Materials Science Corrosion Internship Overview

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Abstract

The overarching purpose of this semester-long internship at the National Aeronautics and Space Administration's (NASA) John F. Kennedy Space Center (KSC) was to study the impacts of corrosion regarding the development of ground support equipment (GSE), launch support structures, and flight hardware in aid of the Space Launch System (SLS) and Orion program. Environmental corrosion is known as one of the largest material degradation issues for any structure comprised of metal on the Space Coast and requires the initiation of special protective measures for proper corrosion mitigation. The four (4) projects to be described were conducted with NASA Civil Servants and NASA Contractors who provided necessary resources to ensure the highest quality of data acquisition and knowledge transfer. The main objective shared between all four (4) of the following projects was to assess the modes by which corrosion takes place in multiple environments as well as the methods by which these modes of corrosion can be reduced for the enhancement of the mechanical, structural, and chemical compatibility of those respective environments with different candidate metals. A multitude of test methods were performed over the duration of this internship to assess the corrosive properties of these different candidate metals.

Nomenclature

ACL	= Applied Chemistry Laboratory
ASST	= Alternating Seawater Spray Test
ASTM	= American Society of Testing and Materials
CCT	= Cyclic Corrosion Testing
CM	= Crew Module
CPP	= Cyclic Potentiodynamic Polarization
DoD	= Department of Defense
ECLSS	= Environmental Control and Life Support System
EM-2	= Exploration Mission 2
ESC	= Engineering Services Contract
GSDO	= Ground Systems Development and Operations
GSE	= Ground Support Equipment
IVA	= Intra-Vehicular Activity
JSC	= Lyndon B. Johnson Space Center
KSC	= John F. Kennedy Space Center
LC-39B	= Launch Complex 39B
LETF	= Launch Equipment Test Facility
µm	= microns
mbar	= millibar
NASA	= National Aeronautics and Space Administration
NE	= Engineering Directorate
NIFS	= NASA Interns, Fellows, and Scholars

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NLT	= No Later Than
OCSS	= Orion Crew Survival System
SCE	= Saturated Calomel Electrode
SLF	= Shuttle Landing Facility
SLS	= Space Launch System
SS	= Stainless Steel
UNS	= Unified Numbering System
UV	= Ultraviolet
VAB	= Vehicle Assembly Building

I. Introduction

The projects enumerated in this report are directly representative of the work that was completed during this internship as a NIFS intern for NASA KSC. The four (4) projects that were completed during this internship included the *Corrosion Technology Laboratory Website Redesign Project*, *Timescale Correlation between Marine Atmospheric Exposure and Accelerated Corrosion Testing Project*, *Cyclic Potentiodynamic Polarization (CPP) Testing Project,* and *Plasma Passivation Testing on Stainless Steel (SS) Project.* Due to the intensity of these projects as well as the depth and breadth of knowledge that I have received during the fulfillment of project tasks and assignments, I have included all relevant information to the best of my ability and have made great strides towards making this dream a reality.

II. Objectives, Methods, and Findings

A. Corrosion Technology Laboratory Website Redesign Project

The *Corrosion Technology Laboratory Website Redesign Project* was originally meant to improve the overall compatibility and user-friendliness of the website's interface which includes the development of prototypes of certain website design features such as an interactive historical timeline and interactive map of the KSC corrosion test sites. Once these features are created, they will ultimately serve to enhance the user experience of the website as a whole. The current version of the Corrosion Technology Laboratory website provides a multitude of useful information pertaining to corrosion analysis of different materials (metals and their respective alloys) under the effects of the intensive salt content of the coastal marine environment as well as the acidic rocket exhaust (composed of alumina with hydrochloric acid). Although this website contains extremely valuable information, it does not necessarily contain the most up-to-date information. This indication of much needed improvement strongly prompted the development of a new web interface.

This project aligns with the goals of the NE-L4 organization at NASA KSC by introducing accurate and up-to-date corrosion data to those who are interested in obtaining this data for their own use. For example, the DoD (Department of Defense) is a prominent customer of NASA KSC's atmospheric corrosion test site and makes use of the resulting data to assist their own applications within the field. One outcome of this project was for myself (as the intern) to learn as much as possible about the experimentation and data analysis that is associated with corrosion at KSC as well as other locations around the world. Another outcome of this website redesign project is to enable the public audience, potential customers, and NASA employees to be able to access the data and information contained on this site in a presentable manner that allows the user to navigate the site with relative ease.

B. Timescale Correlation between Marine Atmospheric Exposure and Accelerated Corrosion Testing Project

Much of the corrosion testing performed at NASA KSC is for materials that will be enduring long-term exposure in saline-intensive environments. Entities of NASA KSC that are under the influence of the rich amount of sodium chloride include launch support structures, GSE, flight hardware, and military vehicle components. Because these entities are constantly subjected to the harsh marine environment, they require advanced experimentation to ensure that the candidate materials are ready for the job of protecting the infrastructure of our Space Coast as well as other locations across the United States. As such, the advanced experimentation must be carried out in a systematic approach that coincides with the goals and overall scope of the customer and/or NASA. This experimentation includes rigorous long-term exposure at the Beachside Atmospheric Corrosion Test Site, which can last periods of 1.5 years, 3 years, 5 years, or 10 years depending upon the goals of the customer and/or NASA. Although this long-term, real-time exposure is an excellent method for acquiring accurate data, it does not allow for the possibility of an accelerated process. One method developed by the corrosion team at NASA KSC that will allow for a catalytic process includes the accelerated corrosion test methods. These accelerated corrosion test methods include the use of a Q-Fog programmable CCT-1100 cyclic corrosion salt fog chamber shown in Fig. 1 as well as the ASST (Alternating Seawater Spray Test) apparatus shown in Fig. 2.

Figure 1. Q-Fog programmable CCT-1100 cyclic corrosion salt fog chamber.

Figure 2. Alternating Seawater Spray Test apparatus.

Previous studies have been performed to compare the two test methods (long-term and accelerated) for data quality purposes. Per one of the multiple studies, the Beachside Atmospheric Corrosion Test Site was utilized to test both long-term and accelerated test methods. The long-term method consisted of 1010 steel (UNS 10100) panels that were angled at a 30° inclination toward the Atlantic Ocean located 100 feet from the high tide line.[1] The accelerated method consisted of 1010 steel (UNS 10100) panels that were angled at a 30° inclination relative to the seawater spray system as well as a neutral salt fog chamber exposed to 5% sodium chloride per ASTM B117 standard.[1] The ASST was developed for the purpose of working with accelerated testing by using the salt water pumped directly from the Atlantic Ocean.

This project aligns with the goals of the NE-L4 organization by providing an accurate representation of the difference between utilizing the long-term exposure test methods as opposed to the accelerated test methods. By implementing accelerated test methods, the corrosion engineering team in particular will be able to properly assess the performance of each kind of test method for experimenting with certain candidate materials later down the road at an expedited rate. Another similar study that analyzed the correlation of long-term and accelerated corrosion of 1010 steel showed that the corrosion rates concerning the accelerated test method (0.71 mm/y) were greater than the long-term exposure method (0.55 mm/y).[2] Expected outcomes of this study include obtaining more up-to-date data, making larger strides for identifying a quicker test method, and satisfying the customers' needs and wants. These will contribute to the advancement and success of the overarching effort by showing that only accelerated corrosion testing could be a possible option for future materials corrosion analysis. The current status of the project is considered to be ongoing and will likely continue for a considerable amount of time.

Figure 3. 1018 Carbon steel calibration panel following 97 days of ASST exposure.

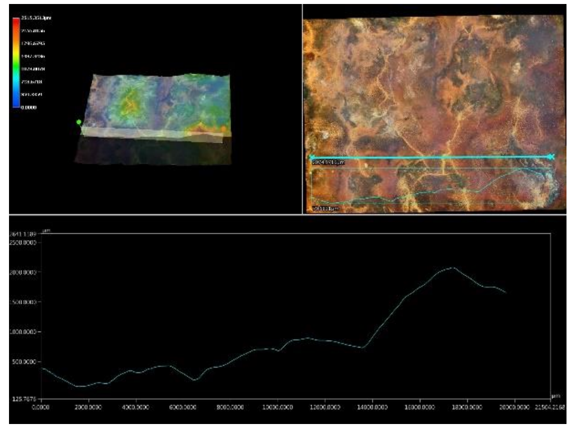

Figure 4. Three-dimensional topography scan and roughness plot of the corresponding calibration panel in Fig. 3.

Figure 5. 1018 Carbon steel calibration panel following 119 days of atmospheric exposure.

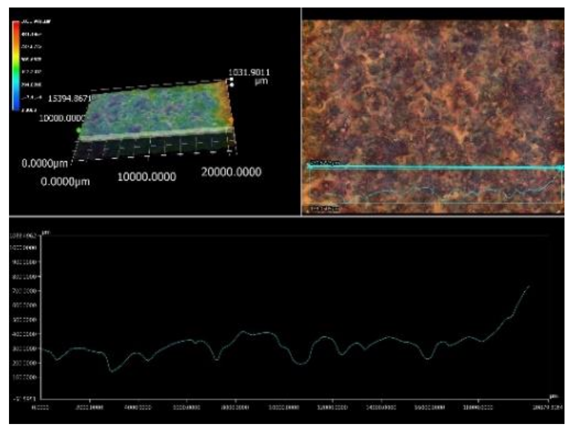

Figure 6. Three-dimensional topography scan and roughness plot of the corresponding calibration panel in Fig. 5.

Findings of this project include data acquisition such as mass loss and surface roughness. The mass loss of each calibration panel was measured to the nearest 100th of a gram using an OHAUS Pioneer® Plus Precision balance while the surface roughness was measured using a Keyence VHX-5000 Digital Microscope. Post-processing is also performed on the panel prior to the final mass evaluation in order to reduce any residual debris that may be lingering on the panel's surface after field testing via a blasting method that involves the use of a TRINCO™ Cabinet with a Dust Collector. The blasting cabinet's tungsten carbide (WC) nozzle is capable of ejecting silicon carbide (SiC) pellets at extremely high velocities which ensures the removal of 99.9% of loose debris from the panel. For example, the 1018 carbon steel calibration panel in Fig. 3 was assessed after 97 days of ASST exposure where the panel yielded a total mass loss of 43.42 g which constituted a 12.41% decrease in mass from its initial mass of 349.88 g. In addition to the evaluation of the mass loss of the corresponding 1018 carbon steel calibration panel, the surface roughness of the specimen was measured prior to using the blasting method. While using the Keyence VHX-5000 Digital Microscope, it was determined that a maximum deviation of approximately 2200 µm occurred on the surface of the panel within the specified region which is displayed in Fig. 4. The same procedure was performed for the 1018 carbon steel calibration panel in Fig. 5 which was assessed after 119 days of atmospheric exposure where the panel yielded a total mass loss of 28.10 g which constituted an 8.03% decrease in mass from its initial mass of 349.75 g. The surface roughness measurement was completed in the same manner as the previously stated ASST panel which yielded a maximum deviation of 600 µm. Upon comparing the mass loss and surface roughness of the two panels under the two different test methods (ASST and atmospheric exposure), the results show that the ASST is much more rigorous in its corrosive capabilities as opposed to the atmospheric exposure even with a lessened duration of exposure. The difference in surface roughness between the two panels reveal that long-term atmospheric exposure yields a more uniformly corroded surface topography while the accelerated exposure yields a rougher, less uniform surface topography.

This previously stated accelerated testing was performed in addition to long-term atmospheric exposure testing. During the long-term atmospheric exposure testing, the 1018 carbon steel calibration panels were not impacted by any sort of accelerating factor like those panels under the influence of ASST or the Q-Fog programmable CCT-1100 cyclic corrosion salt fog chamber. These panels were instead exposed to the naturally occurring environmental impacts like rain, wind, UV radiation, and chloride concentration at real-time rates. Test panels that endured the long-term testing were located at multiple sites on NASA KSC property including the LETF, Doppler site, VAB, LC-39B, and the Beachside Atmospheric Corrosion Test Site. At all site locations with the exception of the VAB, a group of panels on an experimental test rack were purposefully covered with a metallic overlay to compare the shielding effects of protected panels versus unprotected panels towards evaluation of the UV radiation. All site locations are equipped with a chloride concentration collection candle wick, as shown in Fig. 7, whose main functionality is to collect chlorides from the ambient atmosphere for later chemical evaluation by which the setup is detailed in *ISO-9225: Corrosion of Metals and Alloys - Corrosivity of Atmospheres - Measurement of Pollution*.[3] This chemical evaluation consists of a process known as titration by which the responsible laboratory personnel attempts to determine the concentration of the chloride based upon the concentration of another solution as indicated by *SW-846 Test Method 9212: Potentiometric Determination Of Chloride In Aqueous Samples With Ion-Selective Electrode.*[4]

Figure 7. Chloride concentration collection candle wick located at the Ascent Wind Profiler site near the Shuttle Landing Facility (SLF).

NASA KSC has assessed hundreds of panels since the birth of experimental testing in 1966 and plans to continue this ongoing study for many years to come.

C. Cyclic Potentiodynamic Polarization (CPP) Testing Project

The goal of the Orion Crew Module (CM) will ultimately be to transport astronauts on the SLS rocket set to launch on the course to Mars near the year 2030. Intra-Vehicular Activity (IVA) suits are currently being assembled, modified, and tested to ensure the astronauts' safety during the Exploration Mission 2 (EM-2) to occur no later than (NLT) 2021. Materials compatibility between two dissimilar metals and Orion's chosen biocide solution within the cooling loop at the Orion Crew Survival System (OCSS) and Environmental Control and Life Support System (ECLSS) is being tested. CPP (Cyclic Potentiodynamic Polarization) testing should allow personnel involved in this project to understand how the system can be improved and ultimately made safe for the future Orion crew members. Candidate metallic alloys will serve as test coupons during the experimentation phase.

The experimental setup includes a Saturated Calomel Electrode (SCE), biocide solution, corrosion cell chamber, potentiostat, and a paint cell. Prior to performing any CPP experiments, it was necessary to successfully calibrate each available SCE to ensure that the reference electrode was within the set tolerance of ±7.0 mV as shown in Fig. 8.

Experiments have not yet been performed for this study as they are to occur after the submission of this report. This CPP testing project is a joint project between NASA JSC and NASA KSC which will ultimately provide essential data for future materials selection.

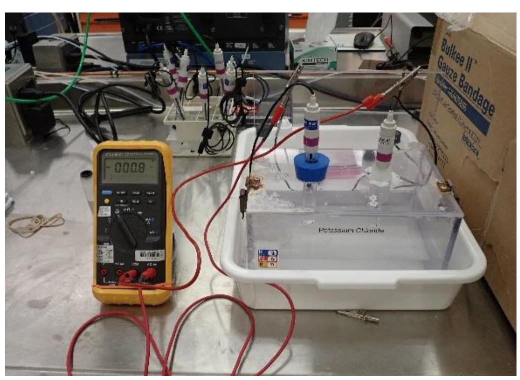

Figure 8. SCE calibration setup. Calibration electrode is located on the left and the reference electrode on the right within the transparent corrosion cell labeled "Potassium Chloride."

D. Plasma Passivation Testing on Stainless Steel (SS) Project

Because corrosion is always needing to be monitored and controlled, the Applied Chemistry Laboratory (ACL) at NASA KSC has developed a possible method of treating different types of stainless steel utilized in the surrounding environment within GSE and launch support structures. The objective of this project was to assess the overall effect of the gaseous plasma on 304SS, 316SS, 440SS, and A286SS and analyze physical attributes of the specimen such as appearance, surface roughness, and possible step height after exposure within the plasma chamber.

Figure 9. Front view of the plasma chamber.

The setup involved the use of a plasma chamber (shown in Fig. 9 and Fig. 10) with capabilities of pressure, process gas (hydrogen, oxygen, argon, etc.), power, and exposure time modification. Each specimen was taped on one half with Kapton tape while the other half was not taped as shown in Fig. 11. This taping procedure was meant to assess the protective properties, if any, of the taped half as opposed to the fully exposed half of each specimen. So far, three (3) experiments have been completed in the plasma chamber. During one of these experiments, two (2) specimens of each stainless steels were exposed for the duration of four (4) hours. Parameters for this particular test included a chamber pressure of 0.1 mbar and initial gas supply duration of one (1) minute. Following every set of experiments, the recently tested experimental specimens were compared to specimens that have only been exposed to the laboratory environment for approximately one week for general appearance evaluation (i.e. indications of significant corrosive properties following one week of exposure). Following the initial first two (2) tests, it was decided to utilize a water break test which involves the cleansing of specimens to ensure that no contaminants or debris were present on the specimens prior to testing in the plasma chamber. This included the use of an Ultrapure (Type 1) Water Purification System and Liquinox soap for cleansing and rinsing the specimens.

Figure 10. Isometric view of the internal structure of the plasma chamber.

Figure 11. 440SS specimen shielded by Kapton tape on one half and not taped on the other half.

After testing and a one (1) week evaluation, the specimens were analyzed on a Keyence VK-X200 Laser Microscope (shown in Fig. 12) equipped with VK Viewer and VK Analyzer software for the purpose of attaining surface roughness and possible increase/decrease in step-size at the taped/non-taped interface. Laser microscopy on this device revealed no sudden change at the interface as shown in Fig. 13.

Only three (3) experiments have been performed for this study as the project will continue after the submission of this report.

Figure 12. Keyence VK-X200 Laser Microscope.

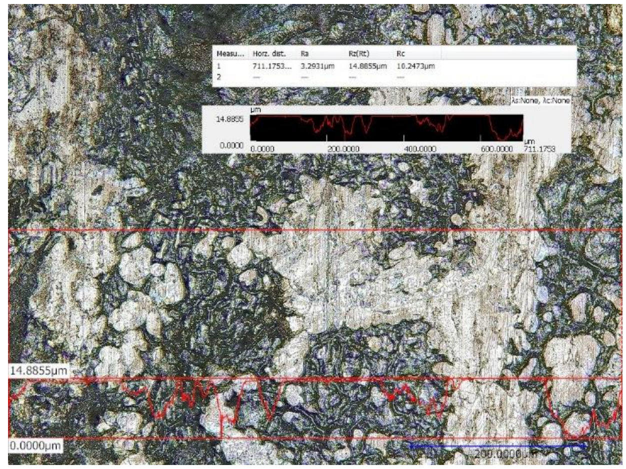

Figure 13. Roughness measurement obtained from the VK Analyzer software at 400x magnification.

III. Conclusion

As demonstrated in this report, there has been an extensive amount of information presented to me throughout my internship which will certainly stick with me throughout my academic and professional career. Every project that I worked on at NASA KSC has given me the knowledge and ingenuity to exceed greater heights and pursue challenging projects that will help me to assist others in the enhancement and embracement of the overall capabilities and scope of NASA. Throughout my journey at NASA KSC, I was able to meet the predicted amount of technical and social accomplishments and much more. If you love your job, you will never have to work a day in your life. I love my job at NASA.

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[2]Montgomery, E.L., Calle, L.M., Curran, J.P., Kolody, M.R., “Timescale Correlation between Marine Atmospheric Exposure and Accelerated Corrosion Testing,” NASA Kennedy Space Center.

[3]ISO-9225 (latest revision), “Corrosion of Metals and Alloys - Corrosivity of Atmospheres - Measurement of Pollution”, *(Geneva, Switzerland ISO).*

[4]SW-846 Test Method 9212 (latest revision), “Potentiometric Determination of Chloride in Aqueous Samples with Ion-Selective Electrode”, (*Washington, DC, USA EPA*).