NASA Technology Evaluation for Environmental Risk Mitigation
Kennedy Space Center, FL 32899

Hexavalent Chrome Free Coatings for Electronics Electromagnetic Interference (EMI) Shielding Effectiveness (SE)

Interim Test Report

June 1, 2015

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1 Introduction

1.1 Background

The replacement of hexavalent chromium in the processing of aluminum for aviation and aerospace applications remains a goal of great significance within the aviation and aerospace community. Aluminum is the major manufacturing material of structures and components in both the aircraft (military and commercial) and space flight arena; consequently, the processing and maintenance of this material against degradation and corrosion is of prime importance. For years, hexavalent chromium has been a widely used element within applied coating systems because of its self-healing and corrosion resistant properties. Occupational Safety and Health Administration (OSHA) studies have concluded that hexavalent chromium (hex chrome) is carcinogenic and poses significant risk to human health. On May 5, 2011, amendments to the Defense Federal Acquisition Regulation Supplement (DFARS) were issued in the Federal Register. Subpart 223.73 prohibits contracts from requiring hexavalent chromium in deliverables unless certain exceptions apply. These exceptions include authorization from a general or flag officer and members of the Senior Executive Service from a Program Executive Office, and unmodified legacy systems. Otherwise, Subpart 252.223-7008 provides the contract clause prohibiting contractors from using or delivering hexavalent chromium in a concentration greater than 0.1 percent by weight for all new contracts and to be included down to subcontractors for supplies, maintenance and repair services, and construction materials. National Aeronautics and Space Administration (NASA), Department of Defense (DoD), and industry stakeholders continue to search for alternatives to hex chrome in coatings applications that meet their performance requirements in corrosion protection, cost, operability, and health and safety, while typically specifying that performance must be equal to or greater than existing systems.

1.2 Objective

The purpose of this testing is to determine the suitability of trivalent chromium conversion coatings that meet the requirements of MIL-DTL-5541, Type II, for use in applications where high-frequency electrical performance is important. The two applications to be evaluated are: the ability of conversion coated aluminum to form adequate EMI seals and to provide adequate corrosion protection. Testing assesses performance of the trivalent chromium coatings against the known control hexavalent chromium MIL-DTL-5541 Type I Class 3 before and after they have been exposed to a set of environmental conditions.

Previous testing has been performed to down select trivalent formulations and processes that are capable of providing resistance to general corrosion, while maintaining low DC surface resistivity. These formulations were further evaluated for their high-frequency performance and compared against the baseline hexavalent chromium conversion coating per MIL-DTL-5541, Type I, class 3. No pass/fail criteria for the electrical properties were defined beforehand. A comparison of the EMI performance and contact electrical testing between the trivalent options and the hexavalent baseline is provided in this report.

2 Test Articles

This section outlines the preparation of the test panels from alloy selection through non-chrome conversion coating application.

2.1 Alloys

The alloys selected for this project were selected because of their common use in avionics and electronics housing applications. All aluminum materials were procured mill finished without mill markings. Mill finish is as supplied from the mill (raw material manufacturer), is not polished and most likely has a dull matte appearance. The following alloys were selected for this project:

- 5052-H32
- 6061-T6

2.2 Non-Chrome Conversion Coatings

The non-chrome conversion coatings evaluated for this project are listed in Table 1. The hexavalent chrome free conversion coatings selected for this project were selected based on previous studies conducted by the project stakeholders.

Table 1 – Conversion Coating Systems

Conversion Coating Systems	**Processing Location**
Hexavalent Chrome Baseline	AOTCO Metal Finishing, Inc.
Metalast TCP	AOTCO Metal Finishing, Inc.
SurTec 650	AMZ Manufacturing Corp.

2.3 Test Panels

Test panels were used for Contact Electrical Resistance and Surface Resistance Testing. The test panels were 3”x10”x0.32” and procured mill finished without mill markings. Test panel size is called out in the test description sections.

2.4 Test Plate Sets

Test specimen configuration was provided by Parker Chomerics. The EMI gasket used in this project was Cho-Seal 6503E. Black oxide alloy steel socket head bolts were used to hold the plates together. Non-conductive spacers were used to control the amount of compression on the gaskets.

The following test fixture specifications were provided by Parker Chomerics. The CHO-TP09 test plate sets selected for this project consist of two aluminum plates manufactured to the specifications detailed in CHO-TP09. The first plate, referred to as the test frame, is illustrated in Figure 1. The test frame is designed with a cutout in the center and two alternating bolt patterns. One pattern is used to bolt the test frame to the corresponding test cover plate (Figure 2), forming a test plate set. The second pattern accepts the hardware used to mount the fully assembled test plate set to the main adapter plate (Figure 3).

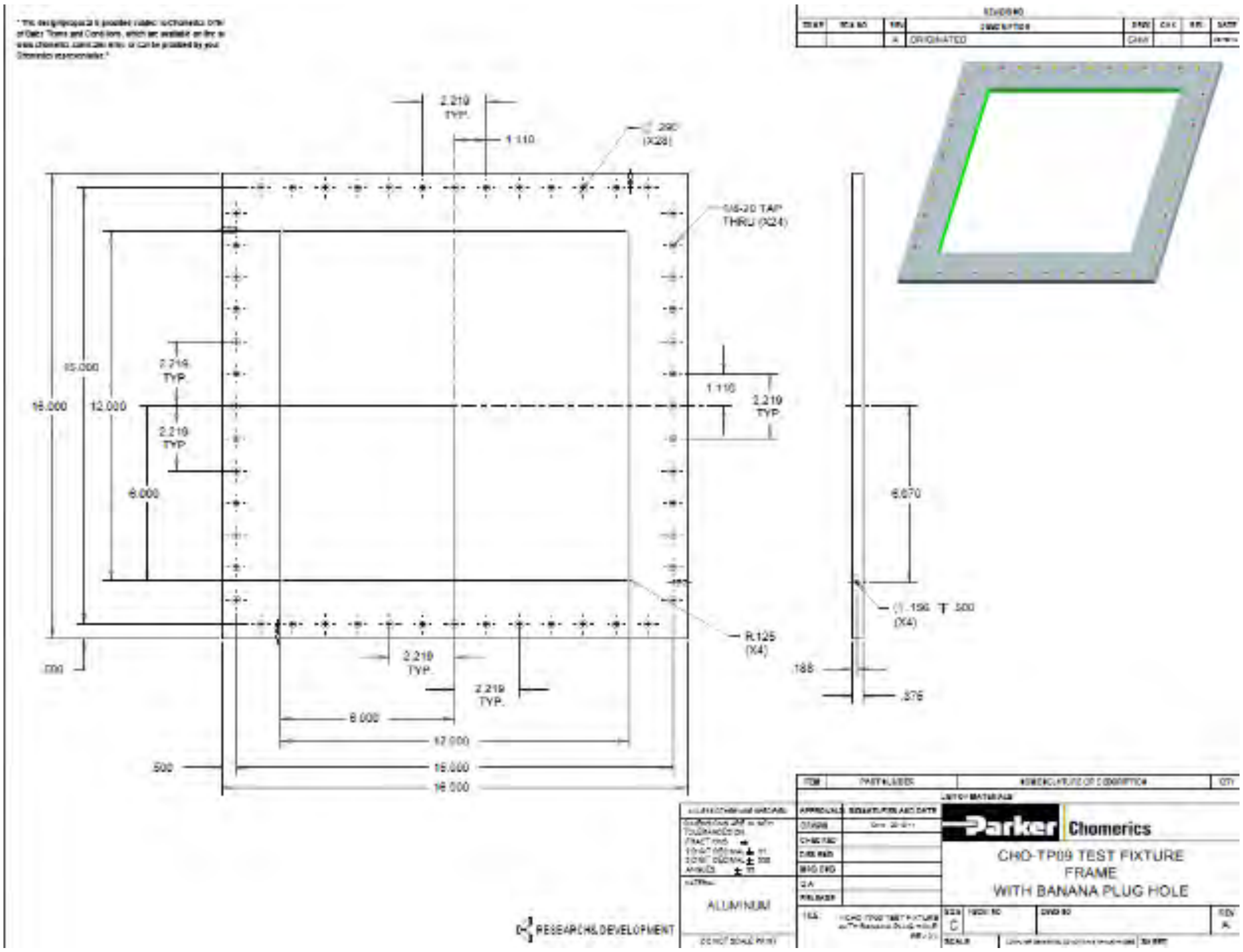


Figure 1 – CHO-TP09 Test Frame

The test cover plate (Figure 2) is also made from aluminum and has the identical bolt hole configuration as the test frame described above.

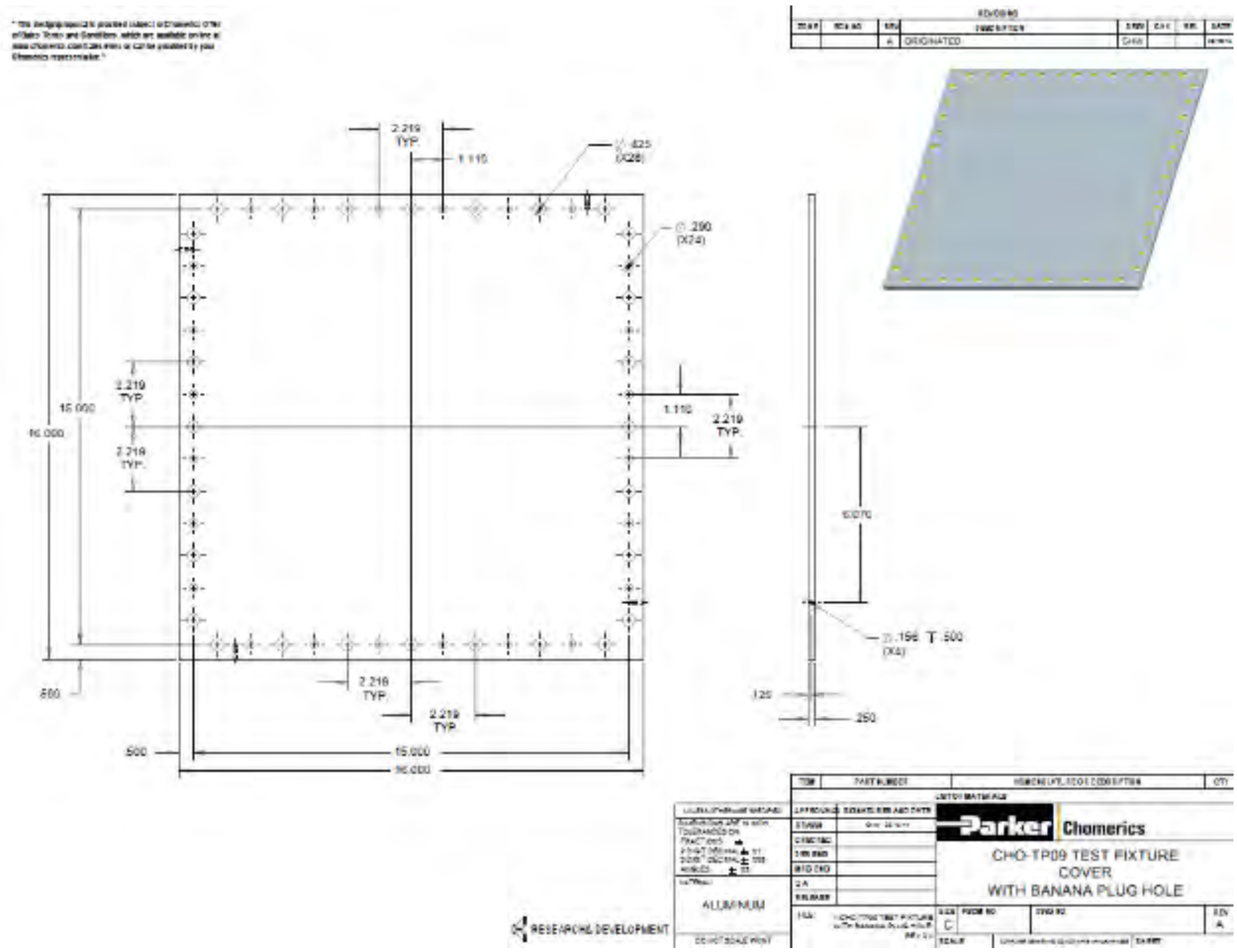


Figure 2 – CHO-TP09 Test Cover Plate

In order to monitor changes with the gasket interface between the test frame and cover plate, through resistance readings will be recorded three times during the project; following initial plate set assembly, after thermal cycle preconditioning, and prior to test set disassembly after all testing is complete. Holes were drilled into the edge of the test frames and cover plates to accommodate through resistance readings.

A 0.500-inch thick aluminum main adapter plate illustrated in Figure 3 is used to mount the test plate sets to the shielded room wall. The outer bolt pattern detailed in Figure 3 is used to mate the adapter plate to the wall of the shielded room. The inner bolt pattern accepts the Test Plate set.

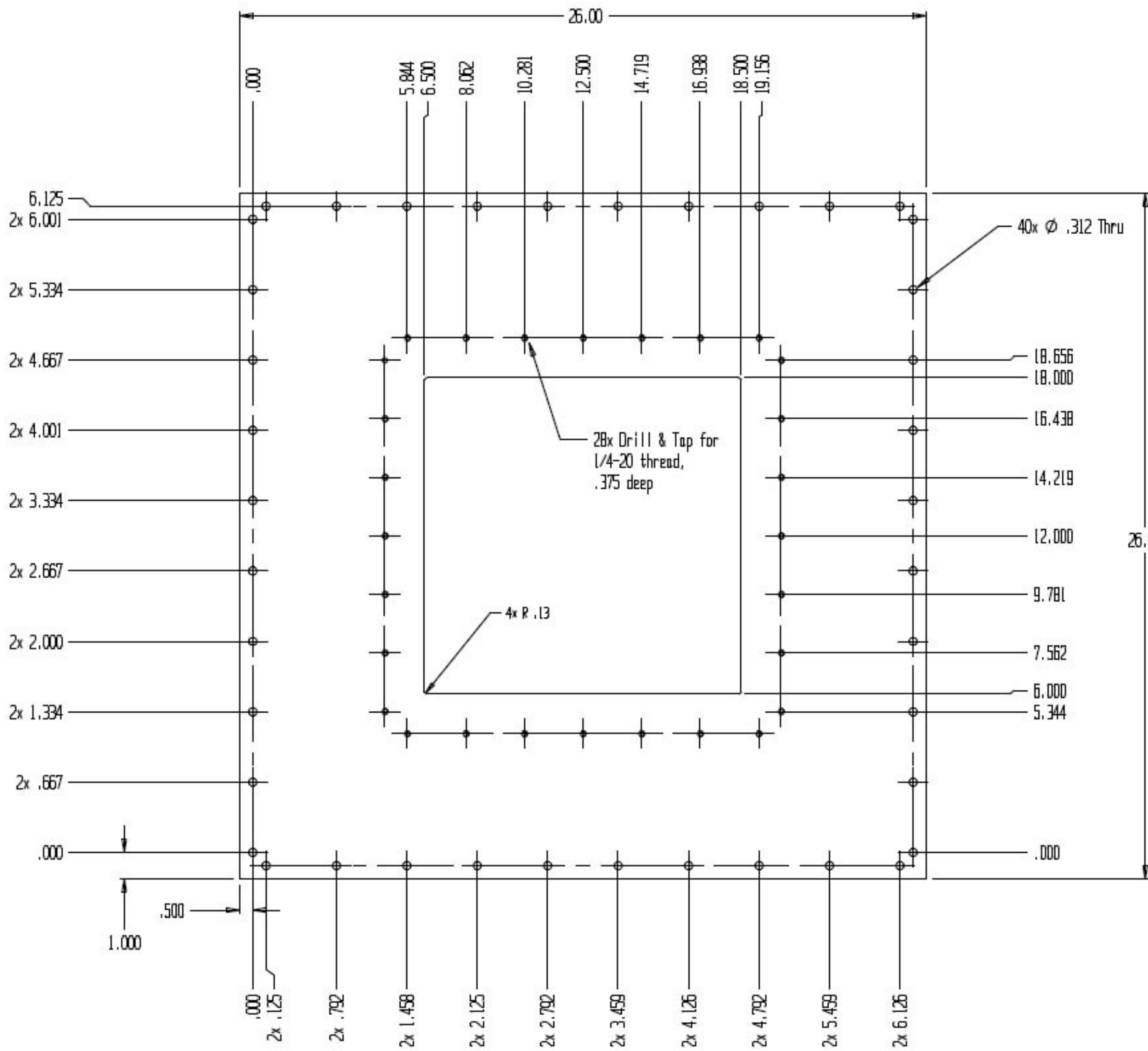


Figure 3 – Main Adapter Plate for Mounting Test Plate Sets to Wall of Shielded Enclosure

2.4.1 Fixture Hardware

Specifications regarding test fixture hardware were provided by Parker Chomerics. In addition to the test plates, non-conductive washers were used as compression stops to target a nominal gasket deflection of 13.1%. The washers on the plate sets prevent uneven deflection in regions adjacent to the bolts. Twenty four washers are used per Test Plate set. Washers are to be 0.750-inch outside diameter by 0.257-inch inside diameter and 0.148-inch thick. Black oxide alloy steel socket head cap screws were used to bolt the Test Plate Covers and Frames together and to bolt the plate sets to the shielded room wall.

2.4.2 EMI Gasket Specifications

In order to select the right gasket material, Parker Chomerics completed an extensive in-house corrosion evaluation in accordance with Chomerics Test Method CHO-TM-101. This test method evaluates the corrosion resistance of EMI gasket materials by examination of galvanic weight loss and dimensional changes of an EMI gasket after 504 hours of salt fog exposure. The testing was performed on five different EMI gasket materials, two aluminum alloys (6061-T6 and 5052-H32), and two different conversion coatings (Sur Tec 650 and Metalast TCP). The purpose was to determine which gasket was best to recommend. Based on the test data, Cho-Seal 6503E EMI gasket material exhibited superior galvanic weight loss and dimensional change after 504 hours of salt fog exposure. The NASA Shielding Effectiveness project stakeholders agreed to use Cho-Seal 6503E EMI gasket material for the NASA Shielding Effectiveness Project.

2.5 Test Plate Set Assembly

The following equipment was used to assemble the test plate sets:

- Mitutoyo Model ID-C125TB Height Gage
- Cordless Drill

The hardware required to assemble plate sets are contained in Table 2.

Table 2 – CHO-TP09 Test Plate Set Hardware

Hardware Description	Qty. per Plate Set	Total Qty. (36) Plate Sets
CHO-TP09 Test Plate Frame	1	**36**
CHO-TP09 Test Plate Cover	1	**36**
CHO-TP09 Gasket Test Window Washers	24	**864**
0.25 inch diameter by 3.00 inch long set pins	24	**24 – reused on each plate set**
0.75 Inch long, 1/4 – 20 thread black oxide alloy steel socket head cap screws	24	**864**

2.5.1 Test Plate Set Assembly Procedure

The following assembly procedure was provided by Parker Chomerics. Using a height gage, height measurements are taken at six inch intervals for every test sample. Based on the mean height of the sample population, the washer thickness is selected to achieve a nominal deflection of 13.1% when the test plate set was fully assembled. The selected washer thickness is also verified at the extreme minimum and maximum height measurements within the sample population to ensure that the deflection would be no less than 8.2% and no greater than 16.7% at any point along the gasket.

Prior to assembly, all surfaces of the Test Plate sets are wiped down with an isopropyl alcohol soaked rag and allowed to air dry for five minutes. Once dry, the test plate sets are assembled by laying the frame on a flat surface and installing the washers using 24 set pins to keep each washer in place. The set pins are to be placed in the same holes the black oxide alloy steel socket head screws are inserted. With the washers in place, the gasket was installed with the flat side seated on the surface of the frame. The gasket configuration is a square “picture frame” with outside dimensions adequate to fit inside the bolt pattern of the cover plate while maintaining separation from the compression stops (washers). Regardless of material grade (molded and extruded), the gaskets are assembled by butting the complimentary 45 degree ends of the parts together producing in a square “picture frame” gasket held firmly in place by the force of friction. An example of a CHO-TP09 Test Plate set mid-assembly can be found in Figure 4 below. In this picture, a continuous strip length of gasket is used and butted together or overlapped at the end. From Parker Chomerics experience, this technique has no impact on the test data although this is not ideal. The preferred gasket is using splices at four corners. The test plate cover is then screwed to the test plate frame using 24 socket head cap screws referenced in Table 2 above. In using washers as compression stops, the set pins were removed one by one and the steel socket head screws inserted to ensure the washers stay in position. The screws are tightened as much as possible to the compression stop without stripping, stretching or breaking. The set pins are then removed and the fixture “Test Set” is ready for testing.

The Test Sets are not disassembled until all environmental and shielding effectiveness testing is complete.

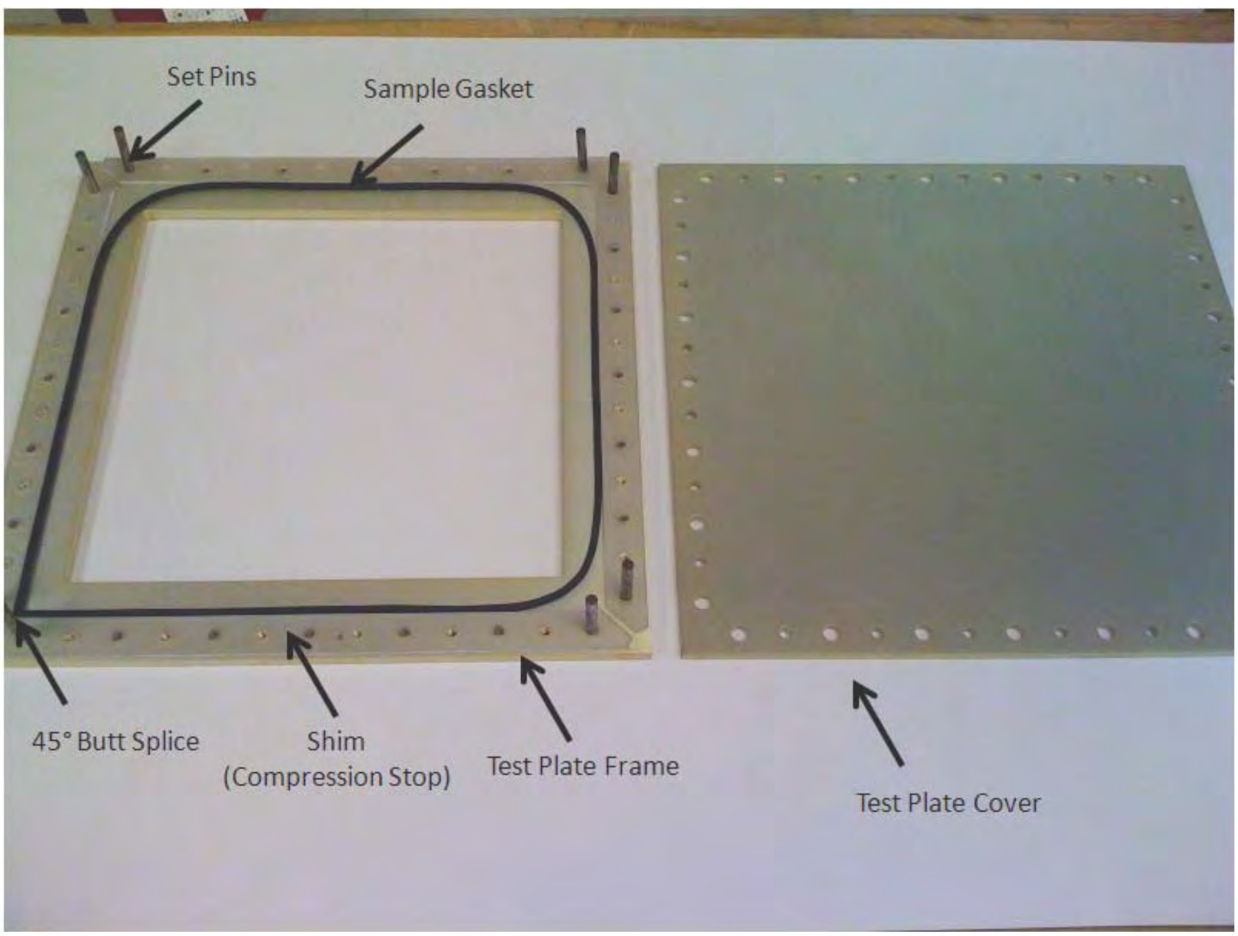


Figure 4 – Example of CHO-TP09 Test Plate Set

3 Testing

Testing was conducted at Chomerics, KSC Corrosion Technology Laboratory and Beachside Corrosion Laboratory, Raytheon, and UTC Aerospace Systems. The testing was divided into two separate sections based on test article; Plate Sets and Test Panels.

3.1 Plate Sets – Shielding Effectiveness Testing

Table 3 – EMI Testing Overview

Test	Test Method	Duration	Evaluation Criteria	Location
Through Resistance		N/A	Record Data	Chomerics
Thermal Preconditioning	$0^{o}C$ to $100^{o}C$	100 Cycles	N/A	Raytheon
EMI Testing	IEEE-STD-299	N/A	Record Data	Chomerics
Salt Spray Resistance	ASTM B 117	1,000 Hours	MIL-DTL-5541	KSC Corrosion Lab
Static Heat and Humidity	85°C +/- 1°C and 85% RH +/- 5% RH	1,000 Hours	MIL-DTL-5541	KSC Corrosion Lab
Marine Environment	ASTM D 1014	12 Months	NASA-STD-4003	KSC Corrosion Lab

There were 2 replicate plate sets per alloy (2) per non-chrome conversion coating type (3) per environmental test (3) requiring 36 total plate sets; 12 salt spray, 12 static heat and humidity, and 12 marine environment. A total of 72 EMI measurements were taken; 36 before testing and 36 after testing.

Table 4 – Testing Overview, EMI Plate Set Count per Test

Test	Alloy	Conversion coating	Quantity
SE Testing {Initial}	6061-T6	Hexavalent Chrome Baseline	6
		Metalast TCP	6
		SurTec 650V	6
	5052-H32	Hexavalent Chrome Baseline	6
		Metalast TCP	6
		SurTec 650V	6
Thermal Preconditioning	6061-T6	Hexavalent Chrome Baseline	6
		Metalast TCP	6
		SurTec 650V	6
	5052-H32	Hexavalent Chrome Baseline	6
		Metalast TCP	6
		SurTec 650V	6
SE Testing {Limited}	6061-T6	Hexavalent Chrome Baseline	1
		Metalast TCP	1
		SurTec 650V	1
	5052-H32	Hexavalent Chrome Baseline	1
		Metalast TCP	1
		SurTec 650V	1
Salt Spray Resistance	6061-T6	Hexavalent Chrome Baseline	2
		Metalast TCP	2
		SurTec 650V	2
	5052-H32	Hexavalent Chrome Baseline	2
		Metalast TCP	2
		SurTec 650V	2
Static Heat and Humidity	6061-T6	Hexavalent Chrome Baseline	2
		Metalast TCP	2
		SurTec 650V	2
	5052-H32	Hexavalent Chrome Baseline	2
		Metalast TCP	2
		SurTec 650V	2
Marine Environment	6061-T6	Hexavalent Chrome Baseline	2
		Metalast TCP	2
		SurTec 650V	2
	5052-H32	Hexavalent Chrome Baseline	2
		Metalast TCP	2
		SurTec 650V	2
SE Testing {Final}	6061-T6	Hexavalent Chrome Baseline	6
		Metalast TCP	6
		SurTec 650V	6
	5052-H32	Hexavalent Chrome Baseline	6
		Metalast TCP	6
		SurTec 650V	6

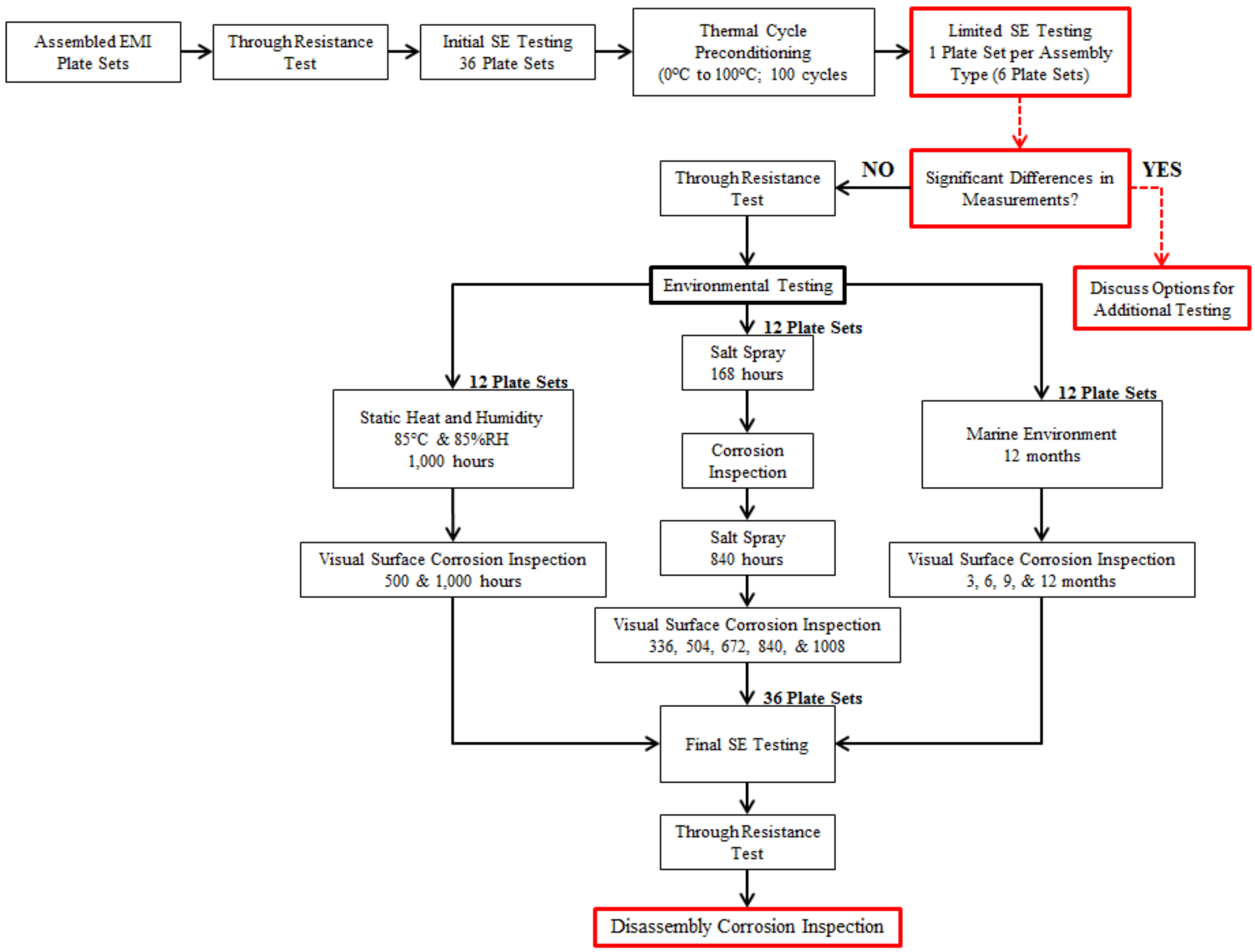


Figure 5 – Plate Set Testing Project Flow

3.1.1 Thermal Preconditioning

This procedure was selected by the stakeholders to replicate storage conditions that products could see in their life cycle prior to being fielded.

3.1.1.1 Test Procedure

Plate sets are subjected to 0°C to 100°C for 100 cycles.

3.1.2 Shielding Effectiveness (SE) Testing

This testing evaluated the Shielding Effectiveness (SE) performance of the test panels before and after environmental exposure. The SE testing was conducted in accordance with IEEE-STD-299.

3.1.2.1 Test Method

The Test Sets were tested to the requirements of this section.

One antenna polarization is required due to the symmetrical nature of the Test Plate Sets. Although it is true that other aspects of the test setup effect the test data (e.g., room dimensions) with the antenna at the opposite polarization, from Parker Chomerics experience, it has been determined that the extra time and cost to test both polarizations is not a benefit.

The antenna polarization used shall be the same for both Open Reference measurements and final shielding effectiveness measurements. The transmit and receive antenna polarizations shall be identical. The transmitting and receiving antennas shall be directed at each other, the distance between antennas, measured from antenna tip to antenna tip, shall be 5 feet (+/- 2.0-inches) if possible.

Open Reference measurements are to be made using two methods as defined in Section 3.1.2.2. First, Open Reference measurements are to be made with the antennas in free space in accordance with IEE-STD-299. A second Open Reference measurement is to be taken by transmitting the signal through the open aperture on the shielded room wall where the Test Set is to be positioned/mounted.

The antennas and frequency range shall be as follows:

Table 5 – Antenna and Frequency Ranges

Test Frequency Range	Transmit Antenna	Receive Antenna
250MHz to 1GHz	EMCO 3106 Dual Ridge Guide	EMCO 3106 Dual Ridge Guide
1GHz to 18GHz	EMCO 3115 Horn Antenna	EMCO 3115 Horn Antenna

The EMCO 3106 Dual Ridge Guide antenna(s) may be substituted with an EMCO 3143 Log Periodic antenna(s) or a similar linearly polarized substitute.

The instrumentation shall be stepped through the test frequencies, and the received signal strength for each test frequency and antenna polarization shall be recorded for each test area (or test point) and configuration.

The transmit signal is controlled through automation using ETS-Lindgren TILE software. Measurements shall be recorded manually. Frequency stepping shall be interrupted as necessary to perform antenna/amplifier/signal generation changes.

For each test area or test point, shielding effectiveness measurements shall be made at the following test frequencies: 50, 100, 250, 300, 400, 500, 600, 700, 800, 900, 1000 MHz for electric field and 2, 4, 6, 8, 10, 12, 14, 16 and 18 GHz for plane wave shielding effectiveness measurements.

The shielding effectiveness is calculated by taking the power level recorded during the open reference measurement(s), and subtracting it from the power level recorded from the final SE measurement(s). Below is a sample calculation.

$$
\begin{aligned}
\text{Shielding Effectiveness} &= \text{Open Reference Level} - \text{Final Measurement} \\
&= +10\text{dBm} - (-120\text{dBm}) \\
&= 130\text{dBm}
\end{aligned}
$$

Two Shielding Effectiveness values are to be calculated. One using the “free space” open references (IEEE-STD-299) and one using the “thru-hole” reference measurement to allow for both the shielded and aperture effects to be analyzed.

Identical antennas, equipment, cables and equipment settings (except internal attenuator settings) shall be used in the reference and measurement setups.

The reference level data for each test frequency shall be compared with the noise floor in the test chamber for the frequency under test and the dynamic range determined by subtracting the noise floor from the reference level and recorded.

3.1.2.2 Calibration Procedure

Parker Chomerics shall conduct “thru-hole” open reference measurements with only the adapter frame from Figure 3 mounted to the shielded room. This procedure is conducted in the SE chamber. The transmit and receive antennas shall be directed at each other through the open aperture, the distance between antennas, measured from antenna tip to antenna tip, shall be 5 feet (+/- 2.0-inches) if possible. The transmit antenna in the transmit room shall be placed 1-foot from the thru-hole opening and the receive antenna in the receive room shall be placed 4 feet from the thru-hole opening. The Thru-hole Reference measurement test setup is illustrated in Figure 6.

In addition, “Free Space” Open Reference measurements for all test frequencies shall be performed per Figure 3(a) and 3(b) of IEEE-STD 299-1997. This procedure shall be conducted outside the SE chamber. The transmit and receive antennas spacing and arrangement for free space open reference shall be identical to the thru-hole open reference procedure stated above. The Free Space Open Reference measurement test setup is illustrated in Figure 7. Free Space Open Reference Measurements can be conducted at any time in the process.

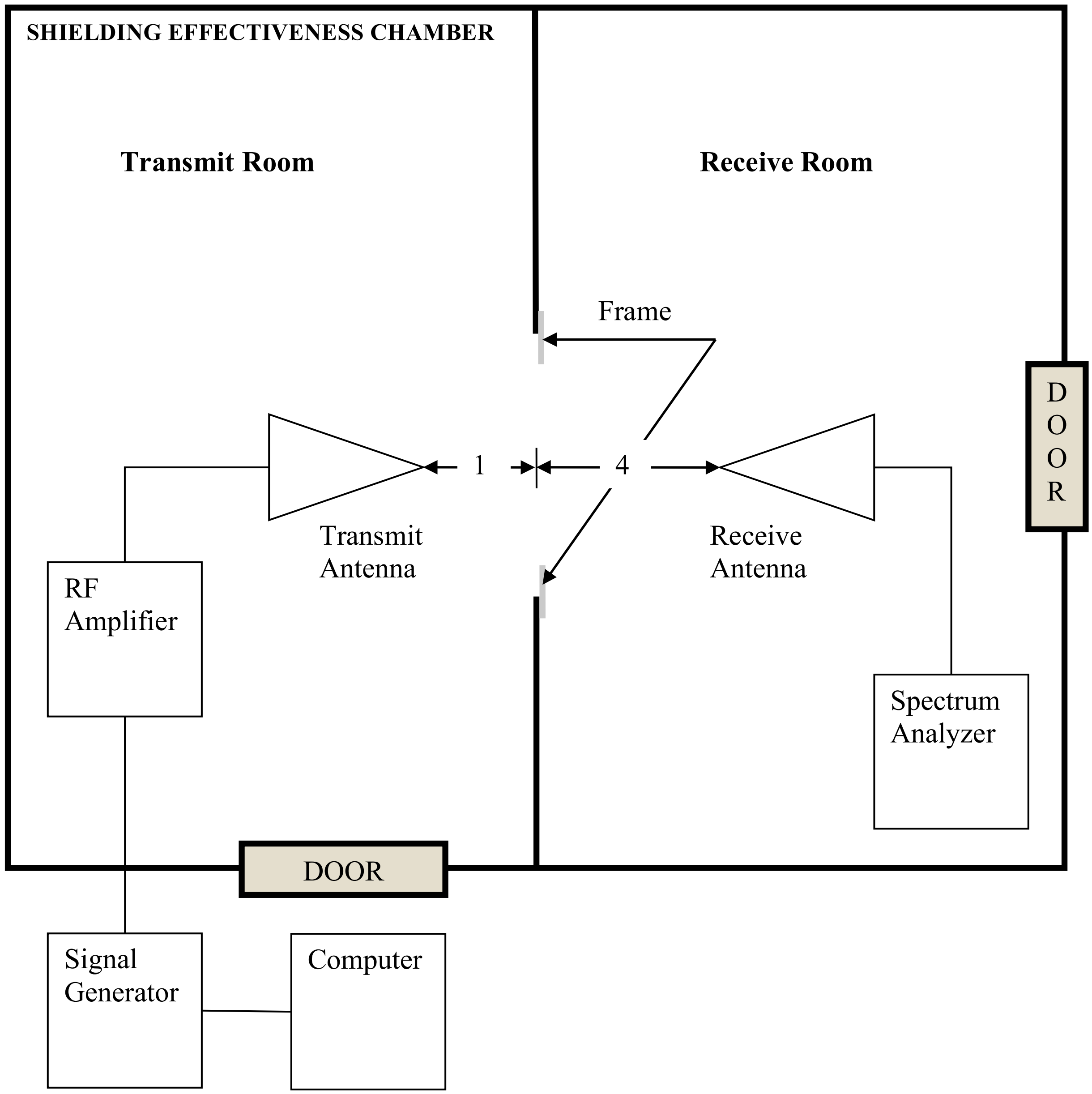
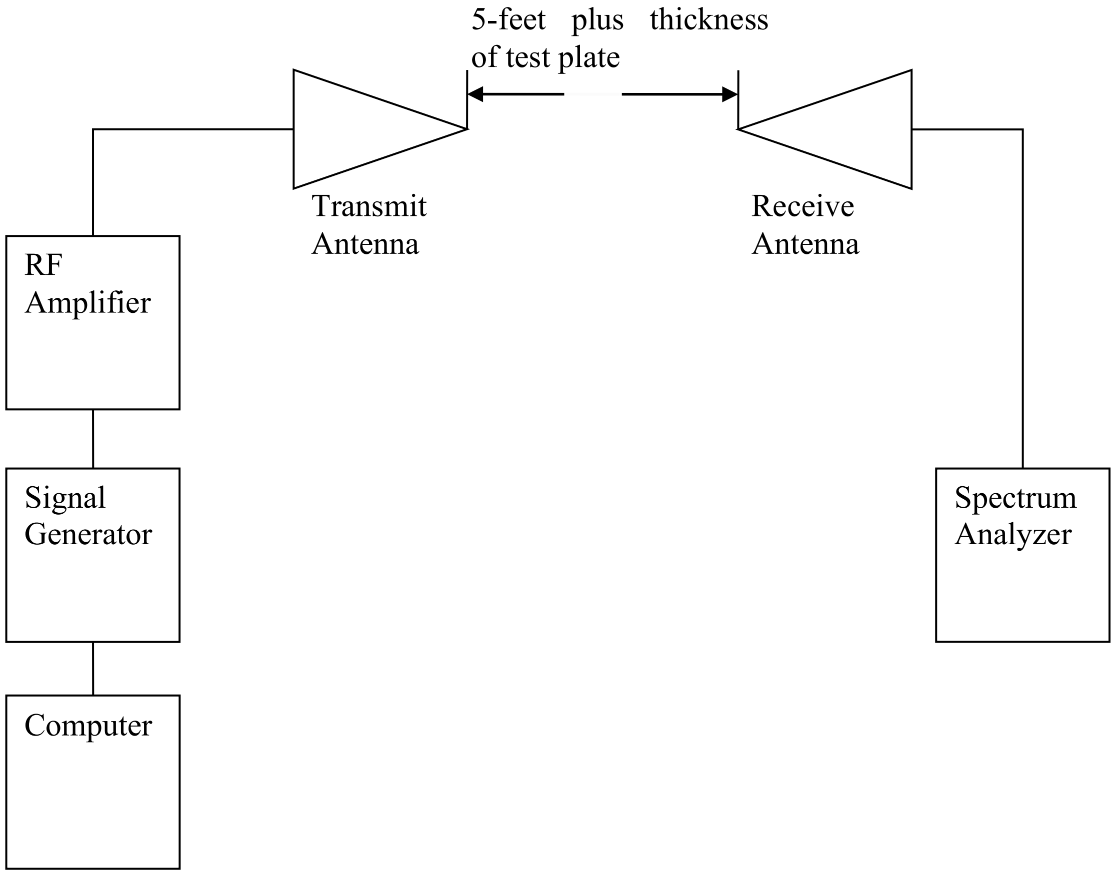


Figure 6 – Thru-Hole Open Reference Measurements



According to IEEE STD 299

Figure 7 – Free Space Open Reference Measurements

Panels are to be marked with the orientation of how they are mounted on the wall so the same position will be used throughout the test.

3.1.2.3 Test Sequence

The testing sequence for the Test Sets is as follows.

1. Free Space Open Reference Measurements. Free space measurements may be done at any time in the process.
2. Thru-hole Open Reference measurements with only Frame fixture (Figure 3) mounted to SE chamber aperture. Only required for one fixture.
3. 1st SE test. All assembled panels (36 Test Sets). (Initial baseline)
4. Static Heat and Humidity – 12 Plate Sets.

5. Salt Fog Testing – 12 Plate Sets.
6. Marine Environment – 12 Plate Sets.
7. 2nd SE test. All assembled panels (36 Test Sets).

3.1.2.4 Test Equipment

Table 6 – Test Equipment

Test Equipment	Asset #	Serial #	Cal Date
HP 83620B Signal Generator	625	3844A00955	NCR
AR Amplifier 30W1000M7 30 Watts 25 - 1000MHz	480	15657	NCR
Logimetrics A300/S-08 2-4GHz Amplifier	133	3016	NCR
Logimetrics A300/C-08 4-8GHz Amplifier	132	3012	NCR
Logimetrics A300/IJ 8-18GHz Amplifier	134	3094	NCR
Agilent E4440A Spectrum Analyzer	704	US41421236	TBD
EMCO 3115 Ridge Guide Horn Antenna	376	2796	TBD
EMCO 3115 Ridge Guide Horn Antenna	377	2175	TBD
EMCO 3106 Ridge Guide Horn Antenna	117	2213	TBD
EMCO 3106 Ridge Guide Horn Antenna	120	2212	TBD
ETS-Lindgren TILE! EMC Software Version 4.0.A.9	N/A	N/A	NCR
Dell PC Computer	N/A	N/A	NCR
Valhalla Digital Ohm Meter 4100 ATC	158	2-2818	TBD
Parker Chomerics Cho-probe	N/A	N/A	NCR

Any equipment identified within this document may be substituted at the time of test to accommodate availability and calibration cycles if necessary.

3.1.2.5 Shielding Effectiveness (SE) Test Results

3.1.2.5.1 Shielding Effectiveness (SE) Results Before Thermal Preconditioning

Prior to thermal preconditioning, the test plates were subjected to shielding effectiveness testing in accordance with IEEE-STD-299. Appendix X

3.1.2.5.2 Shielding Effectiveness (SE) Results After Thermal Preconditioning

Following thermal preconditioning, the test plates were subjected to shielding effectiveness testing in accordance with IEEE-STD-299. Appendix X

3.1.3 Salt Spray Resistance

This test is used to rapidly evaluate the performance of a coating or coating system and how well it prevents corrosion. Salt Spray Resistance is a requirement of MIL-DTL-5541.

3.1.3.1 Test Procedure

Plate sets are subjected to a 5 percent NaCl salt spray, pH-adjusted to a range of 6.5 – 7.2, in accordance with ASTM B 117 (Standard Practice for Operating a Salt Spray (Fog) Apparatus). The plate sets are placed into the salt spray chamber diagonally (see Figure 8) to prevent moisture from pooling on the gasket.

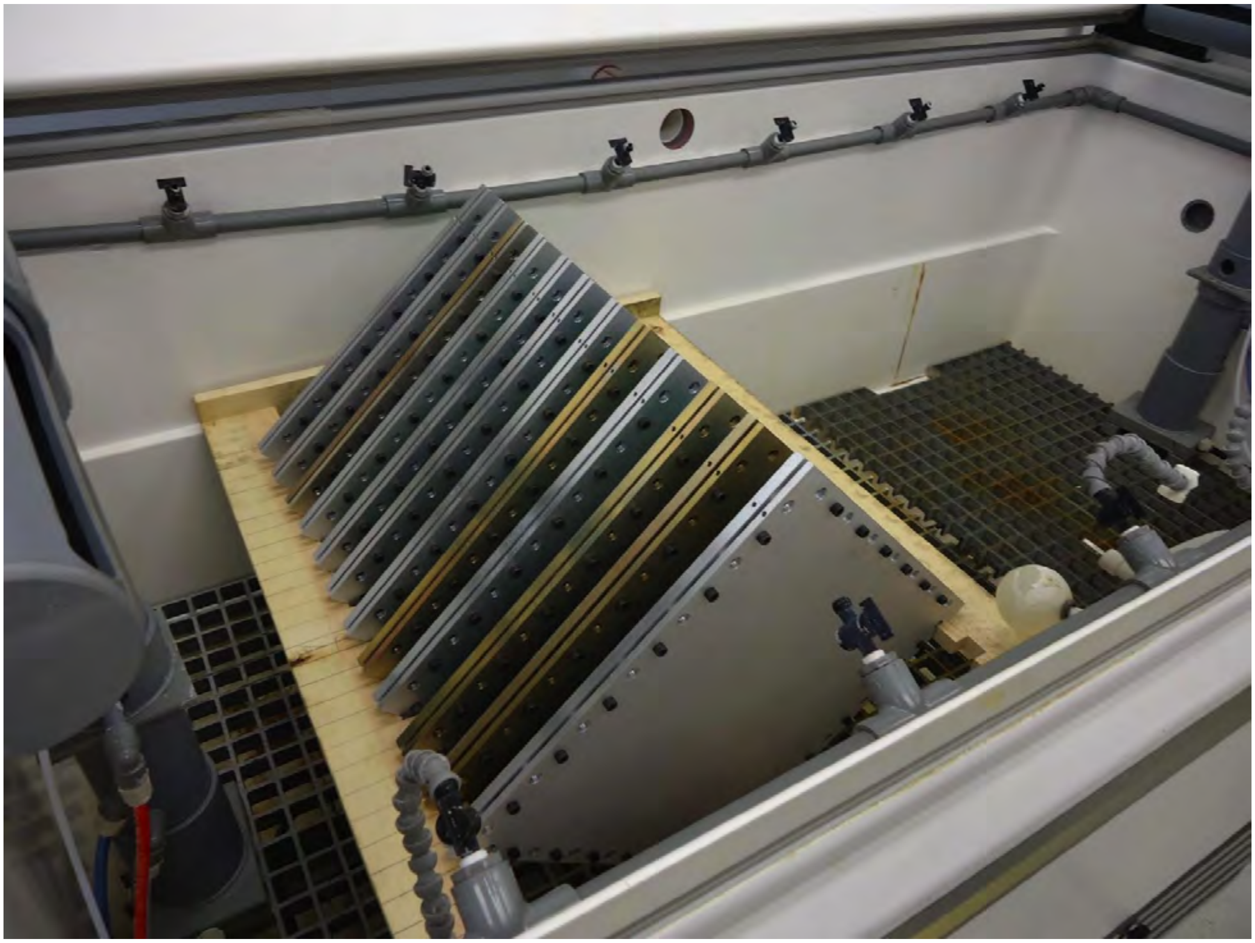


Figure 8 – ASTM B 117 Salt Spray Setup

3.1.3.2 Evaluation Procedure

Plate set evaluations took place at 168 hour intervals. During plate set evaluation, signs of corrosion that appear on the test articles were circled with a felt tip pen (Sharpie or equivalent) and photos were taken for each plate set. Following inspection, the panels were rotated a quarter turn when placed back into the salt spray chamber.

3.1.3.3 Salt Spray Resistance Test Results

During salt spray resistance testing, the black oxide alloy steel socket head cap screws corroded. Corrosion product from the steel socket head cap screws ran down the length of the test panels. After each 168 hour inspection, the test plates were rotated a quarter turn. As testing continued and the corrosion product from the steel socket head cap screws increased, a checkered pattern formed on the surface of the test plates. The checkered pattern made inspecting the test plates for signs of pitting difficult. No pitting was observed on the surface of the test plates during the duration of testing. Any pitting that is observed during test plate disassembly will be noted. Photos of the test plates following salt spray testing are located in Appendix C – Salt Spray Testing.

3.1.4 Static Heat and Humidity

Plate sets are subjected to 85°C +/- 1°C and 85% RH +/- 5% RH for 1,000 hours. The plate sets are placed into the salt spray chamber diagonally (see Figure 9) to prevent moisture from pooling on the gasket.

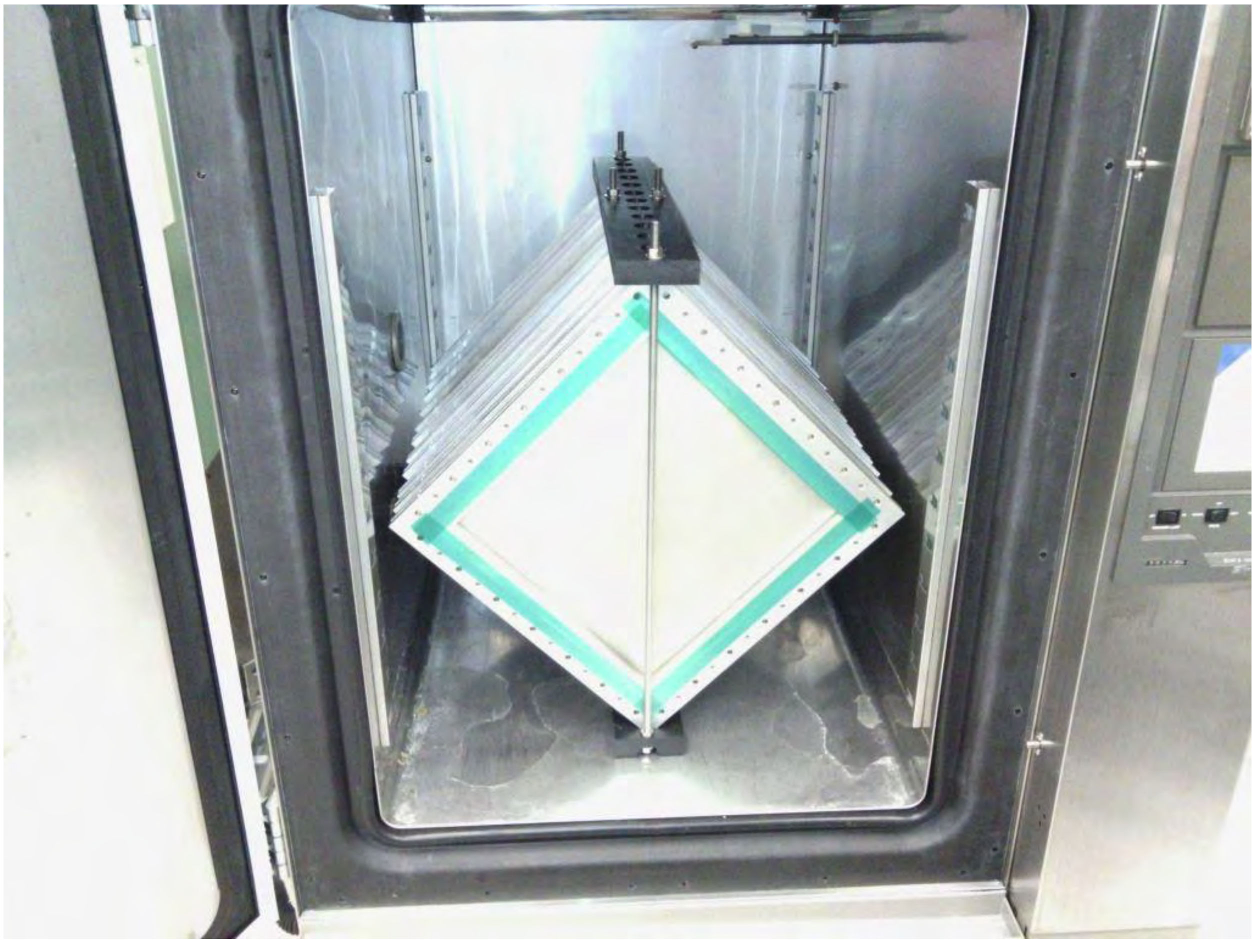


Figure 9 – Static Heat and Humidity Test Setup

3.1.4.1 Evaluation Procedure

Following 1,000 hours of testing, the plate sets were evaluated. Signs of corrosion that appear on the test articles were circled with a felt tip pen (Sharpie or equivalent) and photos were taken for each plate set.

3.1.4.2 Static Heat and Humidity Test Results

Following 1,000 hours of testing, no pitting was observed on the surface of the test plates. The only signs of corrosion on the test plates is attributed to the oxide alloy steel socket head cap screws. For a limited number of the test plates, the steel socket head cap screws that we located near the humidity inlet corroded. The corrosion from these screws was spattered along the edge of the test panel. Photos of the test plates following static heat and humidity testing are located in Appendix D – Static Heat and Humidity.

3.1.5 Marine Environment

This test evaluates the performance of the test and control coatings during outdoor exposure in a marine environment. Accelerated testing is useful for comparing the performance of coatings under accelerated conditions; however, correlations to actual service performance have been difficult due to different corrosion mechanisms prevalent in the two situations. Therefore, outdoor exposure in the environment of performance is a critical test necessary to determine the effect actual weather patterns and real-world exposure has on the coatings of interest. Comparing data collected from atmospheric and accelerated testing provides insight into anticipated performance of a coating system before being field-tested.

3.1.5.1 Test Procedure

Atmospheric exposure testing follows ASTM D 1014 (Standard Practice for Conducting Exterior Exposure Tests of Paints and Coatings on Metal Substrates).

Test articles are installed diagonally (see Figure 10) at the KSC Beachside Corrosion Lab, located at latitude 28.594°N, longitude -80.582°W, and approximately 100 feet (30 meters) from the high tide line.

Figure 10 – KSC Beachside Testing

3.1.5.2 Evaluation Procedure

During plate set evaluation, signs of corrosion that appeared on the test articles were circled with a felt tip pen (Sharpie or equivalent) and photos were taken for each plate set.

3.1.5.3 Marine Environment Test Results

Currently in test

3.2 DC Resistance Testing

3.2.1 Test Panel - Resistance Testing

For the following tests, 3"x10"x0.32" test panels were used in two alloy types 6061-T6 and 5052-H32.

Table 7 – Resistance Testing Overview

Test	Test Method	Panel Count	Evaluation Criteria	Location
Contact Electrical Resistance	MIL DTL 81706	Set 1 = 30	not greater than 5,000 microhms	UTC Aerospace Systems
Surface Resistance Test	ASTM D 257	Set 1 = 30	Data collection	Raytheon
Salt Spray Resistance	ASTM B 117	168 Hours	MIL-DTL-5541	KSC Corrosion Lab
Contact Electrical Resistance	MIL DTL 81706	Set 2 = 30	not greater than 5,000 microhms	UTC Aerospace Systems
Surface Resistance Test	ASTM D 257	Set 1 = 30	Data collection	Raytheon

Table 8 – Resistance Testing, Test Panels Breakout

MIL-DTL-81706 Contact Resistance				
Numer of samples	Alloy	Conversion Coating	Set 1	Total Number of Test Panels
5	6061-T6	Hex Chrome	Before Salt Spray	15
5		SurTec	Before Salt Spray	
5		Metalast	Before Salt Spray	
Numer of samples	Alloy	Conversion Coating	Set 1	Total Number of Test Panels
5	5052-H32	Hex Chrome	Before Salt Spray	15
5		SurTec	Before Salt Spray	
5		Metalast	Before Salt Spray	
Numer of samples	Alloy	Conversion Coating	Set 2	Total Number of Test Panels
5	6061-T6	Hex Chrome	After Salt Spray	15
5		SurTec	After Salt Spray	
5		Metalast	After Salt Spray	
Numer of samples	Alloy	Conversion Coating	Set 2	Total Number of Test Panels
5	5052-H32	Hex Chrome	After Salt Spray	15
5		SurTec	After Salt Spray	
5		Metalast	After Salt Spray	
ASTM D 257 Surface Resistance				
Numer of samples	Alloy	Conversion Coating	Set 1	Total Number of Test Panels
5	6061-T6	Hex Chrome	Before& After Salt Spray	15
5		SurTec	Before& After Salt Spray	
5		Metalast	Before& After Salt Spray	
Numer of samples	Alloy	Conversion Coating	Set 1	Total Number of Test Panels
5	5052-H32	Hex Chrome	Before& After Salt Spray	15
5		SurTec	Before& After Salt Spray	
5		Metalast	Before& After Salt Spray	

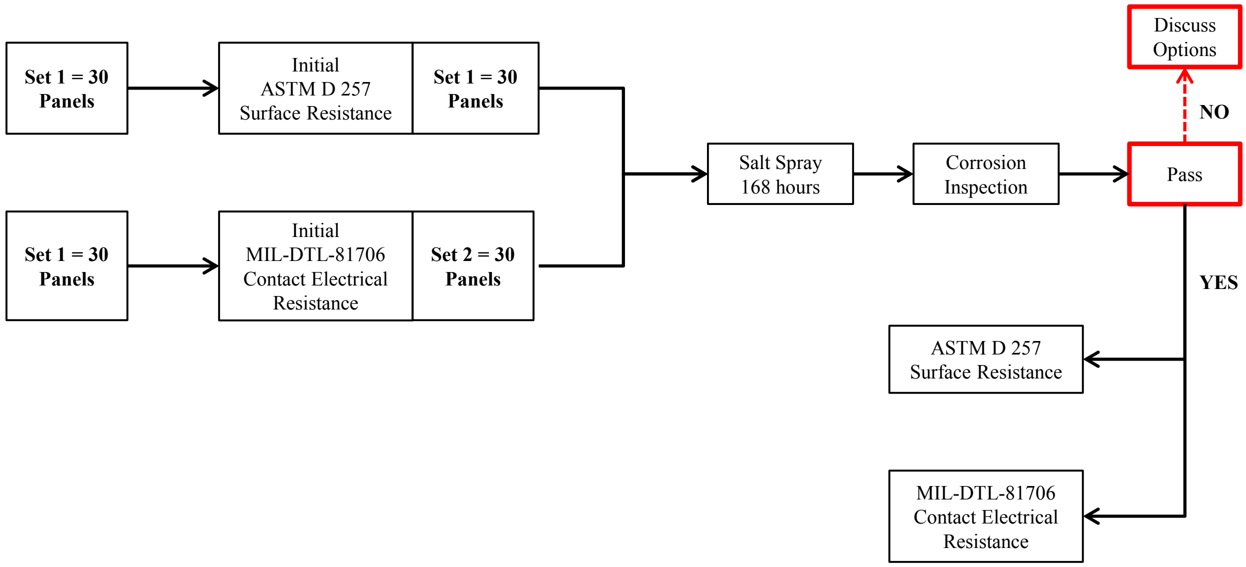


Figure 11 – Resistance Testing Project Flow

3.2.2 Contact Electrical Resistance

Low contact electrical resistance properties are a qualification requirement of MIL-DTL-81706B. Readings were taken prior to and following ASTM B 117 salt spray testing. A total of 60 test panels underwent testing; five (5) replicates, (2) alloys, (3) conversion coatings, (2) panel sets; set 1 was used for electrical resistance readings prior to salt spray testing. Set 1 was not subjected to salt spray testing. Set 2 was subjected to salt spray testing (168 hours) and then electrical resistance readings were taken.

3.2.2.1 Test Procedure

The test should be conducted similar to the test set-up in Figure 12. The applied load shall be within one percent of the calculated 200 pounds per square inch (psi) applied pressure. The contacting electrodes shall be copper or silver-plated copper with a finish not rougher than that obtained by the use of 000 metallographic abrasive paper. The electrodes shall be flat enough so that when the load is applied without a specimen between them, light will not be visible through the contacting surface. The area of the upper electrode shall be one square inch (25 square mm) and the area of the lower electrodes shall be larger. Ten measurements shall be made on each panel in the areas shown on Figure 13.

1. Two copper rods a minimum of 1-inch thick shall have the end surfaces polished to a mirror finish. One electrode shall be 1” diameter and the other shall be 1.5” diameter.
2. The panels shall be double rinsed with clean, running, lukewarm DI water (less than 100°F) for approximately 30 seconds. The panels shall then be blown dry with nitrogen and wrapped in clean paper towels to protect them from scratching each other. The clean panels shall air dry for 24 hours at room temperature prior to testing.
3. Before taking readings on each panel, baseline electrical resistance readings of the copper rods alone shall be taken. These values shall be subtracted from the panel electrical resistance values. The copper electrical resistance values shall be observed to look for any increase in baseline resistance, which would indicate a need to re-polish the electrodes.

4. The larger diameter copper rod shall be positioned in the middle of the lower Instron compression plate. The test panel shall be positioned on top of the larger diameter copper rod and then the smaller diameter copper rod centered over the lower. 200 pounds of force shall be applied using the Instron. The electrical resistance compression test method shall be selected, which will automatically stop the compressive loading at approximately 200 pounds. When approximately 200 pounds of force is achieved, electrical resistance readings shall be taken. The HP Agilent HP 4338B electrical meter shall be used for readings using 16143B probes. The probes shall be pushed against the side of the copper rods and the meter reading recorded. Ten electrical resistance readings shall be taken on each panel, evenly distributed over the panel. After each panel, the copper rods shall be cleaned using a dry, lint free, non-abrasive cloth.
5. Using the HP 4338B Agilent Meter: The four connection mating cable shall be plugged into the front of the meter, matching the LCUR, LPOT, HPOT and HCUR designations on the connector and meter. The Auto Meas light will be lit up green and the screen will read, "R:-29.9 kΩ LVL: Auto AVG: 1". As you push down on the probe tips, the sheath makes contact and a reading is displayed on the meter. The reading may be continuously changing on the last decimal place; in this case, an average reading shall be recorded.
6. The electrical resistance readings shall be averaged and the baseline copper plate electrical resistance subtracted from the average, and then this value divided by two to give the coating electrical resistance value. These values shall then be tabulated and reported.
7. The copper plates shall be re-polished to a mirror finish after each testing day.

3.2.2.2 Evaluation Procedure

The contact electrical resistance of aluminum alloy panels treated with class 3 materials under an applied electrode pressure of 200 pounds psi shall be not greater than 5,000 microhms psi as applied and 10,000 microhms psi after salt spray exposure. Individual readings not greater than 20 percent in excess of the specified maximums shall be acceptable, provided that the average of all readings does not exceed the specified maximum resistance.

Figure 12 – Contact Electrical Resistance Testing

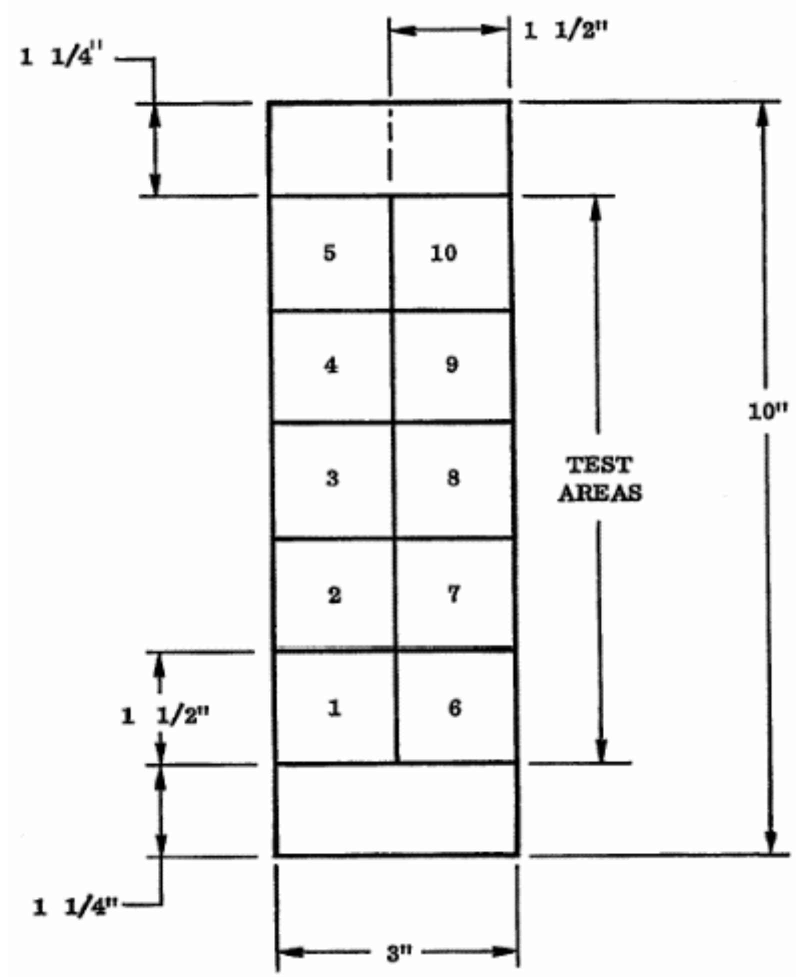


Figure 13 – Contact Electrical Resistance Test Pattern

3.2.2.3 Contact Electrical Resistance Test Results

Following the completion of the contact electrical resistance testing, it was determined that all test panels did not meet the qualification requirements of MIL-DTL-81706B; alloy panels treated with class 3 materials under an applied electrode pressure of 200 pounds psi shall not be greater than 5 milliohms psi as applied before salt spray testing and 10 milliohms psi as applied following salt spray testing. Previous studies have yielded similar high readings for test panels that have been stored for weeks prior to contact electrical resistance testing. The reason storing test panels prior to testing has this effect is not fully understood at this time. The following tables contain the results from contact electrical resistance testing.

Table 9 – Resistance Values in Milliohms before Salt Spray Testing

Alloy	Conversion Coat	Test Panel ID	Location on Test Panel 1	2	3	4	5	6	7	8	9	10	Mean	Median	Standard Deviation	Copper Electrode to Electrode Resistance
6061	Alodine 1200S	1	80	11	9.4	36.5	210	60	78	164	73	143	86.49	75.5	66.32781	0.31
		2	75	72	62	163	141	19.5	180	120	190	250	127.25	130.5	70.67738	0.48
		3	84	240	26	81	15	21	7.6	41	48	31	59.46	36	68.48183	0.3
		4	127	40	108	157	69	33	186	14	192	88	101.4	98	63.65916	0.85
		5	187	15	120	33	81	115	99	76	160	247	113.3	107	70.14754	1.2
6061	SurTec 650	6	51	1900	34	4.2	7.6	62	22	18	113	380	259.18	42.5	587.264	0.49
		7	326	295	72	64	163	54	120	53	1020	78	224.5	99	296.6023	0.81
		8	560	456	59	526	600	11	24	29	35	128	242.8	93.5	256.3248	0.37
		9	92	65	570	36	50	200	64	23	22	139	126.1	64.5	165.5975	0.69
		10	97	28	140	10	48	8.4	76	45	15	76	54.34	46.5	42.87087	0.35
6061	Metalast TCP-HF	11	153	403	20	228	460	33	158	153	327	228	216.3	193	145.419	3
		12	338	321	111	400	344	1180	2600	8700	61	296	1435.1	341	2663.468	1.6
		13	17	1200	1130	58	1.4	12	48	6.6	15	2.7	249.07	16	483.3816	0.45
		14	61	2800	6.6	4.8	2.6	3.4	3	28	323	113	334.54	17.3	871.9408	0.27
		15	42	15	18	480	110	8	4.9	28	331	17.7	105.46	23	164.7696	0.74

Alloy	Conversion Coat	Test Panel ID	Location on Test Panel 1	2	3	4	5	6	7	8	9	10	Mean	Median	Standard Deviation	Copper Electrode to Electrode Resistance
5052	Alodine 1200S	1	32	60	15	15	4.2	36	43	24	23	79	33.12	28	22.64042	2
		2	18	21	6.6	14	94	74	44	26	54	81	43.26	35	31.07569	1.2
		3	33	8.8	19	39	99	24	112	55	73	43	50.58	41	34.30108	1.6
		4	7.8	18	42	40	65	19	92	90	75	75	52.38	53.5	31.11305	2.1
		5	23	35	30	64	37	35	11	60	60	59	41.4	36	18.27688	0.69
5052	SurTec 650	6	27	43	240	140	65	48	19	45	25	41	69.3	44	69.10065	1.2
		7	19	141	25	110	16	18	48	14	5.2	3.8	40	18.5	47.24461	0.17
		8	9.6	4.9	4.8	20	12	11	41	11	62	45	22.13	11.5	19.93835	0.93
		9	14	38	14	13	30	11	16	29	26	33	22.4	21	9.834181	1.8
		10	10	19	15	7.5	18	9	34	31	31	16	19.05	17	9.730964	1
5052	Metalast TCP-HF	11	95	37	52	49	300	18	15	70	460	15	111.1	50.5	148.8254	0.74
		12	170	49	110	30	29	81	71	170	50	45	80.5	60.5	53.08955	0.14
		13	110	270	9	63	18	290	130	31	46	11	97.8	54.5	104.3092	0.79
		14	68	180	32	4.1	53	17	8.4	6.5	18	42	42.9	25	52.66194	0.85
		15	74	44	47	140	92	18	18	5.2	80	35	55.32	45.5	41.34142	0.2

Requirement = 5 milliohms, maximum

Table 10 – Resistance Values in Milliohms after Salt Spray Testing

Alloy	Conversion Coat	Test Panel ID	Location on Test Panel										Mean	Median	Standard Deviation	Copper Electrode to Electrode Resistance
			1	2	3	4	5	6	7	8	9	10				
6061	Alodine 1200S	16	290	208	320	140	120	160	160	140	520	120	217.8	160	126.9276	0.69
		17	180	280	81	62	74	140	140	140	140	140	137.7	140	62.4216	0.79
		18	140	60	130	180	55	106	82	94	36	110	99.3	100	43.60441	2.6
		19	190	55	130	36	88	12	150	310	250	84	130.5	109	96.06855	3.6
		20	75	110	75	15	38	76	7.1	140	16	220	77.21	75	66.23826	2.1
6061	SurTec 650	21	510	107	83	1200	120	360	2800	620	105	110	601.5	240	849.3096	2.2
		22	23	15	12	21	36	160	105	90	150	260	87.2	63	82.61127	0.83
		23	27	30	43	170	190	11	100	330	23	220	114.4	71.5	108.2971	1.8
		24	560	30	86	160	31	140	250	650	130	33	207	135	221.7496	0.79
		25	14	170	74	130	160	11	180	1060	54	65	191.8	102	311.3522	1.3
6061	Metalast TCP-HF	26	52	79	67	350	120	33	210	19	93	530	155.3	86	164.7396	2.3
		27	53	310	22	350	33	320	320	280	330	320	233.8	315	137.7831	3.5
		28	500	320	16	36	1	15	150	390	3.4	29	146.04	32.5	187.4844	1.5
		29	1500	86	120	540	170	130	55	150	28	25	280.4	125	453.3687	0.54
		30	43	40	54	14	31	11	110	87	270	50	71	46.5	76.2321	0.55

Alloy	Conversion Coat	Test Panel ID	Location on Test Panel										Mean	Median	Standard Deviation	Copper Electrode to Electrode Resistance
			1	2	3	4	5	6	7	8	9	10				
5052	Alodine 1200S	16	24	19	30	102	14	31	35	49	97	60	46.1	33	31.23549	0.77
		17	11	53	110	17	29	2.6	67	79	26	51	44.56	40	33.8589	0.45
		18	51	32	10	5.4	49	69	71	11	77	61	43.64	50	27.25123	2.1
		19	40	28	30	19	38	108	39	53	14	32	40.1	35	26.29512	0.53
		20	22	71	30	56	34	11	16	85	37	33	39.5	33.5	23.978	0.79
5052	SurTec 650	21	34	14	6.6	33	45	14	16	46	18	56	28.26	25.5	16.83675	1.5
		22	9.3	26	10	8.3	33	32	6.5	23	7	11	16.61	10.5	10.68077	0.97
		23	15	9.8	6	34	6.4	14	5.3	11	35	14	15.05	12.5	10.82725	1.1
		24	71	59	5.6	4.9	4.9	26	9.3	11	24	9.8	22.55	10.4	23.73906	1.4
		25	11	91	7.1	7.4	6.9	38	5.4	8.4	7.9	10	19.31	8.15	26.94057	1.4
5052	Metalast TCP-HF	26	170	120	46	25	17	8.2	13	14	140	110	66.32	35.5	61.89491	0.79
		27	44	110	20	17	120	28	32	9	37	27	44.4	30	38.58382	1.9
		28	5.5	7.2	32	15	330	110	100	25	85	74	78.37	53	96.74624	0.78
		29	39	4.9	11	75	210	130	200	250	6	74	99.99	74.5	92.08873	2
		30	85	130	3.8	15	20	26	14	11	45	33	38.28	23	39.74622	2.2
Requirement = 10 milliohms, maximum																

3.2.3 Surface Resistance Test

Stakeholders expressed interest in having this test for comparison with the contact electrical resistance test. A major difference in the ASTM D 257 procedure is the greatly reduced applied pressure on the electrodes. Readings were taken prior to and following ASTM B 117 salt spray testing. A total of 30 test panels underwent testing; five (5) replicates, (2) alloys, (3) conversion coatings. Only a single set of panels is used for surface resistance testing. Surface resistance readings are taken prior to salt spray testing and again, using the same test panels, following 168 hours of salt spray testing.

3.2.3.1 Test Procedure

The following Surface Resistance Test procedure was provided by Raytheon:

1. Use the ASTM D257 Certified Probe made by Electro-Tech Systems (Model 803B)
2. Connect probe to Agilent 34401A multimeter with 4 point hook up and set to 4 point resistance measurements (Figure 14):
   a. Connect black and red leads on probe to the black and red leads on multimeter

b. Connect green lead to probe case (not color coded) and black terminal of multimeter Input
c. Set multimeter to 4W resistance mode

Figure 14 – Surface Resistance Test Set-Up

3. Inspect the panel visually for any evidence of surface contamination. Solvent clean the panel using isopropyl alcohol and wipe, with a lint free towel when necessary.
4. Place probe on surface making full contact with coupon and apply medium pressure (less than 20 pounds of pressure with a new probe) in center of probe from above until resistance measurement stabilizes, for at least 15 seconds.

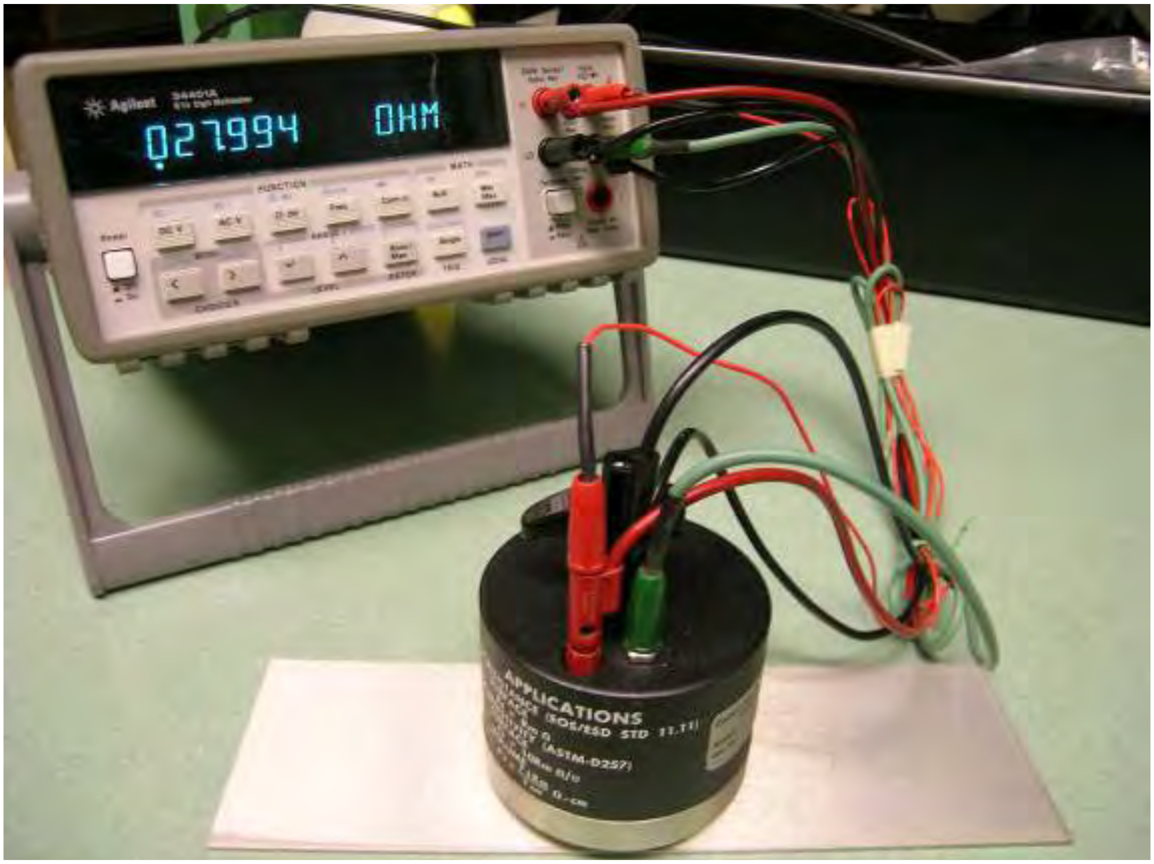


Figure 15 – Surface Resistance Testing

5. Use equation on side of probe to determine that the surface resistance in ohms per square is equal to measured resistance times 10.
6. Record surface resistance value. If required, determine if the test pass or fail in accordance with the criteria established.
7. Depending on size of coupon repeat up to 10 times per coupon testing each side 5 times, less times if coupon is smaller (standard coupon size is roughly 3.5" x 8")

3.2.3.2 Evaluation Procedure

The intent of this testing is to collect the data for each test specimen before and after environmental testing. The surface electrical resistance of the test panels was measured and documented for additional data analysis.

3.2.3.3 Surface Resistance Test Results

Following the completion of the surface resistance testing, it was determined that all of the measurements were well below the 15 ohms per square requirement. There was a small measurable increase in the surface resistance for all combinations after salt spray testing. The Alodine 1200S pretreated test panels showed the lowest increase in surface resistance, followed by the Metalast TCP-HF, with the SurTec 650 test panels showing the greatest increase in surface resistance after salt spray testing. The 5052-H32 alloy test panels showed lower surface resistivity than the 6061-T6 alloy test panels. The following tables contain the results from surface resistance testing.

Table 11 – Surface Resistance Test Results; 5052-H32 Alloy Test Panels

5052-H32: Hex Cr Alodine 1200S

Panel # 31	Pre-Salt	Post-Salt	Panel # 32	Pre-Salt	Post-Salt	Panel # 33	Pre-Salt	Post-Salt	Panel # 34	Pre-Salt	Post-Salt	Panel # 35	Pre-Salt	Post-Salt		
1	8.1	8.5	1	8.4	8.1	1	8.0	8.3	1	7.8	8.8	1	8.9	8.9		
2	8.2	8.7	2	8.1	8.4	2	8.0	8.2	2	7.3	8.2	2	8.7	8.1		
3	6.7	8.0	3	7.9	8.3	3	8.3	8.0	3	8.1	8.4	3	8.0	8.0		
4	8.5	8.3	4	7.7	8.3	4	8.2	8.4	4	7.8	8.5	4	7.9	7.9		
5	7.2	8.9	5	8.5	8.3	5	8.1	8.7	5	8.0	8.3	5	8.5	8.2	**Average of All Panels:**	
Average:	**7.7**	**8.5**	**Average:**	**8.1**	**8.3**	**Average:**	**8.1**	**8.3**	**Average:**	**7.8**	**8.4**	**Average:**	**8.4**	**8.2**	**8.0**	**8.3**
															Pre-Salt	**Post-Salt**

5052-H32: SurTec 650

Panel # 31	Pre-Salt	Post-Salt	Panel # 32	Pre-Salt	Post-Salt	Panel # 33	Pre-Salt	Post-Salt	Panel # 34	Pre-Salt	Post-Salt	Panel # 35	Pre-Salt	Post-Salt		
1	6.5	7.9	1	6.3	7.7	1	6.6	7.8	1	6.2	8.0	1	6.7	7.9		
2	6.2	7.8	2	6.1	7.9	2	6.3	7.8	2	6.5	7.7	2	6.8	7.7		
3	6.4	7.7	3	6.1	8.0	3	6.6	7.9	3	6.0	7.6	3	6.9	7.9		
4	6.7	7.8	4	6.1	7.7	4	6.6	7.7	4	6.1	7.8	4	5.9	7.9		
5	6.0	7.9	5	6.5	7.7	5	6.8	7.9	5	6.3	7.9	5	6.4	7.6	**Average of All Panels:**	
Average:	**6.4**	**7.8**	**Average:**	**6.2**	**7.8**	**Average:**	**6.6**	**7.8**	**Average:**	**6.2**	**7.8**	**Average:**	**6.5**	**7.8**	**6.4**	**7.8**
															Pre-Salt	**Post-Salt**

5052-H32: Metalast-TCP-HF

Panel # 31	Pre-Salt	Post-Salt	Panel # 32	Pre-Salt	Post-Salt	Panel # 33	Pre-Salt	Post-Salt	Panel # 34	Pre-Salt	Post-Salt	Panel # 35	Pre-Salt	Post-Salt		
1	6.1	7.0	1	5.9	7.3	1	6.0	6.9	1	6.3	7.4	1	6.0	6.9		
2	6.4	7.0	2	5.9	7.0	2	5.9	6.8	2	6.2	7.1	2	6.0	6.9		
3	6.3	7.2	3	6.4	7.1	3	6.1	6.9	3	6.3	7.0	3	6.1	6.8		
4	6.4	6.9	4	6.2	7.1	4	6.1	6.7	4	6.1	7.2	4	6.2	7.2		
5	5.9	7.3	5	6.3	7.1	5	6.0	7.2	5	6.3	6.9	5	6.1	7.0	**Average of All Panels:**	
Average:	**6.2**	**7.1**	**Average:**	**6.1**	**7.1**	**Average:**	**6.0**	**6.9**	**Average:**	**6.2**	**7.1**	**Average:**	**6.1**	**7.0**	**6.1**	**7.0**
															Pre-Salt	**Post-Salt**

ASTM D257 - Model 803B Probe

****All Measurements are in Ohms/Square****

Table 12 – Surface Resistance Test Results; 6061-T6 Alloy Test Panels

6061-T6: Hex Cr Alodine 1200S

Panel # 31	Pre-Salt	Post-Salt	Panel # 32	Pre-Salt	Post-Salt	Panel # 33	Pre-Salt	Post-Salt	Panel # 34	Pre-Salt	Post-Salt	Panel # 35	Pre-Salt	Post-Salt		
1	5.8	6.5	1	6.1	6.6	1	6.0	7.0	1	6.2	6.2	1	5.9	6.8		
2	6.0	6.7	2	6.8	6.7	2	6.1	6.5	2	6.1	6.5	2	5.9	6.7		
3	5.9	6.8	3	6.4	6.8	3	6.0	6.4	3	6.2	6.6	3	6.0	6.4		
4	6.1	6.6	4	6.2	6.8	4	6.0	6.8	4	6.3	6.7	4	5.8	6.2		
5	5.8	6.7	5	5.9	6.2	5	6.0	6.2	5	6.0	6.8	5	5.7	6.8	**Average of All Panels:**	
Average:	**5.9**	**6.7**	**Average:**	**6.3**	**6.6**	**Average:**	**6.0**	**6.6**	**Average:**	**6.2**	**6.6**	**Average:**	**5.9**	**6.6**	**6.0**	**6.6**
															Pre-Salt	**Post-Salt**

6061-T6: SurTec 650

Panel # 31	Pre-Salt	Post-Salt	Panel # 32	Pre-Salt	Post-Salt	Panel # 33	Pre-Salt	Post-Salt	Panel # 34	Pre-Salt	Post-Salt	Panel # 35	Pre-Salt	Post-Salt		
1	6.1	7.5	1	5.8	7.4	1	5.9	7.3	1	5.4	7.7	1	5.5	7.6		
2	5.8	7.4	2	5.1	7.2	2	6.0	7.4	2	5.4	7.4	2	5.3	7.5		
3	5.6	7.4	3	5.4	7.4	3	5.3	7.5	3	5.6	7.3	3	5.7	7.4		
4	5.7	7.3	4	5.6	7.2	4	6.1	7.4	4	5.6	7.5	4	6.1	7.5		
5	5.8	7.6	5	5.9	7.2	5	5.7	7.4	5	5.2	7.6	5	5.4	7.2	**Average of All Panels:**	
Average:	**5.8**	**7.4**	**Average:**	**5.6**	**7.3**	**Average:**	**5.8**	**7.4**	**Average:**	**5.4**	**7.5**	**Average:**	**5.6**	**7.4**	**5.6**	**7.4**
															Pre-Salt	**Post-Salt**

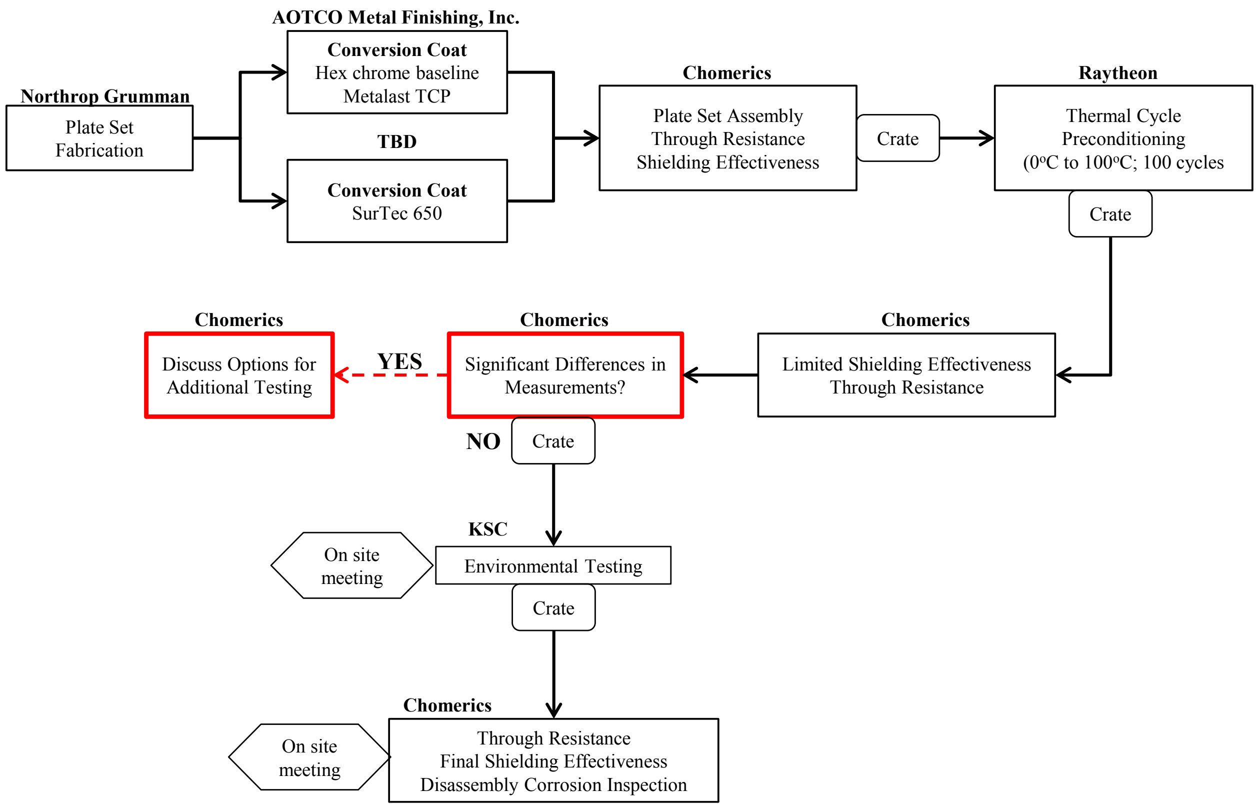
6061-T6: Metalast-TCP-HF

Panel # 31	Pre-Salt	Post-Salt	Panel # 32	Pre-Salt	Post-Salt	Panel # 33	Pre-Salt	Post-Salt	Panel # 34	Pre-Salt	Post-Salt	Panel # 35	Pre-Salt	Post-Salt		
1	5.4	7.0	1	5.1	6.5	1	4.9	6.9	1	4.9	6.2	1	5.6	6.1		
2	5.4	6.8	2	4.9	7.1	2	4.9	6.9	2	5.0	6.8	2	5.3	6.0		
3	5.2	7.2	3	5.3	6.7	3	5.0	6.8	3	4.8	6.9	3	5.2	6.3		
4	5.3	6.7	4	5.4	6.7	4	5.1	6.7	4	5.3	6.2	4	5.4	6.4		
5	5.1	7.3	5	5.6	7.2	5	5.0	6.6	5	5.4	7.1	5	5.1	6.2	**Average of All Panels:**	
Average:	**5.3**	**7.0**	**Average:**	**5.3**	**6.8**	**Average:**	**5.0**	**6.8**	**Average:**	**5.1**	**6.6**	**Average:**	**5.3**	**6.2**	**5.2**	**6.7**
															Pre-Salt	**Post-Salt**

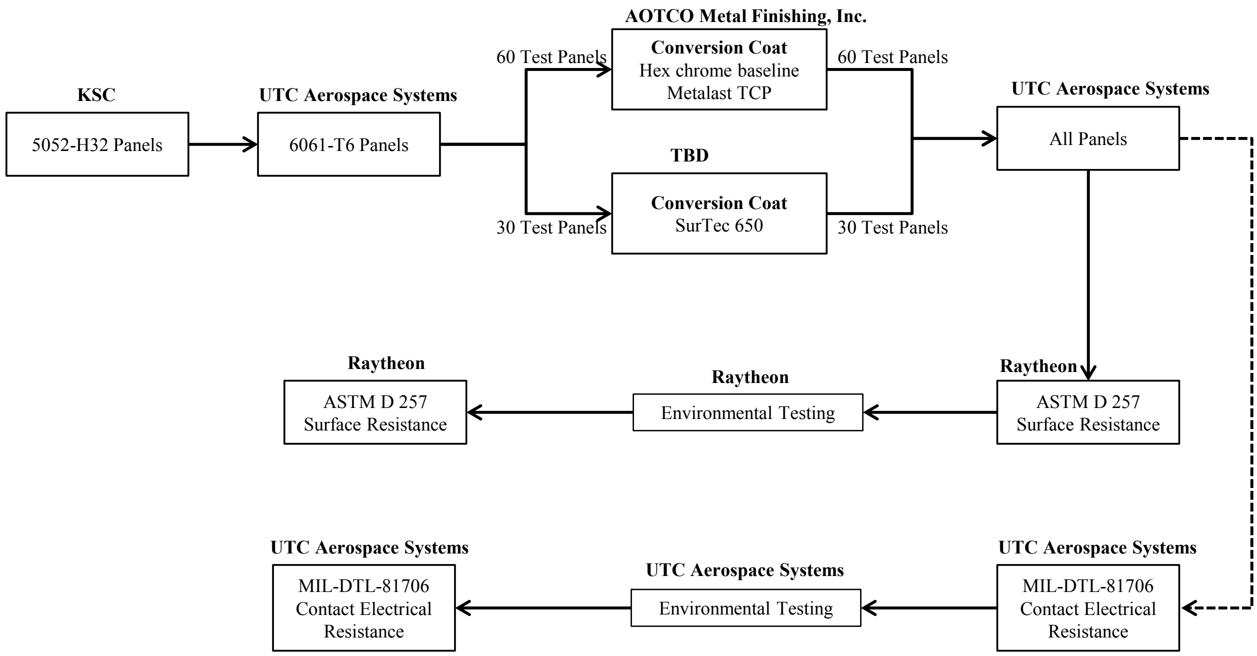
ASTM D257 - Model 803B Probe

****All Measurements are in Ohms/Square****

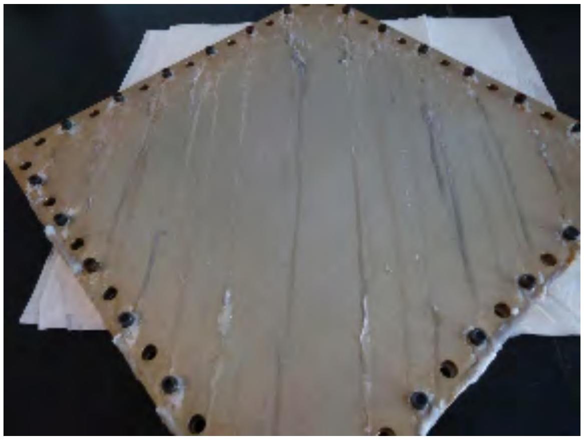
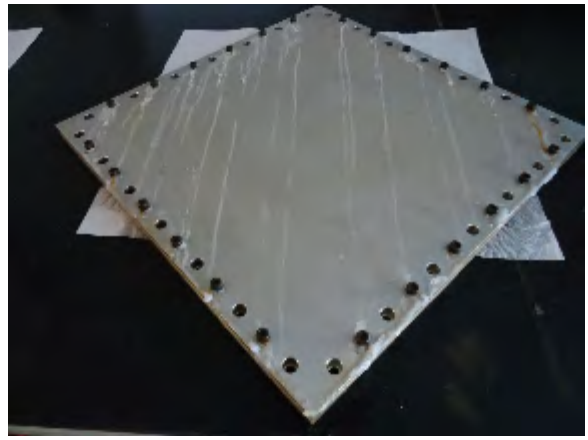
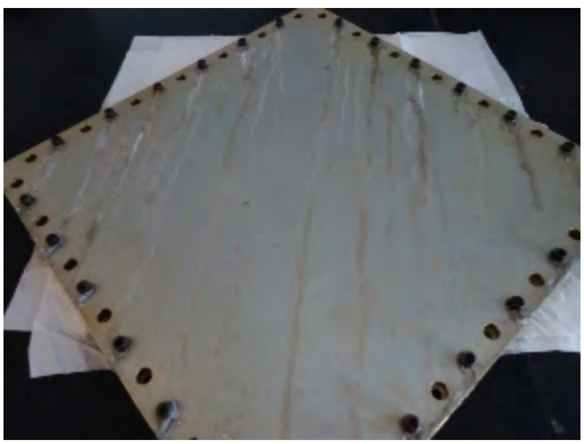
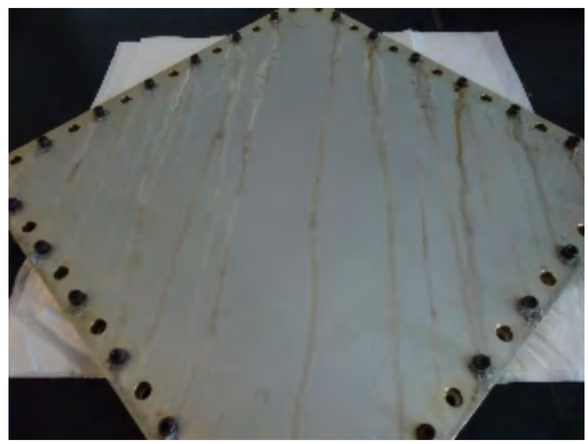
Appendix A – Plate Set Testing Task Flow



Appendix B – Test Panel Testing Task Flow



Appendix C – Salt Spray Testing

<table>
<tr><td colspan="2">168 Hours – Alodine 1200S (Hexavalent Chrome Baseline)</td></tr>
<tr><td>5051-H32 (5A01)</td><td>5051-H32 (5A02)</td></tr>
<tr><td></td><td></td></tr>
<tr><td>6061-T6 (6A01)</td><td>6061-T6 (6A02)</td></tr>
<tr><td></td><td></td></tr>
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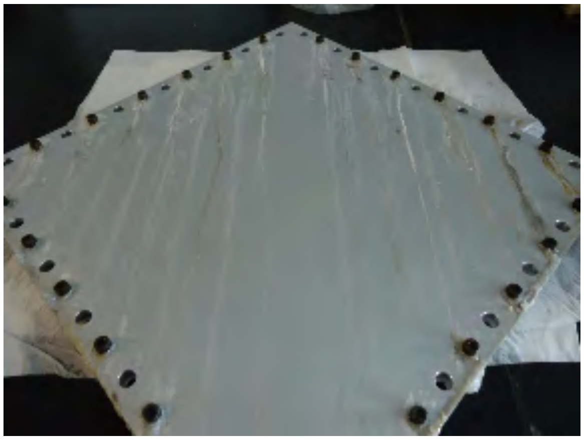
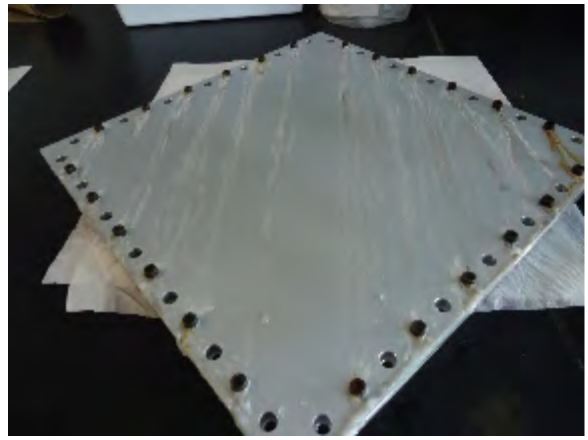
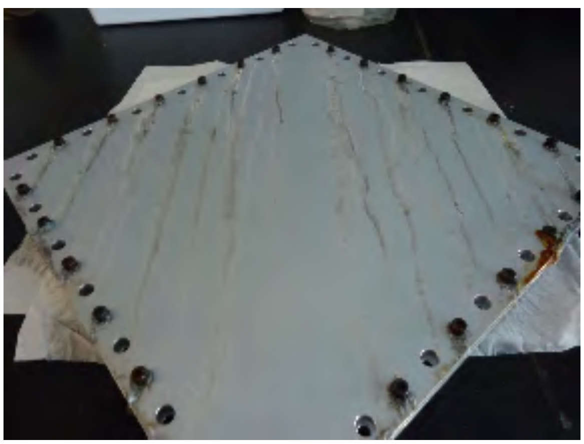
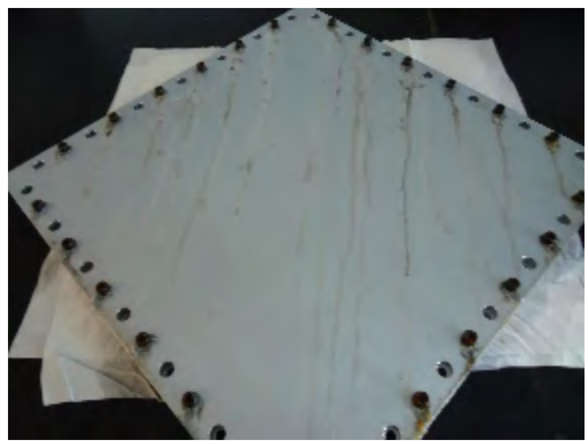
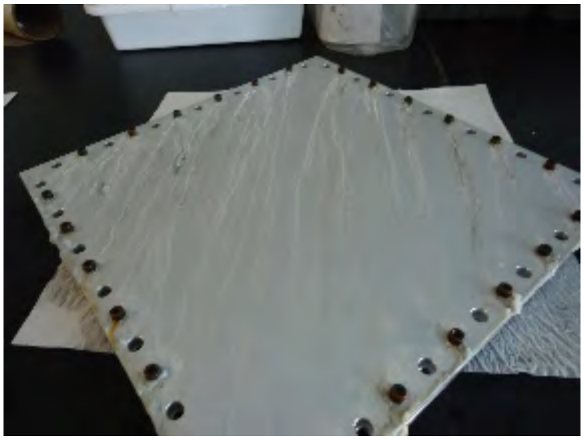
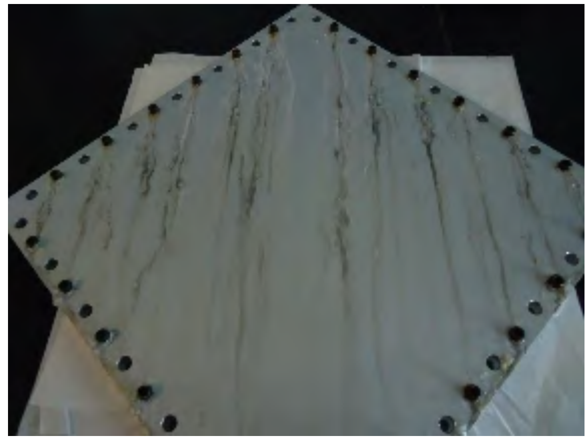
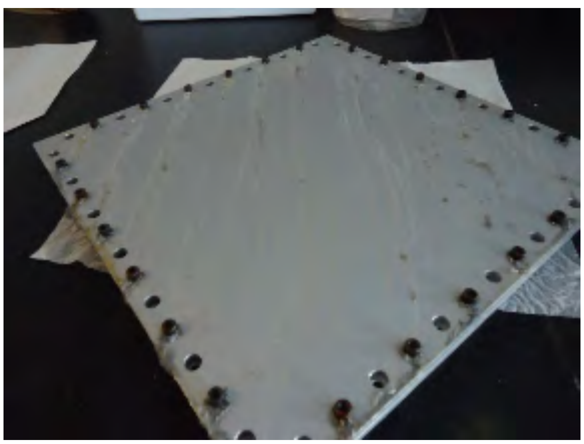
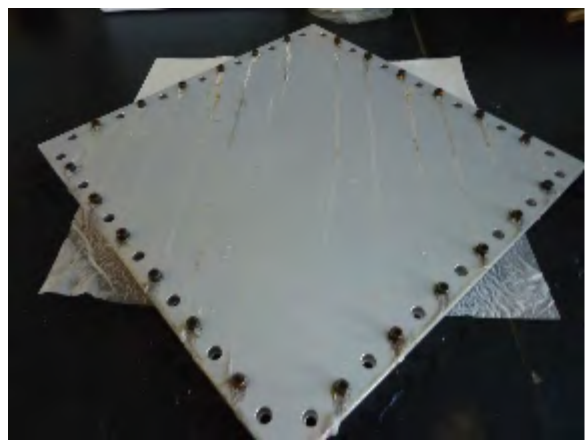
168 Hours – Metalast TCP	
5051-H32 (5M01)	5051-H32 (5M02)
	
6061-T6 (6M01)	6061-T6 (6M02)
	

168 Hours – SurTec 650	
5051-H32 (5S01)	5051-H32 (5S02)
	
6061-T6 (6S01)	6061-T6 (6S02)
	

<table>
<tr><td colspan="2">336 Hours – Alodine 1200S (Hexavalent Chrome Baseline)</td></tr>
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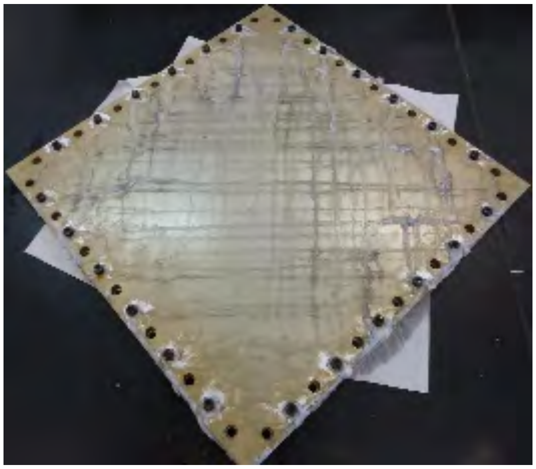
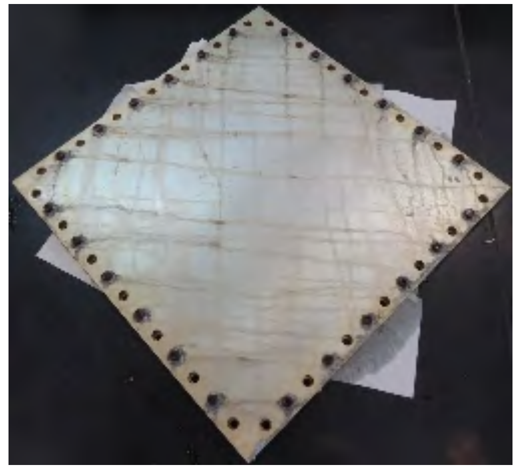
<tr><td></td><td></td></tr>
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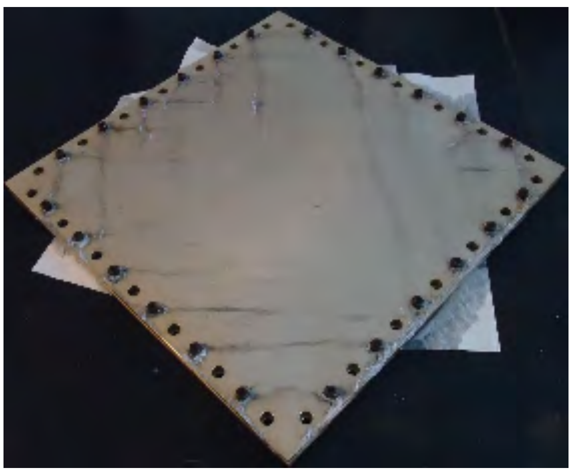
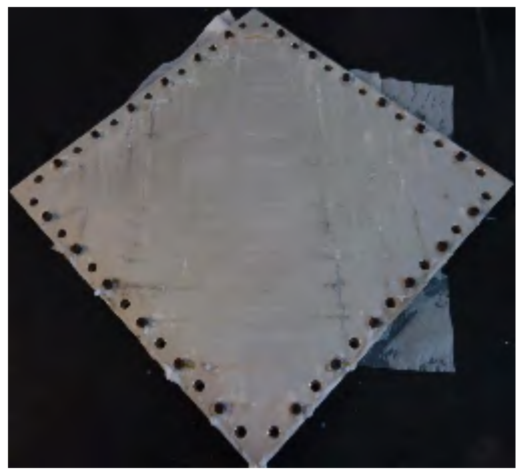
<tr><td></td><td></td></tr>
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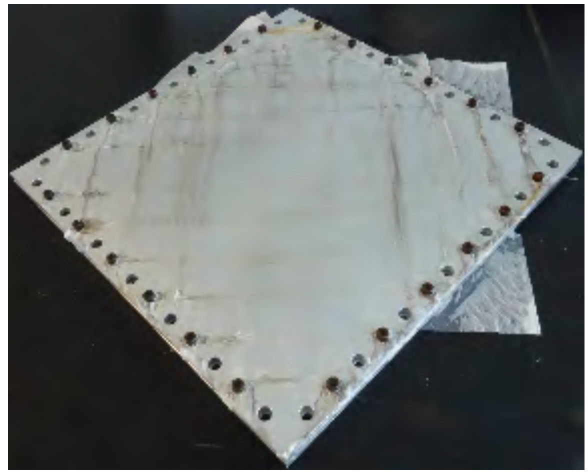
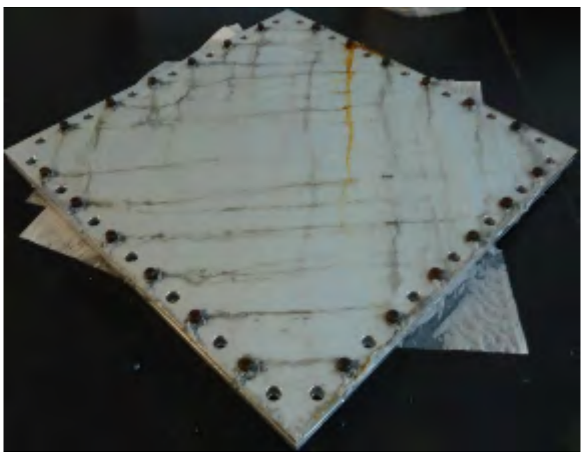
336 Hours – Metalast TCP	
5051-H32 (5M01)	5051-H32 (5M02)
	
6061-T6 (6M01)	6061-T6 (6M02)
	

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<tr><th colspan="2">336 Hours – SurTec 650</th></tr>
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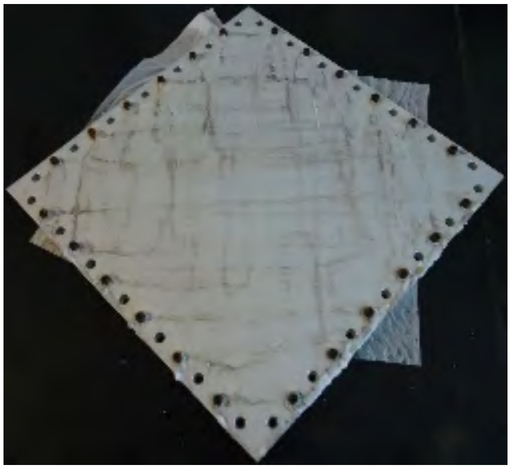
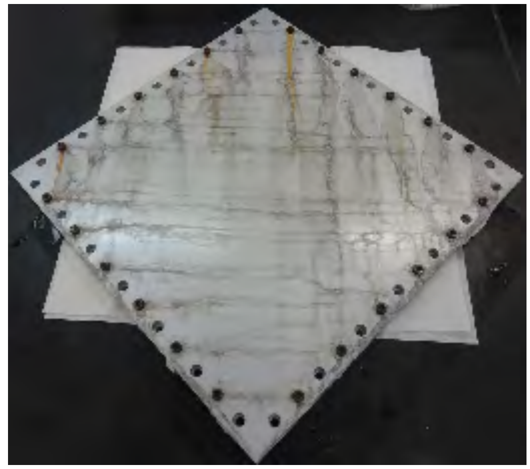
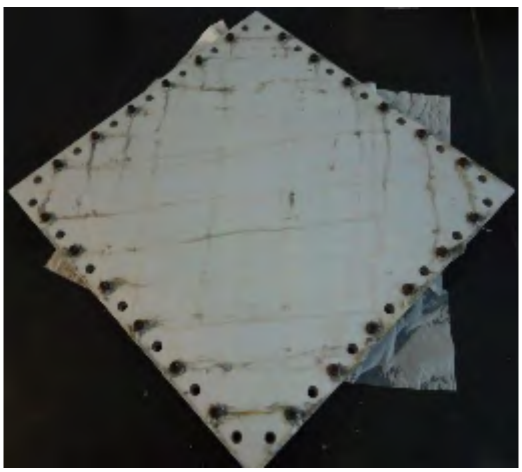
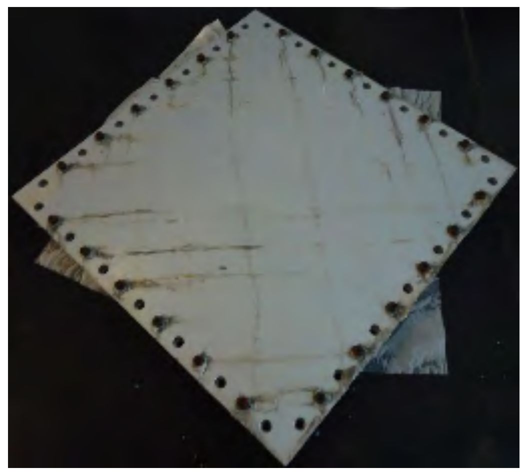
<tr><td></td><td></td></tr>
<tr><td>6061-T6 (6S01)</td><td>6061-T6 (6S02)</td></tr>
<tr><td></td><td></td></tr>
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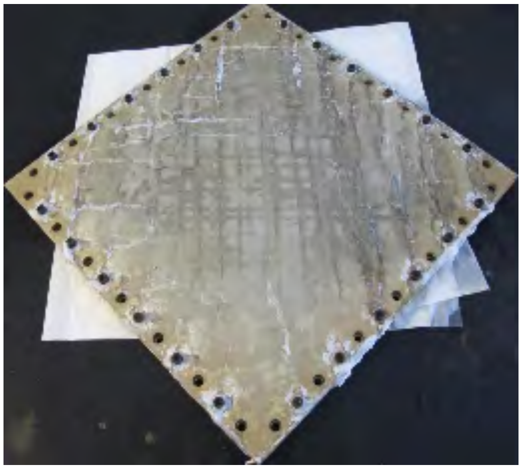
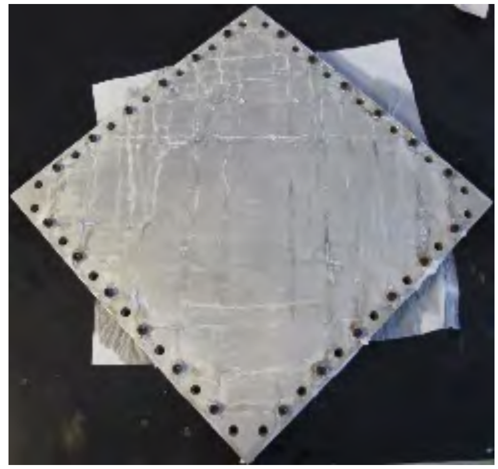
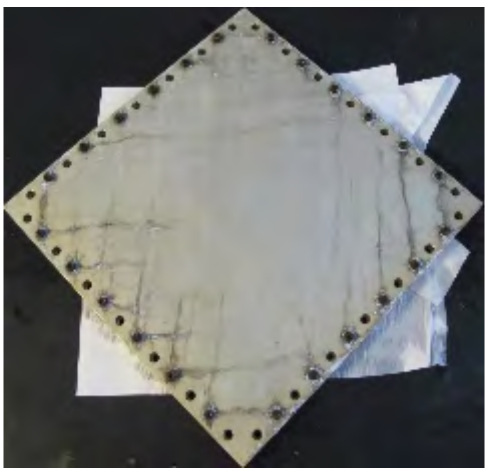
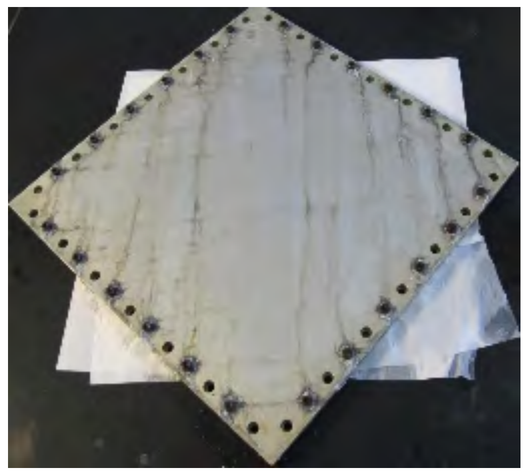
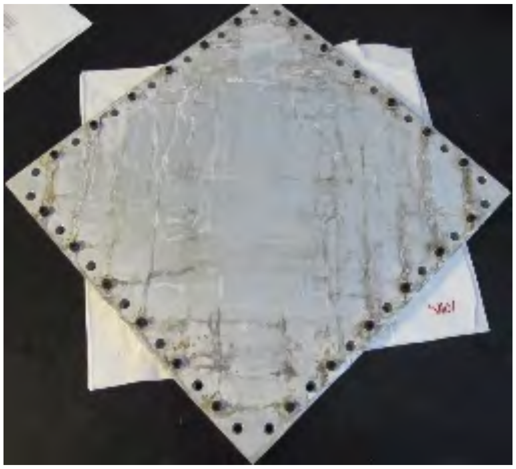
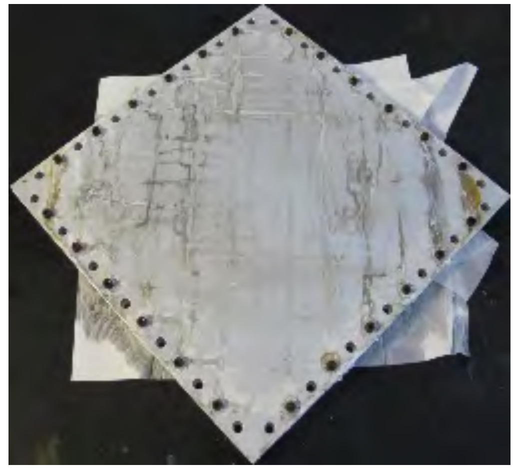
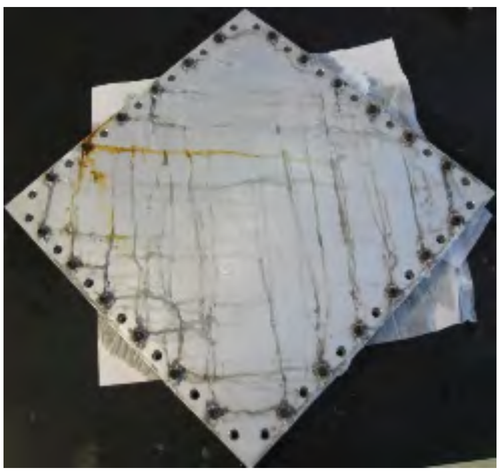
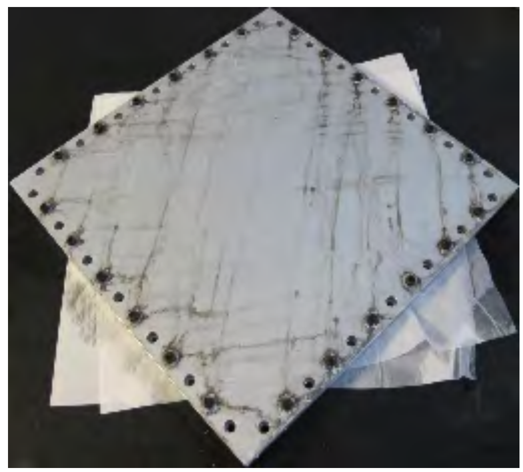
504 Hours – Alodine 1200S (Hexavalent Chrome Baseline)	
5051-H32 (5A01)	5051-H32 (5A02)
	
6061-T6 (6A01)	6061-T6 (6A02)
	

504 Hours – Metalast TCP	
5051-H32 (5M01)	5051-H32 (5M02)
	
6061-T6 (6M01)	6061-T6 (6M02)
	

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<tr><td colspan="2">504 Hours – SurTec 650</td></tr>
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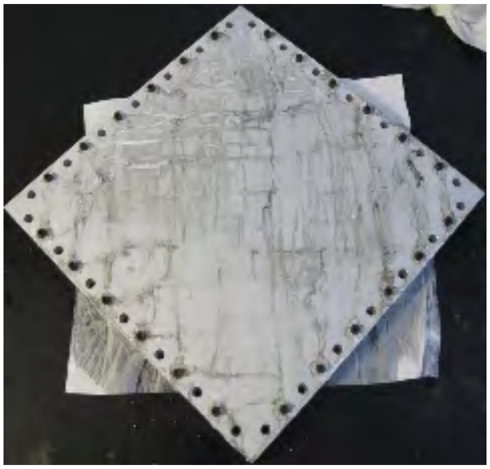
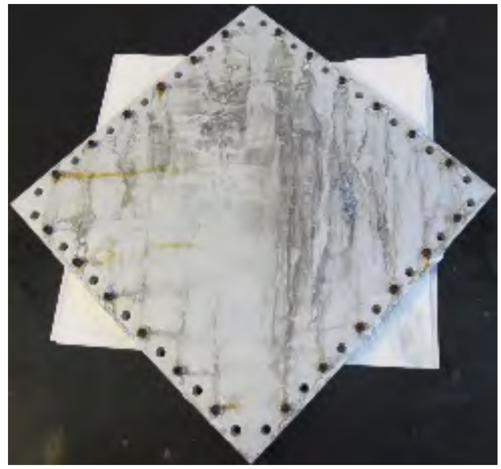
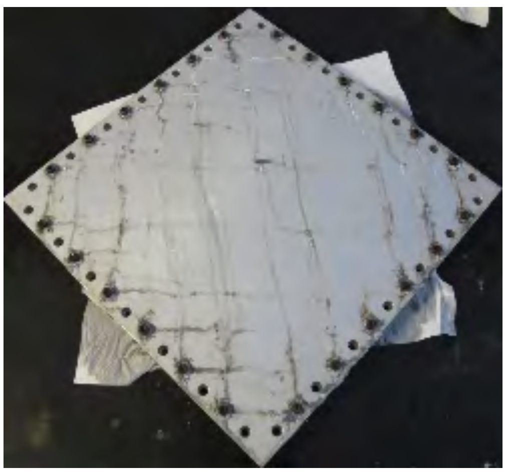
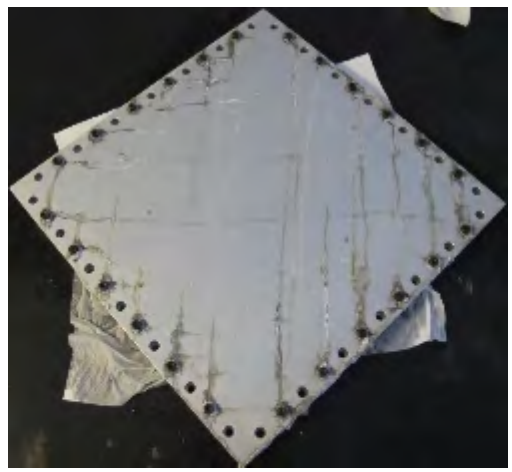
<tr><td></td><td></td></tr>
<tr><td>6061-T6 (6S01)</td><td>6061-T6 (6S02)</td></tr>
<tr><td></td><td></td></tr>
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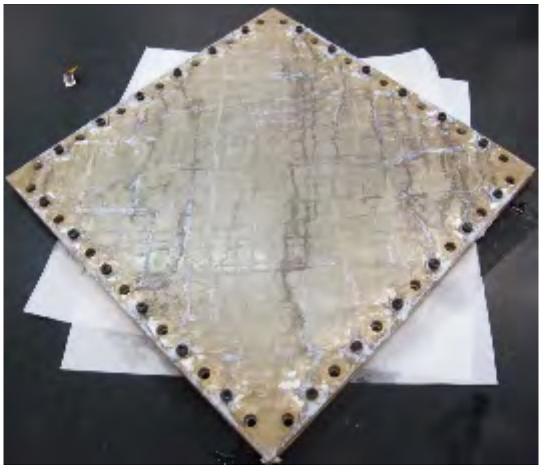
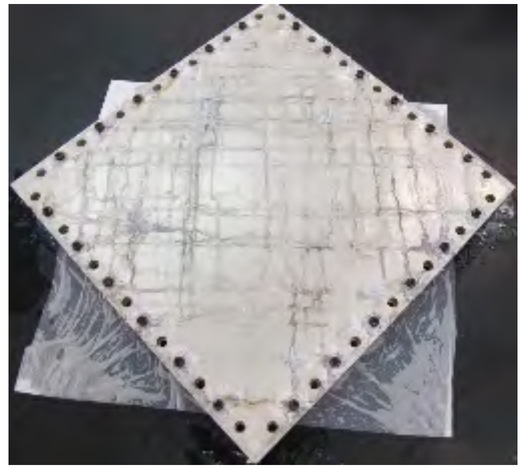
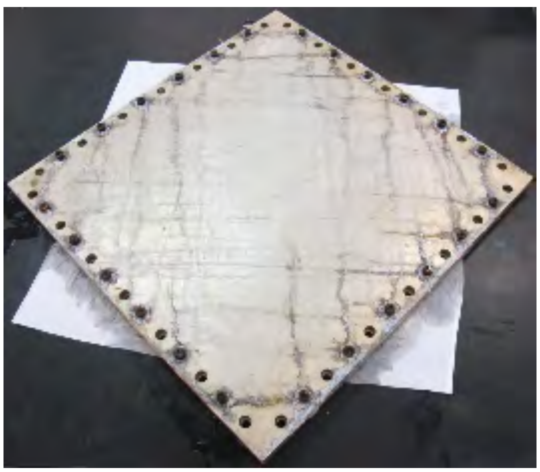
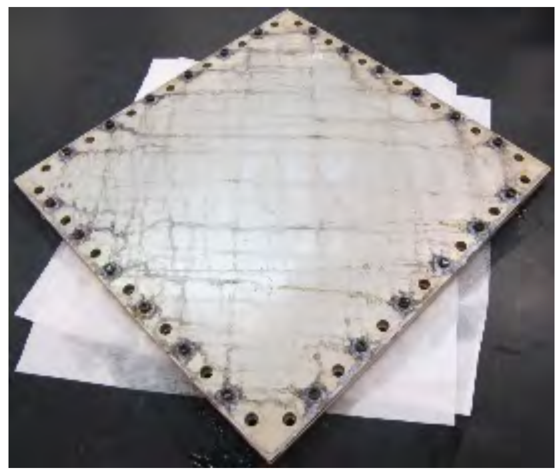
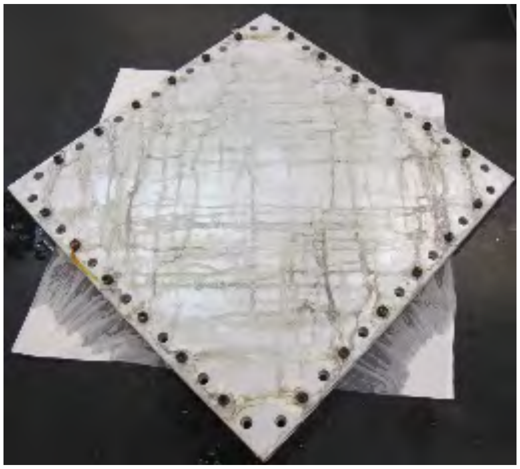
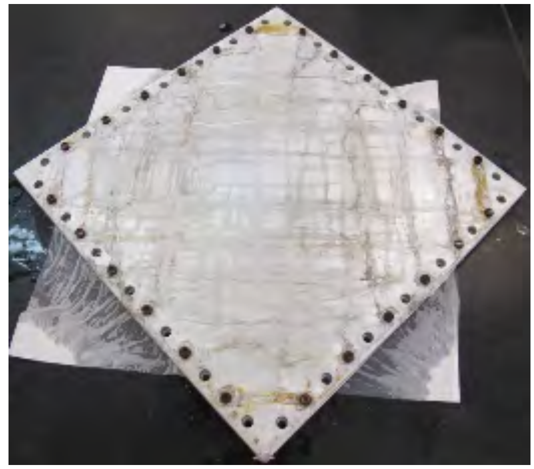
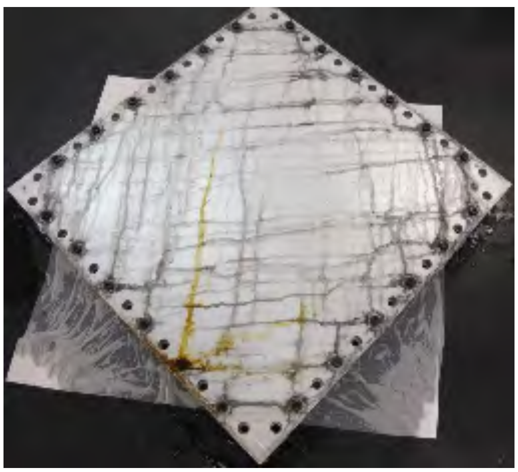
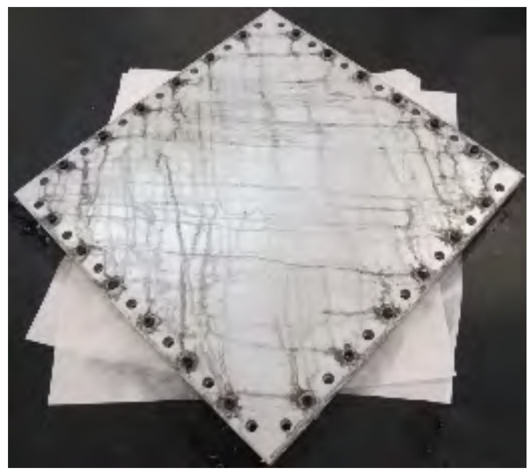
672 Hours – Alodine 1200S (Hexavalent Chrome Baseline)	
5051-H32 (5A01)	5051-H32 (5A02)
	
6061-T6 (6A01)	6061-T6 (6A02)
	

672 Hours – Metalast TCP	
5051-H32 (5M01)	5051-H32 (5M02)
	
6061-T6 (6M01)	6061-T6 (6M02)
	

<table>
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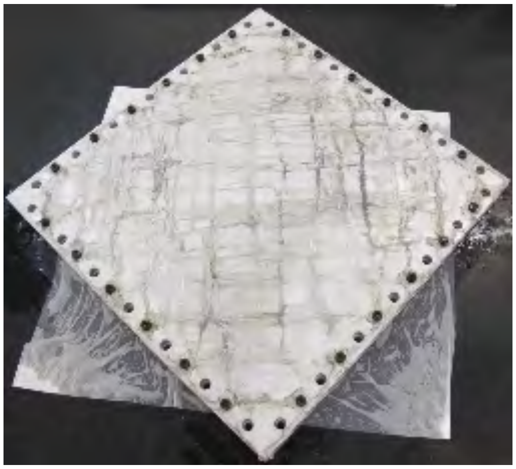
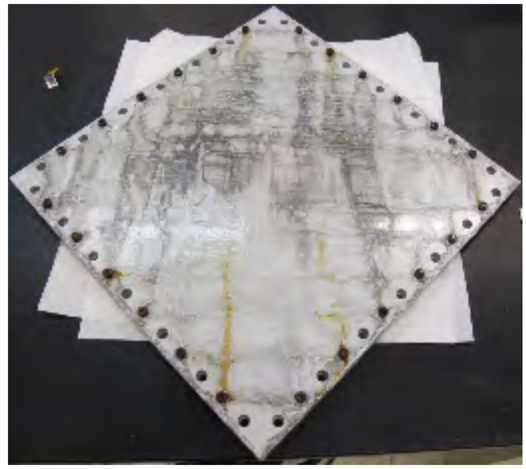
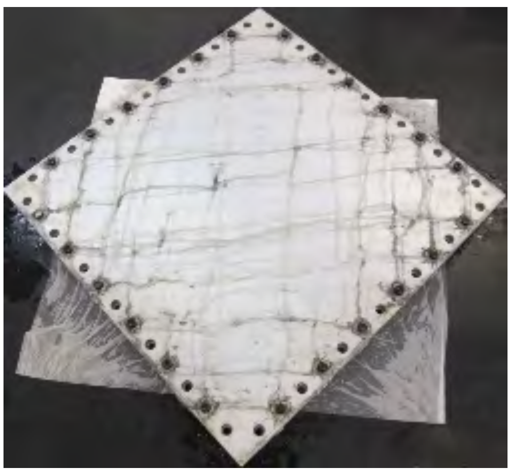
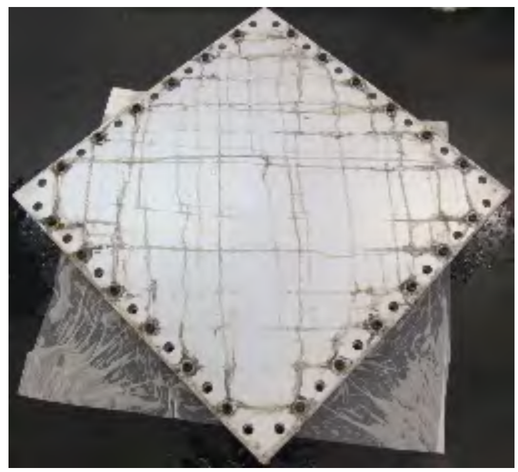
<tr><td></td><td></td></tr>
<tr><td>6061-T6 (6S01)</td><td>6061-T6 (6S02)</td></tr>
<tr><td></td><td></td></tr>
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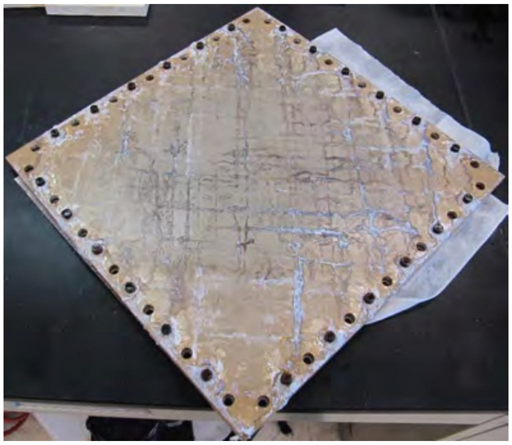
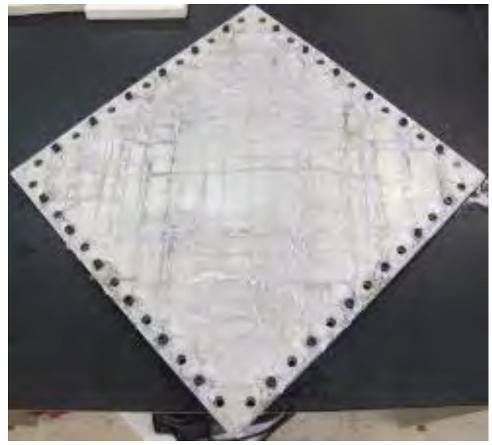
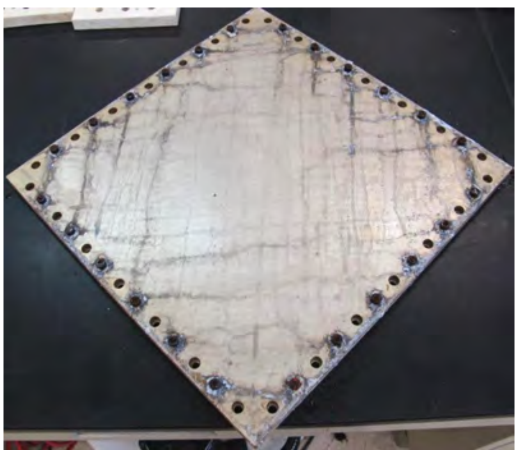
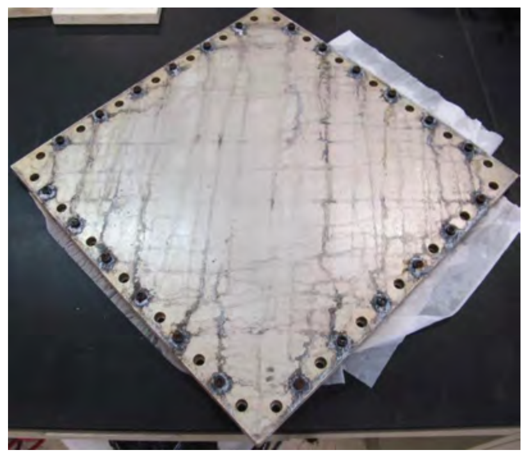
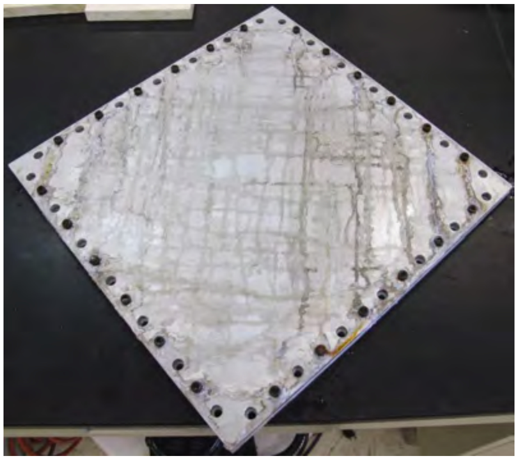
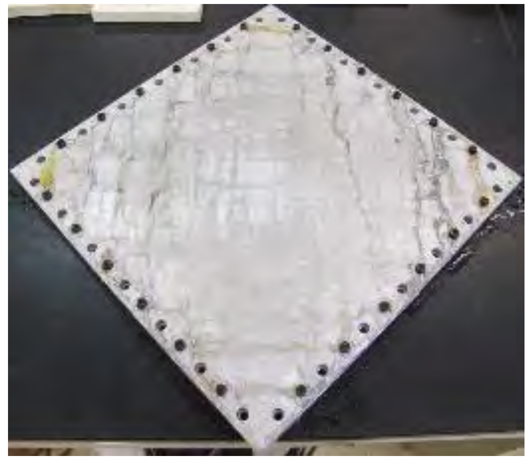
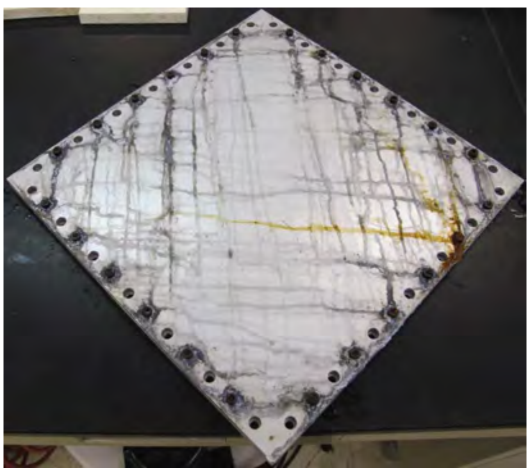
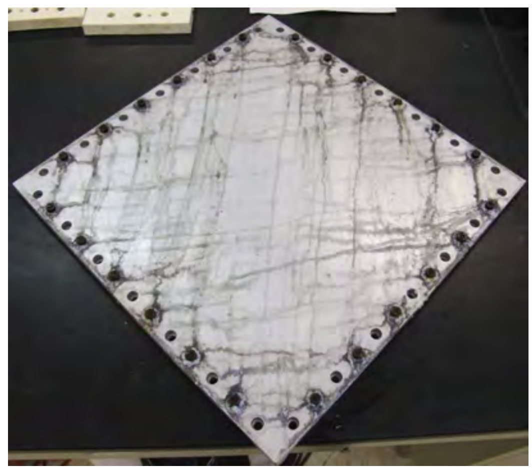
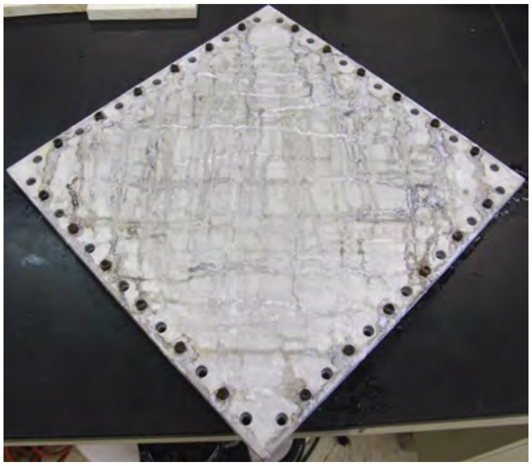
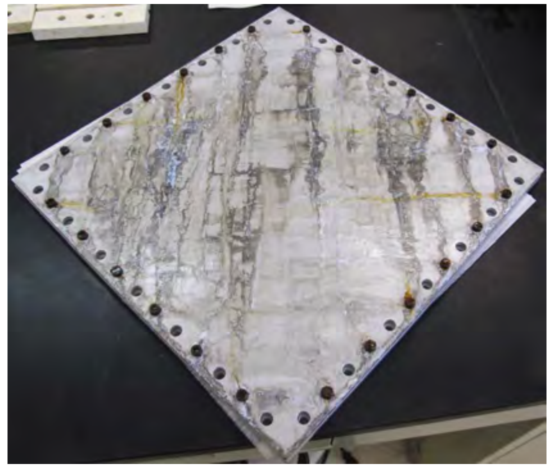
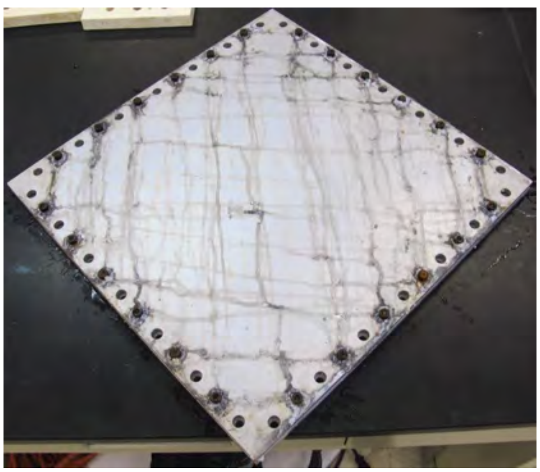
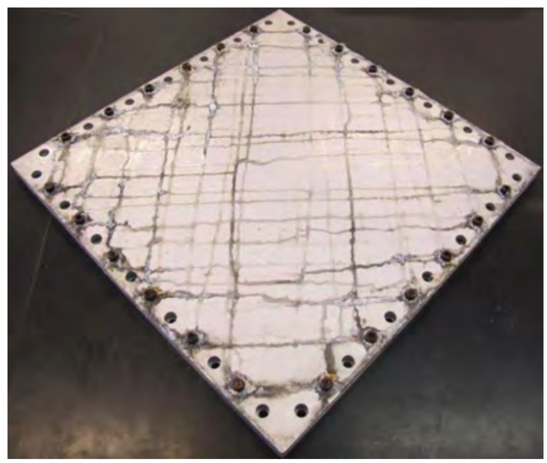
840 Hours – Alodine 1200S (Hexavalent Chrome Baseline)	
5051-H32 (5A01)	5051-H32 (5A02)
	
6061-T6 (6A01)	6061-T6 (6A02)
	

840 Hours – Metalast TCP	
5051-H32 (5M01)	5051-H32 (5M02)
	
6061-T6 (6M01)	6061-T6 (6M02)
	

840 Hours – SurTec 650	
5051-H32 (5S01)	5051-H32 (5S02)
	
6061-T6 (6S01)	6061-T6 (6S02)
	

<table>
<tr><th colspan="2">1,008 Hours – Alodine 1200S (Hexavalent Chrome Baseline)</th></tr>
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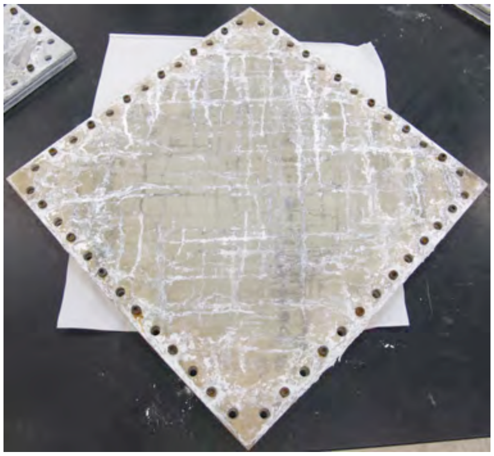
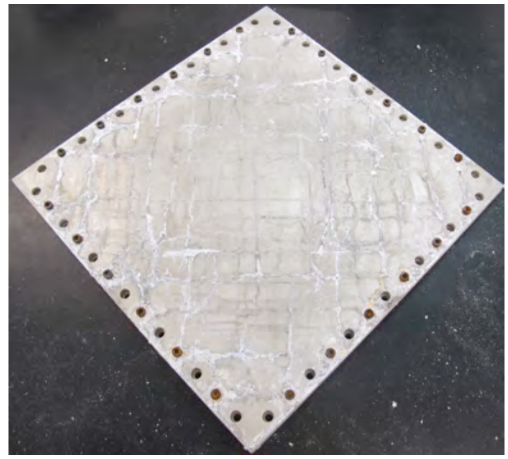
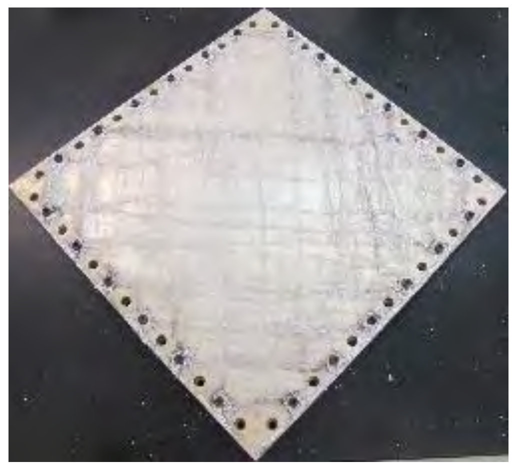
<tr><td></td><td></td></tr>
<tr><td>6061-T6 (6A01)</td><td>6061-T6 (6A02)</td></tr>
<tr><td></td><td></td></tr>
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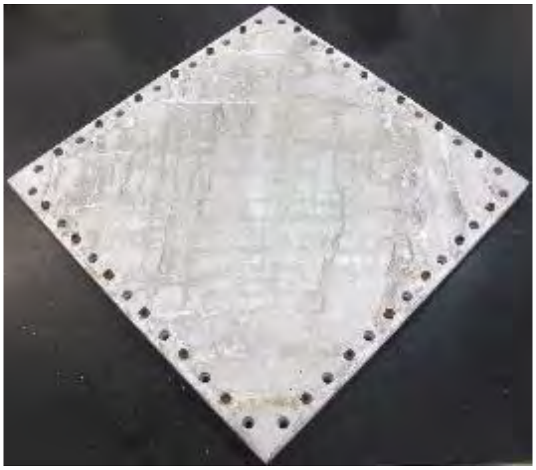
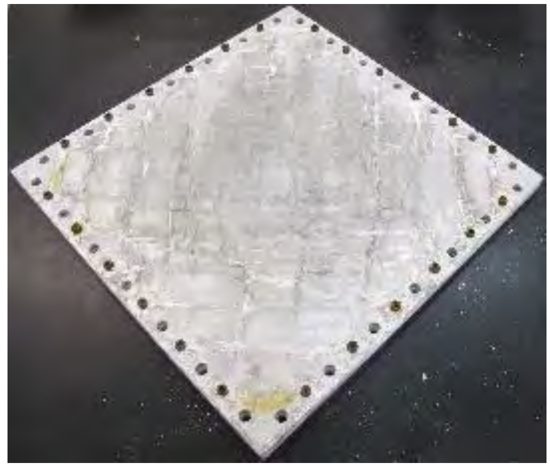
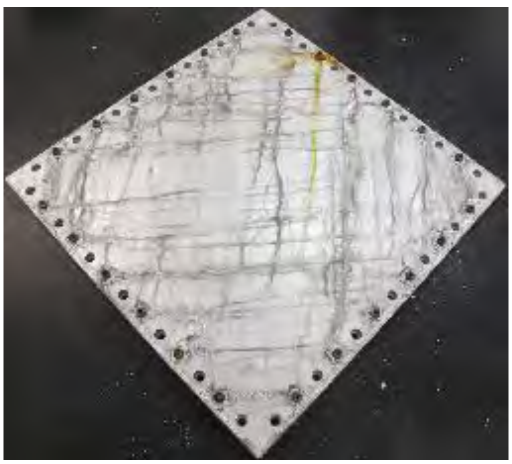
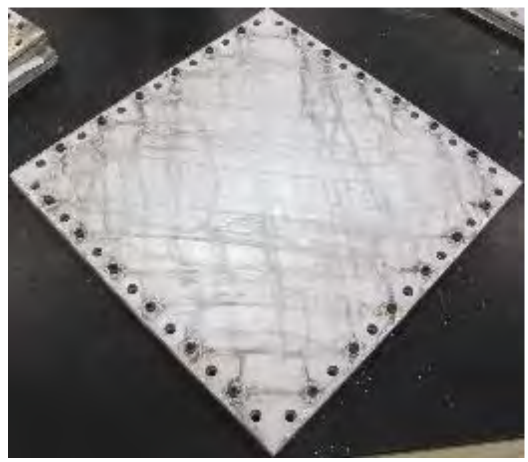
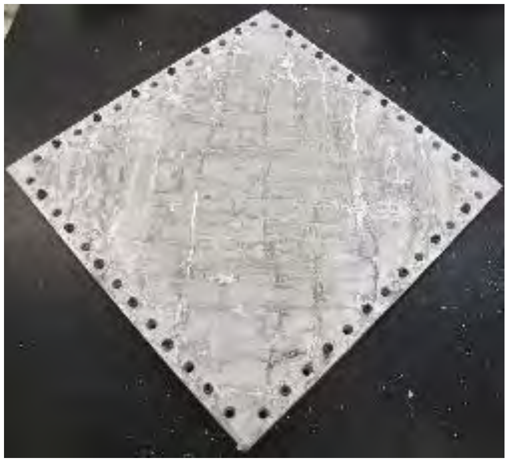
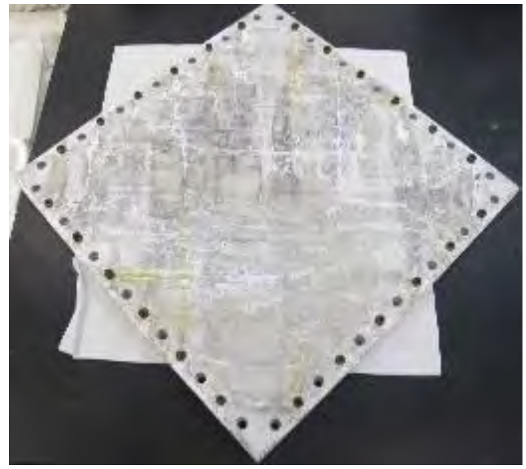
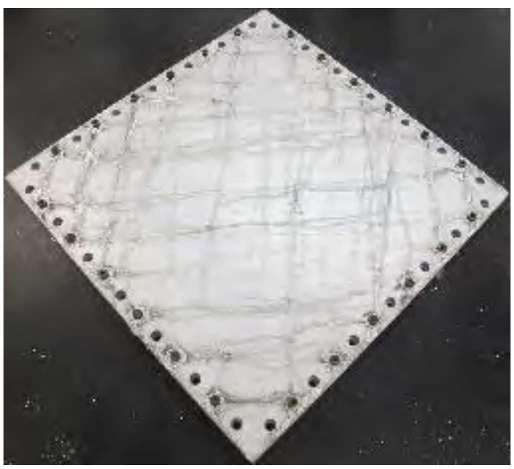
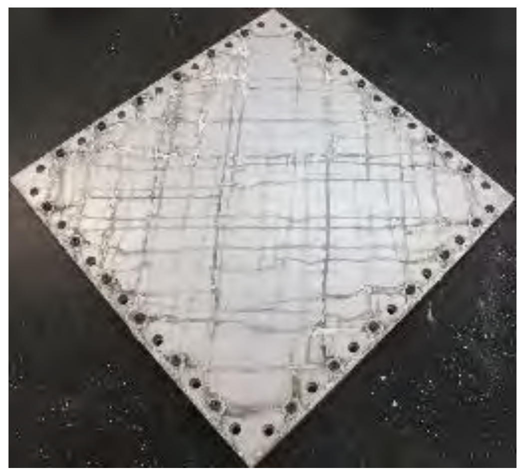
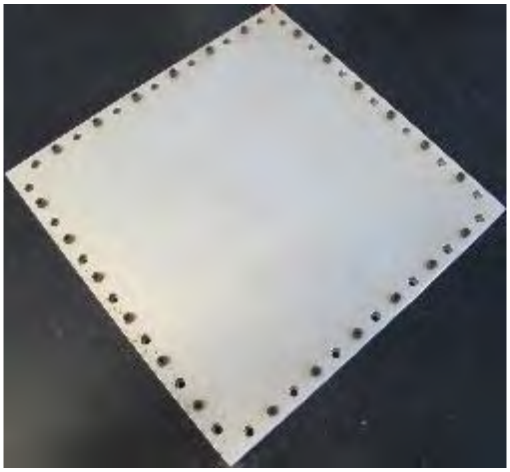
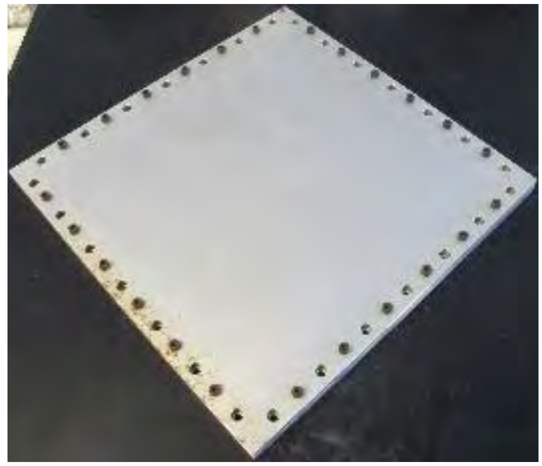
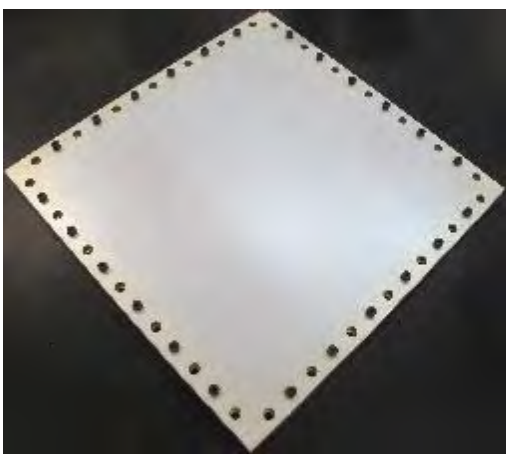
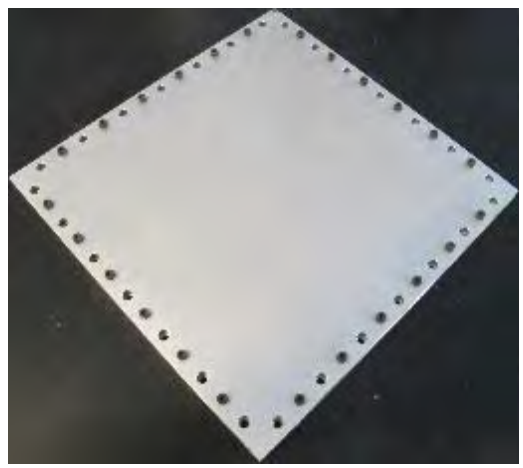
1,008 Hours – Metalast TCP	
5051-H32 (5M01)	5051-H32 (5M02)
	
6061-T6 (6M01)	6061-T6 (6M02)
	

1,008 Hours – SurTec 650	
5051-H32 (5S01)	5051-H32 (5S02)
	
6061-T6 (6S01)	6061-T6 (6S02)
	

Appendix D – Static Heat and Humidity

<table>
<tr><td colspan="2">1,000 Hours – Alodine 1200S (Hexavalent Chrome Baseline)</td></tr>
<tr><td>5051-H32 (5A03)</td><td>5051-H32 (5A04)</td></tr>
<tr><td></td><td></td></tr>
<tr><td>6061-T6 (6A03)</td><td>6061-T6 (6A04)</td></tr>
<tr><td></td><td></td></tr>
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1,000 Hours – Metalast TCP	
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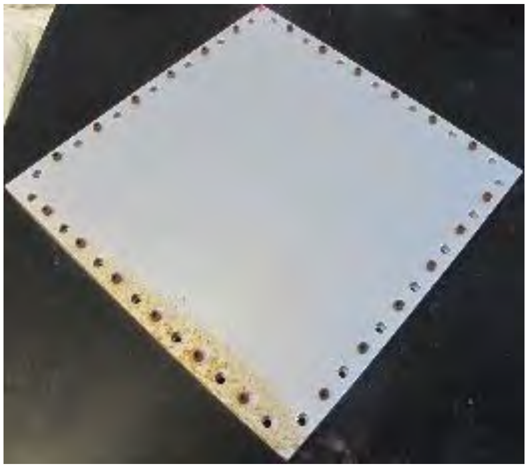	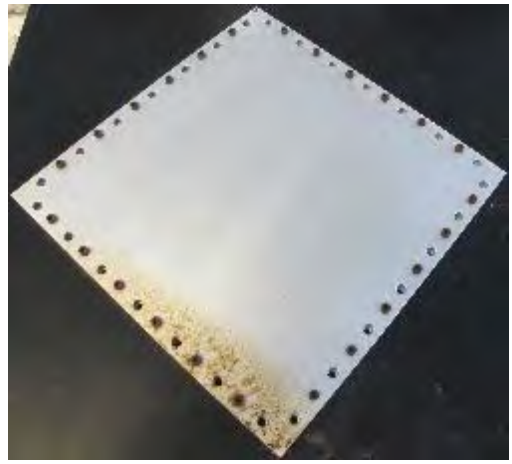
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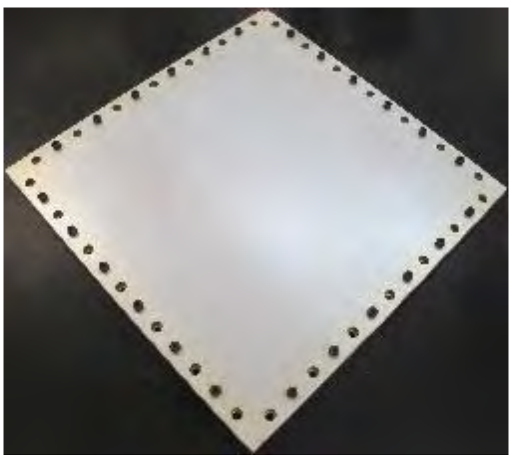
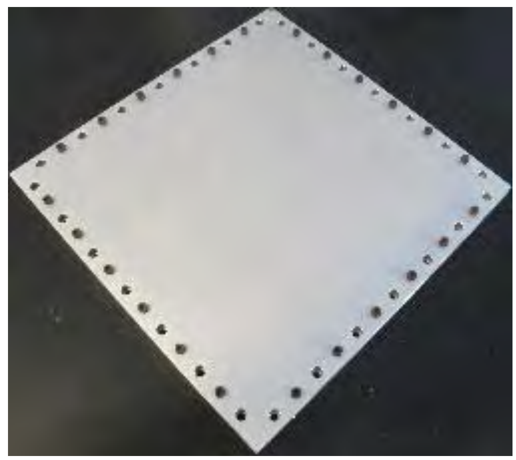
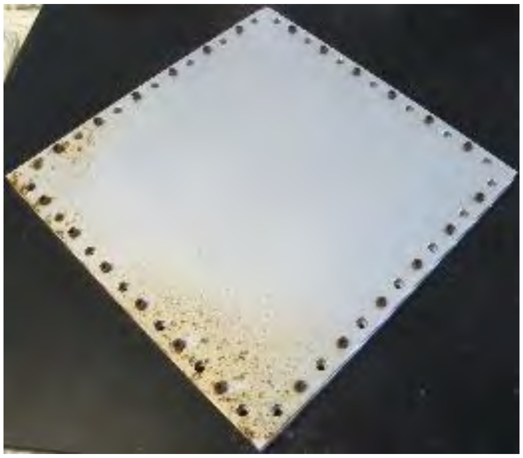
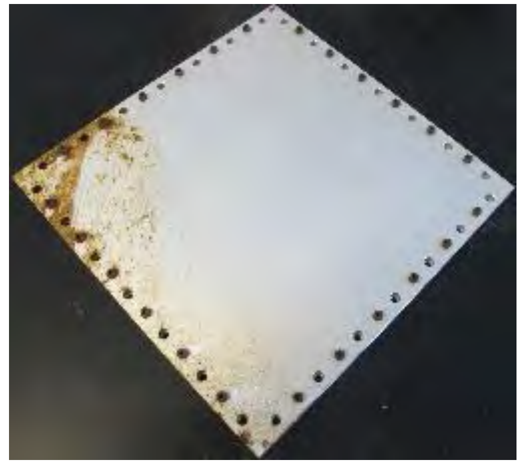
	

1,000 Hours – SurTec 650	
5051-H32 (5S03)	5051-H32 (5S04)
	
6061-T6 (6S03)	6061-T6 (6S04)