFGS) were reviewed relative to possible updates based on the results of this study. The following revisions are suggested to promote implementation of appropriate corrosion-resistant fencing and railing materials:

UFGS 32 31 13 (August 2010), Chain Link Fences and Gates

1. For increased corrosion resistance, add reference to ASTM F668, Class 2b coating (fuse-bonded PVC).
2. Add reference to aluminum alloy 6061-T94 as an alternative fence fabric with good corrosion resistance at a lower life-cycle cost to galvanized steel fencing. The aluminum alloy fabric may not be suitable for high-security areas.
3. Add a note cautioning about using galvanized steel fencing in highly corrosive environments. While first costs may be lower, life-cycle costs could be significantly higher than other alternatives.

UFGS-32 31 13.53 (April 2008), High-Security Chain Link Fences and Gates

1. Class 2b polyvinyl chloride (PVC) coated steel fabric is currently mentioned in the note under 2.1, Fence Fabric. Add ASTM F668, Class 2b coating (fuse-bonded PVC) in the references.
2. Add a note cautioning about using galvanized steel fencing in highly corrosive environments. While first costs may be lower, life-cycle costs could be significantly higher than other alternatives, such as fuse-bonded PVC.

UFGS-31 31 26 (April 2008), Wire Fences and Gates (also referred to as "Farm-Style Fence")

This specification covers non-security applications for farm-style fences. While no particular provision is made for wire materials for highly corrosive environments, it is of interest to note that corrosion-resistant composite polyester resin reinforced posts are shown as an alternative to zinc-coated metal posts. The composite posts shall meet the strength requirements of ASTM F 1043 (*Strength and Protective Coatings on Metal Industrial Chain-Link Fence Framework*) for industrial fencing.

UFGS-05 52 00 (February 2011), Metal Railings

1. Add a note cautioning that painted carbon steel railings are not recommended for use in a corrosive environment such as coastal or industrial locations where exposure to chlorides or other corrosive chemicals are a possibility.
2. Add reference to aluminum alloy 6063, anodized, as an alternative railing material for use in corrosive environments.
3. Add a note referring to UFGS-06 82 14, Fiberglass Reinforced Plastic (FRP) Pipe and Tube Railings, as alternative to metallic railings for use in highly corrosive environments.

UFGS-06 82 14 (May 2012), Fiberglass Reinforced Plastic (FRP) Pipe and Tube Railings

Add a note about use of FRP railings in corrosive environments as well as cautioning about degradation from exposure to high-intensity solar UV radiation. It is imperative to ensure that stainless steel 316 fasteners are used as specified and that UV inhibitors and coatings are used as specified.

5.2.3 Future reassessment of installed systems and coupons

The short period of assessment of 12 months really does not permit a significant quantification of material degradation in an atmospheric exposure to substantially establish performance characteristics of corrosion. A follow-on study of these materials over an extended period of time is recommended which could narrow down the realistic life cycles of each fencing material and better define the recommended criteria for their application. It should be noted that untested coupons were left in place at each site that would help facilitate such a follow-on effort.

References

ASTM A817. 2007. “Standard Specification for Metallic Coated Steel Wire for Chain-Link Fence Fabric and Marcelled Tinsel Wire.” West Conshohocken, PA: ASTM International.

ASTM B825. 2008. "Standard Test Method for Coulometric Reduction of Surface Films on Metallic Test Samples." West Conshohocken, PA: ASTM International.

ASTM F668. 2011. “Standard Specification for Polyvinyl Chloride (PVC) and Other Organic Polymer-Coated Steel Chain-Link Fence Fabric.” West Conshohocken, PA: ASTM International.

ASTM G1. 2003. "Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens." West Conshohocken, PA: ASTM International.

ASTM G7. 2013, “Standard Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials.” ASTM International, West Conshohocken, PA.

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UFGS 32-31-13. “Chain Link Fences and Gates.” Washington D.C.: Department of Defense.

UFGS 32-31-13.53. “High Security Chain Link Fences and Gates.” Washington D.C.: Department of Defense.

Appendix A: Corrosion-Resistant Fencing Application at Bradshaw Army Airfield, Pohakuloa Training Area, HI

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Abstract: Traditional galvanized steel wire security fencing can become severely corroded in as little as 5 years in tropical coastal regions, where the atmosphere is humid and infused with chlorides. Even conventional PVC-coated galvanized steel fencing can prematurely corrode in these environments. Military equipment, supplies, and buildings are often protected with a perimeter of security fencing, so aggressive corrosion can reduce the effectiveness of access control, or increase its life-cycle cost due to accelerated maintenance and replacement requirements. This report describes a study undertaken to assess a variety of corrosion-resistant materials for fencing in corrosive environments and compare them with conventional materials. The tested fencing materials included fuse-bonded PVC galvanized steel, stainless steel, aluminized steel, Galfan®, and aluminum alloy. The test exposure site was the Bradshaw Army Airfield at Pohakuloa Training Area, HI.

Editorial note: This text is extracted from a contractor report on an application of corrosion-resistant fencing materials that was performed in coordination with DoD Corrosion Prevention and Control Program Project F09-AR02. The results documented in this appendix supplement and support the conclusions, recommendations, and return-on-investment calculation presented in the main body of this report.

A1 Introduction

Problem statement

The military's standard metallic wire fencing materials, specified in Unified Facilities Guide Specification (UFGS) 32-31-13, *Chain Link Fences and Gates* [Ref 1], corrode in extreme environments, such as coastal and tropical regions, where the atmosphere is humid and laden with salt. The result of this is increased cost to prematurely repair and replace the fencing and the compromising of security when fencing is in a deteriorated state. Military vehicles, equipment, supplies, and buildings requiring controlled access need security fencing that is not compromised by corrosion.

Fencing damaged due to corrosion is typically replaced with the same system that was installed, thus repeating the cycle and increasing total maintenance costs. Corrosion-resistant fencings are an alternative that may greatly reduce maintenance costs and assure a better, more cost-effective system of security. This project was undertaken to provide a basis for selection of durable, cost-effective fencing for use in corrosive and high ultraviolet (UV) radiation exposures throughout the DoD.

Objective

The objectives of this project were to demonstrate and evaluate five types of advanced corrosion-resistant security fencing materials for use in corrosive environments. Two additional materials were installed as controls and their performance compared to that of the five security fencing materials installed. This project provides material selection guidance to facilitate proper implementation of the technology based on facility-specific locations and climate considerations. As a result, updates to guidance for use of these materials in a corrosive environment can be suggested.

Approach

The project approach was to identify an area requiring a perimeter fence in a severe corrosion environment. The government selected Bradshaw Army Airfield (BAA), Pohakuloa Training Area, HI (the Big Island) as the test location and coordinated with the local Director of Public Works (DPW) to select the specific layout and material. A preliminary on-site meeting was held with the Construction and Engineering Research Laboratory (CERL), DPW, Mandaree Enterprise Corporation (MEC) and Islandwide Fencing, Inc., project team members. The team surveyed the BAA perimeter to plan and program the execution of the project.

The BAA perimeter included 20,190 lineal feet of chain link security fencing and gates. Three different material types of commercial-grade security fencing were installed and monitored over the course of a year to determine their durability and applicability for use in corrosive environments. The terrain was graded along the entire fence line in order for the installed fencing to meet security clearance requirements between the bottom of the fence fabric and the ground. This also will provide a cleared path for access and patrol of the perimeter. Each fencing section was mounted in concrete for stability. Additionally, four smaller sections of other fencing materials were installed as a comparison to the materials used around the perimeter of BAA.

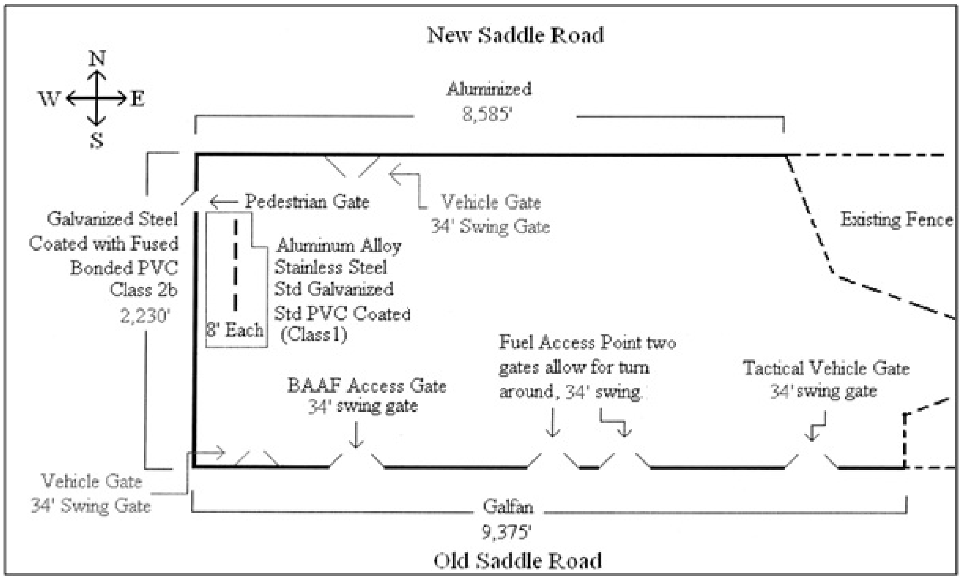
An atmospheric corrosion rack was installed with six different metallic materials. These coupons were collected over the course of one year and analyzed for corrosion to establish relative corrosivity of the site. A weather station was erected within the perimeter to record environmental data in support to the corrosion findings after one year.

A2 Technical investigation

Project overview

Before installing the perimeter fencing, the area was surveyed and grated to provide a suitable terrain. The layout for the different fencing types and general placement of the gates for the perimeter fencing are shown in Figure A1. The four smaller fencing test sections face east in an unobstructed area in the northwest corner, and also are identified in Figure A1.

Figure A1. General layout of perimeter fencing and test sections (not to scale).



Installation

Perimeter fence. The three types of corrosion-resistant fencing materials demonstrated in the perimeter fence were as follows:

- Galvanized steel coated with fuse-bonded PVC powder coating (green) (ASTM F-668[Ref 2], Class 2b)
- Galfan comprised of a coating of 5% aluminum/95% zinc by weight, which is metallurgically bonded to the steel core (ASTM A-817[Ref 3], Type III)
- Aluminized steel (ASTM A-817[Ref 3], Type I)

Stainless steel with 18% Chromium - 8% nickel by weight (AISI 304 alloy) and aluminum alloy 6061-T94 were installed as eight foot long test sections separate from the perimeter fence (Figure A2), as shown in Figure A3. Standard galvanized steel fencing meeting Unified Facilities Guide Specification (UFGS) 32-31-13.53, *High Security Chain Link Fences and Gates* [Ref 4], and standard PVC-coated fencing meeting ASTM F-668[Ref 2], Class 1, were also installed in eight long foot test sections as controls.

The openings for the vehicle access gates are thirty four feet wide and have two, seventeen foot wide swing gates. Additional hardware was included to make sure the gates are securely fixed in the open position and locked when in the closed position. The one personnel gate is forty two inches wide with latches that may be locked as shown in Figure A4. All chain link fencing fabrics were seven feet high, commercial nine gauge with a mesh opening and have twisted and barbed selvages at the top and bottom. Three rows of double-strand, galvanized barbed wire were mounted on the top of the fence and gates using forty five degree outriggers pointing away from the fenced-in area. As required for security, the bottom tension wire was twisted and drawn tight on the inside of the perimeter. Conventional methods of fencing installation were used along with the manufacturer's suggested procedures and UFGS 32-31-13[Ref 1].

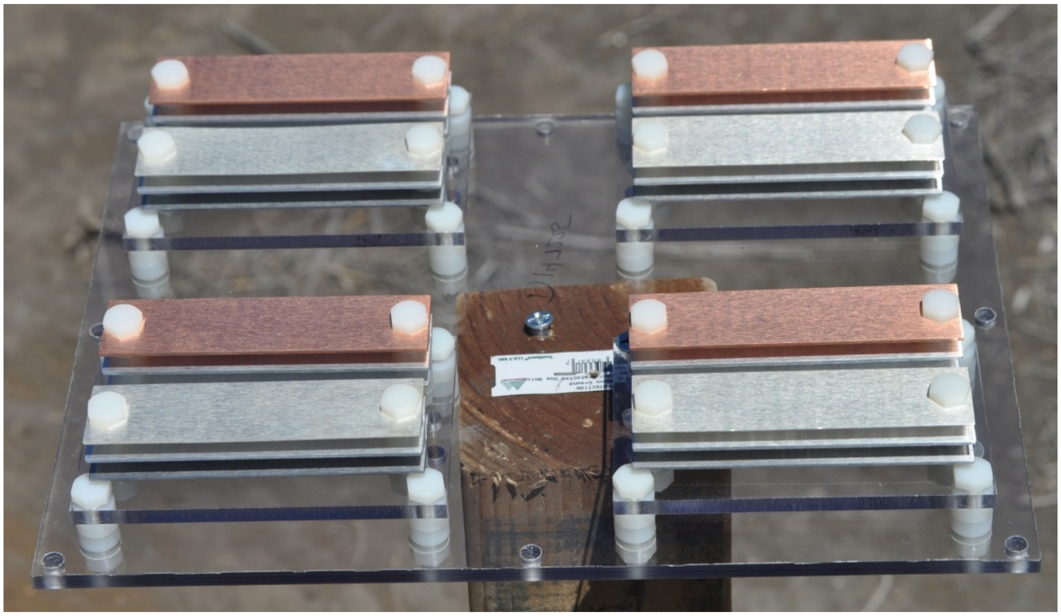
Figure A2. Galfan fence at south end BAA perimeter adjacent to Old Saddle Road.

Figure A3. Fuse-bonded PVC fencing at west BAA perimeter from Old Saddle Road to New Saddle Road (right) and four test sections of control materials (left).

Figure A4. Personnel gate with three rows of barbed wire and locking hardware.

Atmospheric coupon rack. An atmospheric coupon rack to determine the relative corrosivity of the site was installed facing ninety degrees from vertical. The corrosion coupons as shown in Figure A5 included silver, copper, 1010 steel, and three aluminum alloys: 2024 T3, 6061 T6 and 7075 T6 and measured 1 inch wide by 4 inch long by 1/16 inch thick Theses coupon were collected after three, six, nine, and twelve months of exposure. The mass of each coupon was recorded before being exposed to the test environment. The silver coupon was tested for chlorides in accordance with ASTM B825 [Ref 5] Standard Test Method for Coulometric Reduction of Surface [Ref 4]. The remaining coupons were analyzed for mass loss in accordance with ASTM G1 [Ref 6] Standard Practice for Preparing, Cleaning and Evaluating Corrosion Test Specimens [Ref 5].

Figure A5. Atmospheric coupon rack.



Weather station. A weather station was installed to measure and record environmental characteristics throughout the exposure period as shown in Figure A6. The station measured temperature, relative humidity, solar irradiance, wind speed and direction, and rainfall. The weather station was powered by a solar panel and a rechargeable battery. A data logger was used to store the measurements which were recorded every 15 minutes. Data was downloaded manually during each semiannual inspection through the use of a laptop computer. The data logger and each sensor were powered by rechargeable battery connected to a solar panel. The data logger has a storage capacity to continue storing data at 15 minute intervals for approximately two and half years. Upon reaching full capacity, the data logger will truncate the oldest data point to create room for new incoming data.

Figure A6. Weather station.

Field monitoring

Visual inspections were performed after 6 and 12 months of exposure. The approximate percentage of the areas of corrosion observed was documented. Measurements were taken from the weather station every 15 minutes and recorded on a data logger. The data were downloaded from the logger during each inspection.

A3 Discussion

Metrics

The installed fencing sections met the requirements as described in Field Manual, FM 3-19.30 [Ref 6], *Physical Security*, Chapter 4, “Fencing.” The vehicle and personnel gates met the security requirements in Section 3 of Mil Handbook 1013/10 [Ref 9] and FM 3-19.30 [Ref 7].

Corrosion assessment was performed by visual inspection.

The atmospheric coupon rack was built and tested in accordance with ASTM G1 [Ref 6], with the exception of the silver coupons. The silver coupons were tested in accordance with ASTM B825 [Ref 5].

Results

Visual inspection. The results of the visual inspection are listed in Table A1. Figures A7 – A20 show the growth of corrosion of each material over the 12 month exposure period.

The standard PVC, fuse-bonded PVC and aluminum fencing showed the least amount of corrosion over a 12 month period of exposure. However, the PVC coatings are susceptible to damage which creates an opportunity for corrosion of the exposed wire fencing. Corrosion found on the PVC coated wire fencing were areas that the coating was damaged. This localized corrosion attack can be more extensive in severity than general corrosion of completely exposed wire. The Galfan also showed very little signs of corrosion. Areas that were corroded included less than 10% of the total area and were extremely localized with holidays as large as 1/16 inch. Galfan is a specific 95 % zinc/5% aluminum coating metallurgically bonded to the substrate. It is possible that insufficient control of this coating process allowed holidays to develop and is causing corrosion of the zinc coating at pinhole locations. Galvanized and aluminized steel are also different zinc and aluminum coatings that are hot dipped; however these materials have begun to show signs of pitting, and build up of corrosion products. Stainless steel has begun to discolor as the outside surface suffers oxidation.

Table A1. Visual inspection of corrosion on fencing specimens after 12 months of exposure.

Fencing Material	Corrosion	Staining	Comments
Standard PVC	No	No	Corrosion only exists under damaged coatings
Fuse Bonded PVC	No	No	Minimal corrosion only exists under damaged coatings
Stainless Steel	Yes	Yes	Minor surface oxidation
Aluminum	No	No	No corrosion
Galfan	Yes	Yes	Localized oxidation: 10% of total area
Aluminized	Yes	No	Corrosion on less 5% of the total area
Galvanized	Yes	No	Oxidation of the sacrificial zinc coating

Figure A7. Fuse-bonded PVC after 6 months exposure.

Figure A8. Stainless steel after 6 months exposure.

Figure A9. Aluminum after 6 months exposure.

Figure A10. Galvanized steel after 6 months exposure.

Figure A11. Aluminized after 6 months exposure.

Figure A12. Standard PVC after 6 months exposure.

Figure A13. Galfan PVC after 6 months exposure.

Figure A14. Aluminized after 12 months exposure showing corrosion on less than 5% of the total surface area.

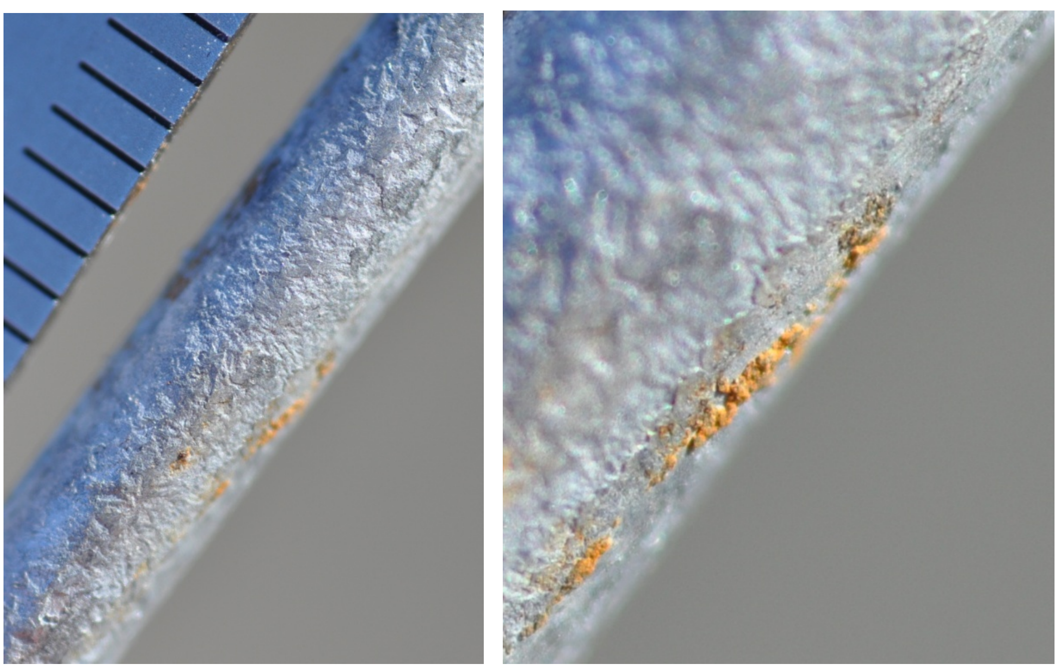


Figure A15. Standard PVC undamaged (left) and damaged (right) after 12 months exposure.

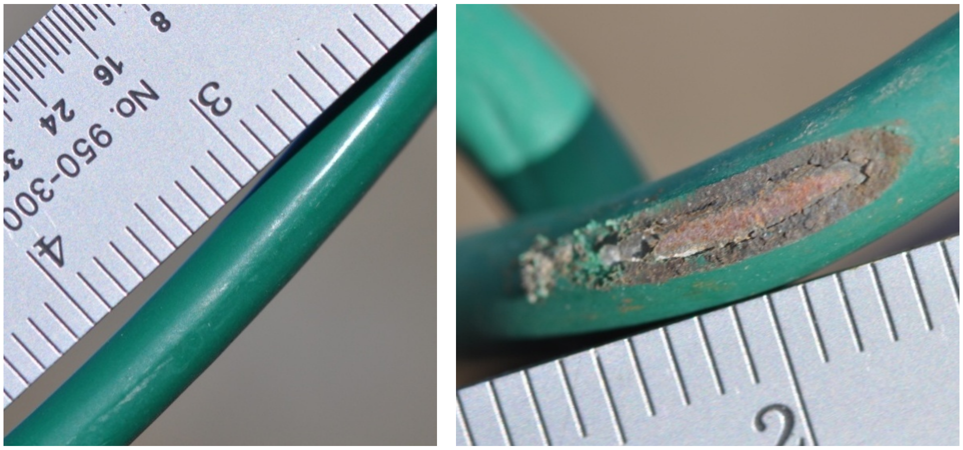


Figure A16. Galfan showing localized corrosion on 10% of its total surface after 12 months exposure.

Figure A17. Fuse-bonded PVC undamaged (left) and damaged (right) after 12 months exposure.

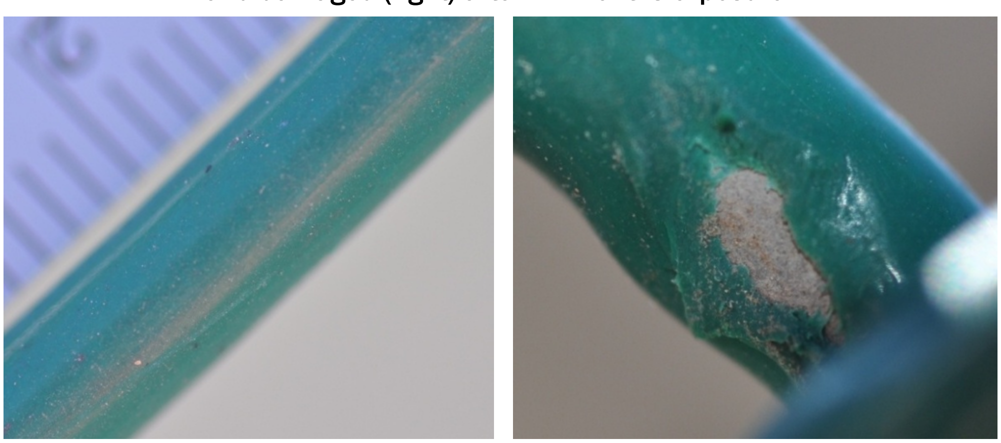


Figure A18. Aluminum 6061 T6 after 12 months exposure.

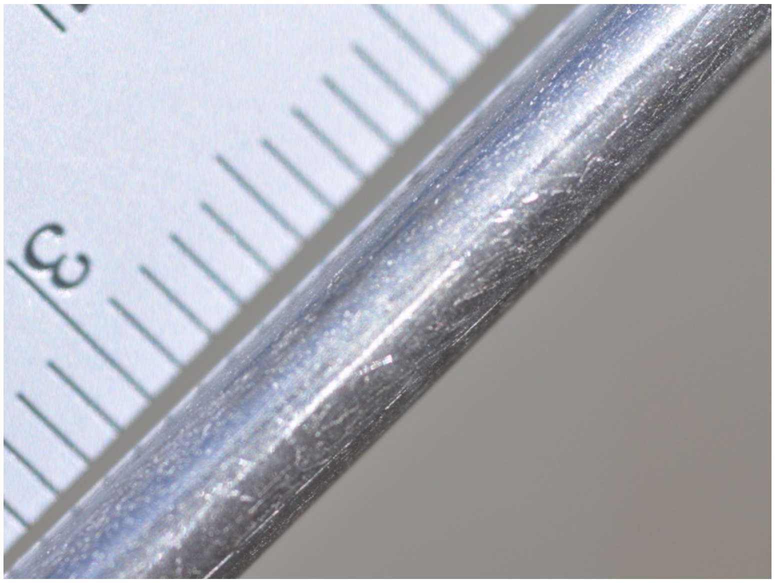


Figure A19. Galvanized after 12 months exposure.

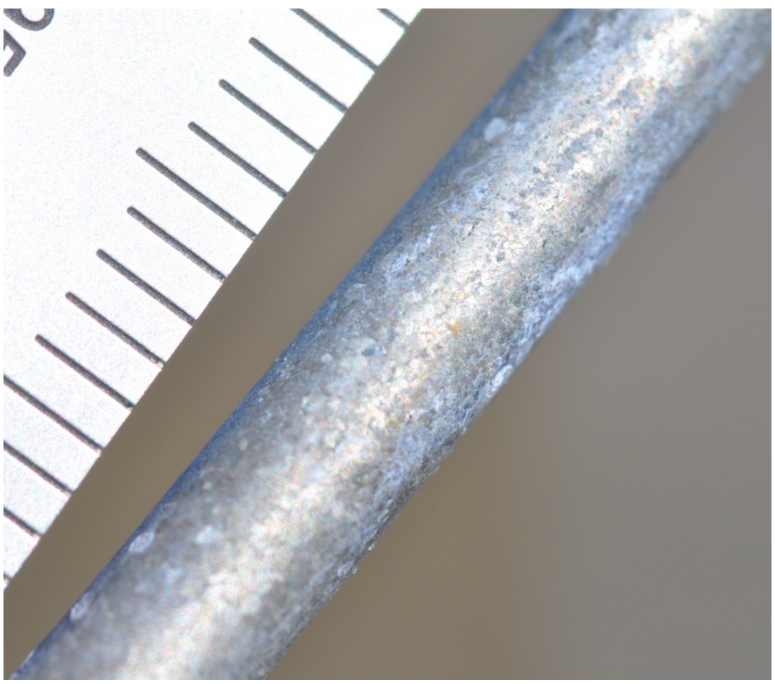
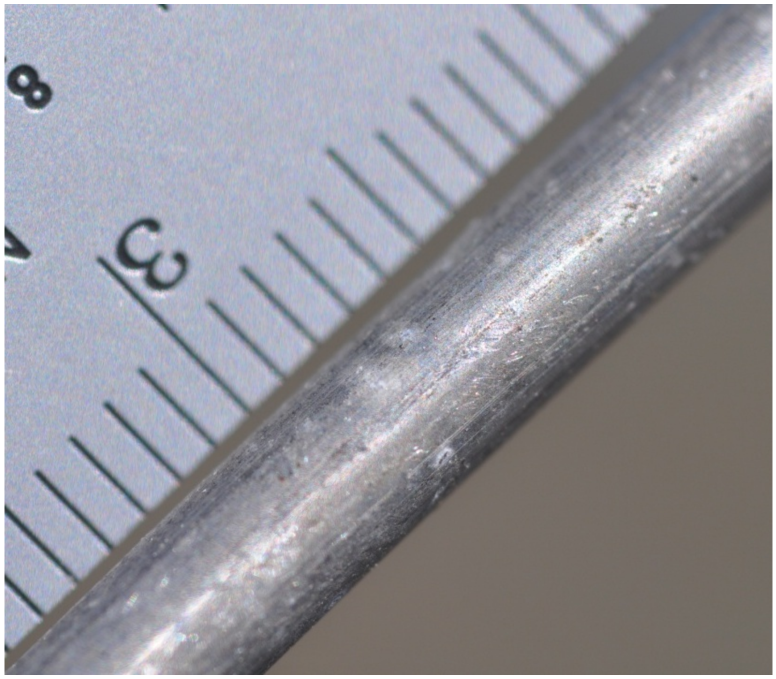


Figure A20. Stainless steel after 12 months exposure.



Atmospheric coupon laboratory results. The corrosion rates calculated in accordance with ASTM G1 [Ref 6] are listed and graphically depicted in Figure A21. Results from the silver coupon coulometric reduction analysis in accordance with ASTM B825 [Ref 5] are re listed in Table A2. Similar testing was accomplished under CPC project F09-AR02 (see section 3.2.3 in the main text of this report). As expected the PTA is not subject to the same levels of chlorides as Duck, NC, or Kahuku, HI, due to its geographical location away from the coast. The results suggest that the corrosivity of PTA is moderate in comparison to a marine location.

Figure A21. Corrosion rates of steel, copper and aluminum alloy atmospheric coupons after 3, 6, 9 and 12 months of exposure at PTA.

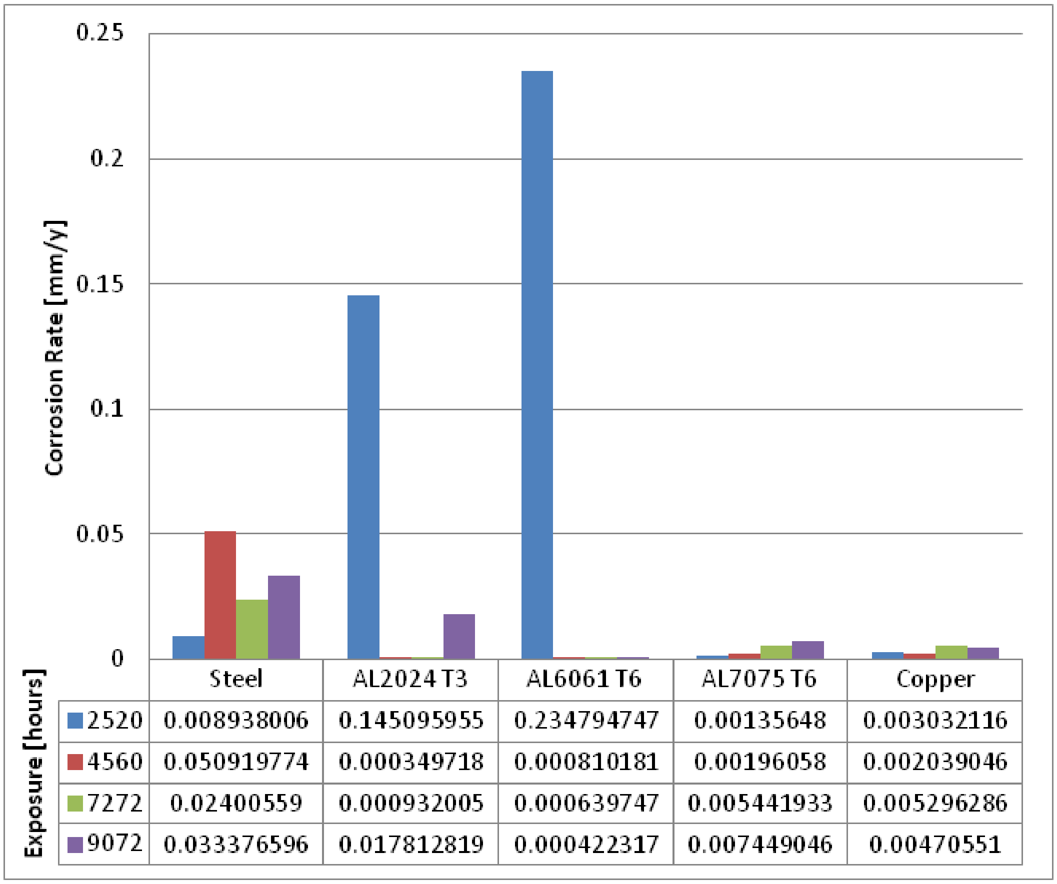


Table A2. Coulometric reduction time and film thickness of AgCl present after environmental exposure at PTA.

Approximate Exposure [months]	Reduction Time [seconds]	AgCl Film Thickness [ångströms]
3	405	27.80186
6	1460	100.1224
9	940	64.5278
12	4070	279.3916

Weather data. The data represented in Table A3 was recorded from 27 April 2010 through 12 April 2011. Individual data points were continuously logged in 15 minute intervals.

Table A3. Yearly weather data recorded from April 2010 – April 2011.

	Rain [in]	Solar Radiation [W/m²]	Wind Speed [mph]	Gust Speed [mph]	Wind Direction [ø]	Temp [°F]	RH [%]
Monthly Average	0.000139*	258.334	2.231971	5.232184	191.1737	56.74334	64.24043
Standard Deviation	0.003002	358.2697	3.94431	6.86344	93.67432	9.543312	20.34593
Maximum	0.21	1276.9	25.32	41.5	355.2	81.509	97.2
Minimum	0	0.6	0	0	0	32.891	2.7
Mode	0	0.6	0	0	299	48.227	83.8

* < 0.002 in. per year

Lessons learned

Site selection. Areas of the BAA were once used for heavy artillery training, so unexploded ordnance (UXO) was a potential safety hazard. During construction of the fence perimeter, UXO was found and reported to the DPW. Further construction was halted until a UXO sweep of the area was completed. The results of the sweep showed that the intended fence line would not be safe for construction, so the fence was recessed inward 80 feet to avoid the hazard.

Installation. The initial requirement for vehicle gates was for 24 ft openings. It was found that a 24 ft gate would not be adequate for military vehicles to enter and exit the BAA perimeter with enough clearance for turning onto adjacent roads. The opening specification was later modified to 34 ft gates, which effectively addressed the problem.

A4 Economic Summary

Costs and assumptions

Table A4 represents the cost for each type of fencing and railing material evaluated in this report. The installation procedure for each material is the same; therefore the cost of installation per each type of material was assumed to be equal. The bid cost of labor and equipment to erect 20410 linear feet of fencing was $710,000. From that, was assumed that the total cost to erect fencing per linear foot was approximately $35.

Table A4. Cost per linear foot of fencing material.

Fencing Material Type	Size	Unit Cost per foot	+ Installation $35/ft
Standard galvanized	9 gage	$5.28	$40.28
Fuse bonded PVC coated galvanized	9 gage	$10.94	$43.94
PVC Coated galvanized	9 gage	$19.66	$54.66
Galfan	9 gage	$25.19	$60.19
Aluminum alloy	9 gage	$25.97	$60.97
Aluminized steel	9 gage	$30.58	$65.58
Stainless steel	9 gage	$71.86	$106.86

Life-cycle cost analysis

Based on the 12 month performance evaluation of the materials at PTA, HI, an anticipated life cycle was determined. Since the exposure period was not long enough to adequately determine the realistic life cycle of the materials, the limited warranty period of several manufacturers of chain link fencing was used. The material life of the galvanized was reduced from 10 years to 5 years based on the corrosion seen during testing. The manufacturer says of the Galfan material last 2–3 times longer than standard galvanized to come up with 10 years. The total cost per year of installing and replacing fencing and railing materials over their life cycle was then calculated and listed in Table A5 in rank order from lowest to highest. The fuse bonded fence material was determined to cost 63.6% less than traditional galvanized fencing over their respective life cycles.

Table A5. Life-cycle cost of fencing material (per foot per year).

Fencing Material Type	Total cost per foot	Anticipated Life Cycle [Years]	Life-Cycle Cost Per foot per Year
Fuse-Bonded Galvanized PVC Coated	$43.94	15	$2.93
Standard PVC Coated Galvanized	$54.66	15	$3.64
Aluminum Alloy	$60.97	15	$4.06
Aluminized Steel	$65.58	15	$4.37
Galfan	$60.19	10	$6.02
Stainless Steel	$106.86	15	$7.12
Standard Galvanized	$40.28	5	$8.06

A5 Conclusions

Conclusions

The corrosion rates calculated from the atmospheric coupons suggest that the PTA location is not as severe of an environment as a coastal location similar to Duck, NC, or Kahuku, HI. However, the environment does produce conditions for corrosion that will degrade metallic structures over time. The weather data collected supports the corrosion rate data from the atmospheric coupons. Moisture is a primary vehicle for corrosion to occur. The relative humidity of PTA averages 64% which varies 20% over the year. This suggests that there is enough moisture in the air to act as the electrolyte for corrosion and oxidation. The presence of chlorides comes from the loose soil that is transferred by the wind and deposited onto the material; however this activity is not as severe in comparison to a salt water, coastal, location. Fresh water rainfall has the ability to rinse the chlorides from the coupons; however PTA recorded very little rain over the 12 month test period.

The short period of assessment of 12 months did not permit a significant quantification of material degradation in an atmospheric exposure to substantially establish performance characteristics of corrosion. Based on the observations made during the 12 months, the three fence test materials Fuse Bonded PVC, Galfan, and Aluminized Steel all performed well. The galvanized coating provides an additional protection that the standard PVC does not. When the standard PVC coating is damaged the exposed wire begins to rust. Both the Galfan and aluminized steel fencing did not outperform the aluminum or stainless steel fencing with regards to corrosion in quantity or severity. However, they did outperform the standard galvanized fencing material with lesser visible corrosion.

The aluminum fencing material outperformed the other fencing materials with no corrosion or discoloration and was one of the less expensive materials. The Standard PVC and the Fuse Bonded PVC were a close second with corrosion only under damaged coatings and also being fairly inexpensive but the PVC coatings are susceptible to damage which creates an opportunity for corrosion of the exposed wire fencing. The stainless steel fencing material was by far the most expensive and in the short time it was exposed, the stainless it began to show discoloration due to surface oxidation.

While the corrosivity at BAA/PTA is not as aggressive as it is at Duck, NC, or KTA at Kahuku, HI, and the calculated life-cycle costs per foot per year were different, the relative ranking of the different fencing materials came out the same for both investigations (compare Table 28 with Table E).

References

1. UFGS 32-31-13. "Chain Link Fences and Gates." Washington D.C.: Department of Defense.

2. ASTM F668, 2011, "Standard Specification for Polyvinyl Chloride (PVC) and Other Organic Polymer-Coated Steel Chain-Link Fence Fabric." West Conshohocken, PA: ASTM International.

3. ASTM A817, 2007, "Standard Specification for Metallic Coated Steel Wire for Chain-Link Fence Fabric and Marcelled Tinsel Wire." West Conshohocken, PA: ASTM International.

4. UFGS 32-31-13.53. "High Security Chain Link Fences and Gates." Washington D.C.: Department of Defense.

5. ASTM B825. 2008. "Standard Test Method for Coulometric Reduction of Surface Films on Metallic Test Samples." West Conshohocken, PA: ASTM International.

6. ASTM G1, 2003. "Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens." West Conshohocken, PA: ASTM International.

7. Field Manual FM 3-19.30, 2001 "Physical Security." Washington D.C.: Headquarters, U.S. Army.

8. Roberge, P. 2008. Corrosion Engineering: Principles and Practice, New York, NY: The McGraw-Hill Companies, Inc.

9. Mil Handbook 1013/10. 14 May 1993. *Design Guidelines for Security Fencing, Gates, Barriers, and Guard Facilities*. Washington, DC: Department of Defense.

Appendix B: Quarterly Site Inspections

B1 Duck, NC, Exposure Coupon Inspection Reports

Visual Inspection Report

Date: 5/18/2010
Location: Duck, NC
Exposure Period: 3 Months

	Material	% of Surface Corroded	Type of Corrosion	Notes
Fence Wire Coupons				
	Standard PVC Coated Galvanized	0%	N/A	No visible corrosion
	Fuse Bonded PVC Coated Galvanized	0%	N/A	No visible corrosion
	Standard Galvanized	20%	Oxidation	White oxidation of the zinc/AL coating
	Stainless Steel	50%	Oxidation	Surface oxidation
	Aluminum	25%	Pitting	Pitting and White corrosion product
	Galfan	0%	N/A	No visible corrosion
	Aluminized Steel	75%	Oxidation	White oxidation of the AL coating
Fabricated Fencing				
	Stainless Steel	10%	Oxidation	Surface oxidation has discolored the material
	Aluminum	25%	Pitting	Pitting more prevalent on the posts
	Galfan	50%	Oxidation	White oxidation of the zinc/AL coating
	Aluminized Steel	0%	N/A	No visible corrosion
	Fuse Bonded PVC Coated Galvanized	0%	N/A	PVC coating has been damaged due to fabrication
	Std Galvanized	10%	Oxidation	White oxidation of the zinc sacrificial coating
Railing Coupons				
	Stainless Steel	50%	Oxidation	Surface oxidation has discolored the material.
	Aluminum	<5%	Pitting	Pitting has begun in areas where the anodize may have been damaged
	Coated Steel	10%	Rust	Rust has begun to form where the coating has failed. Discoloring of the coating due to the rust.
	FRP	0%	N/A	No visible corrosion
Fabricated Railing				
	Stainless Steel	95%	Oxidation	Surface oxidation has discolored the material.
	Aluminum	<5%	Pitting	Pitting has begun in areas where the anodize may have been damaged
	Coated Steel	10%	Rust	Rust has begun to form where the coating has failed. Coating around the rust has begun to blister. Discoloring of the coating due to the rust.
	FRP	0%	N/A	No visible corrosion

Figure B1. FRP Railing Coupon

Figure B2. Fabricated FRP Railing

Figure B3. Coated Steel Coupon

Figure B4. Coated Steel Railing

Figure B5. Stainless Steel Coupon

Figure B6. Stainless Steel T-fittings on fabricated railings

Figure B7. Aluminum Railing Coupon

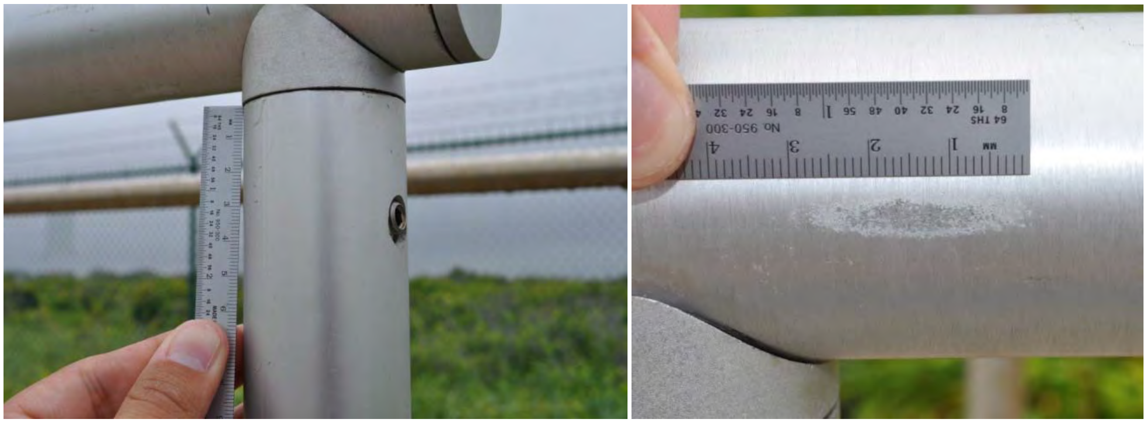


Figure B8. Fabricated Aluminum Railing

Figure B9. Standard PVC Coated Galvanized Wire Coupon

Figure B10. Standard Galvanized Wire Fencing

Figure B11. Standard Galvanized Wire Coupon

Figure B12. Aluminized Steel Wire Fencing

Figure B13. Aluminized Steel Wire Coupon

Photograph not available.

Figure B14. Fuse Bonded PVC Coated Galvanized Wire Coupon

Figure B15. Fuse Bonded PVC Coated Galvanized Wire Fencing

Figure B16. Aluminum Wire Fencing

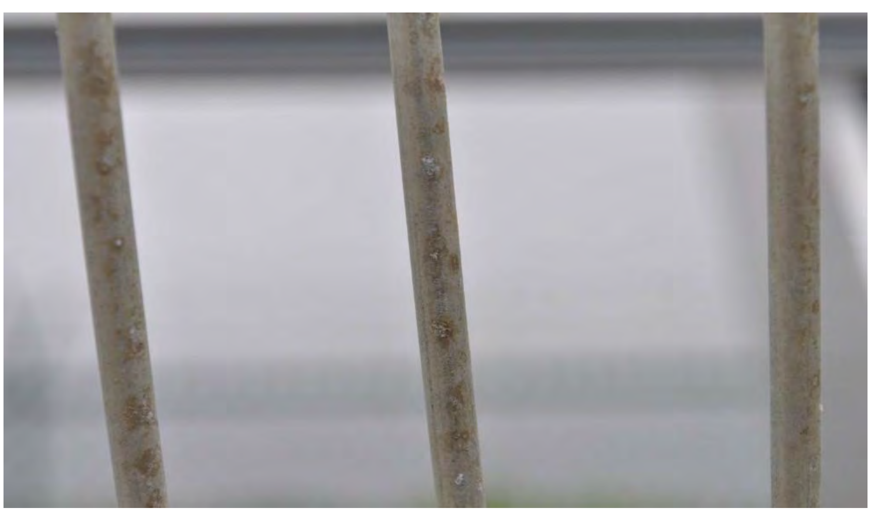


Figure B17. Aluminum Wire Coupon

Figure B18. Stainless Steel Wire Fencing

Figure B19. Stainless Steel Wire Coupon

Figure B20. Galfan Wire Coupon

Visual Inspection Report

Date: 8/17/2010

Location: Duck, NC

Exposure Period: 6 Months

	Material	% of Surface Corroded	Type of Corrosion	Notes
Fence Wire Coupons				
	Standard PVC Coated Galvanized	0%	N/A	No visible corrosion. Covered in chloride residues.
	Fuse Bonded PVC Coated Galvanized	0%	N/A	No visible corrosion. Covered in chloride residues.
	Standard Galvanized	100%	Oxidation	White oxidation of the zinc/AL coating
	Stainless Steel	100%	Oxidation	Surface oxidation
	Aluminum	50%	Oxidation/ Pitting	Pitting and White corrosion product
	Galfan	100%	Oxidation	White oxidation of the zinc/AL coating
	Aluminized Steel	100%	Oxidation	White oxidation of the AL coating
Fabricated Fencing				
	Stainless Steel	100%	Oxidation	Surface oxidation has discolored the material
	Aluminum	50%	Oxidation/ Pitting	White corrosion product
	Galfan	50%	Oxidation	White oxidation of the zinc/AL coating
	Aluminized Steel	50%	Oxidation	White oxidation of the AL coating
	Fuse Bonded PVC Coated Galvanized	5%	Rust	PVC coating has been damaged due to fabrication. Cut Ends are corroded
	Std Galvanized	100%	Oxidation	White oxidation of the zinc sacrificial coating
Railing Coupons				
	Stainless Steel	100%	Oxidation	Surface oxidation has discolored the material.
	Aluminum	<5%	Pitting	Pitting has begun in areas where the anodize may have been damaged
	Coated Steel	20%	Rust	Rust has begun to form where the coating has failed. Discoloring of the coating due to the rust.
	FRP	0%	N/A	No visible corrosion
Fabricated Railing				
	Stainless Steel	95%	Oxidation	Surface oxidation has discolored the material.
	Aluminum	<5%	Pitting	Pitting has begun in areas where the anodize may have been damaged
	Coated Steel	20%	Rust	Rust spots have grown and caused the surrounding coating to blister. Topcoat has also begun to separate from the primer in some areas. Discoloring of the coating due to the rust.
	FRP	0%	N/A	No visible corrosion

Comments:

Chloride deposits have formed on several localized areas. A residue of chlorides cover the PVC coated fencing that faces the coast.

Figure B21. FRP Railing Coupon

Figure B22. Fabricated FRP Railing

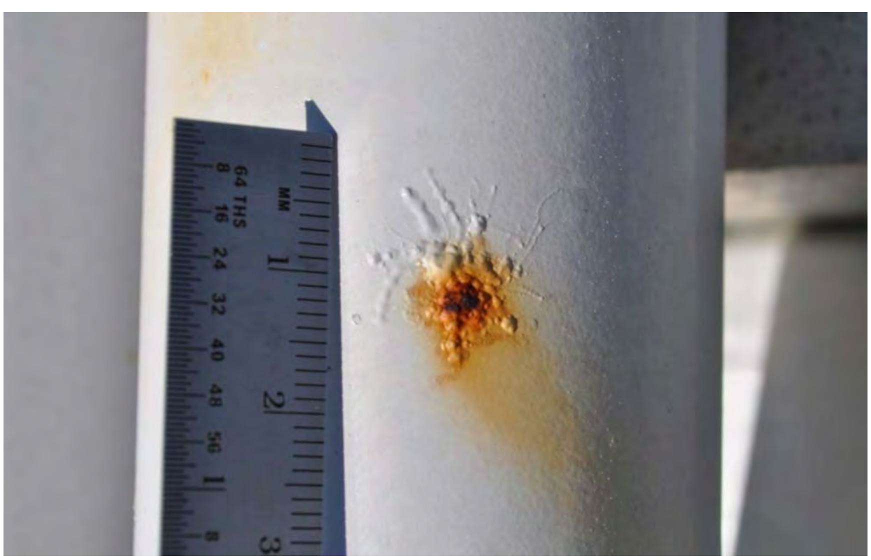


Figure B23. Coated Steel Coupon

Figure B24. Coated Steel Railing

Figure B25. Stainless Steel Coupon

Figure B26. Stainless Steel T-fittings on fabricated railings

Figure B27. Aluminum Railing Coupon

Figure B28. Fabricated Aluminum Railing

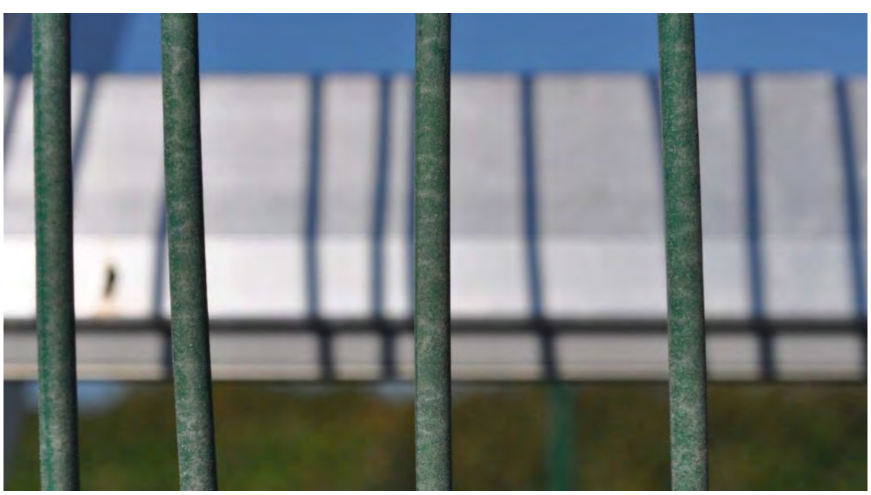


Figure B29. Standard PVC Coated Galvanized Wire Coupon

Figure B30. Standard Galvanized Wire Fencing

Figure B31. Standard Galvanized Wire Coupon

Figure B32. Aluminized Steel Wire Fencing

Figure B33. Aluminized Steel Wire Coupon

Figure B34. Fuse Bonded PVC Coated Galvanized Wire Coupon

Figure B35. Fuse Bonded PVC Coated Galvanized Wire Fencing

Figure B36. Aluminum Wire Fencing

Figure B37. Aluminum Wire Coupon

Figure B38. Stainless Steel Wire Fencing

Figure B39. Stainless Steel Wire Coupon

Figure B40. Galfan Wire Coupon

Figure B41. Galfan Wire Fencing

Visual Inspection Report

Date: 11/8/2010

Location: Duck, NC

Exposure Period: 9 Months

	Material	% of Surface Corroded	Type of Corrosion	Notes
Fence Wire Coupons				
	Standard PVC Coated Galvanized	0%	N/A	No visible corrosion. Covered in chloride residues.
	Fuse Bonded PVC Coated Galvanized	0%	N/A	No visible corrosion. Covered in chloride residues.
	Standard Galvanized	100%	Oxidation	White oxidation of the zinc/AL coating
	Stainless Steel	100%	Oxidation	Surface oxidation
	Aluminum	50%	Pitting	Pitting and White corrosion product
	Galfan	100%	N/A	No visible corrosion
	Aluminized Steel	100%	Oxidation	White oxidation of the AL coating
Fabricated Fencing				
	Stainless Steel	100%	Oxidation	Surface oxidation has discolored the material
	Aluminum	50%	Pitting	Pitting more prevalent on the posts
	Galfan	50%	Oxidation	White oxidation of the zinc/AL coating
	Aluminized Steel	50%	N/A	No visible corrosion
	Fuse Bonded PVC Coated Galvanized	5%	N/A	PVC coating has been damaged due to fabrication
	Std Galvanized	100%	Oxidation	White oxidation of the zinc sacrificial coating
Railing Coupons				
	Stainless Steel	100%	Oxidation	Surface oxidation has discolored the material.
	Aluminum	<5%	Pitting	Pitting has begun in areas where the anodize may have been damaged
	Coated Steel	30%	Rust	Rust spots have grown and blistering has continued. Signs of topcoat separation. Discoloring of the coating due to the rust.
	FRP	25%	UV	Discoloring due to UV exposure on the side of the railing that faces the sun
Fabricated Railing				
	Stainless Steel	95%	Oxidation	Surface oxidation has discolored the material.
	Aluminum	<5%	Pitting	Pitting has begun in areas where the anodize may have been damaged
	Coated Steel	30%	Rust	Rust spots have grown and blistering has continued. Signs of topcoat separation. Discoloring of the coating due to the rust.
	FRP	25%	UV	Discoloring due to UV exposure on the side of the railing that faces the sun

Comments:

All photo documentation for this inspection was lost due to computer theft. Weather data was stored on the logger and was recoverable at the test site.

Visual Inspection Report

Date: 2/23/2011

Location: Duck, NC

Exposure Period: 12 Months

	Material	% of Surface Corroded	Type of Corrosion	Notes
Fence Wire Coupons				
	Standard PVC Coated Galvanized	0%	N/A	No visible corrosion. Covered in chloride residues.
	Fuse Bonded PVC Coated Galvanized	0%	N/A	No visible corrosion. Covered in chloride residues.
	Standard Galvanized	100%	Oxidation	White oxidation of the zinc/AL coating
	Stainless Steel	100%	Oxidation	Surface oxidation
	Aluminum	50%	Oxidation /Pitting	Pitting and White corrosion product
	Galfan	100%	Oxidation	White oxidation of the zinc/AL coating
	Aluminized Steel	100%	Oxidation	White oxidation of the AL coating
Fabricated Fencing				
	Stainless Steel	100%	Oxidation	Surface oxidation has discolored the material
	Aluminum	50%	Oxidation /Pitting	White corrosion product
	Galfan	50%	Oxidation	White oxidation of the zinc/AL coating
	Aluminized Steel	50%	Oxidation	White oxidation of the AL coating
	Fuse Bonded PVC Coated Galvanized	5%	Rust	PVC coating has been damaged due to fabrication. Cut Ends are corroded
	Std Galvanized	100%	Oxidation	White oxidation of the zinc sacrificial coating
Railing Coupons				
	Stainless Steel	100%	Oxidation	Surface oxidation has discolored the material.
	Aluminum	<5%	Pitting	Pitting has begun in areas where the anodize may have been damaged
	Coated Steel	50%	Rust	Rust has begun to form where the coating has failed. Discoloring of the coating due to the rust.
	FRP	25%	UV	Discoloring due to UV exposure on the face of the railing that faces the sun
Fabricated Railing				
	Stainless Steel	95%	Oxidation	Surface oxidation has discolored the material.
	Aluminum	<5%	Pitting	Pitting has begun in areas where the anodize may have been damaged
	Coated Steel	50%	Rust	Rust spots have grown and caused the surrounding coating to blister. Topcoat has also begun to separate from the primer in some areas. Discoloring of the coating due to the rust.
	FRP	25%	UV	Discoloring due to UV exposure on the face of the railing that faces the sun

Comments:

Large deposition of salt crystal/chlorides on all materials.

Figure B42. FRP Railing Coupon

Figure B43. Fabricated FRP Railing

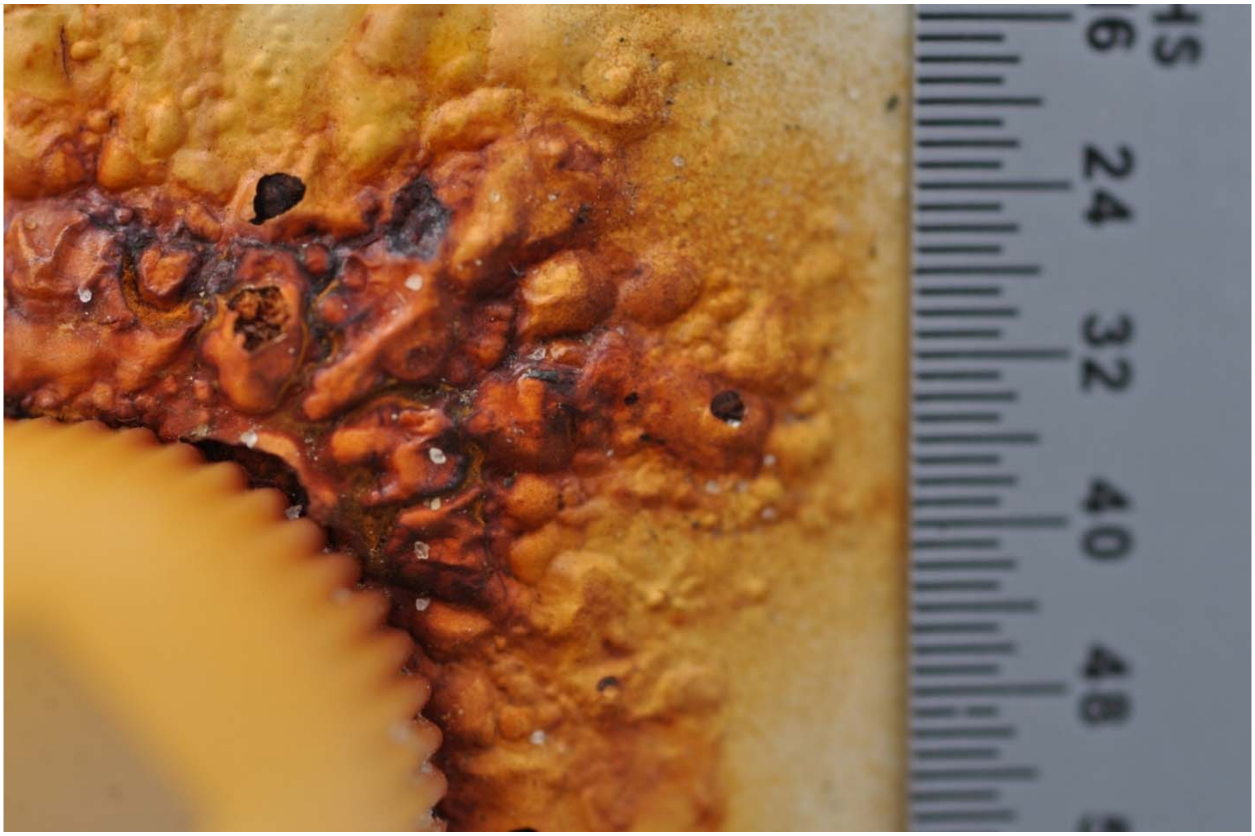


Figure B44. Coated Steel Coupon

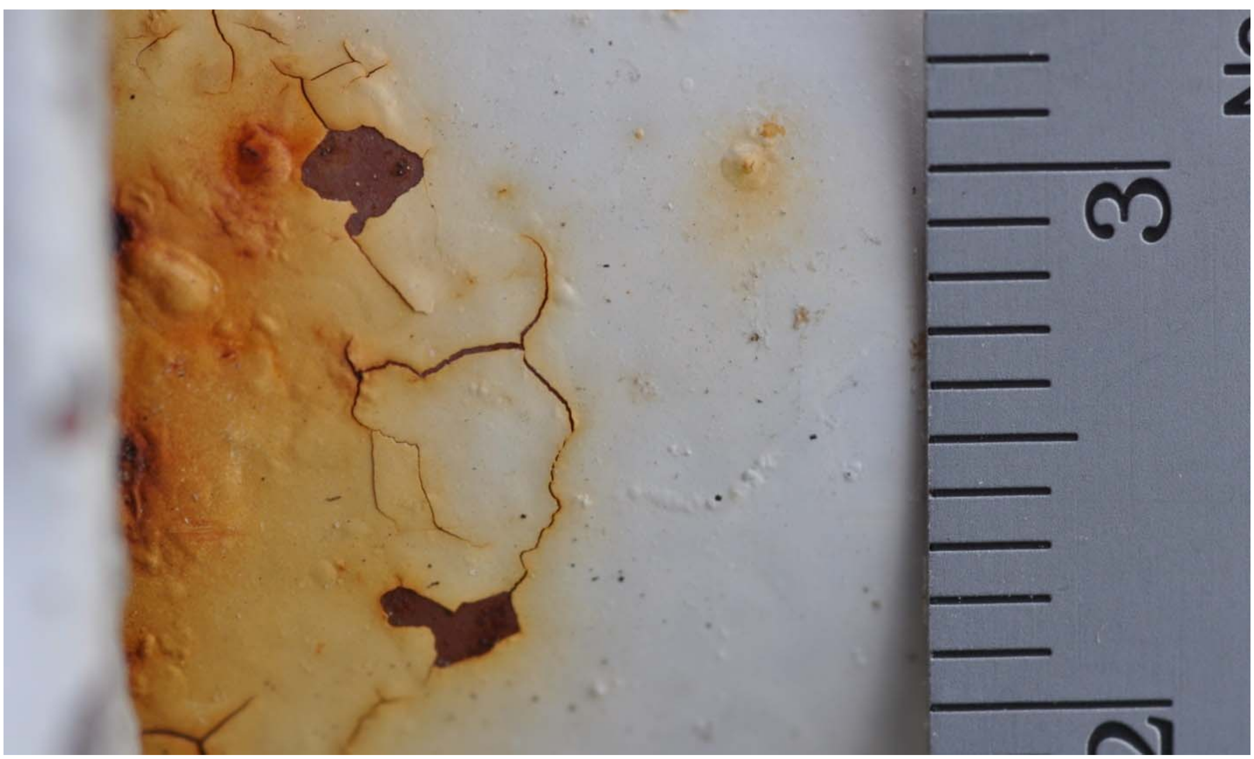


Figure B45. Coated Steel Railing

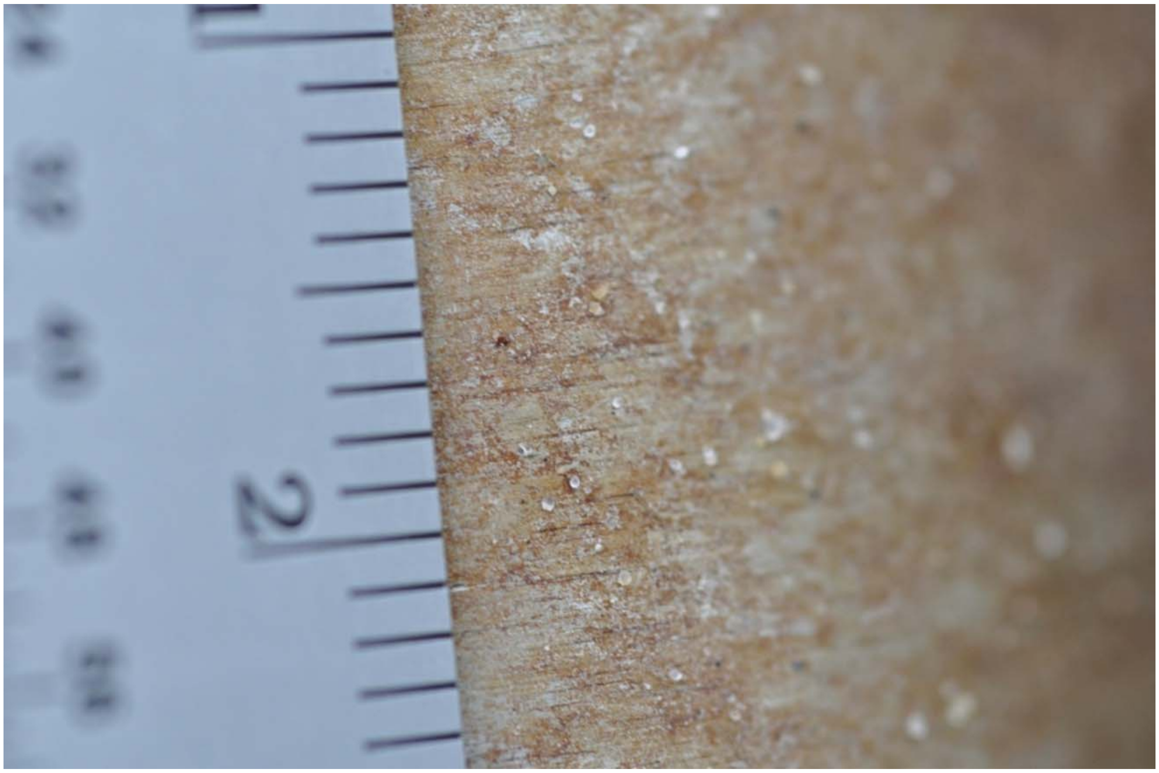


Figure B46. Stainless Steel Coupon

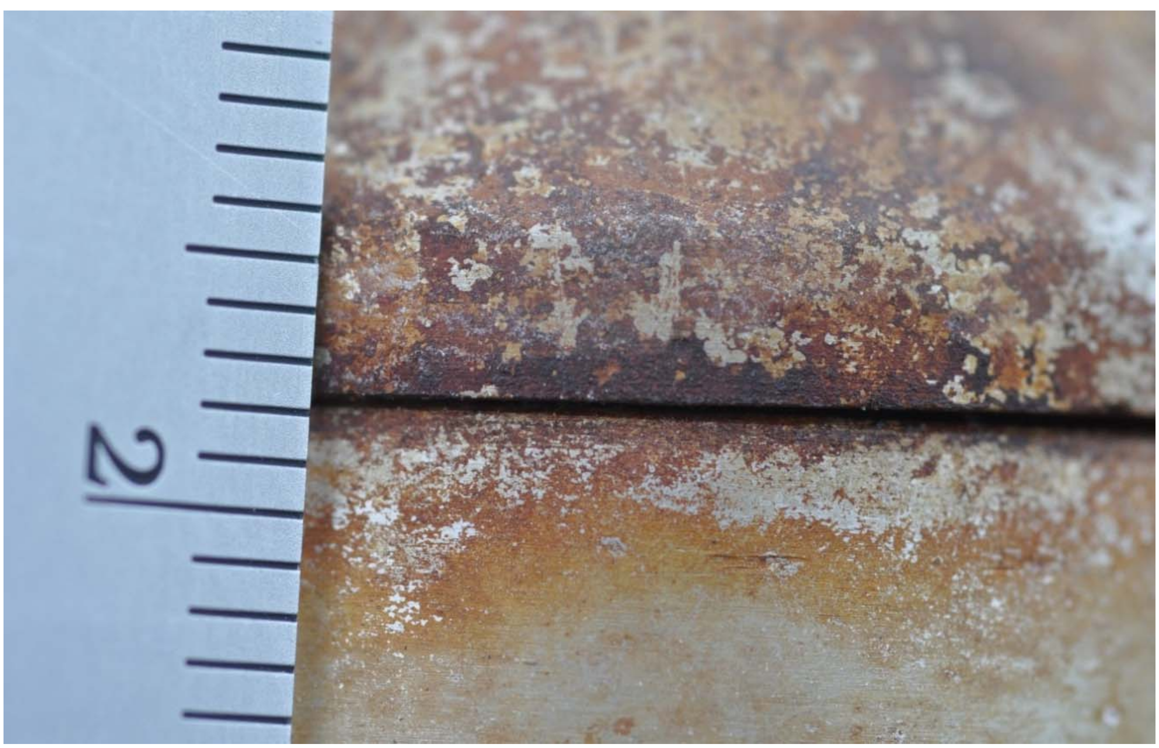


Figure B47. Stainless Steel T-fittings on fabricated railings

Figure B48. Aluminum Railing Coupon

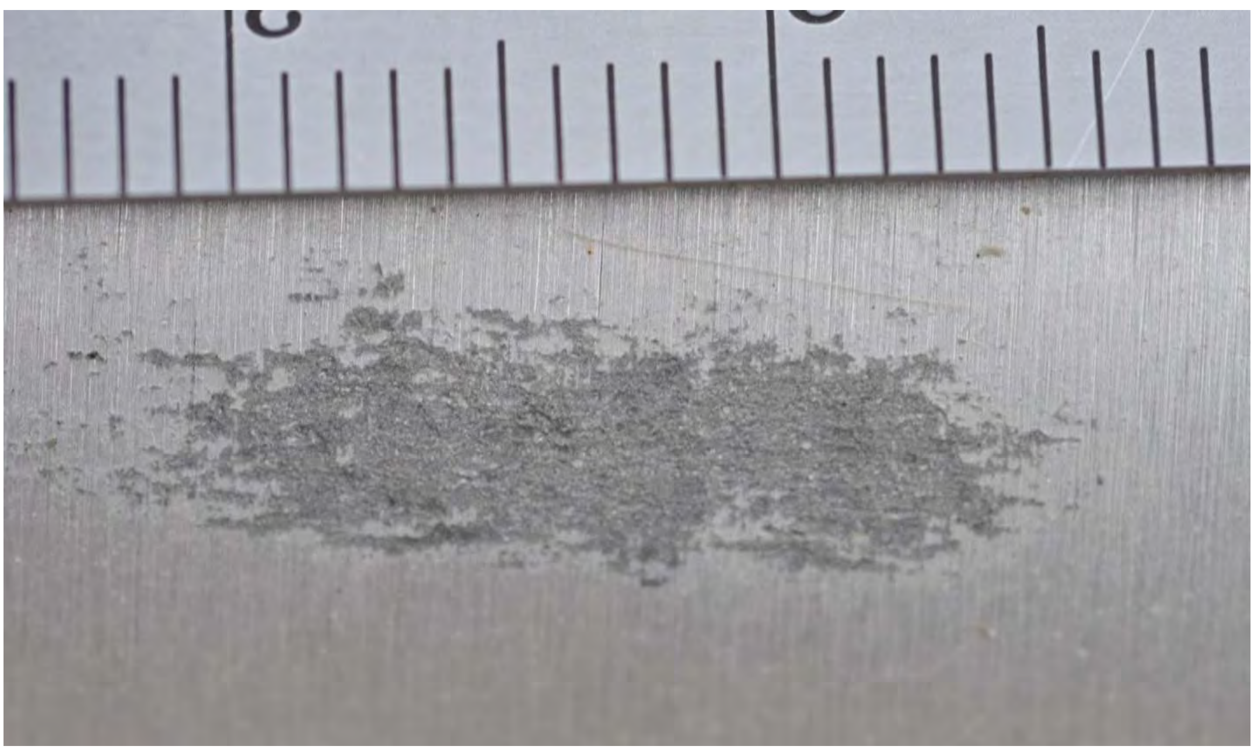


Figure B49. Fabricated Aluminum Railing

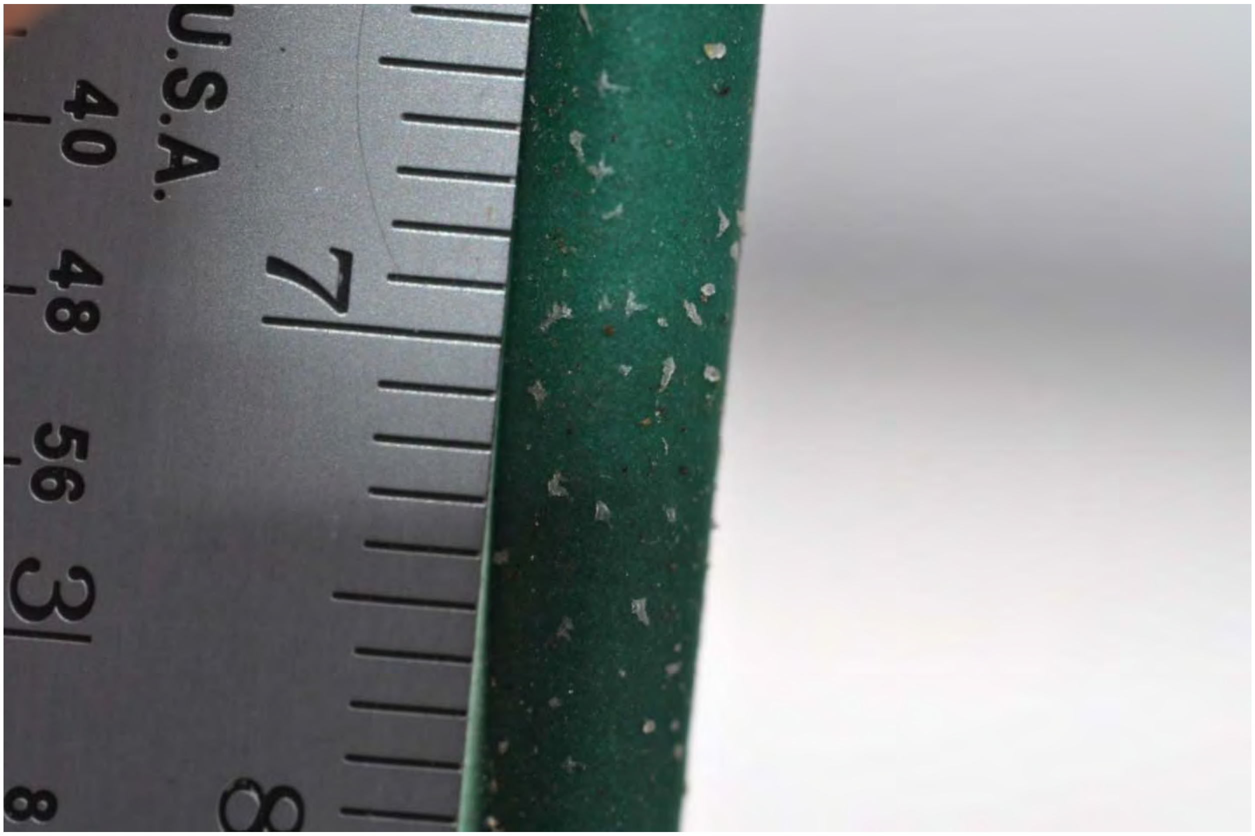


Figure B50. Standard PVC Coated Galvanized Wire Coupon

Figure B51. Standard Galvanized Wire Fencing

Figure B52. Standard Galvanized Wire Coupon

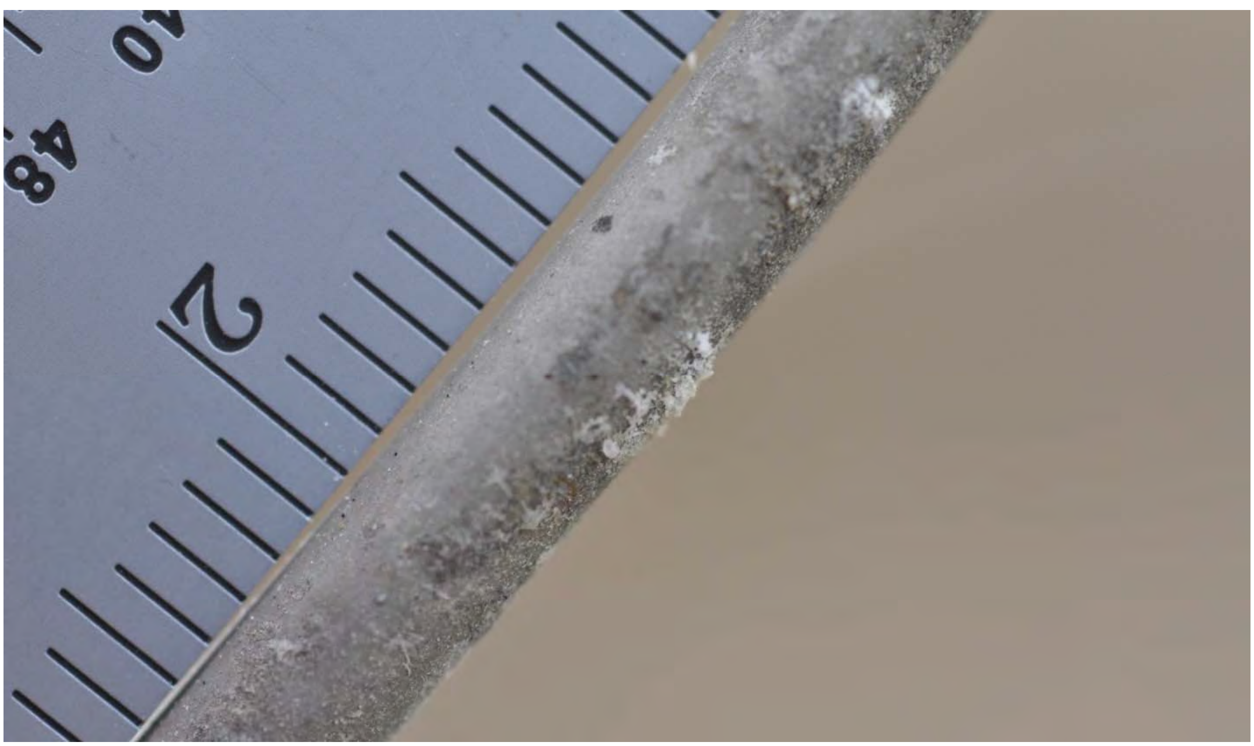


Figure B53. Aluminized Steel Wire Fencing

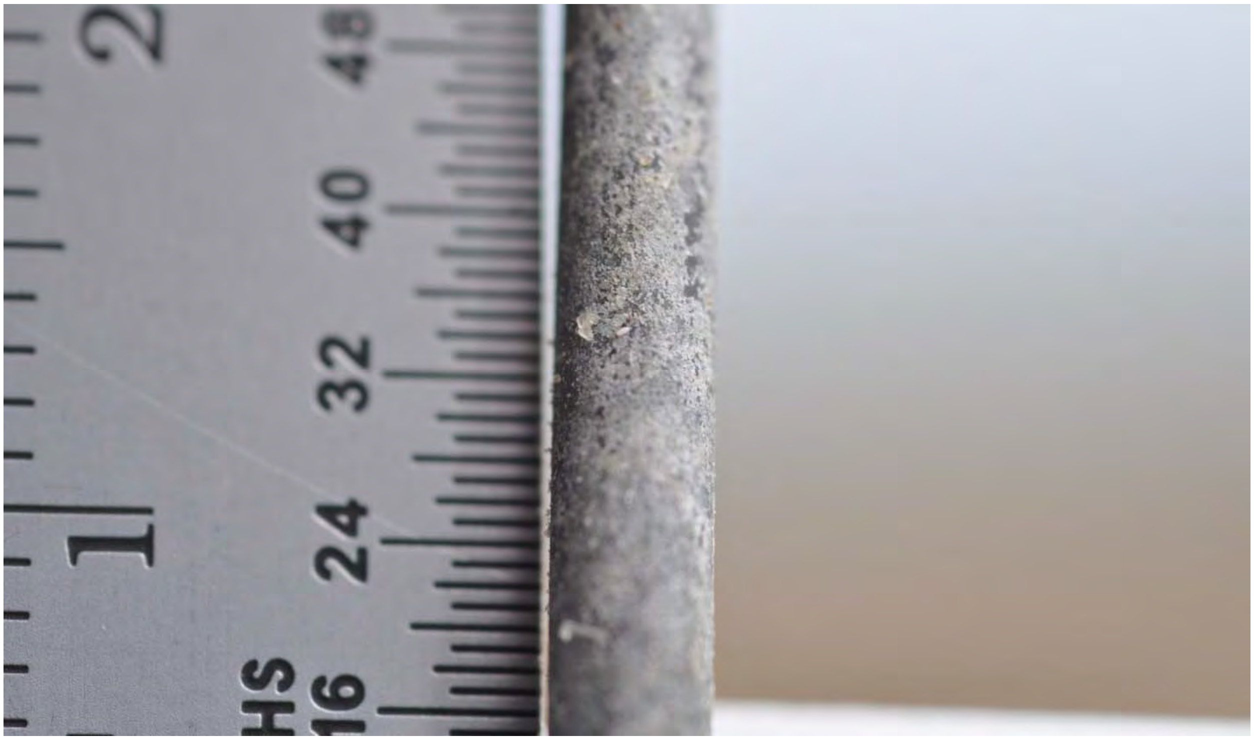


Figure B54. Aluminized Steel Wire Coupon

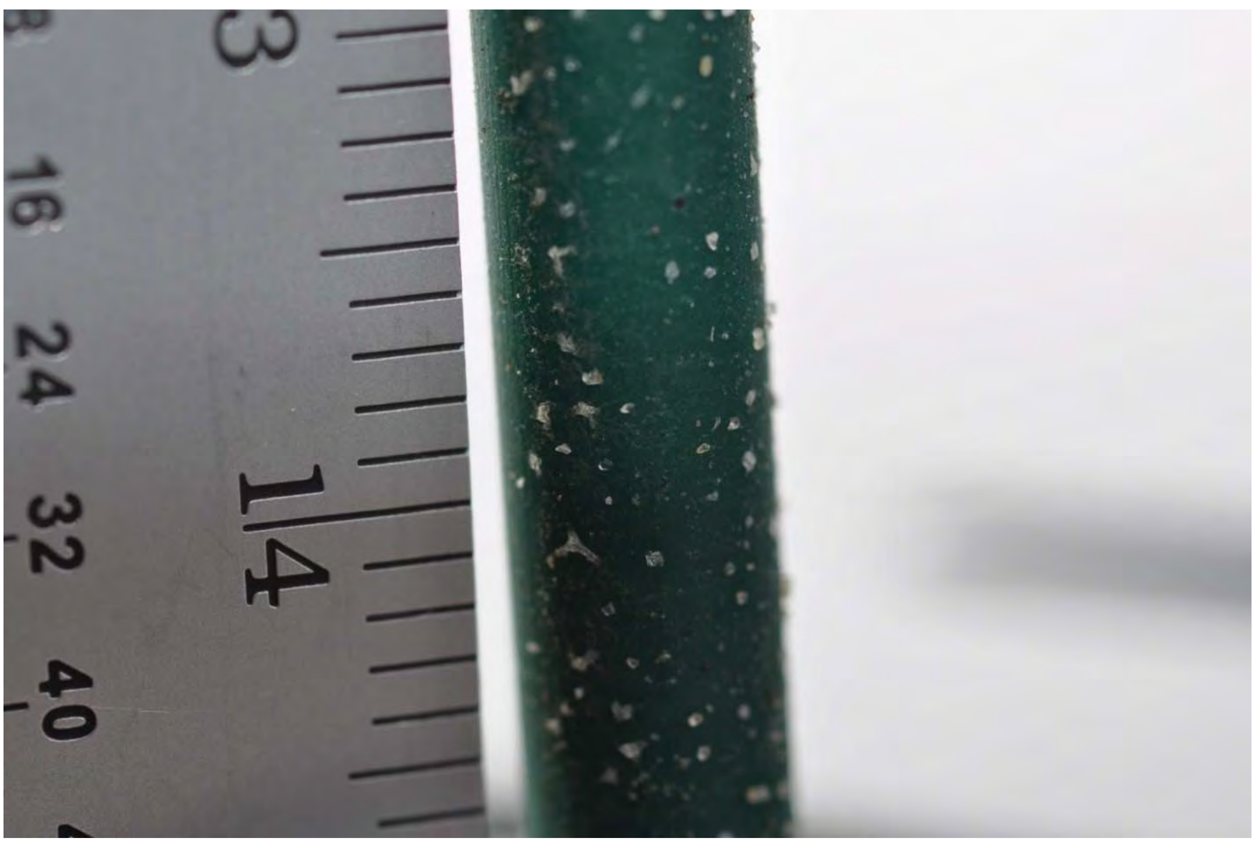


Figure B55. Fuse Bonded PVC Coated Galvanized Wire Coupon

Figure B56. Fuse Bonded PVC Coated Galvanized Wire Fencing

Figure B57. Aluminum Wire Fencing

Figure B58. Aluminum Wire Coupon

Figure B59. Stainless Steel Wire Fencing

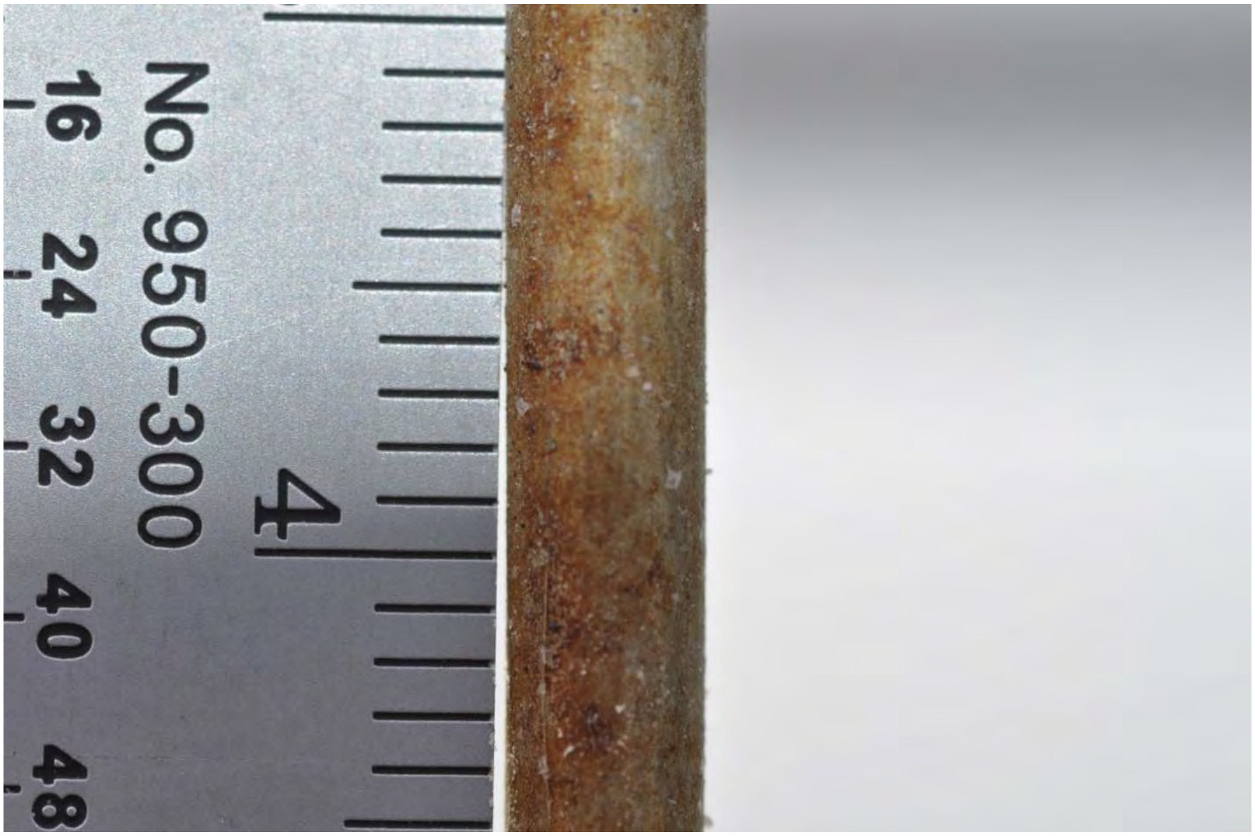


Figure B60. Stainless Steel Wire Coupon

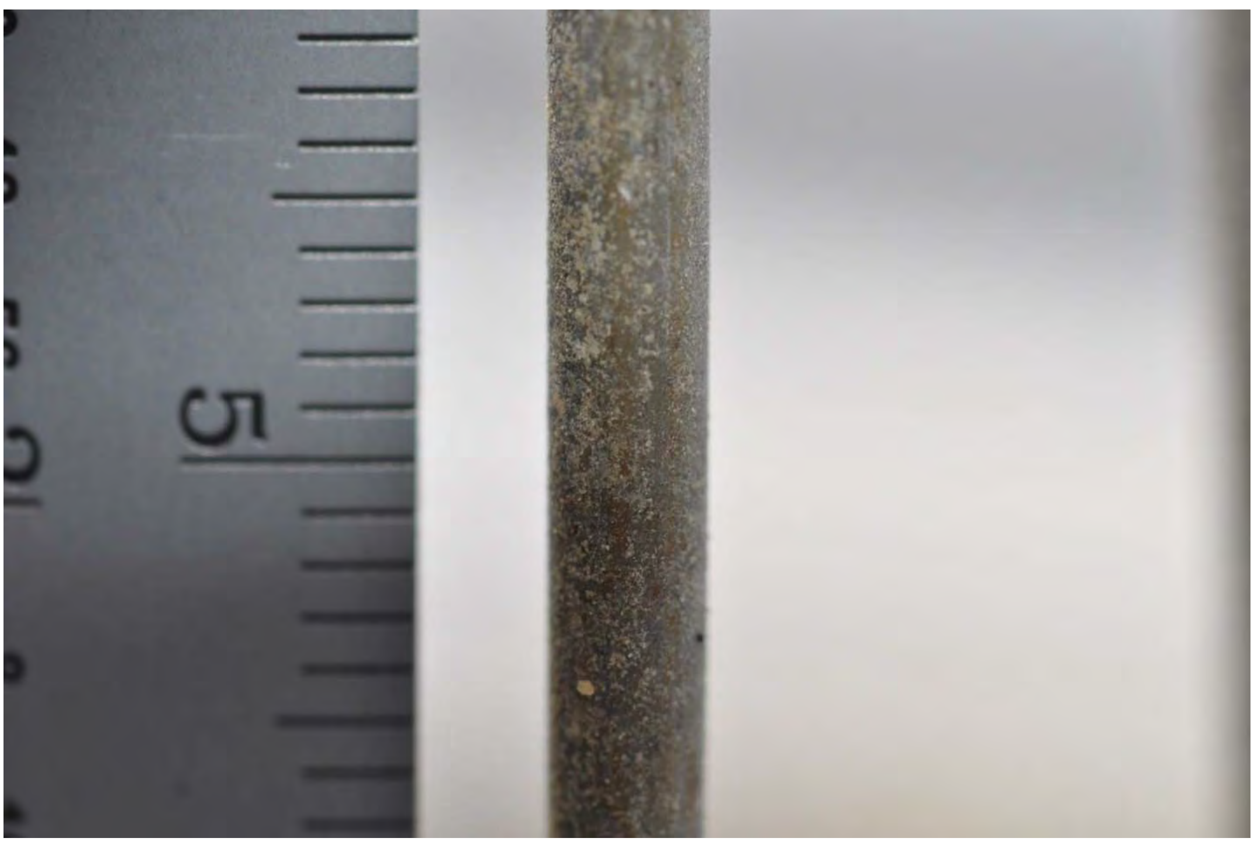


Figure B61. Galfan Wire Coupon

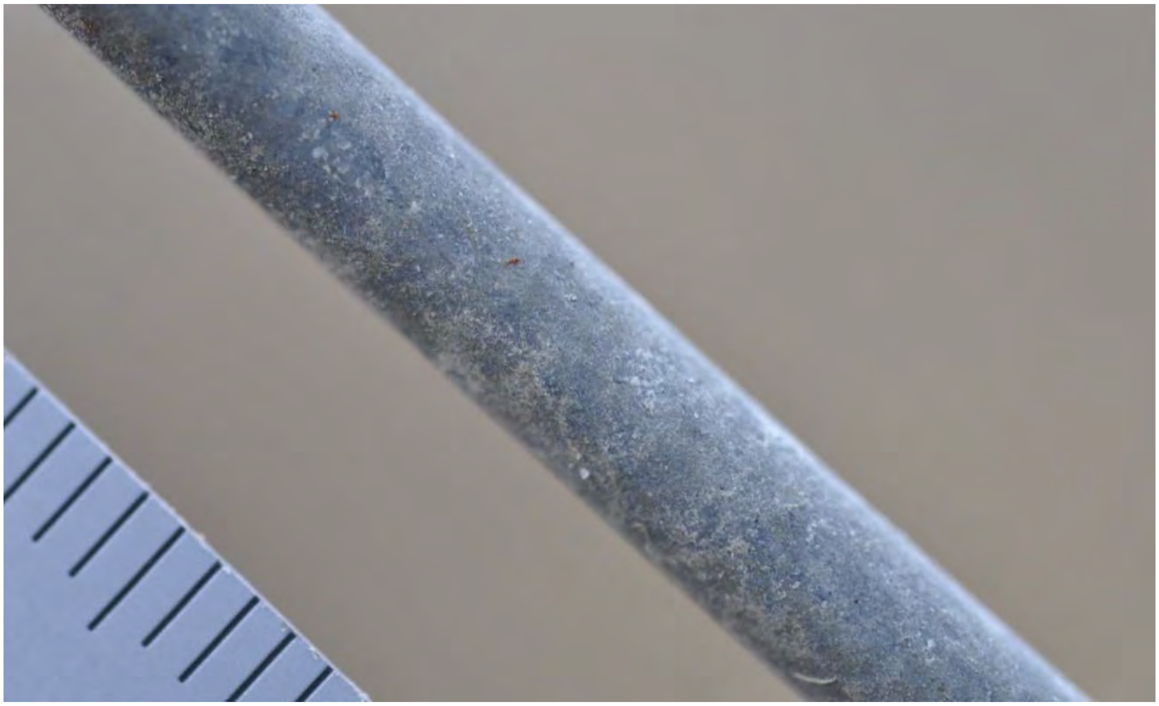


Figure B62. Galfan Wire Fencing

Figure B63. Fuse Bonded PVC Coated Galvanized Wire Fencing Hardware

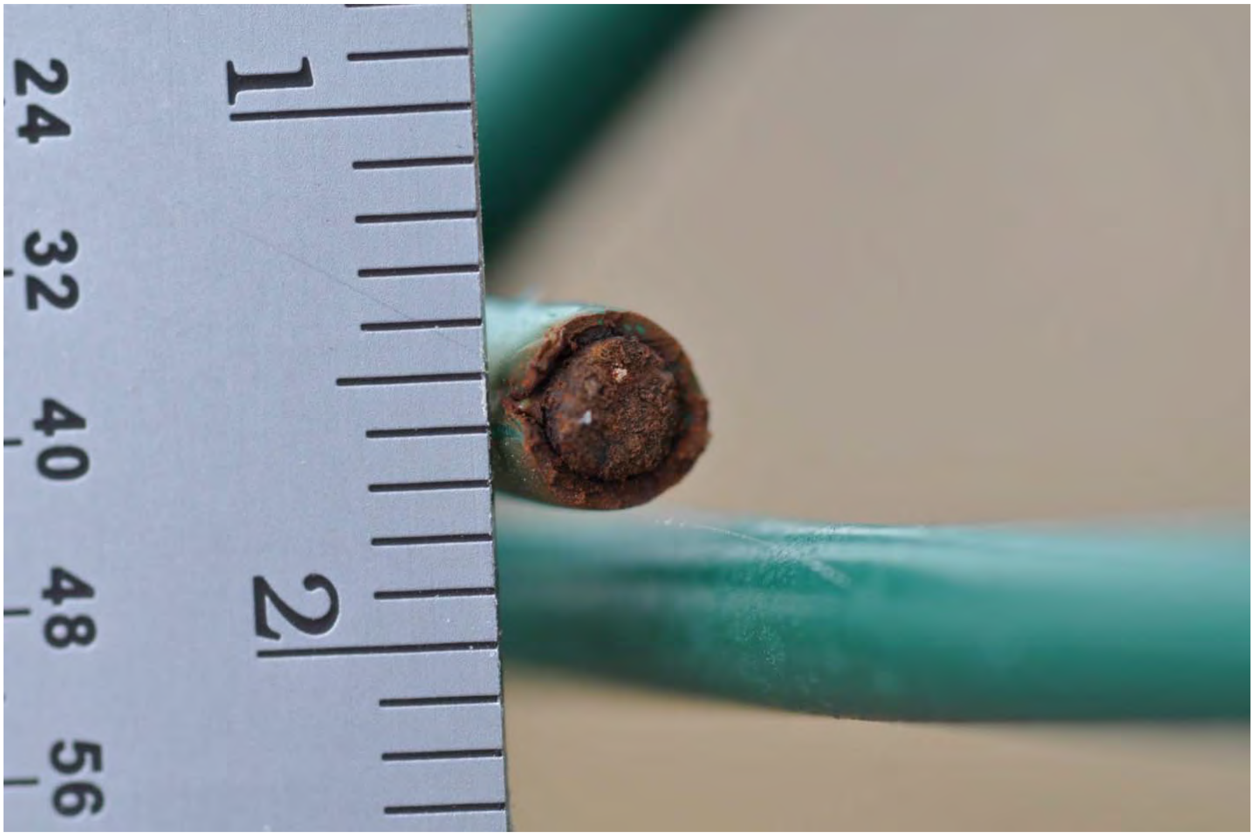


Figure B64. Fuse Bonded PVC Coated Galvanized Wire Fencing Cut Ends

B2 KTA Exposure Coupon Inspection Reports

Visual Inspection Report

Date: 4/26/2010

Location: Kahuku, HI

Exposure Period: 3 Months

	Material	% of Surface Corroded	Type of Corrosion	Notes
Fence Wire Coupons				
	Standard PVC Coated Galvanized	0%	N/A	No visible corrosion
	Fuse Bonded PVC Coated Galvanized	0%	N/A	No visible corrosion
	Standard Galvanized	20%	Oxidation	White oxidation of the zinc/AL coating
	Stainless Steel	80%	Oxidation	Surface oxidation
	Aluminum	5%	Pitting	Minor pitting
	Galfan	50%	Oxidation	White oxidation of the zinc/AL coating
	Aluminized Steel	0%	N/A	No visible corrosion
Fabricated Fencing				
	Stainless Steel	80%	Oxidation	Surface oxidation has discolored the material
	Aluminum	5%	Pitting	Pitting more prevalent on the posts
	Galfan	50%	Oxidation	White oxidation of the zinc/AL coating
	Aluminized Steel	0%	N/A	No visible corrosion
	Fuse Bonded PVC Coated Galvanized	0%	N/A	PVC coating has been damaged due to fabrication
Railing Coupons				
	Stainless Steel	50%	Oxidation	Surface oxidation has discolored the material
	Aluminum	<5%	Pitting	Pitting has begun in areas where the anodize may have been damaged
	Coated Steel	10%	Rust	Rust has begun to form where the coating has failed. Discoloring of the coating due to the rust.
	FRP	0%	N/A	No visible corrosion
Fabricated Railing				
	Stainless Steel	80%	Oxidation	Surface oxidation has discolored the material. T-fittings show 90% surface corrosion likely due to lack of passivation.
	Aluminum	<5%	Pitting	Pitting has begun in areas where the anodize may have been damaged
	Coated Steel	10%	Rust	Rust has begun to form where the coating has failed. Discoloring of the coating due to the rust.
	FRP	0%	N/A	No visible corrosion

Figure B65. (Left) Southern most stainless steel T-fitting, (Center) center stainless steel T-fitting, (Right) northern most stainless steel T-fitting.

Figure B66. (Left) Stainless steel coupons facing away from the ocean; (Right) stainless steel coupons facing the Ocean.

Figure B67. (Left) Painted carbon steel railing coating failure. (Right) Painted carbon steal coupon coating failure.

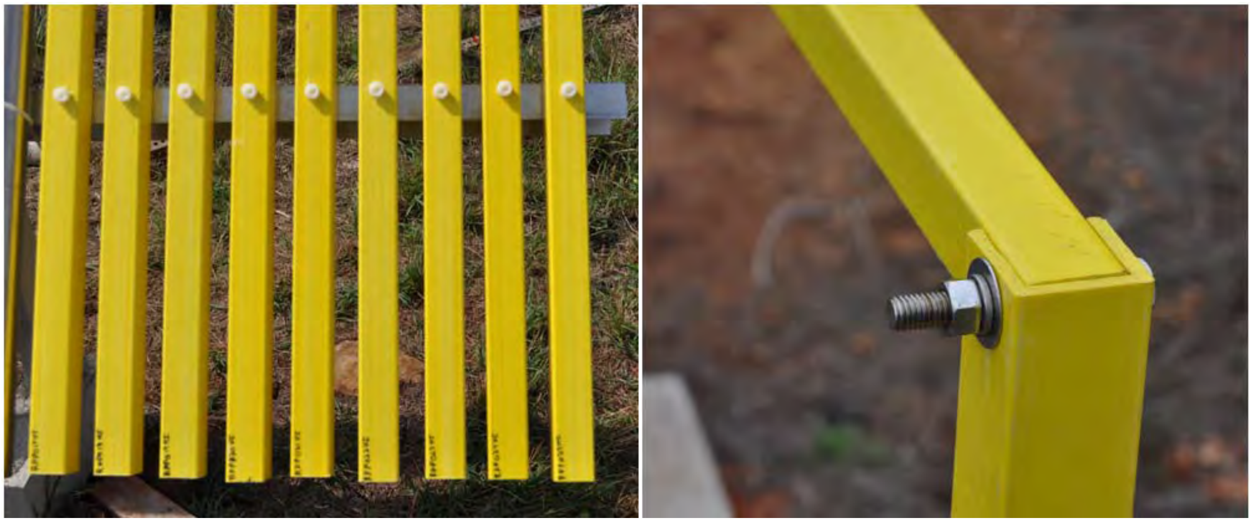


Figure B68. (Left) FRP railing coupons. (Right) FRP railing test section.

Figure B69. (Left) Aluminum railing coupons. (Right) Aluminum railing test section.

Figure B70. (Left) Stainless steel fence after 3 months exposure.
(Right)Stainless steel wire coupons after 3 months exposure.

Figure B71. (Left) Fused bonded PVC coated galvanized steel formation damage. (Right) PVC coated galvanized steel wire coupons

Figure B72. (Left) Aluminized Steel Wire Coupons. (Right) Aluminized Steel fabricated fencing

Figure B73. (Left) Galfan fabricated fencing. (Right) Galfan Wire Coupons

Figure B74. (Left) Alumiunm fabricated fencing. (Right) Aluminum Wire Coupons

Figure B75. Standard galvanized wire coupons

Figure B76. Standard PVC coated galvanized wire coupons

Visual Inspection Report

Date: 10/4/2010

Location: Kahuku, HI

Exposure Period: 6 Months

	Material	% of Surface Corroded	Type of Corrosion	Notes
Fence Wire Coupons				
	Standard PVC Coated Galvanized	0%	N/A	No visible corrosion
	Fuse Bonded PVC Coated Galvanized	0%	N/A	No visible corrosion
	Standard Galvanized	50%	Oxidation/ Rust	50% of the corrosion areas have degraded past the sacrificial zinc coating and have begun to rust.
	Stainless Steel	100%	Oxidation	Surface oxidation
	Aluminum	5%	Pitting	Minor pitting
	Galfan	50%	Oxidation/ Rust	50% of the corrosion areas have degraded past the sacrificial zinc coating and have begun to rust.
	Aluminized Steel	<5%	Oxidation	White oxidation of the zinc/AL coating
Fabricated Fencing				
	Stainless Steel	75%	Oxidation	Surface oxidation has discolored the material
	Aluminum	5%	Pitting	Pitting more prevalent on the posts
	Galfan	80%	Oxidation	White oxidation of the zinc/AL coating
	Aluminized Steel	20%	Oxidation	White oxidation of the zinc/AL coating 95% white corrosion on Galv. Hardware
	Fuse Bonded PVC Coated Galvanized	<5%	Rust	Minor rust has begun to form around cut ends and damaged areas
Railing Coupons				
	Stainless Steel	80%	Oxidation	Surface oxidation has discolored the material.
	Aluminum	<5%	Pitting	Pitting has begun in areas where the anodize may have been damaged
	Coated Steel	10%	Rust	Rust has begun to form where the coating has failed. Discoloring of the coating due to the rust.
	FRP	25%	UV	Discoloring due to UV exposure on the face of the railing that faces the sun
Fabricated Railing				
	Stainless Steel	50%	Oxidation	Surface oxidation has discolored the material. T-fittings show 90% surface corrosion likely due to lack of passivation.
	Aluminum	<5%	Pitting	Pitting has begun in areas where the anodize may have been damaged
	Coated Steel	10%	Rust	Rusting areas have spread larger causing blistering under the coating.
	FRP	25%	UV	Discoloring due to UV exposure on the face of the railing that faces the sun

Some photo documentation for this inspection was lost due to computer theft. Weather data was stored on the logger and was recoverable at the test site.

Figure B77. FRP Railing Coupon

Figure B78. Fabricated FRP Railing

Figure B79. Coated Steel Coupon

Figure B80. Coated Steel Railing

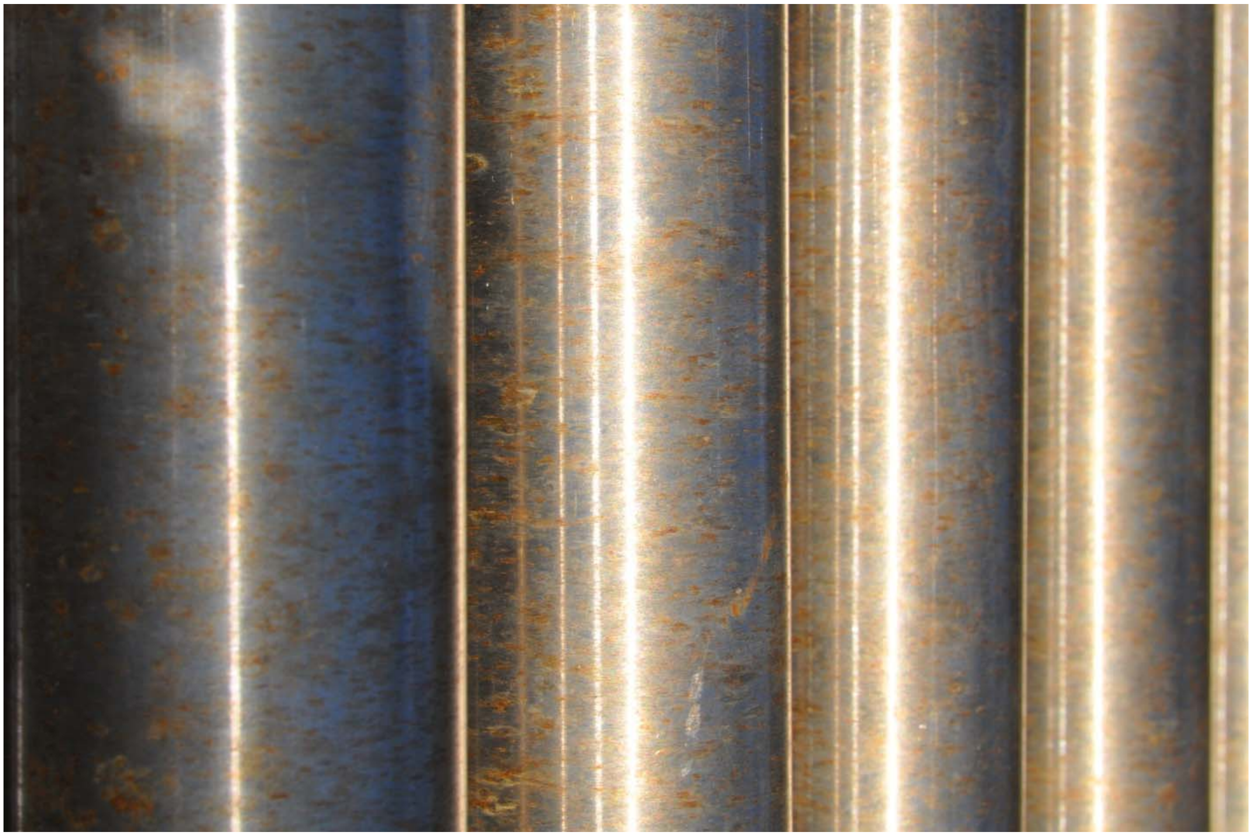


Figure B81. Stainless Steel Coupon

Figure B82. Stainless Steel T-fittings on fabricated railings

Figure B83. Aluminum Railing Coupon

Figure B84. Fabricated Aluminum Railing

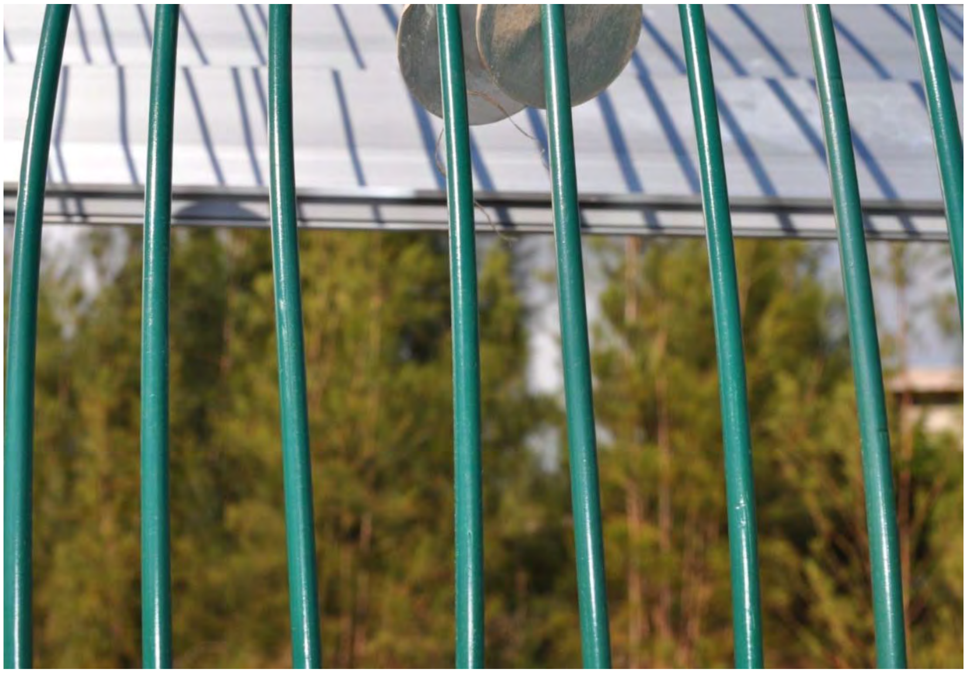


Figure B85. Standard PVC Coated Galvanized Wire Coupon

Figure B86. Standard Galvanized Wire Coupon

Photograph not available.

Figure B87. Aluminized Steel Wire Fencing

Figure B88. Aluminized Steel Wire Coupon

Photograph not available.

Figure B89. Fuse Bonded PVC Coated Galvanized Wire Coupon

Figure B90. Fuse Bonded PVC Coated Galvanized Wire Coupon

Photograph not available.

Figure B91. Aluminum Wire Fencing

Figure B92. Aluminum Wire Coupon

Photograph not available.

Figure B93. Stainless Steel Wire Fencing

Figure B94. Stainless Steel Wire Coupon

Photograph not available.

Figure B95. Galfan Wire Fencing

Figure B96. Galfan Wire Coupon

Visual Inspection Report

Date: 10/4/2010

Location: Kahuku, HI

Exposure Period: 9 Months

	Material	% of Surface Corroded	Type of Corrosion	Notes
Fence Wire Coupons				
	Standard PVC Coated Galvanized	0%	N/A	No visible corrosion
	Fuse Bonded PVC Coated Galvanized	0%	N/A	No visible corrosion
	Standard Galvanized	50%	Oxidation/ Rust	50% of the corrosion areas have degraded past the sacrificial zinc coating and have begun to rust.
	Stainless Steel	100%	Oxidation	Surface oxidation
	Aluminum	5%	Pitting	Minor pitting
	Galfan	50%	Oxidation/ Rust	50% of the corrosion areas have degraded past the sacrificial zinc coating and have begun to rust.
	Aluminized Steel	<5%	Oxidation	White oxidation of the zinc/AL coating
Fabricated Fencing				
	Stainless Steel	75%	Oxidation	Surface oxidation has discolored the material
	Aluminum	5%	Pitting	Pitting more prevalent on the posts
	Galfan	80%	Oxidation	White oxidation of the zinc/AL coating
	Aluminized Steel	20%	Oxidation	White oxidation of the zinc/AL coating 95% white corrosion on Galv. Hardware
	Fuse Bonded PVC Coated Galvanized	<5%	Rust	Minor rust has begun to form around cut ends and damaged areas
Railing Coupons				
	Stainless Steel	80%	Oxidation	Surface oxidation has discolored the material.
	Aluminum	<5%	Pitting	Pitting has begun in areas where the anodize may have been damaged
	Coated Steel	10%	Rust	Rust has begun to form where the coating has failed. Discoloring of the coating due to the rust.
	FRP	25%	UV	Discoloring due to UV exposure on the face of the railing that faces the sun
Fabricated Railing				
	Stainless Steel	50%	Oxidation	Surface oxidation has discolored the material. T-fittings show 90% surface corrosion likely due to lack of passivation.
	Aluminum	<5%	Pitting	Pitting has begun in areas where the anodize may have been damaged
	Coated Steel	20%	Rust	Rusting areas have spread larger causing blistering under the coating.
	FRP	25%	UV	Discoloring due to UV exposure on the face of the railing that faces the sun

Figure B97. FRP Railing Coupon

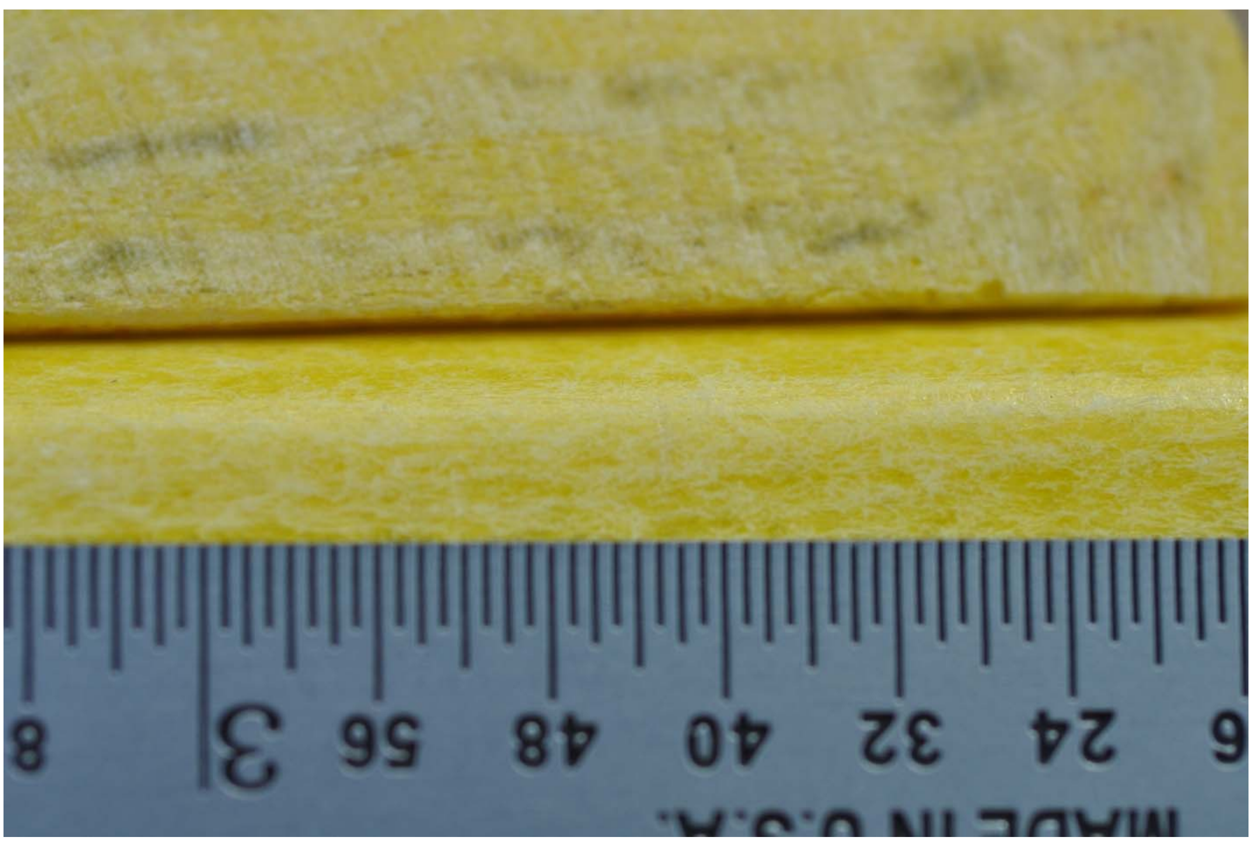


Figure B98. Fabricated FRP Railing

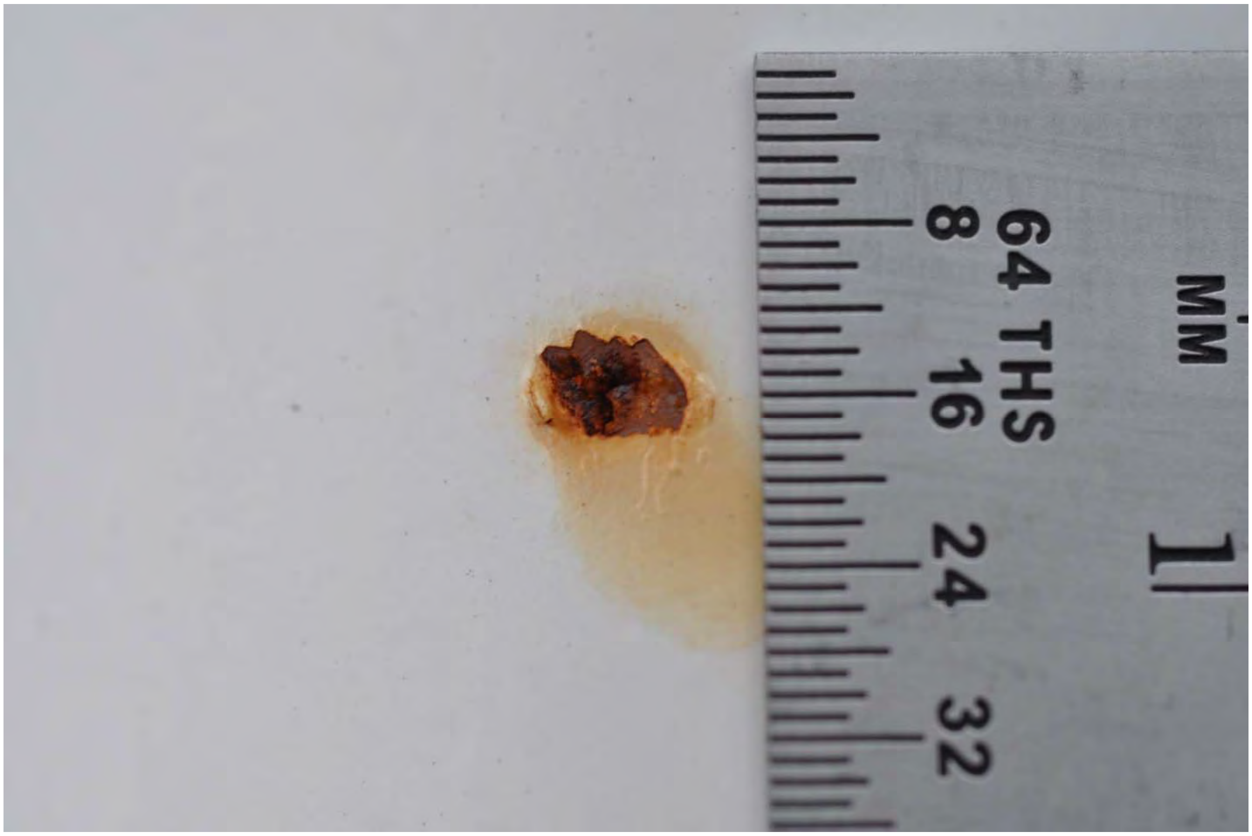


Figure B99. Coated Steel Coupon

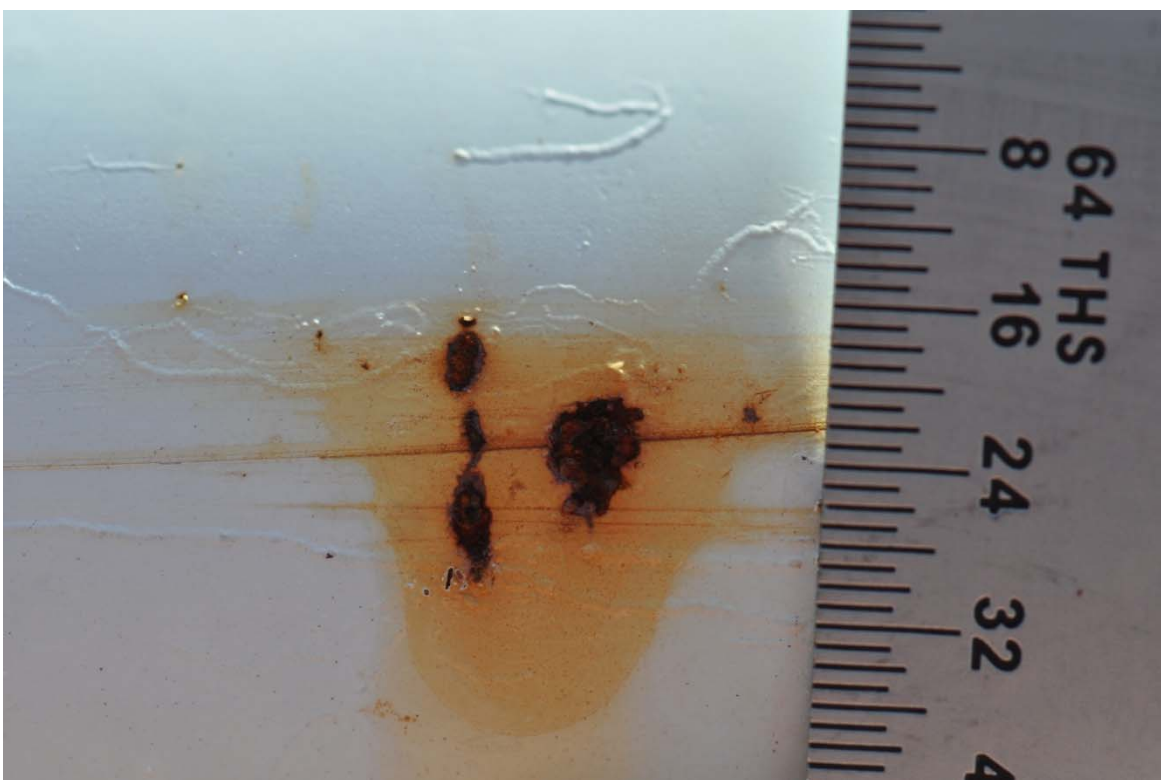


Figure B100. Coated Steel Railing

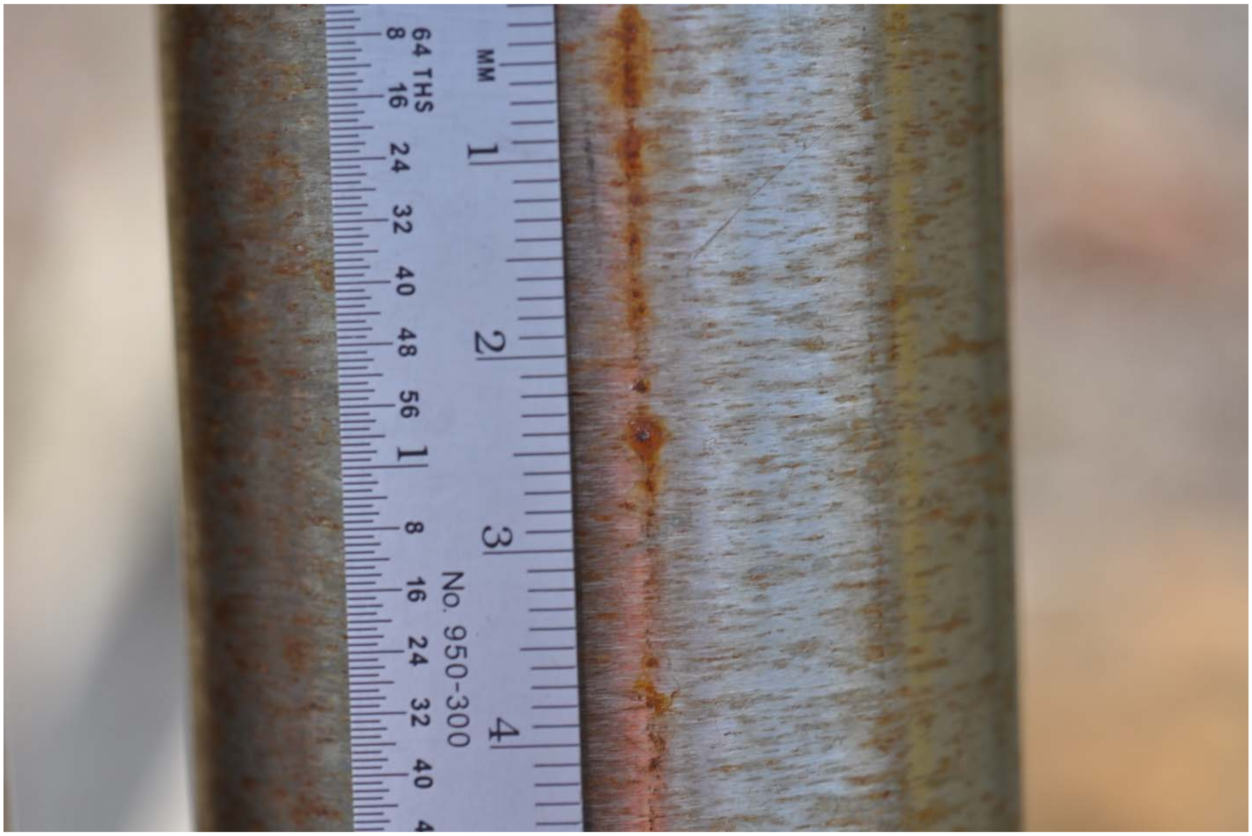


Figure B101. Stainless Steel Coupon

Figure B102. Stainless Steel T-fittings on fabricated railings

Figure B103. Aluminum Railing Coupon

Photograph not available.

Figure B104. Fabricated Aluminum Railing

Figure B105. Standard PVC Coated Galvanized Wire Coupon

Figure B106. Standard Galvanized Wire Coupon

Figure B107. Aluminized Steel Wire Coupon

Figure B108. Aluminized Steel Wire Fencing

Figure B109. Fuse Bonded PVC Coated Galvanized Wire Coupon

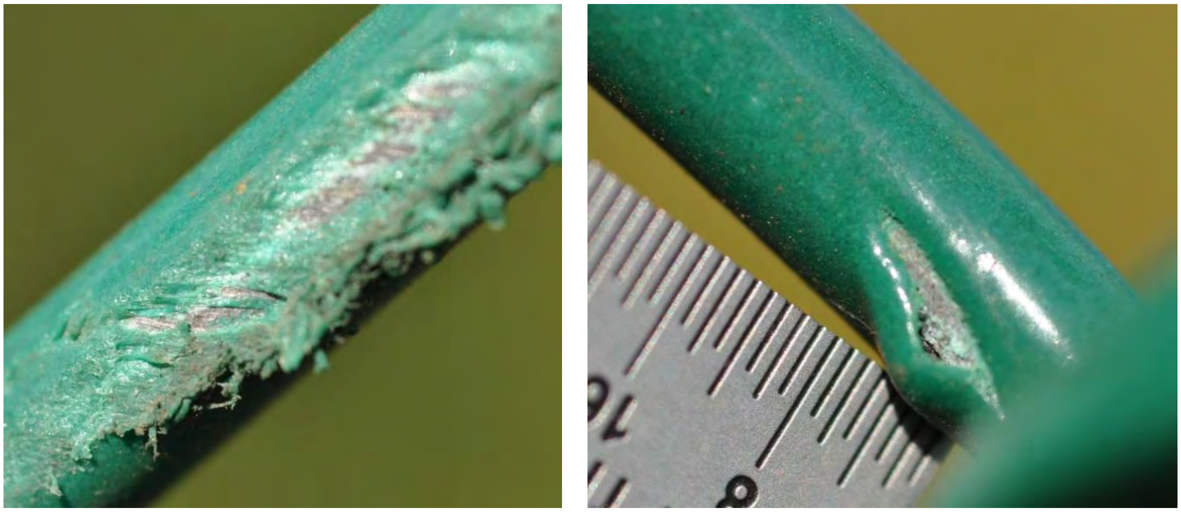


Figure B110. Fuse Bonded PVC Coated Galvanized Wire Fencing

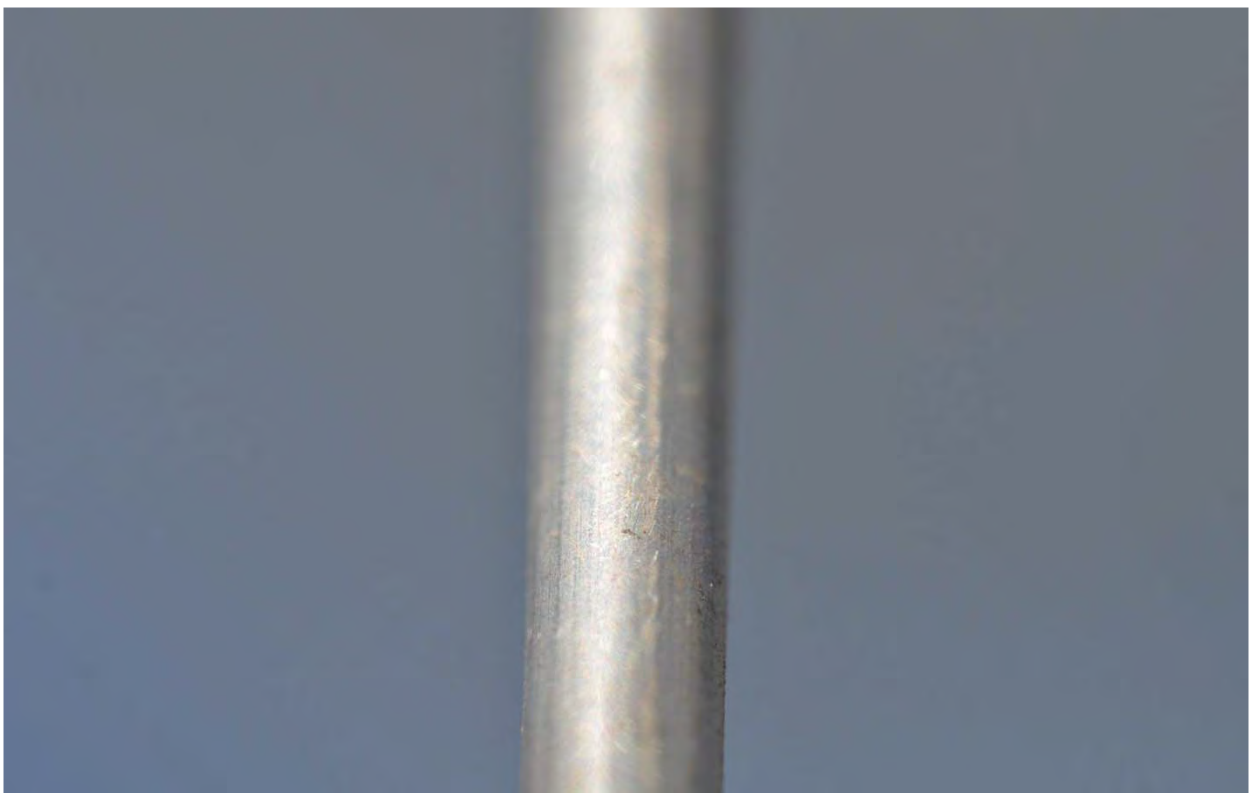


Figure B111. Aluminum Wire Coupon

Figure B112. Aluminum Wire Fencing

Figure B113. Stainless Steel Wire Fencing

Figure B114. Stainless Steel Wire Coupon

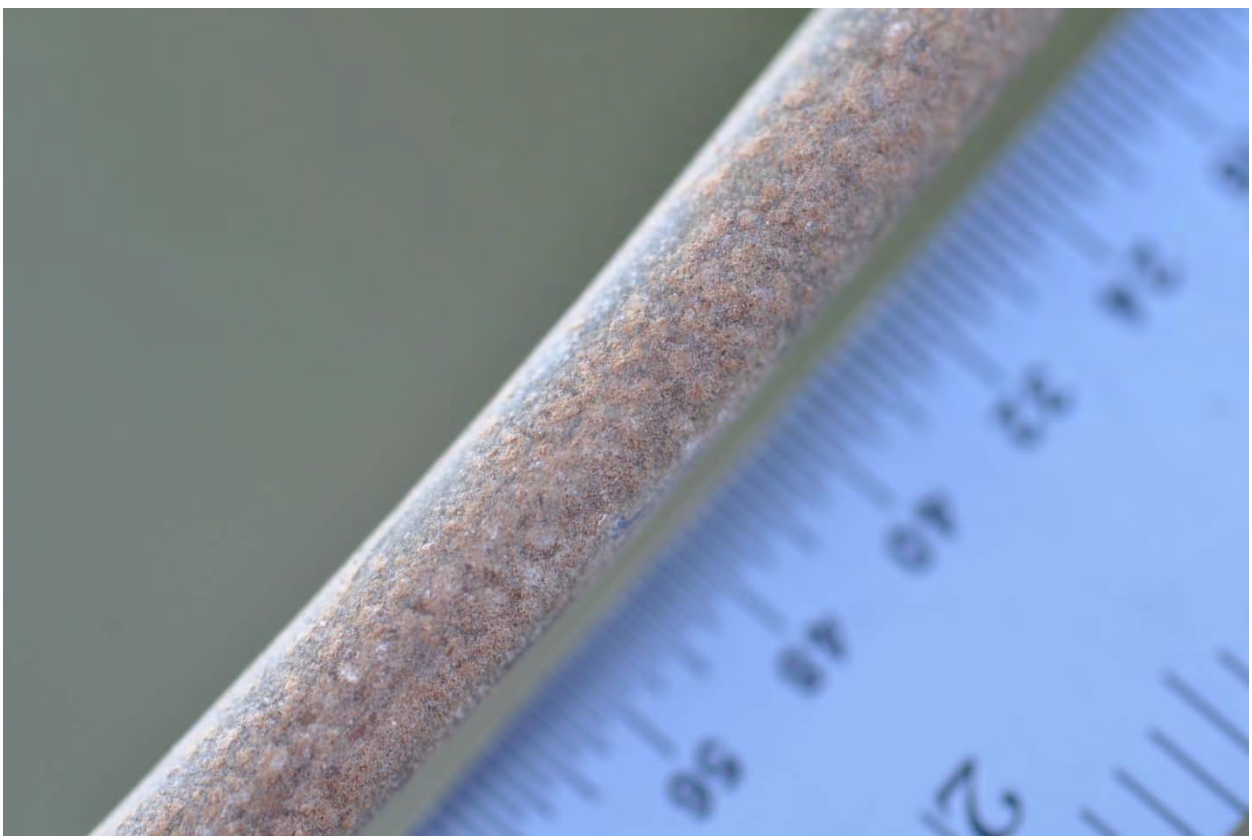


Figure B115. Galfan Wire Fencing

Figure B116. Galfan Wire Coupon

Visual Inspection Report

Date: 1/25/2011

Location: Kahuku, HI

Exposure Period: 12 Months

	Material	% of Surface Corroded	Type of Corrosion	Notes
Fence Wire Coupons				
	Standard PVC Coated Galvanized	0%	N/A	No visible corrosion
	Fuse Bonded PVC Coated Galvanized	0%	N/A	No visible corrosion
	Standard Galvanized	50%	Oxidation/ Rust	50% of the corrosion areas have degraded past the sacrificial zinc coating and have begun to rust.
	Stainless Steel	100%	Oxidation	Surface oxidation
	Aluminum	5%	Pitting	Minor pitting
	Galfan	75%	Oxidation/ Rust	50% of the corrosion areas have degraded past the sacrificial zinc coating and have begun to rust.
	Aluminized Steel	<5%	Oxidation	White oxidation of the zinc/AL coating
Fabricated Fencing				
	Stainless Steel	100%	Oxidation	Surface oxidation has discolored the material
	Aluminum	5%	Pitting	Pitting more prevalent on the posts
	Galfan	50%	Oxidation	White oxidation of the zinc/AL coating
	Aluminized Steel	20%	Oxidation	White oxidation of the zinc/AL coating 95% white corrosion on Galv. Hardware
	Fuse Bonded PVC Coated Galvanized	<5%	Rust	Minor rust has begun to form around cut ends and damaged areas
Railing Coupons				
	Stainless Steel	80%	Oxidation	Surface oxidation has discolored the material.
	Aluminum	<5%	Pitting	Pitting has begun in areas where the anodize may have been damaged
	Coated Steel	20%	Rust	Rust has begun to form where the coating has failed. Discoloring of the coating due to the rust.
	FRP	25%	UV	Discoloring due to UV exposure on the face of the railing that faces the sun
Fabricated Railing				
	Stainless Steel	50%	Oxidation	Surface oxidation has discolored the material. T-fittings show 90% surface corrosion likely due to lack of passivation.
	Aluminum	<5%	Pitting	Pitting has begun in areas where the anodize may have been damaged
	Coated Steel	20%	Rust	Rusting areas have spread larger causing blistering under the coating.
	FRP	25%	UV	Discoloring due to UV exposure on the face of the railing that faces the sun

Figure B117. FRP Railing Coupon

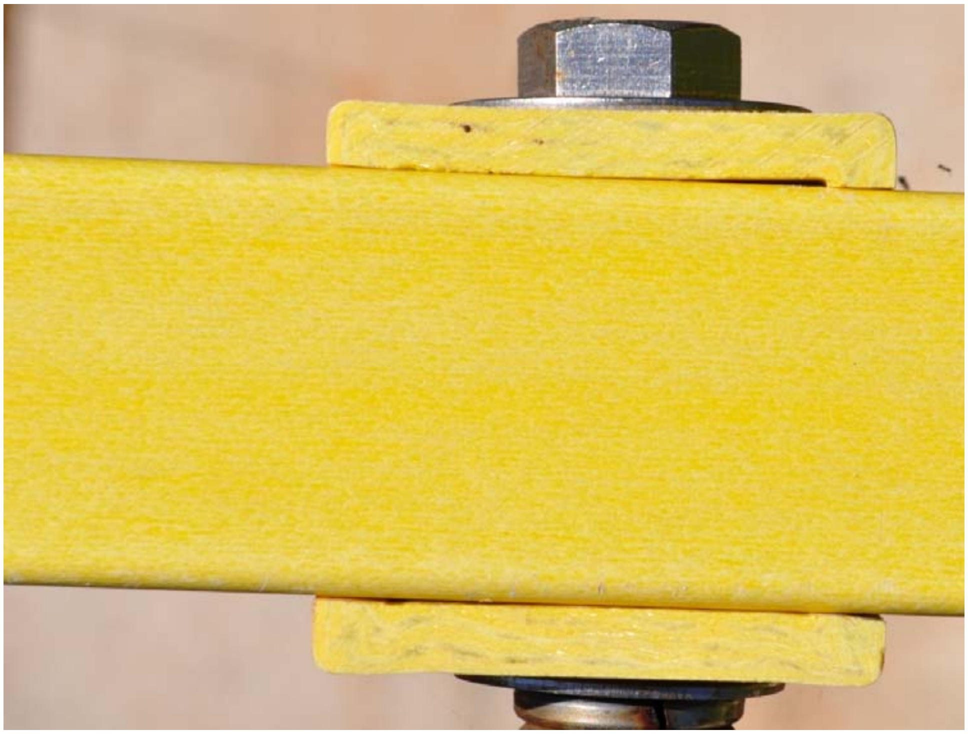


Figure B118. Fabricated FRP Railing

Figure B119. Coated Steel Coupon

Figure B120. Coated Steel Railing

Figure B121. Stainless Steel Coupon

Figure B122. Stainless Steel T-fittings on fabricated railings

Figure B123. Aluminum Railing Coupon

Figure B124. Fabricated Aluminum Railing

Figure B125. Standard PVC Coated Galvanized Wire Coupon

Figure B126. Standard Galvanized Wire Coupon

Figure B127. Aluminized Steel Wire Fencing

Figure B128. Aluminized Steel Wire Coupon

Figure B129. Fuse Bonded PVC Coated Galvanized Wire Fencing

Figure B130. Fuse Bonded PVC Coated Galvanized Wire Coupon

Figure B131. Aluminum Wire Fencing

Figure B132. Aluminum Wire Coupon

Figure B133. Stainless Steel Wire Fencing

B134. Stainless Steel Wire Coupon

Figure B135. Galfan Wire Fencing

Figure B136. Galfan Wire Coupon

Figure B137. Galvanized Fencing Hardware

B3 Treat Island, ME, Exposure Coupon Inspection Reports

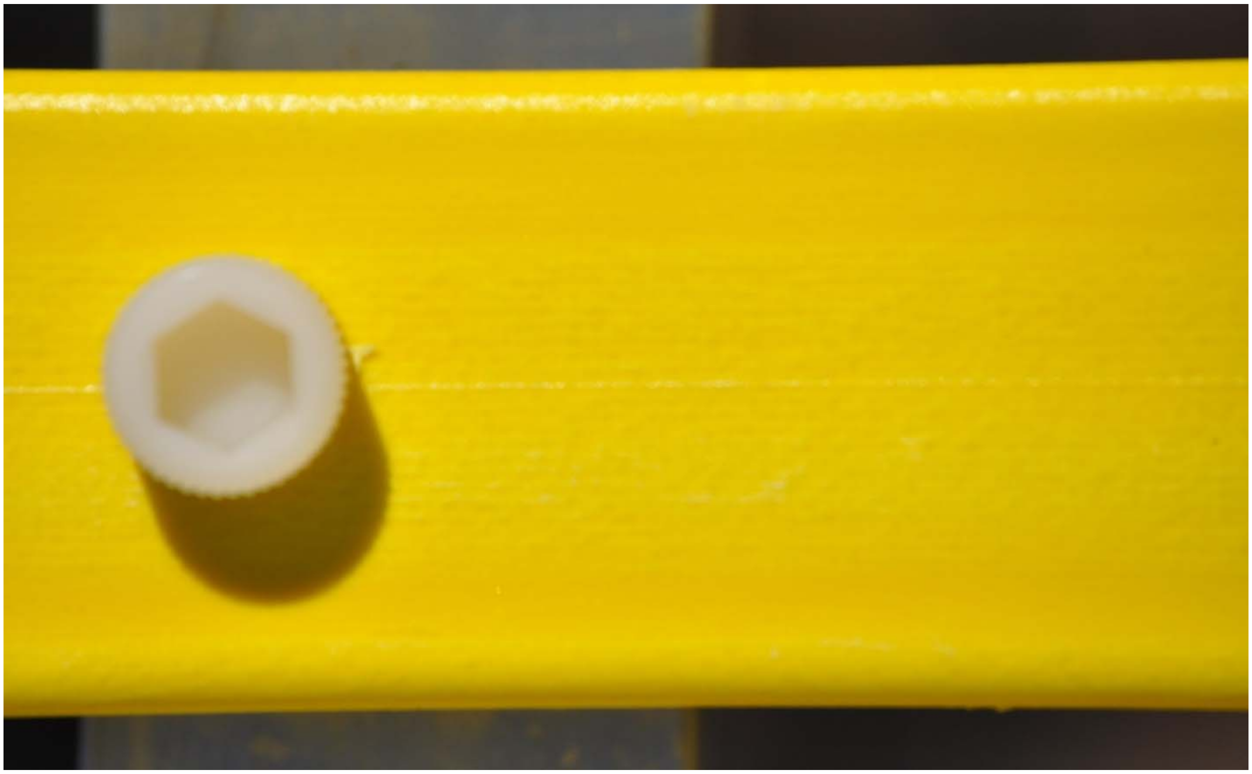


Figure B138. FRP Railing Coupon

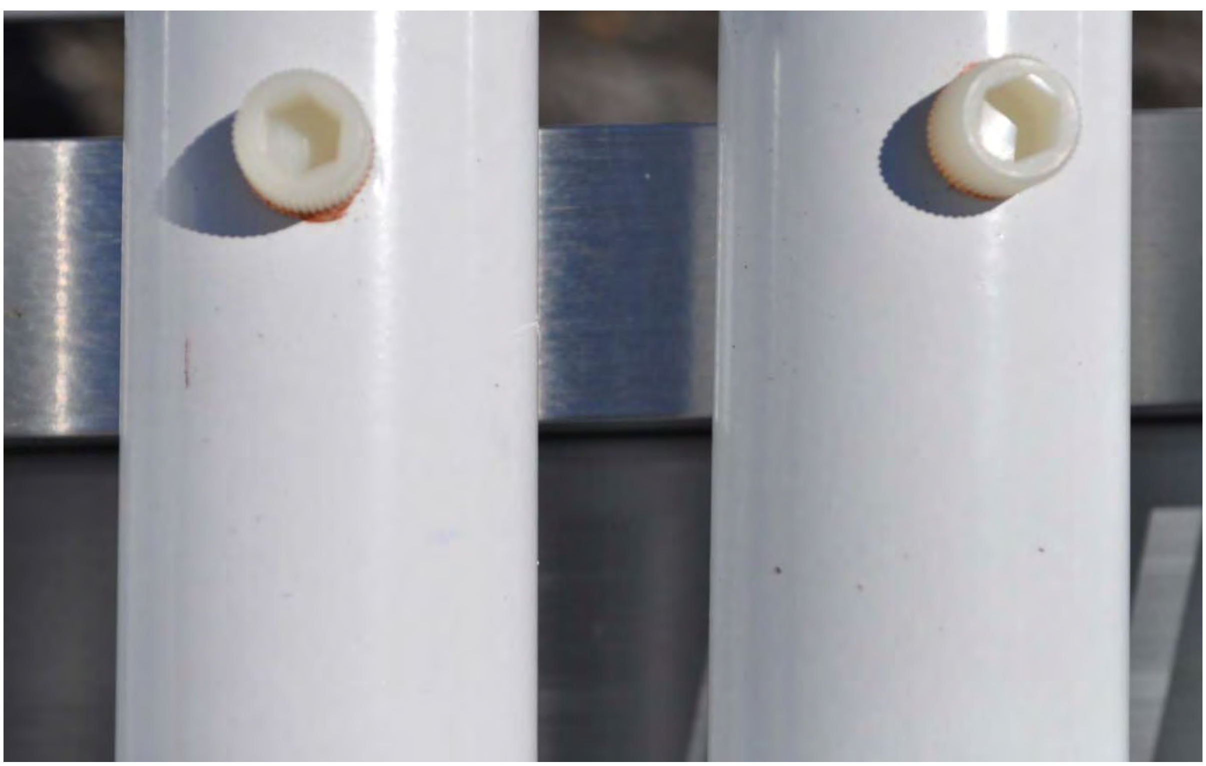


*Figure B139. Coated Steel Ra*iling Coupon

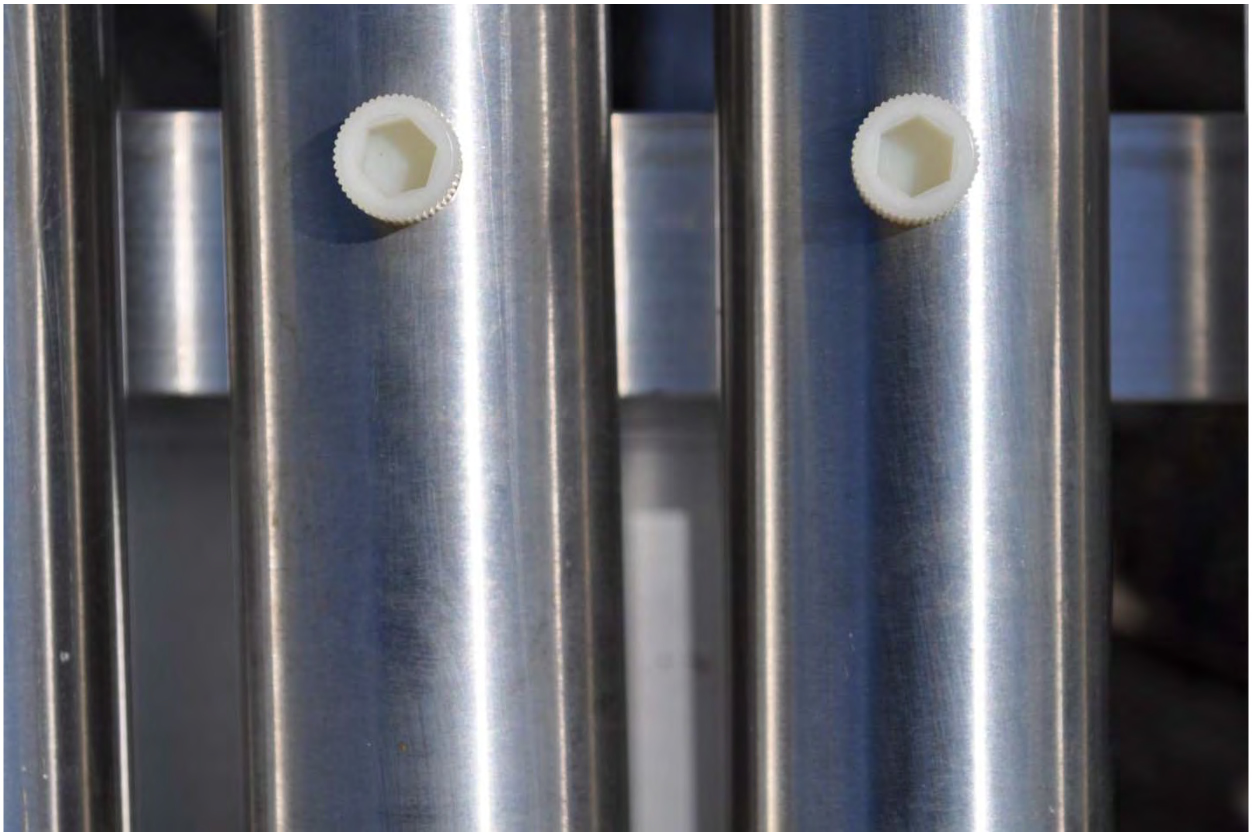


Figure B140.Stainless Steel Railing Coupon

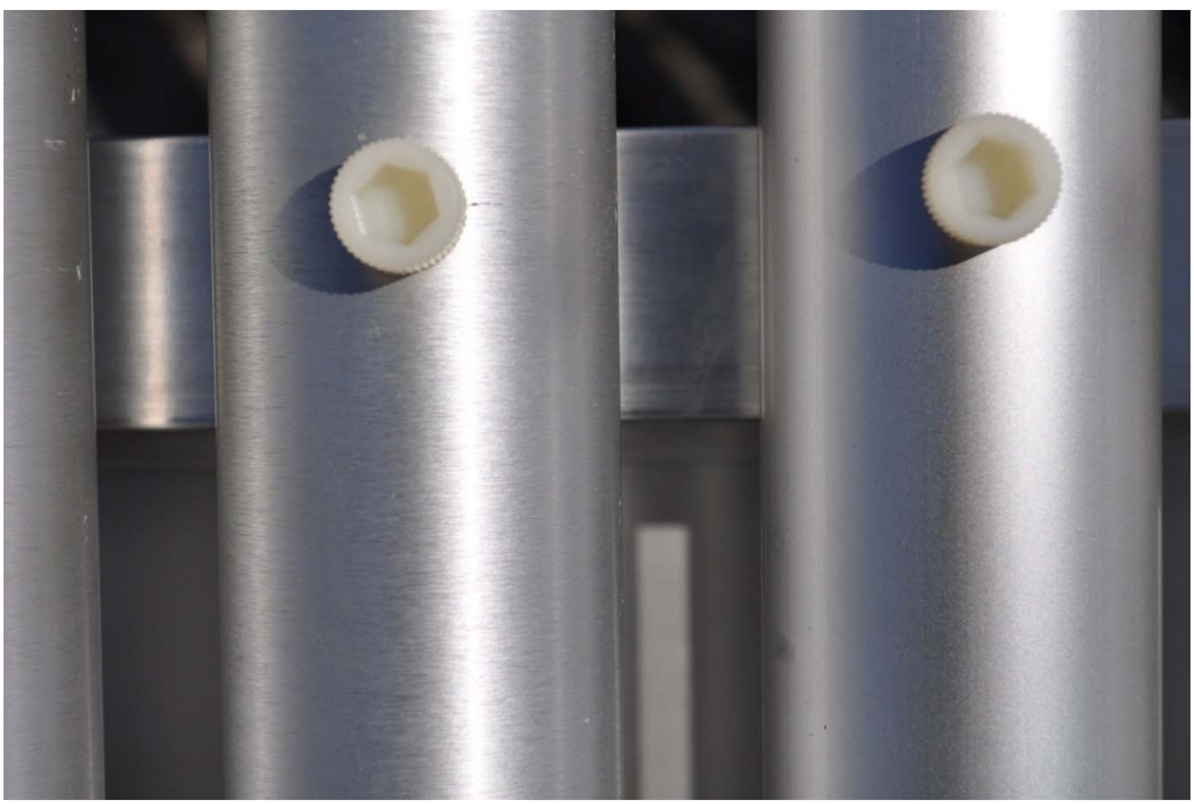


Figure B141. Aluminum Railing Coupon

Figure B142. Fuse Bonded PVC Coated Galvanized Wire Coupon

Figure B143. Aluminized Steel Wire Coupon

Figure B144. Aluminum Wire Coupon

Figure B145. Galfan Wire Coupon

Figure B146. Standard Galvanized Wire Coupon

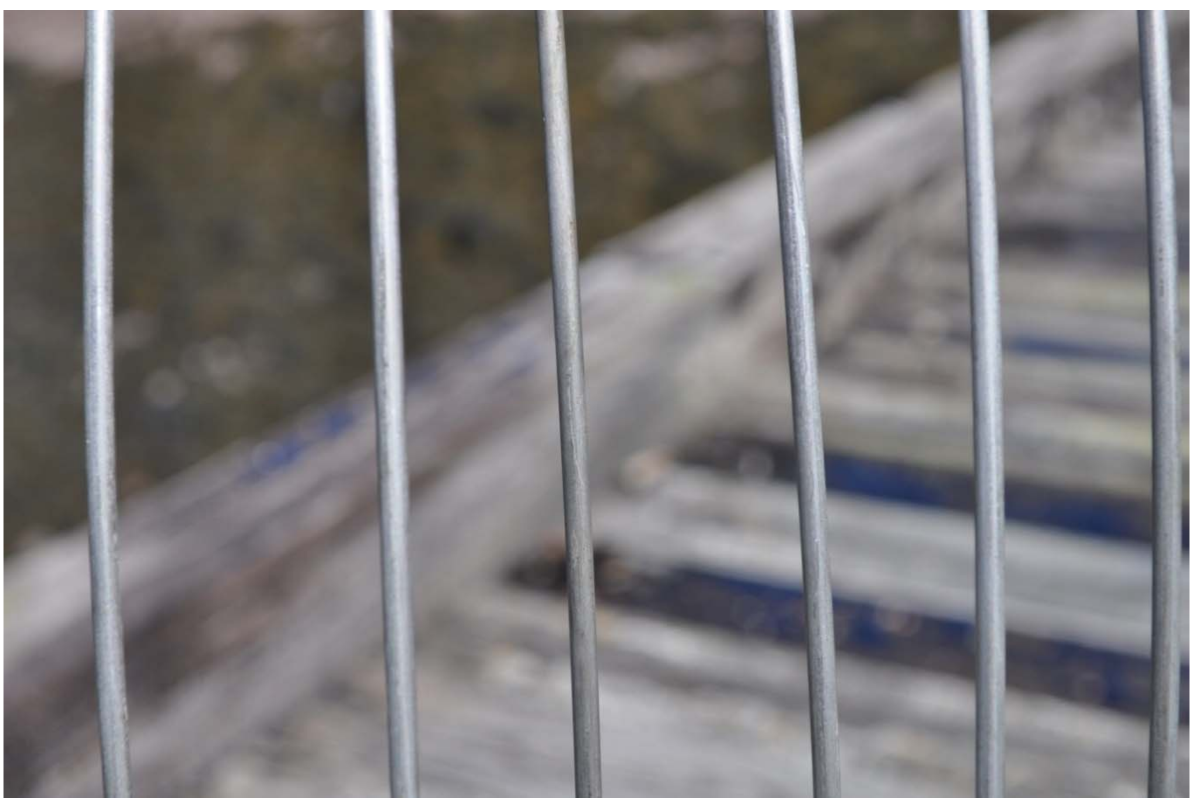


Figure B147. Stainless Steel Wire Coupon

Figure B148. Standard PVC Coated Galvanized Wire Coupon

Visual Inspection Report

Date: 7/29/2010

Location: Treat Island, ME

Exposure Period: 3 Months

	Material	% of Surface Corroded	Type of Corrosion	Notes
Fence Wire Coupons				
	Standard PVC Coated Galvanized	0%	N/A	No visible corrosion
	Fuse Bonded PVC Coated Galvanized	0%	N/A	No visible corrosion
	Standard Galvanized	0%	N/A	No visible corrosion
	Stainless Steel	<5%	Oxidation	Surface oxidation
	Aluminum	<5%	Oxidation	White corrosion product
	Galfan	0%	N/A	No visible corrosion
	Aluminized Steel	0%	N/A	No visible corrosion
Railing Coupons				
	Stainless Steel	<5%	Oxidation	Red rust spots were seen on deep scratches on the material. Otherwise no visible corrosion
	Aluminum	0%	N/A	No Visible Corrosion
	Coated Steel	<5%	Rust	Rust spots have begun to form where the coating has failed.
	FRP	0%	N/A	No visible corrosion

Figure B149. FRP Railing Coupon

Figure B150. Coated Steel Coupon

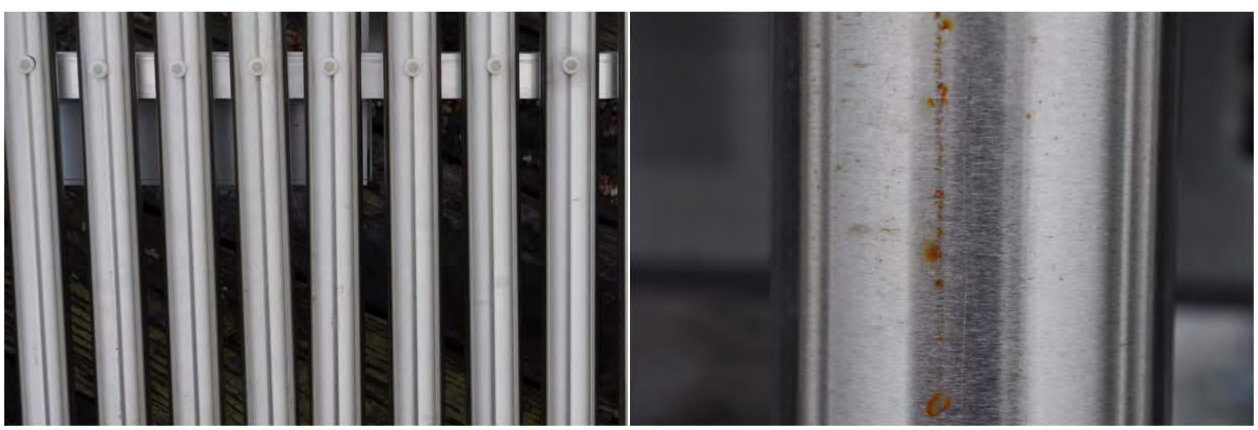


Figure B151. Stainless Steel Coupon

Figure B152. Aluminum Railing Coupon

Figure B153. Standard PVC Coated Galvanized Wire Coupon

Figure B154. Standard Galvanized Wire Coupon

Figure B155. Aluminized Steel Wire Coupon

Figure B156. Fuse Bonded PVC Coated Galvanized Wire Coupon

Figure B157. Aluminum Wire Coupon

Figure B158. Stainless Steel Wire Coupon

Figure B159. Galfan Wire Coupon

Visual Inspection Report

Date: 11/2/2010

Location: Treat Island, ME

Exposure Period: 6 Months

	Material	% of Surface Corroded	Type of Corrosion	Notes
Fence Wire Coupons				
	Standard PVC Coated Galvanized	0%	N/A	No visible corrosion
	Fuse Bonded PVC Coated Galvanized	0%	N/A	No visible corrosion
	Standard Galvanized	<5%	Oxidation	White corrosion product from oxidation of the sacrificial zinc coating.
	Stainless Steel	5%	Oxidation	Surface oxidation
	Aluminum	10%	Oxidation	White corrosion product
	Galfan	<5%	Oxidation	White corrosion product from oxidation of the sacrificial zinc coating.
	Aluminized Steel	0%	N/A	No Visible Corrosion
Railing Coupons				
	Stainless Steel	5%	Oxidation	Surface oxidation
	Aluminum	0%	N/A	No Visible Corrosion
	Coated Steel	<5%	Rust	Continued growth of Rust Spots.
	FRP	25%	UV	Discoloring due to UV exposure on the face of the railing that faces the sun

Comments:

All photo documentation for this inspection was lost due to computer theft. Weather data was stored on the logger and was recoverable at the test site.

Visual Inspection Report

Date: 2/24/2011

Location: Treat Island, ME

Exposure Period: 9 Months

	Material	% of Surface Corroded	Type of Corrosion	Notes
Fence Wire Coupons				
	Standard PVC Coated Galvanized	0%	N/A	No visible corrosion
	Fuse Bonded PVC Coated Galvanized	0%	N/A	No visible corrosion
	Standard Galvanized	5%	Oxidation	White corrosion product from oxidation of the sacrificial zinc coating.
	Stainless Steel	10%	Oxidation	Surface oxidation
	Aluminum	10%	Oxidation	White corrosion product
	Galfan	5%	Oxidation	White corrosion product from oxidation of the sacrificial zinc coating.
	Aluminized Steel	0%	N/A	No Visible Corrosion
Railing Coupons				
	Stainless Steel	10%	Oxidation	Surface oxidation
	Aluminum	0%	N/A	No Visible Corrosion
	Coated Steel	<5%	Rust	Rust spots have increased in size but causing blistering of the coating.
	FRP	25%	UV	Discoloring due to UV exposure on the face of the railing that faces the sun

Comments:

Each wire coupon had visible deposit of chlorides from the salt water environment.

Figure B160. FRP Railing Coupon

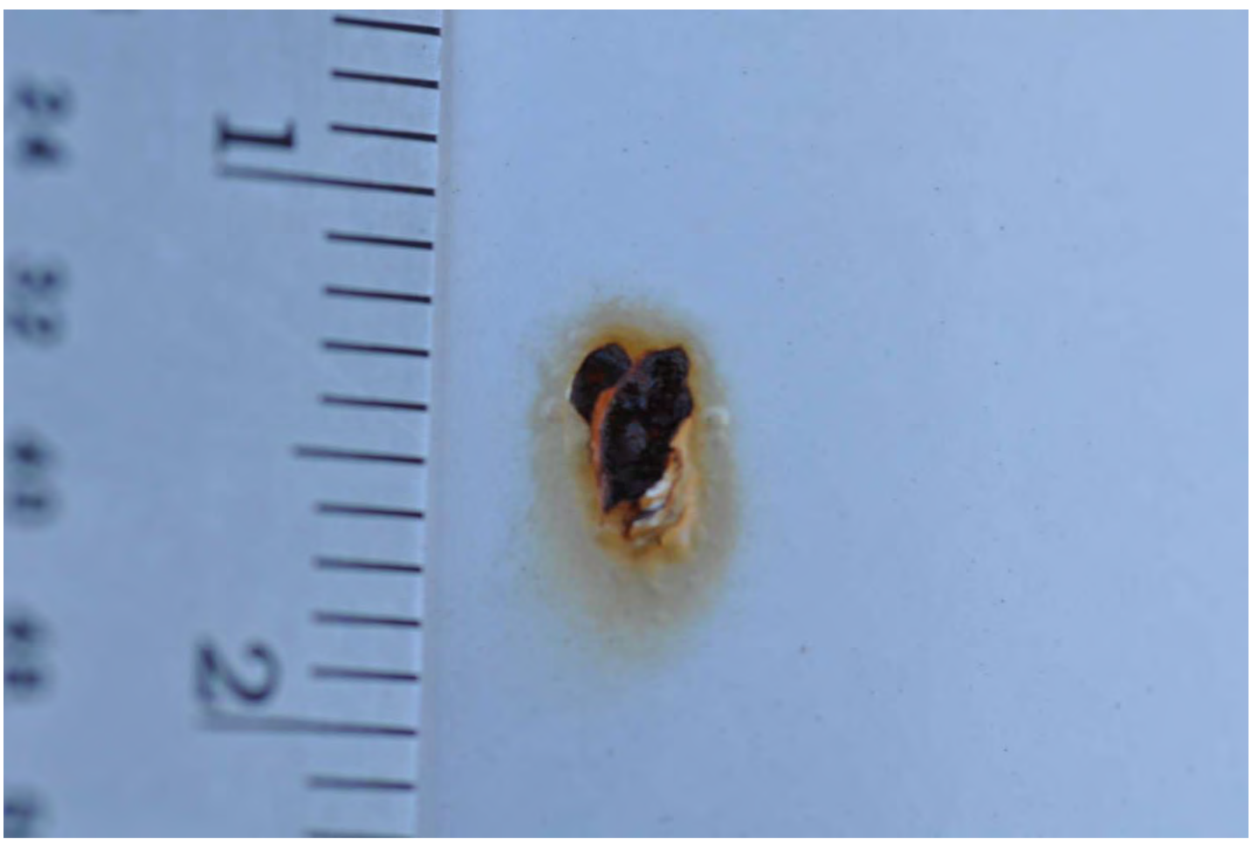


Figure B161. Coated Steel Coupon

Figure B162. Stainless Steel Coupon

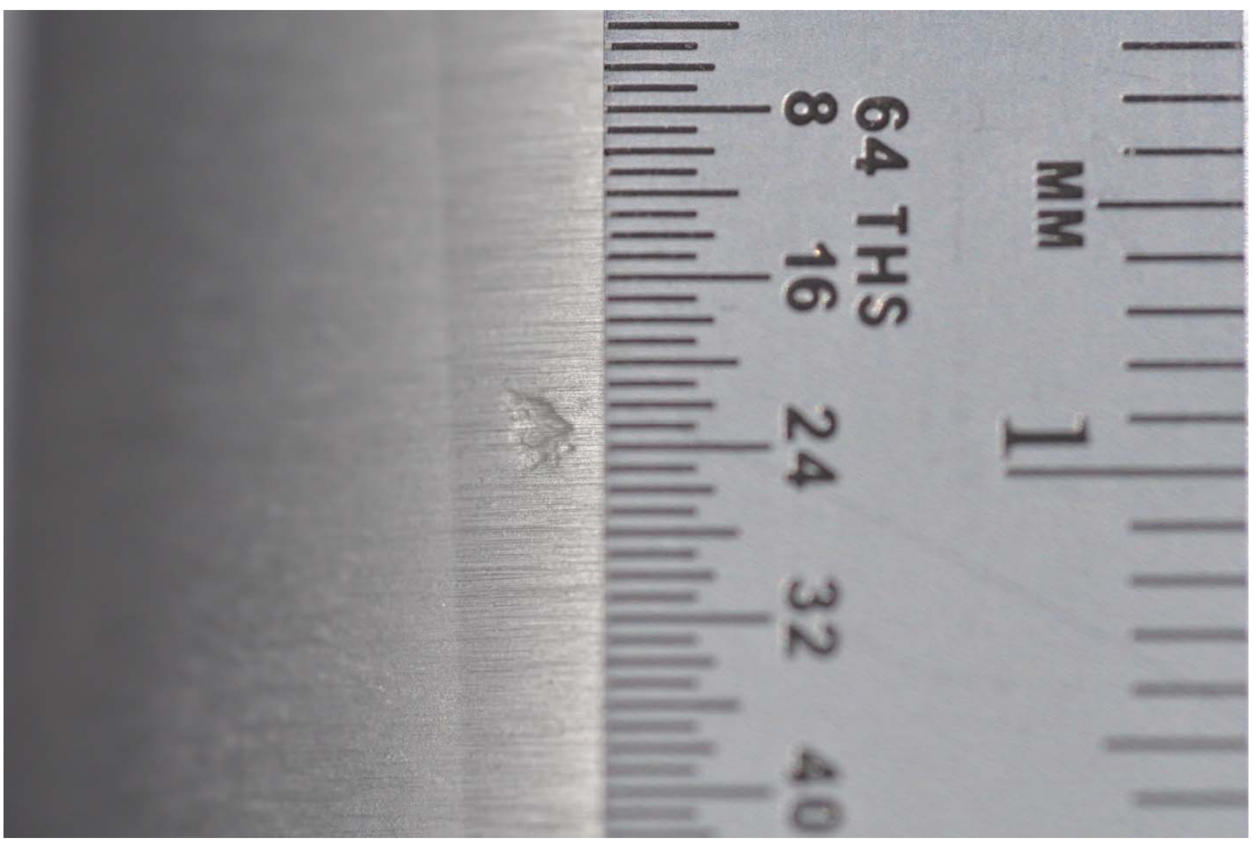


Figure B163. Aluminum Railing Coupon

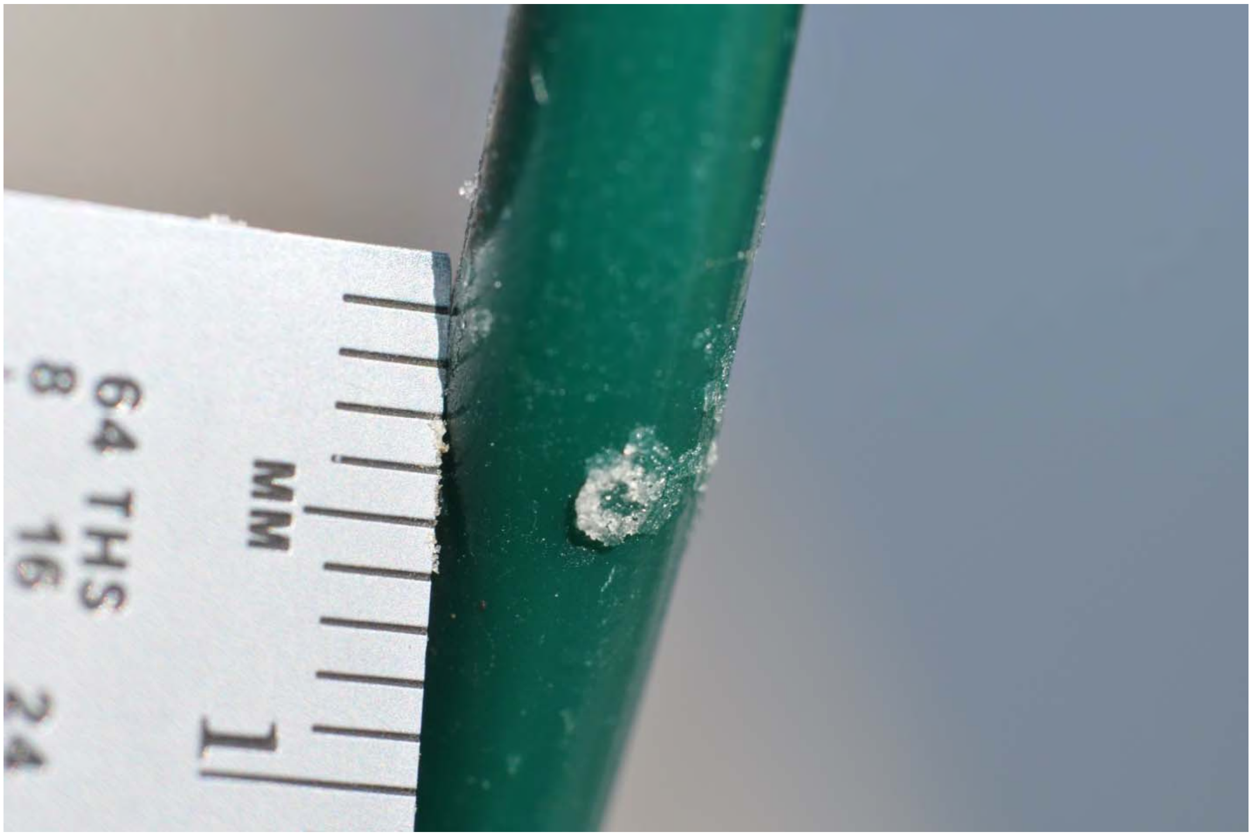


Figure B164. Standard PVC Coated Galvanized Wire Coupon

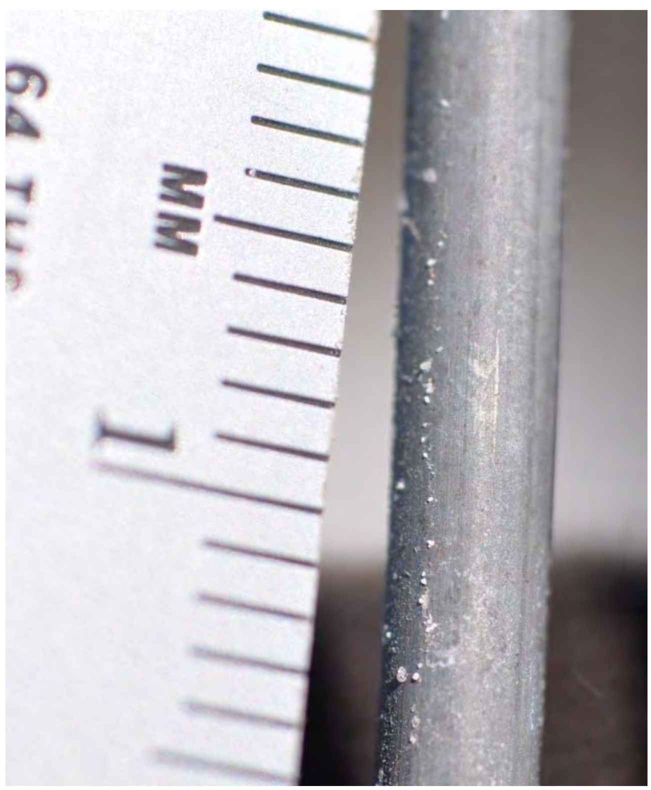


Figure B165. Standard Galvanized Wire Coupon

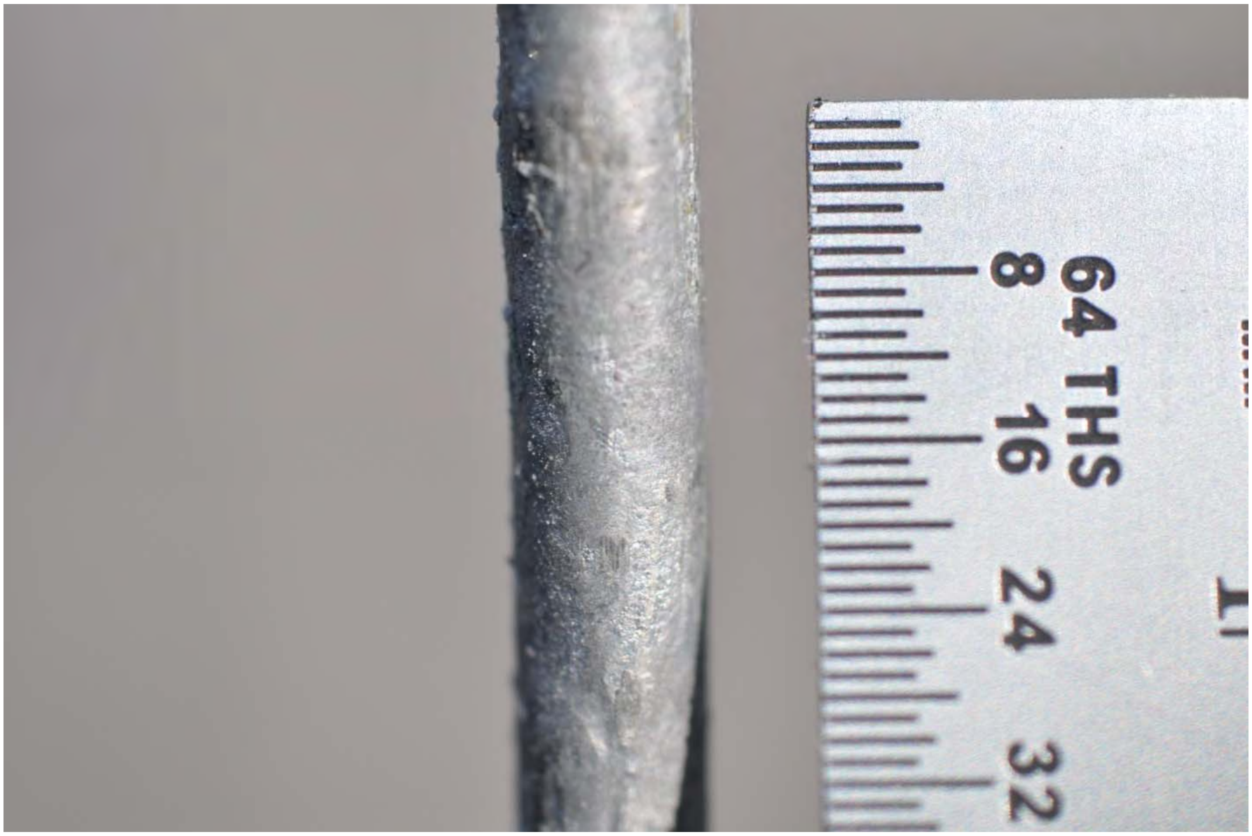


Figure B166. Aluminized Steel Wire Coupon

Figure B167. Fuse Bonded PVC Coated Galvanized Wire Coupon

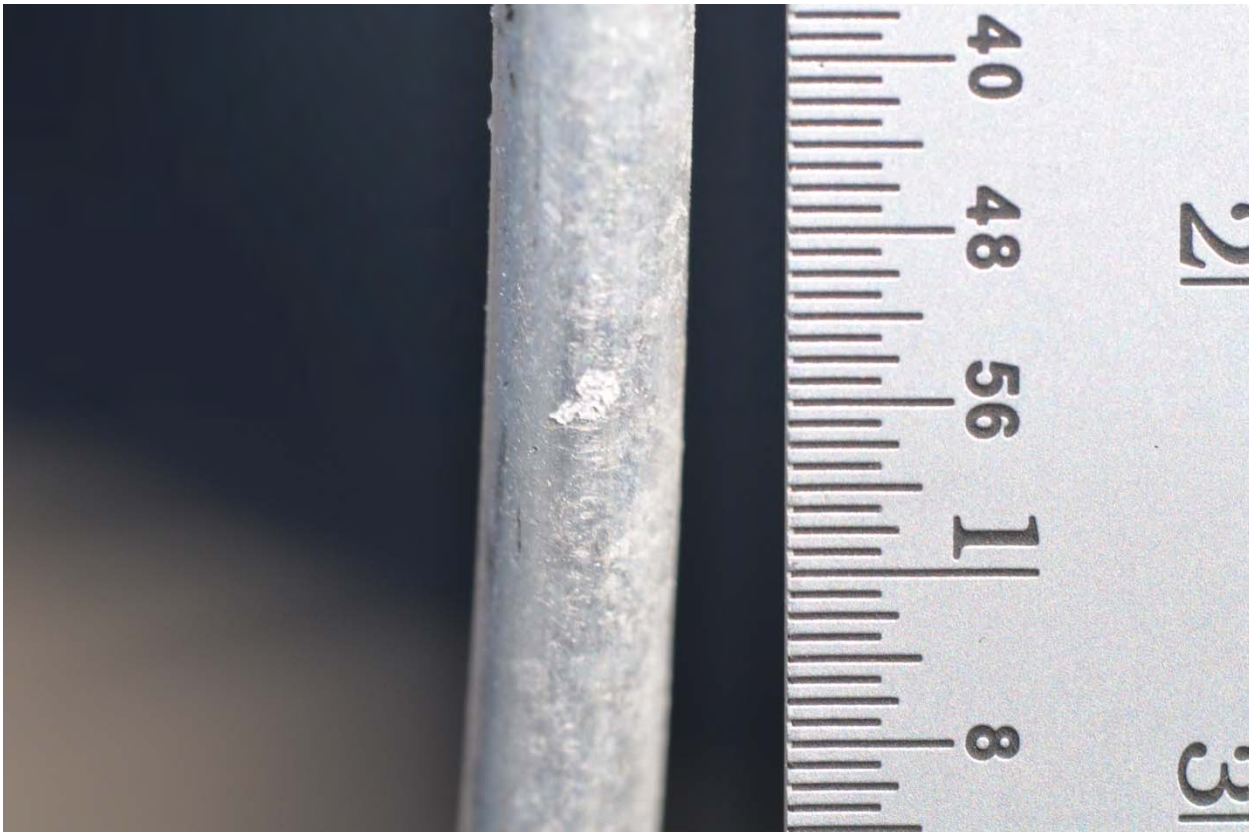


Figure B168. Aluminum Wire Coupon

Figure B169. Stainless Steel Wire Coupon

Figure B170. Galfan Wire Coupon

Visual Inspection Report

Date: 1/25/2011

Location: Treat Island, ME

Exposure Period: 12 Months

	Material	% of Surface Corroded	Type of Corrosion	Notes
Fence Wire Coupons				
	Standard PVC Coated Galvanized	0%	N/A	No visible corrosion
	Fuse Bonded PVC Coated Galvanized	0%	N/A	No visible corrosion
	Standard Galvanized	5%	Oxidation/ Rust	50% of the corrosion areas have degraded past the sacrificial zinc coating and have begun to rust.
	Stainless Steel	10%	Oxidation	Surface oxidation
	Aluminum	0%	N/A	No visible corrosion
	Galfan	5%	Oxidation/ Rust	50% of the corrosion areas have degraded past the sacrificial zinc coating and have begun to rust.
	Aluminized Steel	5%	Oxidation	White oxidation of the zinc/AL coating
Railing Coupons				
	Stainless Steel	10%	Oxidation	Surface oxidation
	Aluminum	0%	N/A	No Visible Corrosion
	Coated Steel	<5%	Rust	Rust has begun to form where the coating has failed. Discoloring of the coating due to the rust.
	FRP	25%	UV	Discoloring due to UV exposure on the face of the railing that faces the sun

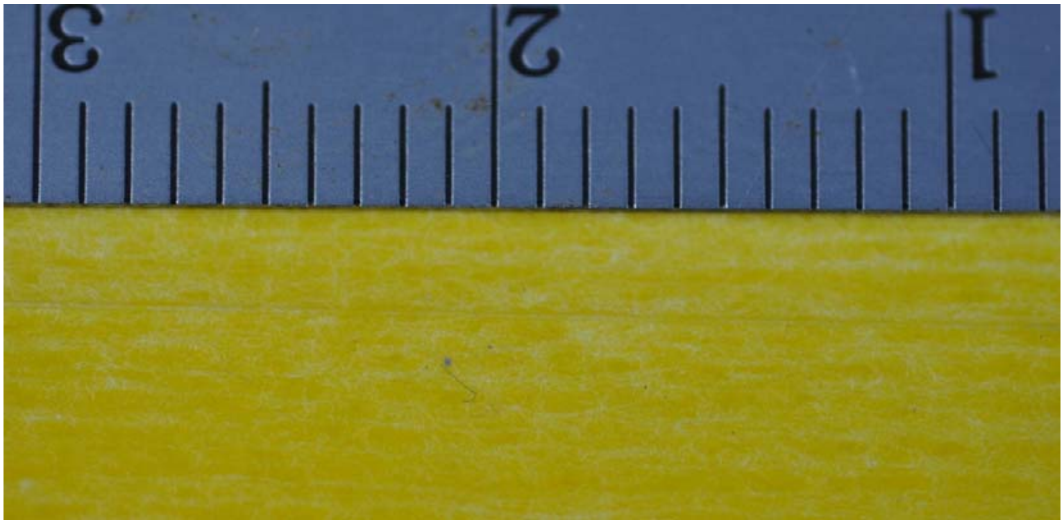


Figure B171. FRP Railing Coupon

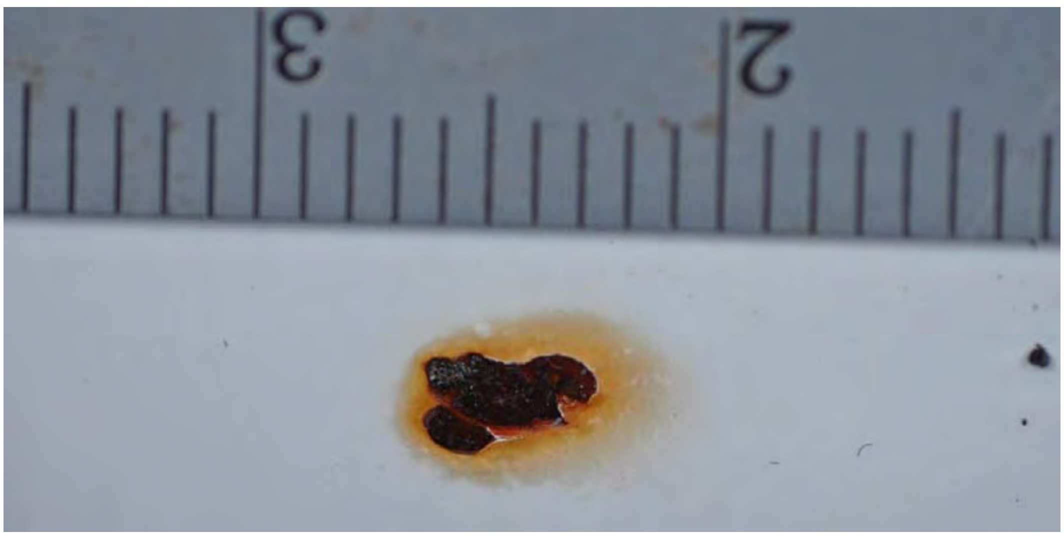


Figure B172. Coated Steel Coupon

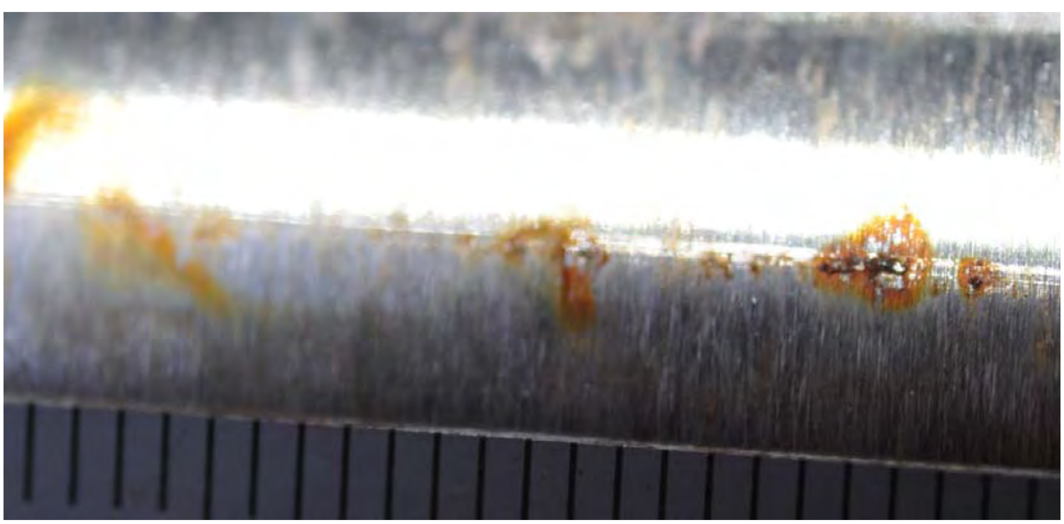


Figure B173. Stainless Steel Coupon

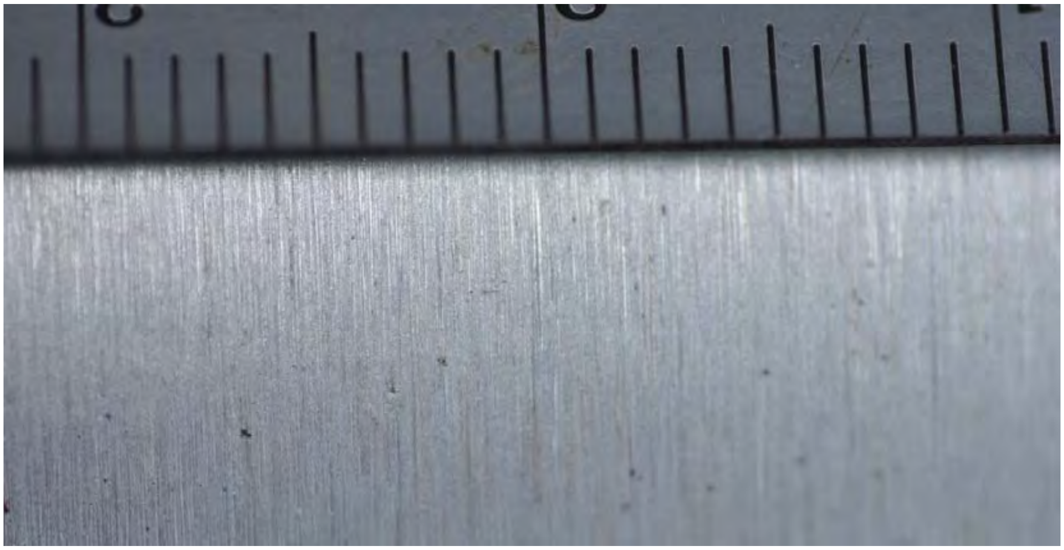


Figure B174. Aluminum Railing Coupon

Figure B175. Standard PVC Coated Galvanized Wire Coupon

Figure B176. Standard Galvanized Wire Coupon

Figure B177. Aluminized Steel Wire Coupon

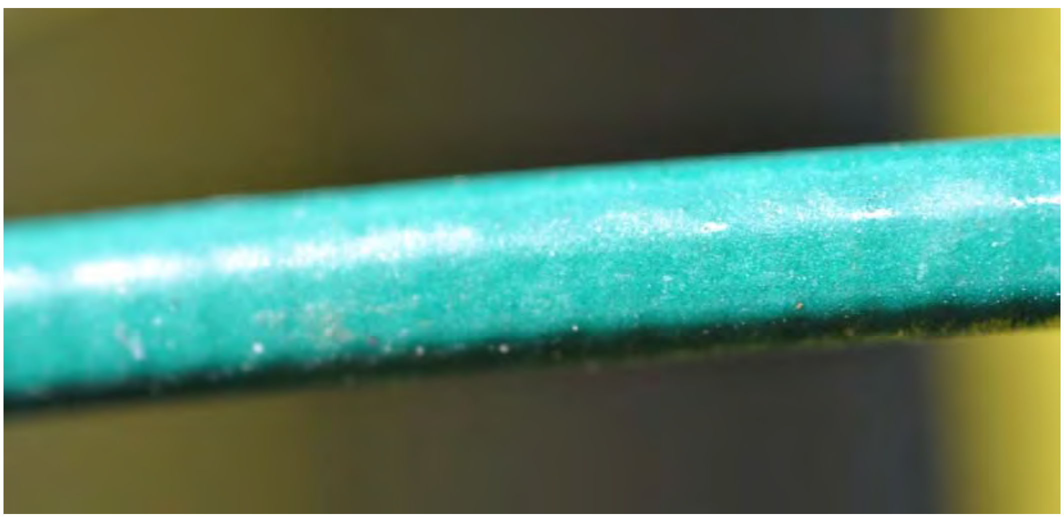


Figure B178. Fuse Bonded PVC Coated Galvanized Wire Coupon

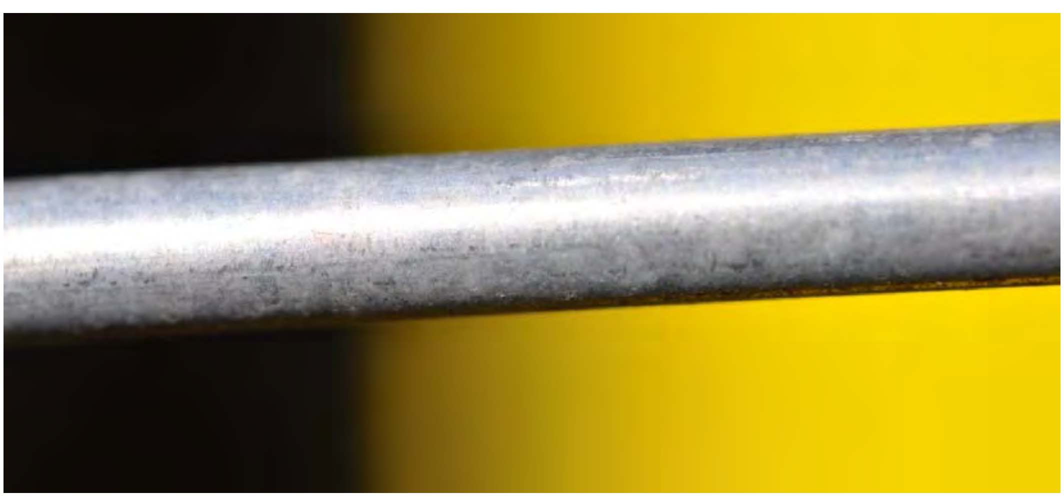


Figure B179. Aluminum Wire Coupon

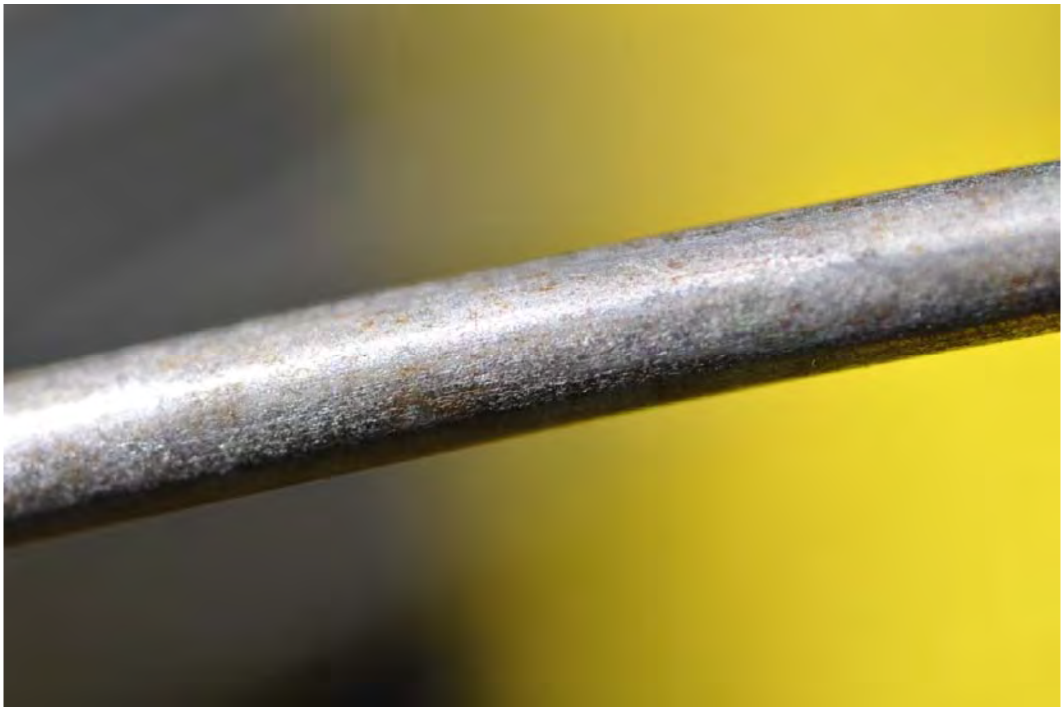


Figure B180. Stainless Steel Wire Coupon

Figure B181. Galfan Wire Coupon

Appendix C: Atmospheric Coupon Data Per ASTM G1

Treat Island, ME

	Constant	Exposure Period (hours)	Area (cm^2)	Pretest Weight (g)	Post-Test Weight (g)	Mass Loss (grams)	Density in (g/cm^3)	Corrosion Rate (mm/y)
Steel	87600	2400	23.7114	29.6088	29.30264	0.30616	7.86	0.059959993
	87600	4704	23.7114	29.07019	28.5754	0.49479	7.86	0.049439943
	87600	7440	23.7114	28.77632	28.0301	0.74622	7.86	0.047143119
	87600	9576	23.7114	30.02969	29.09859	0.9311	7.86	0.045702142
Aluminum (AL2024 T3)	87600	2400	23.7114	10.34276	10.32883	0.01393	2.78	0.007713331
	87600	4704	23.7114	10.43347	10.3976	0.03587	2.78	0.010133656
	87600	7440	23.7114	10.48157	10.4045	0.07707	2.78	0.013766215
	87600	9576	23.7114	10.22071	10.21146	0.00925	2.78	0.001283689
Aluminum (AL6061 T6)	87600	2400	23.7114	7.78889	7.78706	0.00183	2.7	0.001043333
	87600	4704	23.7114	7.87231	7.8659	0.00641	2.7	0.001864549
	87600	7440	23.7114	7.96019	7.8659	0.09429	2.7	0.017341068
	87600	9576	23.7114	7.73552	7.73092	0.0046	2.7	0.00065729
Aluminum (AL7075 T6)	87600	2400	23.7114	10.66922	10.65114	0.01808	2.81	0.009904391
	87600	4704	23.7114	10.62866	10.6011	0.02756	2.81	0.007702869
	87600	7440	23.7114	10.66577	10.6052	0.06057	2.81	0.010703486
	87600	9576	23.7114	10.55158	10.51622	0.03536	2.81	0.004854771
Copper	87600	2400	23.7114	33.20438	33.1528	0.05158	8.94	0.00888136
	87600	4704	23.7114	33.59687	33.5096	0.08727	8.94	0.007666675
	87600	7440	23.7114	33.94038	33.8154	0.12498	8.94	0.006941878
	87600	9576	23.7114	32.5908	32.42548	0.16532	8.94	0.007134288

Field Research Facility, Duck, NC.

	Constant	Exposure Period (hours)	Area (cm^2)	Pretest Weight (g)	Post-Weight (g)	Mass Loss (grams)	Density in (g/cm^3)	Corrosion Rate (mm/y)
Steel	87600	720	23.7114	28.8213	27.62842	1.19288	7.86	0.778733081
	87600	1440	23.7114	28.7786	26.03903	2.73957	7.86	0.894219781
	87600	2160	23.7114	28.9937	24.8633	4.1304	7.86	0.898799297
	87600	2880	23.7114	28.869	23.1114	5.7576	7.86	0.93966568
Aluminum (AL2024 T3)	87600	720	23.7114	9.8202	9.19692	0.62328	2.78	1.150410424
	87600	1440	23.7114	9.4333	9.31703	0.11627	2.78	0.107301871
	87600	2160	23.7114	10.013	9.2854	0.7276	2.78	0.44765254
	87600	2880	23.7114	9.2461	9.0272	0.2189	2.78	0.10100791
Aluminum (AL6061 T6)	87600	720	23.7114	9.5819	9.57136	0.01054	2.7	0.020030476
	87600	1440	23.7114	9.3258	9.31508	0.01072	2.7	0.010186276
	87600	2160	23.7114	9.7803	9.7549	0.0254	2.7	0.016090262
	87600	2880	23.7114	9.1013	9.0611	0.0402	2.7	0.019099267
Aluminum (AL7075 T6)	87600	720	23.7114	9.6942	9.58472	0.10948	2.81	0.199913849
	87600	1440	23.7114	9.4666	9.36492	0.10168	2.81	0.092835405
	87600	2160	23.7114	9.9708	9.2823	0.6885	2.81	0.419074063
	87600	2880	23.7114	9.3233	9.01404	0.30926	2.81	0.141179569
Copper	87600	720	23.7114	31.8853	31.73879	0.14651	8.94	0.084089963
	87600	1440	23.7114	31.4737	31.27698	0.19672	8.94	0.05645409
	87600	2160	23.7114	32.8941	32.7052	0.1889	8.94	0.036139954
	87600	2880	23.7114	30.0587	29.747	0.3117	8.94	0.044725346

Kahuku Training Area, Kahuku, HI.

	Constant	Exposure Period (hours)	Mass Loss (grams/cm^2)	Density in (g/cm^3)	Corrosion Rate (mm/y)
Steel	87600	2808	0.01673	7.86	0.06640188
	87600	5040	0.031743	7.86	0.07019384
	87600	7200	0.053334	7.86	0.08255687
	87600	9360	0.086519	7.86	0.10301897
Aluminum (AL2024 T3)	87600	2808	0.000936	2.78	0.0105036
	87600	5040	0.001735	2.78	0.01084746
	87600	7200	0.002342	2.78	0.01024976
	87600	9360	0.003372	2.78	0.01135196
Aluminum (AL6061 T6)	87600	2808	0.000085	2.7	0.00098211
	87600	5040	0.000185	2.7	0.00119092
	87600	7200	0.00029	2.7	0.00130679
	87600	9360	0.00041	2.7	0.00142118
Aluminum (AL7075 T6)	87600	2808	0.00052	2.81	0.00577303
	87600	5040	0.000952	2.81	0.00588849
	87600	7200	0.00142	2.81	0.00614828
	87600	9360	0.001972	2.81	0.00656794
Copper	87600	2808	0.004352	8.94	0.01518652
	87600	5040	0.008578	8.94	0.01667716
	87600	7200	0.013064	8.94	0.01777912
	87600	9360	0.01906	8.94	0.01995325

* Atmospheric data gather from this site was supplied by Battelle.

Appendix D: Tensile Testing Results

Fence wire tensile test at time zero in (lbf).

	Aluminum Alloy	Alum Z	Galvanized	Galfan	Stainless Steel	Fused Bonded	Standard PVC
1	908.6	1656.1	843.8	839.7	1522.3	1489.3	1529.7
2	918.3	1667.7	841.5	841.1	1520.8	1483.7	1530.2
3	907.5	1658	832.2	836.3	1515.5	1479.9	1508.5
4	917.6	1641.9	838.5	832.5	1527.8	1469.5	1515.2
5	907.1	1666.2	844.9	838.5	1521.6	1469.9	1544.1
Average	**911.8**	**1658**	**840.2**	**837.6**	**1521.6**	**1483.9**	**1525.5**

Six-month tensile tests

KTA fence wire tensile test after 183 days exposure (lbf).

	Aluminum Alloy	Alum Z	Galvanized	Galfan	Stainless Steel	Fused Bonded	Standard PVC
1	879	1618	850	836	1529	1514	1495
2	912	1630	844	835	1522	1517	1492
3	907	1618	855	825	1520	1508	1504
4	911	1614	837	837	1518	1493	1521
5	905	1628	844	834	1527	1526	1517
Average	**903**	**1621**	**846**	**833**	**1523**	**1512**	**1506**

FRF fence wire tensile test after 184 days exposure (lbf).

	Aluminum Alloy	Alum Z	Galvanized	Galfan	Stainless Steel	Fused Bonded	Standard PVC
1	908	1617	843	868	1618	1544	1488
2	918	1622	846	862	1589	1525	1418
3	910	1630	849	858	1600	1530	1449
4	916	1624	843	853	1609	1465	1467
5	907	1606	855	871	1614	1508	1479
Average	**912**	**1620**	**847**	**862**	**1606**	**1514**	**1460**

Treat Island fence wire tensile test after 196 days exposure (lbf).

	Aluminum Alloy	Alum Z	Galvanized	Galfan	Stainless Steel	Fused Bonded	Standard PVC
1	914	1622	869	863	1541	1546	1534
2	921	1635	857	857	1549	1548	1526
3	923	1636	859	852	1543	1515	1533
4	925	1636	862	853	1531	1549	1524
5	918	1632	861	864	1539	1533	1518
Average	**920**	**1632**	**862**	**858**	**1541**	**1538**	**1527**

Twelve-month tensile tests

KTA fence wire tensile test after 377 days exposure (lbf).

	Aluminum Alloy	Alum Z	Galvanized	Galfan	Stainless Steel	Fused Bonded	Standard PVC
1	906	1628	833	833	1555	1518	1507
2	907	1623	839	834	1549	1478	1482
3	903	1644	852	830	1563	1483	1525
4	903	1620	844	829	1549	1478	1510
5	918	1620	841	845	1559	1467	1501
Average	**907**	**1632**	**822**	**834**	**1545**	**1485**	**1505**

FRF fence wire tensile test after 372 days exposure (lbf).

	Aluminum Alloy	Alum Z	Galvanized	Galfan	Stainless Steel	Fused Bonded	Standard PVC
1	900	1626	835	858	1587	1475	1505
2	897	1604	834	831	1580	1444	1492
3	903	1617	832	852	1583	1440	1550
4	901	1616	841	837	1586	1453	1540
5	905	1609	831	835	1576	1462	1496
Average	**901**	**1614**	**835**	**842**	**1582**	**1455**	**1516**

Treat Island fence wire tensile test after 399 days exposure (lbf).

	Aluminum Alloy	Alum Z	Galvanized	Galfan	Stainless Steel	Fused Bonded	Standard PVC
1	894	1608	830	854	1550	1516	1534
2	896	1595	832	843	1560	1505	1514
3	890	1583	852	840	1551	1496	1528
4	897	1609	837	842	1552	1508	1544
5	908	1610	843	838	1553	1511	1505
Average	**897**	**1601**	**839**	**843**	**1553**	**1507**	**1525**

Appendix E: Flexure Testing Results

Fence railing flexure test at time zero.

	Yield Stress [psi]	Yield Deflection [in.]	Ultimate load [lbf]	Ultimate Stress [psi]	Ultimate Deflection [in.]	Tangent Modulous [psi]
Aluminum						
1	24055	0.36	1313	29656	1.71	5233226
2	16501	0.24	1058	23981	2.01	5487146
3	13159	0.21	987	22014	1.55	5416742
4	20271	0.33	1283	27521	1.77	5242484
5	25175	0.38	1434	31667	1.30	5425309
Avg	**19832**	**0.30**	**1215**	**26968**	**1.87**	**5360981**
Steel						
1	37790	0.24	2261	52580	0.63	15266744
2	36736	0.24	2246	51568	0.63	15833664
3	38953	0.25	2258	52510	0.65	15041398
4	40166	0.24	2413	57863	0.66	18742377
5	36828	0.24	2243	52447	0.65	15506952
Avg	**38095**	**0.24**	**2284**	**53394**	**0.64**	**16078227**
Stainless Steel						
1	47648	0.30	3075	73514	1.92	17141627
2	46757	0.24	3123	74502	1.86	17807334
3	43997	0.25	2909	71105	1.40	17813171
4	42655	0.23	3043	69973	1.90	17030075
5	41093	0.25	3034	69847	1.68	17410412
Avg	**44430**	**0.25**	**3037**	**71788**	**1.75**	**17440524**
FRP						
1	9486	0.30	863	18192	0.71	2015635
2	10917	0.34	967	20499	0.67	2054027
3	9469	0.33	835	17571	0.71	1833304
4	9825	0.31	925	19337	0.66	1997536
5	7312	0.26	1050	22254	0.86	1831718
Avg	**9402**	**0.31**	**928**	**19571**	**0.72**	**1946444**

Six-month flexure testing

FRF railing flexure test after 184 days exposure.

	Yield Stress [psi]	Yield Deflection [in.]	Ultimate load [lbf]	Ultimate Stress [psi]	Ultimate Deflection [in.]	Tangent Modulous [psi]
Aluminum						
1	12146	0.19	1091	24448	3.24	5497919
2	13021	0.19	1133	25525	3.51	5658112
3	12682	0.19	1144	25101	3.42	5552841
4	12796	0.19	1142	25283	3.46	5640870
5	26210	0.40	1489	32795	1.35	5265854
Avg	**15371**	**0.23**	**1200**	**26630**	**3.00**	**5523119**
Steel						
1	38845	0.28	2188	50590	0.66	14671726
2	39645	0.29	2236	49662	0.69	13722251
3	39773	0.29	2189	48775	0.60	14589425
4	38515	0.28	2194	49272	0.69	14086956
5	37930	0.28	2449	49148	0.66	15387103
Avg	**38942**	**0.28**	**2251**	**49490**	**0.66**	**14491492**
Stainless Steel						
1	49461	0.30	3016	72239	1.38	16924712
2	50269	0.30	3092	75270	2.04	16849524
3	48933	0.31	2837	68385	2.14	15841088
4	50210	0.31	3058	74355	1.38	16821051
5	49377	0.30	3056	73073	2.08	16648824
Avg	**49650**	**0.30**	**3012**	**72664**	**1.80**	**16617040**
FRP						
1	10655	0.34	937	19576	0.68	1942857
2	10619	0.34	878	18282	0.63	1948323
3	10141	0.32	840	17384	0.70	1906118
4	10648	0.38	934	19501	0.79	1671405
5	10815	0.35	913	18989	0.70	1907431
Avg	**10576**	**0.35**	**900**	**18746**	**0.70**	**1875227**

KTA railing flexure test after 183 days exposure.

	Yield Stress [psi]	Yield Deflection [in.]	Ultimate load [lbf]	Ultimate Stress [psi]	Ultimate Deflection [in.]	Tangent Modulous [psi]
Aluminum						
1	22595	0.34	1364	31131	1.77	5288159
2	13181	0.21	1067	23440	4.00	5340789
3	13078	0.19	1062	23742	2.56	5694101
4	13070	0.20	1047	23676	2.08	5641397
5	20086	0.30	1305	29855	1.74	5466735
Avg	**16402**	**0.30**	**1169**	**26369**	**2.43**	**5486236**
Steel						
1	44367	0.27	2458	59593	0.84	18210043
2	37620	0.26	2178	51532	0.67	14935344
3	36764	0.27	2153	49781	0.71	14026213
4	42481	0.26	2411	58863	0.82	18347510
5	38391	0.27	2131	50501	0.70	14376027
Avg	**39925**	**0.24**	**2266**	**54054**	**0.75**	**15979027**
Stainless Steel						
1	48764	0.31	2802	68489	2.22	17317268
2	49978	0.32	3087	74713	2.03	16710043
3	51880	0.31	3087	76264	1.34	17056969
4	50059	0.32	2931	71642	1.60	15744520
5	49509	0.32	3054	73828	2.08	16681792
Avg	**50038**	**0.32**	**2992**	**72988**	**1.85**	**16702122**
FRP						
1	9761	0.37	900	17928	0.72	1692682
2	10084	0.34	851	17513	0.60	1945297
3	10351	0.38	831	16866	0.66	1733523
4	10301	0.39	929	18950	0.74	1694468
5	10661	0.36	923	19106	0.68	1889379
Avg	**10232**	**0.37**	**887**	**18073**	**0.68**	**1791070**

Treat Island railing flexure test after 196 days exposure.

	Yield Stress [psi]	Yield Deflection [in.]	Ultimate load [lbf]	Ultimate Stress [psi]	Ultimate Deflection [in.]	Tangent Modulous [psi]
Aluminum						
1	12347	0.19	1078	23982	3.46	5611364
2	12296	0.19	1100	23729	3.06	5491509
3	12829	0.19	1123	25276	3.56	5674002
4	13864	0.20	1175	25256	2.43	5325732
5	32828	0.46	1659	41733	1.17	5796667
Avg	**16833**	**0.25**	**1227**	**27995**	**2.74**	**5579855**
Steel						
1	39347	0.22	2166	48980	0.56	13302289
2	40699	0.23	2309	51351	0.62	15118780
3	38683	0.20	2264	52130	0.58	16079196
4	42458	0.17	2428	56332	0.59	18258848
5	47826	0.20	2481	59941	0.52	20237178
Avg	**41805**	**0.20**	**2330**	**53747**	**0.57**	**16599258**
Stainless Steel						
1	46791	0.24	3006	65880	1.71	15802289
2	47043	0.25	3109	72047	1.65	16273926
3	49102	0.25	3086	74644	1.81	16265890
4	44959	0.23	3048	71187	1.73	16010338
5	44780	0.20	3156	74776	1.58	17822116
Avg	**46525**	**0.23**	**3081**	**71707**	**1.70**	**16434912**
FRP						
1	10727	0.36	960	20193	0.72	1942227
2	9128	0.28	938	19027	0.67	2042011
3	9619	0.34	969	19419	0.74	1829115
4	9770	0.32	939	19113	0.67	1739950
5	9414	0.30	911	18644	0.63	2075865
Avg	**9732**	**0.32**	**943**	**19279**	**0.69**	**1925833**

Twelve-month flexure testing

Duck, NC railing flexure test after 372 days exposure.

	Yield Stress [psi]	Yield Deflection [in.]	Ultimate load [lbf]	Ultimate Stress [psi]	Ultimate Deflection [in.]	Tangent Modulous [psi]
Aluminum						
1	16951	0.25	1346	29825	2.04	5356686
2	11619	0.17	1075	23792	2.73	5588181
3	17094	0.25	1381	30266	2.07	5458878
4	13248	0.19	1106	24420	3.06	5791606
5	14793	0.23	1089	24408	3.08	5254831
Avg	**14741**	**0.22**	**1199**	**26542**	**2.60**	**5490036**
Steel						
1	33468	0.19	2174	45761	0.62	13818623
2	33353	0.19	2182	45771	0.64	13996476
3	35994	0.20	2214	46603	0.62	13818623
4	34731	0.19	2178	45846	0.58	14296214
5	33982	0.20	2103	44114	0.64	13611631
Avg	**34306**	**0.19**	**2170**	**45619**	**0.62**	**13908313**
Stainless Steel						
1	45293	0.23	2911	72048	1.32	16540490
2	51047	0.22	3114	76792	1.35	18483489
3	49527	0.22	3086	75477	2.16	18082967
4	44094	0.19	3073	73443	2.13	18239228
5	48507	0.25	2880	69503	2.04	15481364
Avg	**47694**	**0.22**	**3013**	**73452**	**1.80**	**17365508**
FRP						
1	9166	0.26	791	16479	0.59	2169721
2	10500	0.34	907	19047	0.62	2003830
3	10416	0.34	980	20416	0.61	1994592
4	10740	0.33	966	20342	0.68	2059473
5	10399	0.34	947	1950	0.59	1978219
Avg	**10244**	**0.32**	**918**	**19156**	**0.62**	**2041167**

Kahuku, HI railing flexure test after 377 days exposure.

	Yield Stress [psi]	Yield Deflection [in.]	Ultimate load [lbf]	Ultimate Stress [psi]	Ultimate Deflection [in.]	Tangent Modulous [psi]
Aluminum						
1	13733	0.23	1074	23982	2.24	5327498
2	18993	0.29	1307	29033	1.96	5403376
3	16281	0.25	1211	27384	2.43	5500585
4	16137	0.25	1171	26246	2.01	5350181
5	14548	0.23	1138	25667	2.63	5386846
Avg	**15938**	**0.25**	**1180**	**26463**	**2.25**	**5393697**
Steel						
1	40877	0.28	2208	51871	0.74	14798334
2	40172	0.28	2184	51307	0.65	14642543
3	40000	0.27	2271	54072	0.65	16603984
4	40601	0.28	2282	54182	0.66	15636452
5	38183	0.26	2237	51767	0.66	15941200
Avg	**39967**	**0.27**	**2236**	**52640**	**0.67**	**15524503**
Stainless Steel						
1	50896	0.32	2921	71819	2.09	16450820
2	48812	0.30	3083	74318	2.10	17711678
3	50553	0.30	2895	71391	2.24	17860493
4	50746	0.31	3061	75040	2.25	18144224
5	49589	0.31	2828	70828	2.25	17526321
Avg	**50119**	**0.31**	**2958**	**71707**	**2.19**	**17538707**
FRP						
1	9890	0.33	840	17676	0.66	1995754
2	9753	0.30	888	18427	0.62	2119980
3	10196	0.35	950	19373	0.73	1892390
4	9990	0.34	968	20147	0.74	1915170
5	9931	0.36	994	20145	0.74	1865114
Avg	**9952**	**0.34**	**928**	**19154**	**0.70**	**1957682**

Treat Island, ME railing flexure test after 399 days exposure.

	Yield Stress [psi]	Yield Deflection [in.]	Ultimate load [lbf]	Ultimate Stress [psi]	Ultimate Deflection [in.]	Tangent Modulous [psi]
Aluminum						
1	13029	0.15	1107	22362	3.8	5265486
2	16176	0.22	1202	27580	3.29	6024805
3	16589	0.26	1222	26500	2.3	5146759
4	11836	0.17	1128	24724	3.28	5743288
5	14683	0.20	1204	27408	2.01	5699306
Avg	**14463**	**0.20**	**1173**	**25715**	**2.94**	**5575929**
Steel						
1	42479	0.22	2283	52139	0.69	15032388
2	40041	0.21	2283	52537	0.69	15823481
3	38702	0.21	2289	50915	0.69	14602348
4	44248	0.21	2464	56785	0.87	16557673
5	43021	0.23	2293	53036	0.68	15184327
Avg	**41698**	**0.22**	**2322**	**53082**	**0.72**	**15440043**
Stainless Steel						
1	45271	0.22	3149	70399	2.01	16552168
2	54025	0.24	2993	75914	2.07	17620721
3	44229	0.27	3199	61839	1.96	12777778
4	44480	0.22	3072	66268	2.22	15979688
5	48226	0.24	3164	72660	1.42	16177973
Avg	**47246**	**0.24**	**3115**	**69416**	**1.94**	**15821666**
FRP						
1	9528	0.31	853	16587	0.60	1977299
2	10445	0.33	977	19625	0.70	2023738
3	11511	0.40	929	19096	0.76	1886172
4	9949	0.32	810	16789	0.64	1979137
5	10580	0.32	946	19624	0.69	2118332
Avg	**10403**	**0.34**	**903**	**18344**	**0.68**	**1996936**

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14. ABSTRACT

Standard galvanized steel chain-link fencing, including products coated with polyvinyl chloride (PVC), can severely corrode in as little as 5 years in coastal locations where the atmosphere is warm, humid, and infused with chlorides. This problem affects fencing needed to secure military equipment, supplies, and buildings. Painted and galvanized-steel safety railings also can severely corrode in those environments, creating personal-safety hazards. This report describes a study that assessed several alternative corrosion-resistant materials for fencing and railings using atmospheric exposure coupons and full-scale installations. The research design compares the performance of the alternative and conventional materials to identify those that may reduce the Army's corrosion prevention and control costs. Tested materials included fuse-bonded PVC, galvanized steel, stainless steel, aluminized steel, a proprietary material called Galfan®, aluminum alloys, and fiber-reinforced polymer (FRP) composites. The test exposure sites were Kahuku, HI; Duck, NC; and Treat Island, ME.

The report provides cost justification for using specified corrosion-resistant fencing and railing materials that have a higher first cost than standard materials. The project return on investment using fuse-bonded fencing and anodized aluminum railings was calculated at 6.13; using fuse-bonded fencing and FRP composite railings instead of anodized aluminum railings, the calculated project ROI is 5.75.

15. SUBJECT TERMS
Corrosion Prevention and Control Program (CPC); alternative materials; cost savings; return on investment; corrosive environments

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