Development of a Salt Fog Corrosion Test Apparatus

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Abstract

Corrosion is an electrochemical process resulting in deterioration of metals working in reactive environments and loss of material over time. Corrosion is affecting materials' mechanical properties and is ultimately leading to dysfunctional equipment components. In order to test materials' ability to withstand corrosion and find methods to enhance their resistance, commercial testing equipment are available that can create accelerated corrosion conditions; however, the industrial large sized equipment and high price associated to it preclude their use in a small university lab. The project for the senior design team was to build a cost efficient salt fog corrosion testing chamber capable of testing multiple samples by following the American Society for Testing and Materials (ASTM) standard B117-11[1] during the corrosion testing. This paper presents the students' experiences and skills used during the product design and manufacture.

Keywords

Corrosion, ASTM, Materials, Mechanical Engineering

Introduction

Corrosion occurs when a metallic material is exposed to a specific environment and is defined as the loss of material during the deteriorative process. As a result, the strength, ductility and surface appearance of a metal specimen is compromised[2]. Engineers are developing methods of metal treatment that can resist the damaging effects of corrosion. For example, using additional chromium alloying in steels to create stainless steels or using surface treatments to achieve a higher corrosion resistance for the metallic specimens[3,4,5]. High corrosion resistance property is especially important in naval and offshore applications as the exposure to saltwater and high winds creates an extremely corrosive environment. To test the corrosion resistance of metals and various surface coatings, the American Society for Testing Materials (ASTM) developed three types of internationally recognized corrosion test specifications. Specifications B117, G31, and G85 each provides definitions on how to expose metallic specimens to an environment of accelerated corrosion that can efficiently test the corrosion resistance of a metal[1,6,7].

Many commercial apparatuses for accelerated corrosion testing tend to be cumbersome, costly, and designated for large-scale industrial production. Thus, the senior design team task was to design and build an economical laboratory-scaled chamber that is able to test several metallic specimens per individual trial depending on their dimensions. The team was also responsible for developing a test plan to ensure the constructed apparatus is working as specified by the design criteria. The final design of the corrosion testing chamber can be described by the following seven components: the chamber body, solution reservoir, angle viewport, drainage system, solution atomization, heating system, and the specimen holder. These components meet the corresponding feasibility criteria based on the requirements and the ASTM standard B117-11[1].

Salt Fog Equipment Design

The first component is the chamber body which will hold the other components of the corrosion equipment. The chamber body material was chosen knowing the chamber is subjected to a corrosive salt-fog environment and elevated temperatures necessary to meet the ASTM standards requirement[1,6,7]. After analyzing few possible types of chambers, the body was constructed from a Coleman Xtreme 150-quart cooler. The inner walls and outer shell of the cooler are made of polyurethane plastic, materials with good corrosion resistance. Between these two shells there is an 1½ inch thick foam that is providing temperature insulation. The cooler also offered pre-made features that were advantageous to the design, particularly the slots of the inner wall that were used to create separate regions inside the chamber, and a drain plug which was incorporated into the drainage system located underneath the fog chamber. These regions were isolated from one another using 1/8 inch thick acrylic plates. This construction allowed the cooler to be separated into a salt water reservoir, a fog chamber, and an angle positioned subfloor which contains the drainage system.

The second component designed is the solution reservoir shown on the left side of the Figure 1 which will hold the salt water solution at a temperature of 125°F. The partitions that separate the solution reservoir and the chamber body were made using five identical acrylic plates 16 3/16 X 14 1/8 X 1/8 inch. 3M Marine Adhesive/Sealant was used to connect the five plates together before sliding the 5/8 inch thick wall assembly into one of the five premade slots of the inner wall.

Figure 1: The chamber body and the solution reservoir

A generous amount of marine sealant was then used to secure the wall and provide a watertight barrier for the solution reservoir. However, combining the solution reservoir and the chamber body into one system raised some concerns. For example, the ASTM standard B117[1] specified that the fog cannot escape the spraying chamber. In addition, the heat transfer between the chamber body and the solution reservoir needs to be minimized to maintain a constant temperature in the chamber during testing. In order to mitigate these issues, the team added weather stripping to the top of the partition wall. A slot was cut into this stripping to assist in holding the solution-feed tubing in place with respect to the chamber lid. Once the wall was secured in place the team conducted a reservoir leakage test by monitoring the water level over 24 hours. The total volume tested was around 9¼ gallons (the maximum capacity of the chamber). The test was deemed successful since the water level remained constant throughout the duration of testing and no water entered the other side of the reservoir.

Another important component of the chamber was the viewport and its construction began with a 12¼ x 21¾ inch rectangular cut in the lid marking the place for the viewport. Since the foam between the inner and outer shells of the lid became exposed upon cutting the slot, the team used four rectangular acrylic plates to cover the exposed areas. These acrylic plates prevented moisture from contacting the foam and degrading the insulation. Figure 2 shows the acrylic sealing plates glued in place over the foam edges. In order to create the angled viewport, the team cut two rectangular acrylic plates and two triangular acrylic plates and used the marine sealant to secure the pieces together on top of the lid as shown in Figure 3. After the sealant was allowed to fully cure for 24 hours, a durability test was performed to ensure that the structure could maintain an arbitrary load and a spraying atomization test to monitor the movement of the water drops once they condensed on the viewport. Both were successful as the structure could hold the load and the viewport restricted any dripping of condensate on the specimen's holders as requested by the standard.

Figure 2: The four acrylic plates used to cover the foam layer.

Figure 3: The front and side (inset bottom right) of the viewport

The drain plug of the cooler was repurposed as a part of the drainage system of the chamber (Figure 4 A). A subfloor was placed inside the chamber at an angle of 12.5° so that the water flows to the drain. Another purpose for the cooler drain is to allow the excess fog and pressure due to its momentum exiting the nozzle to escape the chamber during operation. The drainage system was tested for the excess water and fog leakage during the operation of the atomization system (Figure 4B).

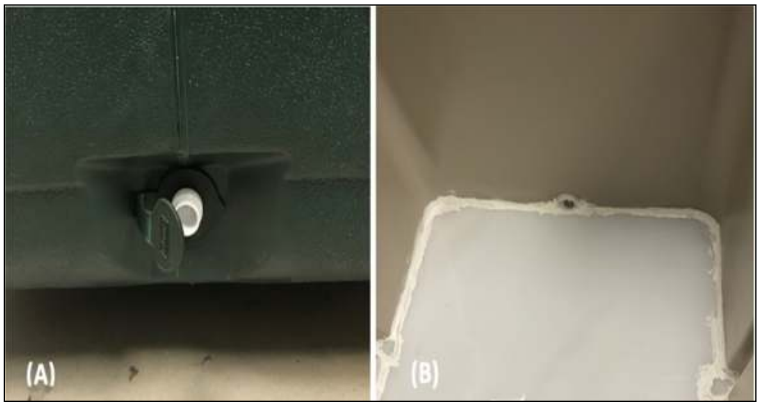

Figure 4: (A) The drainage hole from an exterior view. (B) Interior view of attachment and sealing at subfloor-drain interface.

A 1/8 in XASR 050A pneumatic atomization nozzle[8] was donated by the BETE Engineering, Inc. This nozzle operates by siphoning liquid using inlet air pressure and is able to produce a round fog spray. The nozzle has a low flow rate resulting in a very fine atomization and short to moderate forward spray projection. These characteristics are aligning well with the small scale corrosion chamber while the siphon-fed design of the nozzle allows for a relatively simple operation. Compressed air was supplied from the building at 90 psi and the salt water solution was premixed at temperatures of up to 125 °F. The interface at the nozzle was chosen to be a quick-disconnecting system, as shown in Figure 5, with a supply-side valve to allow for nozzle inspection, removal, or cleaning without solution spilling into the fog chamber upon removal of the tubing from the nozzle. Supplying air to the nozzle required some troubleshooting due to a lack of premade bulkhead adapters that would fit the relatively large 2¼ in thickness of the cooler walls. As such, an adapter was made using a 3-in. long schedule 80 PVC pipe threaded on both ends, two polymer gaskets, and two push-to-connect female fittings as shown in Figure 6.

Figure 5: Assembly of the nozzle and nozzle tower. Solution feed is on the left side of the nozzle and air feed on the right.

Figure 6: Exterior view of assembled bulkhead fitting for pressurized air supply to nozzle.

For the heating system, a polymer heating mat was the most feasible alternative. The option was cost-effective, corrosion resistant, and efficient in creating and maintaining the desired temperature inside the chamber. The OMEGALUX® 5 x 5inch with 10W/in^2 heating pad was selected for the design of this heating system. Additionally, the thermal controller and the thermal sensor were the STC-1000 controller and the NTC sensor with waterproof probe, respectively. In terms of powering the heating system, a series connection was soldered amongst the heating mat, the 100W/100Ω variable power resistor, and a typical 13A two-wire power cord. All exposed electrical connections were insulated using proper electrical tape. The testing of the heating system included testing the functioning of the controlling unit and the heating unit independently.

Finally, the specimen holder was modeled using commercially available software and it was 3-D printed from acrylonitrile butadiene styrene (ABS) plastic. The ABS material was selected in order to ensure that it will not cause any interference with specimens under testing. The rack was designed such that it can be placed in the chamber in a fixed position allowing it to hang from the pre-made structure present around the perimeter of the cooler's interior, as shown in Figure 7. According to ASTM standards[1,6,7], the rack was constructed to hold specimens at an angle of 30° from the vertical to allow for adequate fog contact and condensate drainage. The chamber allows up to four of these specific racks to be placed within the chamber without any problems related to a direct nozzle spray contact.

Figure 7: 3-D printed specimen holder (ABS plastic)

Once the specimen holder was ready, the durability of the specimen holder was tested by loading 12 metallic testing samples in the slots which resulted in a total load of 685 grams. The specimen holder had an adequate strength and durability and carried the weight of all 12 specimens with stability and no deflection.

System Testing

The testing of the system involved running the equipment with heated water and various pressures in order to measure the test duration and the temperatures achieved inside of the chamber. According to calculations and test data extrapolation, when the pressure of the compressed air was set to 25 psi, 9¼ gallons of pre-mixed water and salt were used for a total duration of 24 hours. The testing also proved that the heating elements of the device were able to heat and maintains a constant fluid temperature close to the required 125°F. In order to verify the apparatus, samples consisting of 4140 steel were tested for accelerated corrosion over a period of 4 hours and the results indicated high corrosion rates for the samples exposed to the salty environment.

Student Outcomes

The students were able to use knowledge acquired from multiple classes, create a workable design and build reliable equipment for corrosion testing. Lessons learned in core mechanical engineering classes allowed the students to provide necessary calculations before attempting to build the prototype. All students in mechanical engineering are exposed to machining and rapid prototyping which were skills used for the construction of the device. Typical gateways in senior design class were met and students were evaluated amongst peer group as excellent (5) for their preliminary design report and critical design report using a 5 point Likert scale. The capstone design class is used to assess portions of outcomes 3(b), 3(g), and 3(k) for the Mercer Engineering program with the criteria that a percentage of the groups score 3 or better on a 5 point Likert scale. This group scored 4 (Good) or 5 (Excellent) on the following outcomes. outcome 3(b) by their written test plan and analyzing and interpreting there results on tests; outcome 3(k), by the use of modern tools in mechanical engineering with solid modeling and rapid prototyping of components used in the design; and outcomes 3(g) with their ability to both write and present the information from their design in reports and presentations given to the instructor and other faculty.

Conclusion

The group was able to successfully construct a corrosion test fixture and run preliminary test on the device to show that it can actually run tests that meet basic ASTM standards on different metallic samples. The device was constructed within the senior design budget ($300); however, the pneumatic atomization nozzle was donated by the BETE Engineering, Inc which significantly lowered the overall cost. The team applied engineering analysis, design, and manufacturing principles to construct a device that met the requirement set forth by faculty. This product will be used in student projects and related research in the future years at Mercer University.

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Stephen Hill, Ph.D.

Stephen Hill earned his Ph.D. from the Georgia Institute of Technology. He is currently an associate professor in the School of Engineering at Mercer University. He worked for the oilfield services giant Schlumberger for 14 years before returning to academia in 2013 to pursue his goal of educating the next wave of engineers entering the work force. His experience in the work force was in product development of downhole tools related to the extraction of oil and natural gas from various reservoirs. His current research interests include impact erosion, wear, two phase flow phenomena, solid/liquid phase change, desalination, and highly ionized plasma.

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Dorina M. Mihut graduated with Ph.D. Materials Science from the University of Nebraska, Lincoln, Ph.D. Technical Physics from Babes-Balyai University, Cluj-Napoca, Romania and M.S. Mechanical Engineering from the University of Nebraska, Lincoln. Research interests are in the area of Physical Vapor Depositions (PVD) using Thermal Evaporator, DC and RF Magnetron Sputtering Equipment, evaluations using X-Ray Diffraction, Scanning Electron Microscopy, and Atomic Force Microscopy: Development of thin films for wear, corrosion and erosion protection Manufacture of metallic and ceramic nanotubes using Physical Vapor Deposition via polymer template. Study of metallic nanoparticles deposited on filter paper, polymer nanofibers and their antibacterial properties Structures composed of metallic PVD thin films on carbon nanofiber reinforced polymer substrates for protection against electromagnetic interference. Evaluation of mechanical properties of thin films and materials: hardness, micro hardness, wear, fatigue and fracture analysis

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Dr. Afshar is currently an assistant professor at Mercer University. He earned his B.S and M.S in applied mechanics from Amirkabir University of Technology in Tehran, Iran. He also received his M.S in systems and design and Ph.D. in solid mechanics from the State University of New York at Stony Brook. His teaching and research interests are in the area of solid mechanics including composite materials, finite element analysis, mechanical design and experimental mechanics. Prior to joining Mercer University he taught at Saginaw Valley State University and also worked as a design engineer in oil and gas and injection molding industries.

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Ryan Alyamani is currently a researcher at King Abdullah Petroleum Studies and Research Center (KAPSARC). He earned his B.S in Mechanical Engineering from Mercer University, where he was involved in several research projects. In April 2015, one of the research projects was awarded 1st place at the American Society of Engineering Education's Student Poster Competition (held in the University of Florida, Gainesville, FL.). He also has been selected to be a member of Sigma Xi Research Honor Society for Engineers and Scientist.

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Timothy Welch

Timothy Welch graduated from Mercer University in the spring of 2017 with a bachelor's degree in engineering with a mechanical specialization. He is interested in structural analysis and design, particularly applied to spacecraft and related components. He was accepted into graduate school at the Georgia Institute of Technology in the Aerospace Engineering department and started the program in the fall of 2017.