LOCKHEED MARTIN AERONAUTICS COMPANY, FORT WORTH

MPLR – 101436A
June 10, 2014

MATERIALS & PROCESSES LAB

Hex-Chrome Free Sealant Project

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Note: This is a revision of MPLR – 101436. This revision includes the test data and analysis of the Beachfront test vehicles after the Beachfront exposure near Daytona Beach.

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MPLR – 101436A
June 10, 2014

Hex-Chrome Free Sealant Project

J.S. 101436
Program: Multiple

LOCKHEED MARTIN

Hex-Chrome Free Sealant Project

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AIA/NAS NAS1351 “Screw, Cap, Socket Head, Undrilled and Drilled, Plain and Self-Locking, Alloy Steel, Corrosion-Resistant Steel and Heat-Resistant Steel,” March 10, 2009.

AIA/NAS NAS1102 “Screw, Machine, Flat 100 Degrees Head, Full Thread, Offset Cruciform,” January 31, 2013.

ASTM G85 Annex 4 “Standard Practice for Modified Salt Spray (Fog) Testing,” May 1, 2011.

MIL-DTL-5541F “Chemical Conversion Coatings on Aluminum and Aluminum Alloys,” July 11, 2006.

MIL-DTL-81706B “Chemical Conversion Materials for Coating Aluminum and Aluminum Alloys,” May 2, 2006.

MIL-PRF-23377K “Primer, Coatings: Epoxy, High Solids,” June 7, 2012.

MIL-PRF-81733D “Sealing and Coating Compound, Corrosion Inhibitive,” May 15, 1998.

MIL-PRF-85285E “Coating: Polyurethane, Aircraft and Support Equipment,” January 12, 2012.

MIL-PRF-85582E “Primer Coatings: Epoxy, Waterborne,” October 16, 2012.

1. LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
DFARS	Defense Federal Acquisition Regulation Supplement
DOE	Design of Experiments
HC	Hexavalent Chromium (Containing)
HCF	Hexavalent Chromium Free
HS	High Solids
MIL	Military Specification
NASA	National Aeronautics and Space Administration
NAVAIR	Naval Air Systems Command
RO	Reverse Osmosis
RT	Room Temperature
TBD	To Be Determined
TURI	Toxic Use Reduction Institute
TV	Test Vehicle

2. ABSTRACT

A single test vehicle was used to compare the corrosion inhibition of four sealants:

- PS-870 – a polysulfide sealant which contains hexavalent chromium corrosion inhibitors.
- AC-735 – a polysulfide sealant which contains non-hexavalent chromium corrosion inhibitors.
- PR-1775 – a polysulfide sealant which contains non-hexavalent chromium corrosion inhibitors.
- PR-2001 – a polythioether sealant which contains no corrosion inhibitors.

Test vehicles comprised of three metal plates of either 6061-T6 or 7075-T6 aluminum alloy. All three plates were conversion coated with either Iridite 14-2 or Metalast TCP-HF HPA 100. Two of the plates were butted together and fastened on top of the third plate in a similar fashion to the stressed aluminum assembly described in MIL-PRF-81733 Para. 4.8.9.1 and Figure 2. Sealant was used to protect the butt-joint, faying surfaces, and some of the fastener heads and nuts. Sealant was also used to wet-install all fasteners. Either primer-only or primer/topcoat system was sprayed over the fastened and sealed test vehicles. Damage was initiated to each test vehicle by scribing in certain areas and subjecting each test vehicle to mechanical and thermal stresses. After damage had been initiated, the test vehicles were exposed to SO_2 salt fog (ASTM G85 Annex 4) for up to 1000 hours to determine corrosion resistance. The test vehicles were visually inspected periodically during the exposure (non-destructive inspection). After

completion of SO_2 salt fog exposure, the test vehicles were taken apart and the sealant was removed for further examination (destructive inspection).

Non-destructive inspection of the test vehicles revealed that the fastener heads and nuts that were protected with sealant provided more resistance to corrosion than the fastener heads and nuts that were not protected with sealant.

Destructive inspection of the test vehicles focuses on two major areas of the test vehicles: corrosion inhibition in the butt joints and faying surfaces and corrosion inhibition in the countersinks. The inspections provided the following conclusions:

- Regardless of aluminum alloy, when using an Iridite conversion coating, PS-870, PR-1775, and AC-735 provided the most corrosion resistance in the butt joints and faying surfaces compared to PR-2001.

- Regardless of aluminum alloy, when using a Metalast conversion coating, PR-1775 provided the most corrosion resistance in the butt joints and faying surfaces. AC-735 and PR-2001 provided somewhat less corrosion resistance compared to PR-1775. PS-870 was not tested with a Metalast conversion coating.

- Regardless of conversion coating, all sealants provided similar corrosion resistance in the countersink areas of 6061-T6 aluminum alloy test vehicles.

- Regardless of conversion coating, PR-1775 the most corrosion resistance in the countersink areas of 7075-T6 aluminum alloy test vehicles. PS-870 was the next best, followed by PR-2001, followed by AC-735.

- 6061-T6 aluminum alloy provided more corrosion resistance than 7075-T6 aluminum alloy when similar sealants and conversion coatings were used.

- In general, the Iridite 14-2 conversion coating provided more corrosion resistance than the Metalast TCP-HF HPA 100 conversion coating.

- In general, a primer and topcoat system provided more corrosion resistance than a primer-only system.

3. BACKGROUND

Polysulfide sealants containing soluble hexavalent chromium compounds are currently being used in a variety of applications in aerospace manufacturing. Applications mostly involve the filling of gaps and recesses to prevent water intrusion and collection. These sealants are used on both ferrous and aluminum assemblies and are often over coated with a variety of common paint systems. Hexavalent chromium containing materials are prohibited under the DFARS Part

223.73 and OSHA 29 CFR 1910.1026. This test plan was developed to provide an evaluation of the corrosion resistance of hexavalent-chromium-free sealants and to compare their performance to a hexavalent-chromium-containing sealant.

4. SPECIMEN PREPARATION

4.1. Sealants

The design of the experiments included four sealants (supplied by Raytheon in Tucson, AZ):

- PS-870 – a polysulfide sealant containing hexavalent chromium corrosion inhibitors.
  (MIL-PRF-81733 Type II Class 1 Grade A)

- AC-735 – a polysulfide sealant containing non-hexavalent chromium corrosion inhibitors.
  (MIL-PRF-81733 Type II Class 1 Grade B & AMS 3265 Class B)

- PR-1775 – a polysulfide sealant containing non-hexavalent chromium corrosion inhibitors.
  (AMS 3265 Class B)

- PR-2001 – a polythioether sealant not containing any corrosion inhibitors.
  (AMS 3277 Type II Class B)

4.2. Support Materials

4.2.1. Conversion Coatings

The design of experiments included two conversion coatings:

- Iridite 14-2 (processed at Northrop Grumman in Baltimore, MD) – a conversion coating containing hexavalent chromium corrosion inhibitors.
  (MIL-DTL-81706 Type I Class 1A Form II Method C)

- Metalast TCP-HF HPA 100 (processed at Metalast International in Minden, NV) – a conversion coating containing non-hexavalent chromium corrosion inhibitors.
  (Not qualified to MIL-DTL-81706)

4.2.2. Primers and Topcoats

The design of experiments included two different primers and one topcoat (sprayed at Raytheon in Tucson, AZ):

- Akzo Nobel 10P20-13/EC-213 – a high solids epoxy primer containing hexavalent chromium corrosion inhibitors.
  (MIL-PRF-23377 Type 1 Class C)
  Lot # NF9235UV/NG9601UV, Exp. 31 May, 2013

- Deft 44GN098 – a water reducible high performance epoxy primer not containing non-hexavalent chromium corrosion inhibitors.
  (MIL-PRF-85582 Type 1 Class N)
  Lot # 90537/90538, Exp. 31 October, 2012

- PPG 8211F37886MPY22K – a polyurethane topcoat.
  (MIL-PRF-85285 Type 1)
  Lot # 92786/204806, Exp. 31 May, 2013

4.3. Test Vehicle Design

A single test vehicle was created to test the four sealants. The final test vehicle design is illustrated in Figures 4.3.1 through 4.3.4 below.

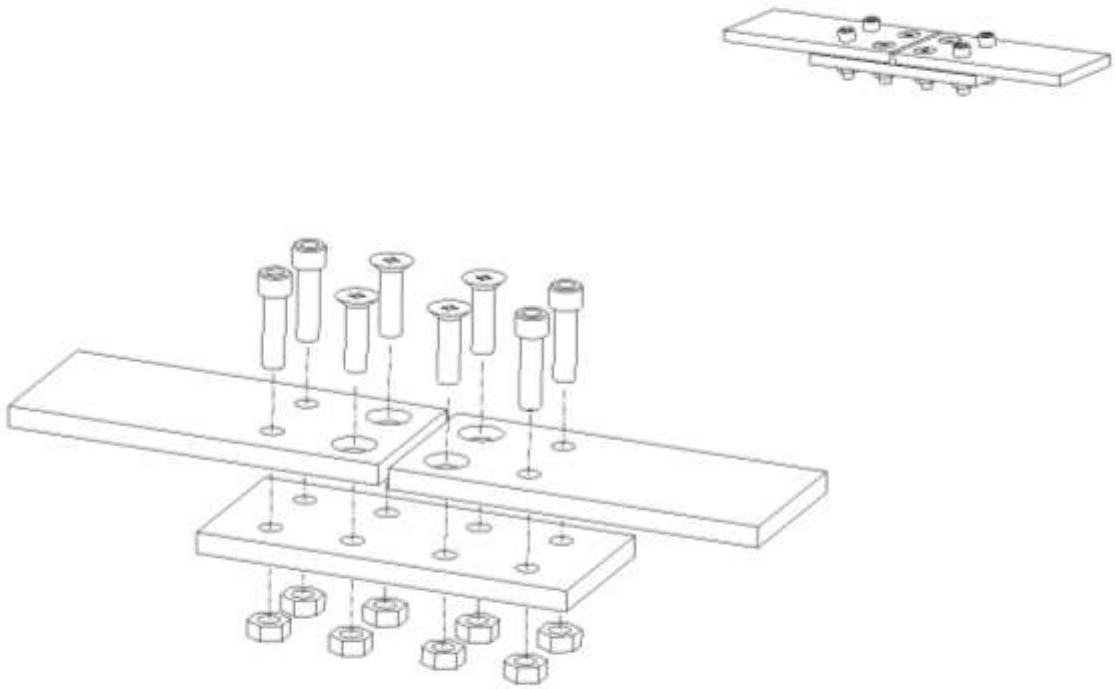


FIGURE 4.2.1 EXPLODED VIEW OF TEST VEHICLE

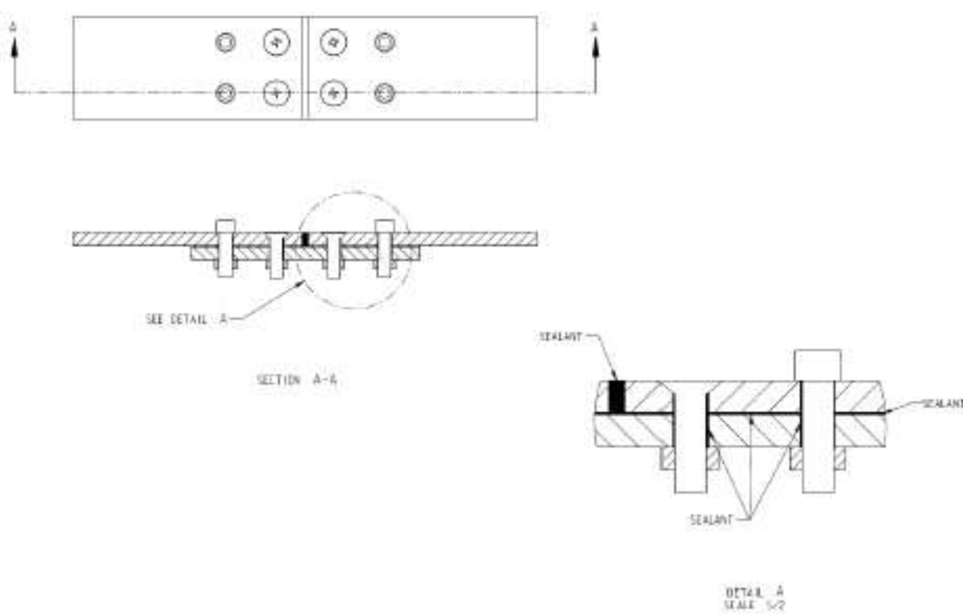


FIGURE 4.3.2 TOP VIEW AND SLICED SIDE VIEW OF TEST VEHICLE

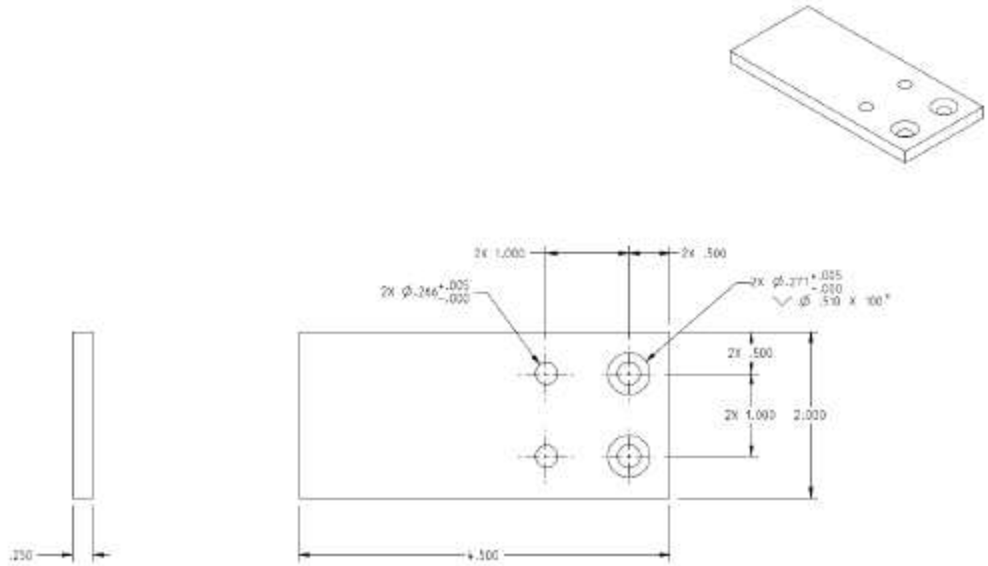


FIGURE 4.3.3 DIAGRAM OF IDENTICAL TOP PANEL OF TEST VEHICLE

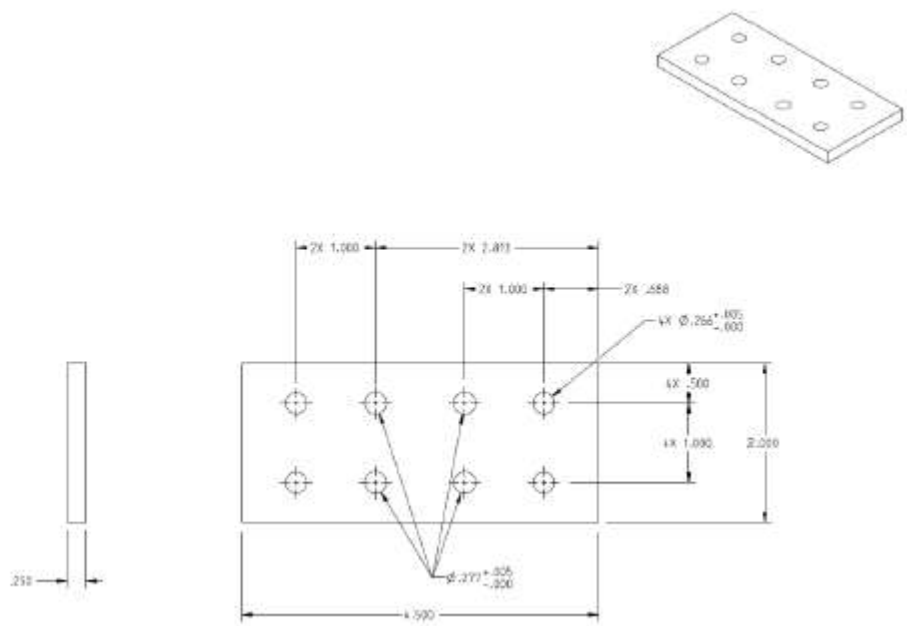


FIGURE 4.3.4 DIAGRAM OF BOTTOM PANEL OF TEST VEHICLE

As illustrated above in Figure 4.3.1 through 4.3.4, each test vehicle consisted of three metal plates with a series of matching holes through which threaded fasteners were inserted and then held in place by nuts. These test vehicles utilized 0.25” thick aluminum plates (alloys 6061 and 7075). Alloy 6061 was used because it is the most common alloy used by participating companies. Alloy 7075 was included because it is considered to be the most challenging aluminum alloy to pass corrosion testing. The aluminum plates were 2.0” wide by 4.5” long.

Each test vehicle had eight fasteners made of stainless steel (A286). The stainless steel material was chosen because it is commonly used by participating companies and presented galvanic mismatch with the aluminum plates. Based upon a mechanical analysis conducted by Northrop Grumman, it was determined that ¼” diameter A286 bolts would provide an adequate margin of safety so that the test vehicles could be loaded up to 5,000 lb_f without bending the plates or shearing the bolts. For each test vehicle, four 100° flat head fasteners (NAS1102E4-14), four socket head cap screws (NAS1351N4-14), and eight plain hex nuts (MS35690-430) were used.

4.4. Test Matrix

The design of experiments followed the test plan detailed in Tables 4.3.1 and 4.3.2.

TABLE 4.4.1 TEST VEHICLE MATRIX FOR FULL TEST

Number	Alloy	Sealant	Conversion Coating	Secondary Finish	Test
1	6061	PS-870	Iridite 14-2	HCF Primer & Topcoat	Salt fog 1,008 hrs
2	6061	PS-870	Iridite 14-2	HCF Primer Only	Salt fog 1,008 hrs
3	6061	AC-735	Metalast TCP	HCF Primer & Topcoat	Salt fog 1,008 hrs
4	6061	AC-735	Metalast TCP	HCF Primer Only	Salt fog 1,008 hrs
5	6061	AC-735	Iridite 14-2	HCF Primer & Topcoat	Salt fog 1,008 hrs
6	6061	AC-735	Iridite 14-2	HCF Primer Only	Salt fog 1,008 hrs
7	6061	PR-1775	Metalast TCP	HCF Primer & Topcoat	Salt fog 1,008 hrs
8	6061	PR-1775	Metalast TCP	HCF Primer Only	Salt fog 1,008 hrs
9	6061	PR-1775	Iridite 14-2	HCF Primer & Topcoat	Salt fog 1,008 hrs
10	6061	PR-1775	Iridite 14-2	HCF Primer Only	Salt fog 1,008 hrs
11	6061	PR-2001	Metalast TCP	HCF Primer & Topcoat	Salt fog 1,008 hrs
12	6061	PR-2001	Metalast TCP	HCF Primer Only	Salt fog 1,008 hrs
13	6061	PR-2001	Iridite 14-2	HCF Primer & Topcoat	Salt fog 1,008 hrs
14	6061	PR-2001	Iridite 14-2	HCF Primer Only	Salt fog 1,008 hrs
15	7075	PS-870	Iridite 14-2	HCF Primer & Topcoat	Salt fog 1,008 hrs
16	7075	PS-870	Iridite 14-2	HCF Primer Only	Salt fog 1,008 hrs
17	7075	AC-735	Metalast TCP	HCF Primer & Topcoat	Salt fog 1,008 hrs

Number	Alloy	Sealant	Conversion Coating	Secondary Finish	Test
18	7075	AC-735	Metalast TCP	HCF Primer Only	Salt fog 1,008 hrs
19	7075	AC-735	Iridite 14-2	HCF Primer & Topcoat	Salt fog 1,008 hrs
20	7075	AC-735	Iridite 14-2	HCF Primer Only	Salt fog 1,008 hrs
21	7075	PR-1775	Metalast TCP	HCF Primer & Topcoat	Salt fog 1,008 hrs
22	7075	PR-1775	Metalast TCP	HCF Primer Only	Salt fog 1,008 hrs
23	7075	PR-1775	Iridite 14-2	HCF Primer & Topcoat	Salt fog 1,008 hrs
24	7075	PR-1775	Iridite 14-2	HCF Primer Only	Salt fog 1,008 hrs
25	7075	PR-2001	Metalast TCP	HCF Primer & Topcoat	Salt fog 1,008 hrs
26	7075	PR-2001	Metalast TCP	HCF Primer Only	Salt fog 1,008 hrs
27	7075	PR-2001	Iridite 14-2	HCF Primer & Topcoat	Salt fog 1,008 hrs
28	7075	PR-2001	Iridite 14-2	HCF Primer Only	Salt fog 1,008 hrs
29	7075	PS-870	Iridite 14-2	HC Primer & Topcoat	Salt fog 1,008 hrs
30	7075	PS-870	Iridite 14-2	HC Primer Only	Salt fog 1,008 hrs
31	7075	AC-735	Iridite 14-2	HC Primer & Topcoat	Salt fog 1,008 hrs
32	7075	AC-735	Iridite 14-2	HC Primer Only	Salt fog 1,008 hrs
33	7075	PR-1775	Iridite 14-2	HC Primer & Topcoat	Salt fog 1,008 hrs
34	7075	PR-1775	Iridite 14-2	HC Primer Only	Salt fog 1,008 hrs
35	7075	PR-2001	Iridite 14-2	HC Primer & Topcoat	Salt fog 1,008 hrs
36	7075	PR-2001	Iridite 14-2	HC Primer Only	Salt fog 1,008 hrs

It was desirable for some failures to occur during the salt fog corrosion testing so that there would be differentiation between the sealants under investigation. To ensure that failures were occurring before the testing was complete, test vehicles 37-40 and 41-44 were removed from exposure at 336 and 672 hours, respectively. These test vehicles were inspected per Paragraph 5.2.1 and 5.2.2 of this report to examine the progression of corrosion over time. In addition, four test vehicles underwent beach front testing instead of salt fog testing. The NASA beach front laboratory is used to conduct realtime corrosion experiments and they provide remote monitoring of surrounding weather conditions including wind speed and direction, and rainfall. The results of the beach testing are not included in this report. Test vehicles used for interim inspection are shown in Table 4.4.2.

TABLE 4.4.2 TEST VEHICLE MATRIX FOR INTERIM INSPECTION AND BEACH FRONT TESTING

Number	Alloy	Sealant	Conversion Coating	Secondary Finish	Test
37	7075	PS-870	Iridite 14-2	HCF Primer Only	Salt fog 336 hrs
38	7075	AC-735	Metalast TCP	HCF Primer Only	Salt fog 336 hrs

Number	Alloy	Sealant	Conversion Coating	Secondary Finish	Test
39	7075	PR-1775	Metalast TCP	HCF Primer Only	Salt fog 336 hrs
40	7075	PR-2001	Metalast TCP	HCF Primer Only	Salt fog 336 hrs
41	7075	PS-870	Iridite 14-2	HCF Primer Only	Salt fog 672 hrs
42	7075	AC-735	Metalast TCP	HCF Primer Only	Salt fog 672 hrs
43	7075	PR-1775	Metalast TCP	HCF Primer Only	Salt fog 672 hrs
44	7075	PR-2001	Metalast TCP	HCF Primer Only	Salt fog 672 hrs
45	7075	PS-870	Iridite 14-2	HCF Primer Only	Beachfront
46	7075	AC-735	Metalast TCP	HCF Primer Only	Beachfront
47	7075	PR-1775	Metalast TCP	HCF Primer Only	Beachfront
48	7075	Optional	Iridite 14-2	Optional	Spare
49	7075	Optional	Iridite 14-2	Optional	Spare
50	7075	PR-2001	Metalast TCP	HCF Primer Only	Beachfront

4.5. Test Plan

The test plan and performance of the test plan was developed by a collaborative effort from engineers and scientists at Raytheon, Northrop Grumman, the Toxics Use Reduction Institute (TURI), NAVAIR, NASA, and Lockheed Martin. All participants performed some part of the fabrication or testing of the test vehicles as indicated by Table 4.5.1.

TABLE 4.5.1 TEST PLAN MAJOR TASKS AND DESIGNATIONS

Task	Responsible	Location	Timeframe
Develop test plan and DOE	All participants	Conference Calls	May – July 2012
Procure aluminum plates for test vehicles (TV).	TURI	Lowell, Massachusetts	June 2012
Conduct test vehicle mechanical stress analysis	Northrop Grumman	Baltimore, Maryland	June 2012
Develop test vehicle mechanical drawings	Raytheon	Tucson, Arizona	July 2012
Drill holes in test vehicles.	TURI	Lowell, Massachusetts	August 2012
Obtain necessary sealant samples and fasteners	Raytheon	Tucson, Arizona	August 2012
Apply hex chrome conversion coating on TVs	Northrop Grumman	Baltimore, Maryland	August 2012

Task	Responsible	Location	Timeframe
Apply trivalent chrome conversion coating on TVs	Metalast	Minden, Nevada	August 2012
Apply sealant to fasteners and test vehicles.	Raytheon	Tucson, Arizona	September 2012
Apply primer, topcoat, and scribes to TVs	Raytheon	Tucson, Arizona	September 2012
Conduct test vehicle mechanical and thermal preconditioning	NAVAIR	Patuxent River, Maryland	September 2012
Conduct salt fog testing for aluminum test vehicles (Total Qty. 44). Conduct inspections at 336, 672, and 1,008 hours, and cross sections of TV fasteners.	Lockheed Martin	Fort Worth, Texas	September - October 2012
Conduct beachfront corrosion test for aluminum test vehicles (Qty. 4).	NASA – Beachside Atmospheric Test Facility	Kennedy Space Center, Florida	September 2012 – September 2013
Conduct statistical analysis (DOE, ANOVA, etc.) for corrosion testing results using Minitab software	TURI	Lowell, Massachusetts	October 2012
Write a technical paper to document the research results of this corrosion testing research and to acknowledge contributors to the research effort	TURI	Lowell, Massachusetts	November 2012

4.6. Test Vehicle Fabrication

The test vehicles were created in the following order:

1. 6061 and 7075 aluminum alloy plates were procured by the Toxics Use Reduction Institute (TURI) and holes were machined according to Figures 4.3.3 and 4.3.4.

2. Bare aluminum plates were sent to Northrop Grumman to be conversion coated with Iridite 14-2 and to Metalast International to be conversion coated with Metalast TCP-HF HPA 100. The Iridite conversion coating was performed per manufacture recommendations MIL-DTL-5541 and the Metalast conversion coating process is described in Table 4.6.1.

TABLE 4.6.1 METALAST TCP-HF HPA 100 CONVERSION COATING PROCESS

Stages	Type	Concentration	Temperature (°F)	Time (min)
Cleaner	METALAST Cleaner 1000	45g/L	120	5.0-10.0
Rinse	RO water	-	Ambient	1.0
Surface Activation	Deox 3300 (A) + *Nitric Acid	45g/L + 20% v/v	Ambient	0.5
Rinse	RO water	-	Ambient	1.0
METALAST TCP-HF HPA 100	-	30% v/v	Ambient	5.0
Rinse	RO water	-	Ambient	0.1
Dry	Forced Air	-	Ambient	-

3. Both Iridite and Metalast conversion coated panels were packaged and mailed to Raytheon in Tucson, AX to be assembled.

4. The top side of the bottom plate was scribed with an “X” as shown in Figure 4.6.1.

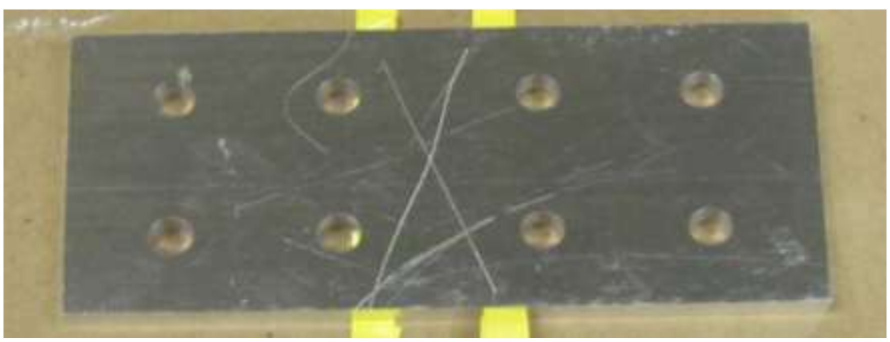


FIGURE 4.6.1 X-SCRIBE ON TOP OF BASE PLATE FOR BUTT JOINT

5. Approximately 0.005” of sealing compound was applied to one side of each panelby spatula. Two 0.005” wires were laid across the top of the base plate to control the thickness of the sealant bond and all three faying surfaces were mated together as shown in Figures 4.6.2 through 4.6.4.

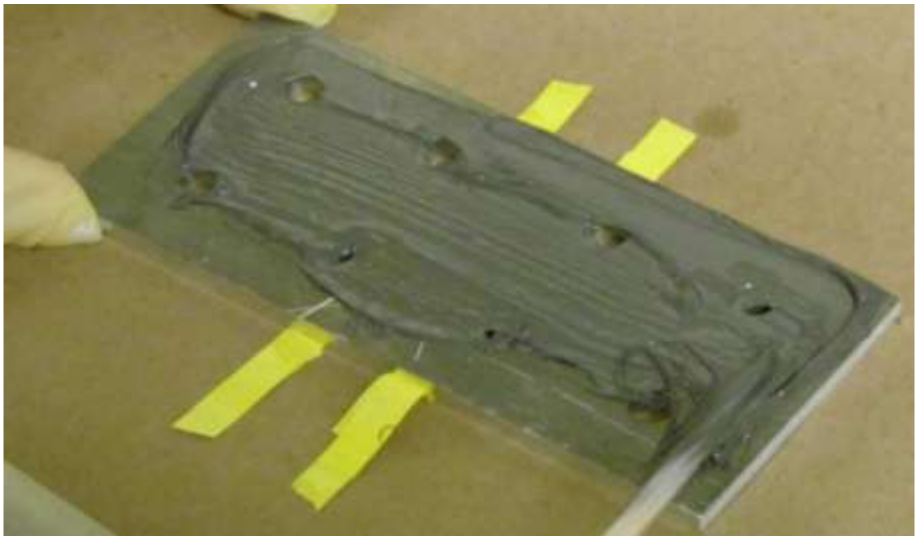


FIGURE 4.6.2 APPLICATION OF SEALANT ON TOP SIDE OF BASE PLATE

FIGURE 4.6.3 APPLICATION OF SEALANT ON BOTTOM SIDE OF TOP PLATES AND ADDITION OF TWO WIRES TO TOP SIDE OF BOTTOM PLATE

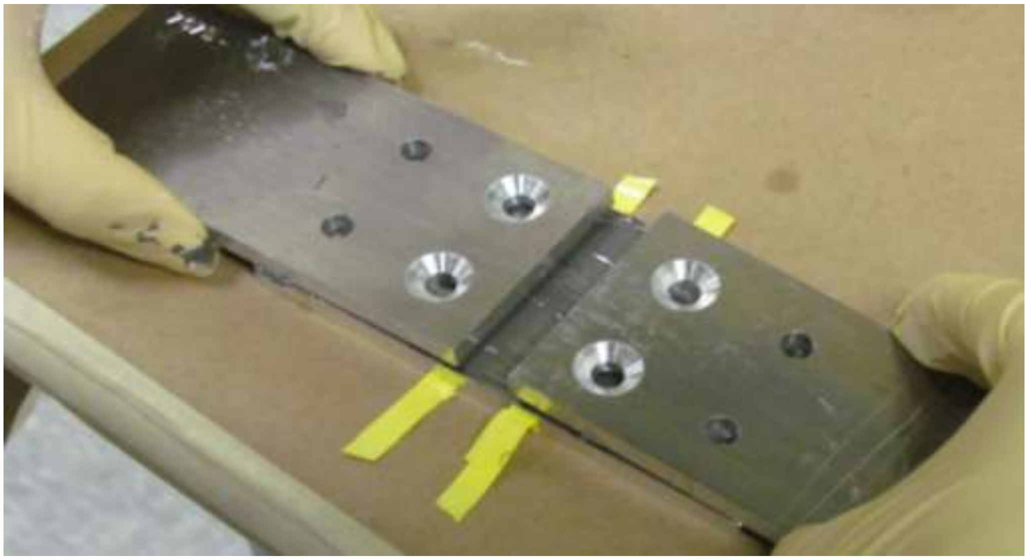


FIGURE 4.6.4 MATING OF TOP PLATES TO BOTTOM PLATE

6. Fasteners were coated by finger with the sealing compound and inserted into the freshly mated panels. Nuts were installed and torqued to 40 in-lb$_f$ which caused the sealant to squeeze out and almost completely fill the butt-joint. See Figures 4.6.5 through 4.6.7.

FIGURE 4.6.5 SEALANT BRUSHED ON TO FASTENERS

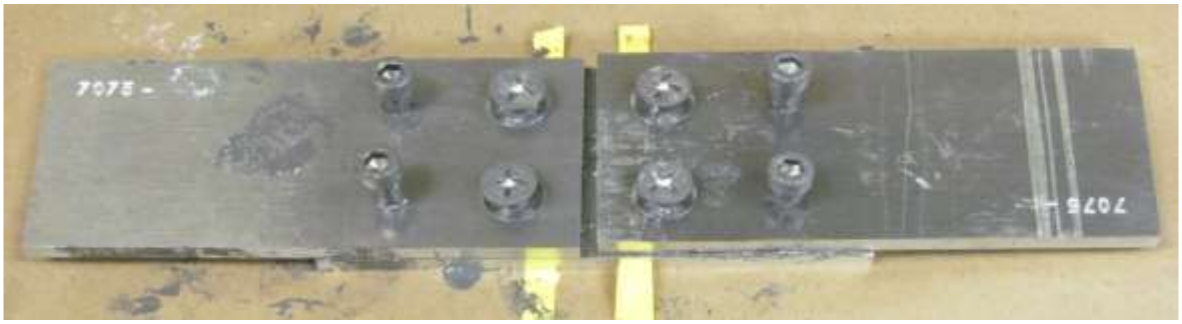


FIGURE 4.6.6 FASTENERS INSERTED INTO FRESHLY MATED PANELS

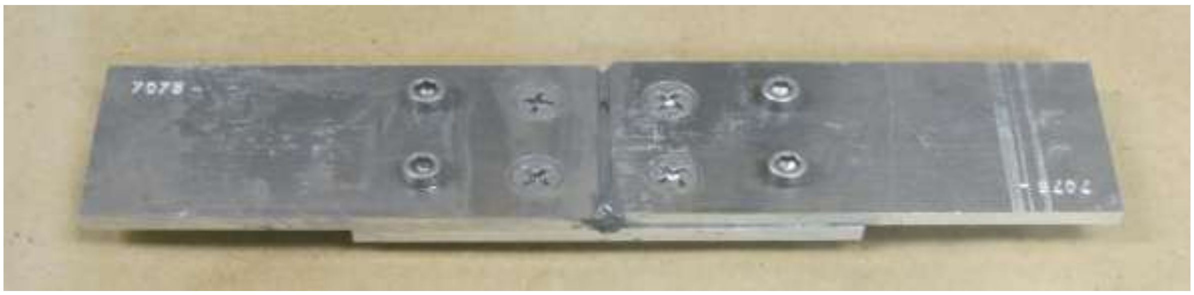


FIGURE 4.6.7 FASTENERS TORQUED TO 40 IN·LB$_F$ (SQUEEZE OUT ALMOST COMPLETELY FILLED BUTT GAP

7. Sealing compound was applied to the butt joint to completely fill the gap using a Q-tip stick.

8. Excess sealant was wiped from the entire test vehicle prior to proceeding.

9. Two of each type of fastener head were completely covered over and around on each plate, as well as the corresponding nuts as shown in Figure 4.6.8 and 4.6.9.

FIGURE 4.6.8 SEALANT APPLIED OVER FASTENER HEADS

10. An area on the back side of the bottom aluminum plate of approximately 0.75" wide by 2" long was brush coated. The brush coat thickness was in the range of 0.005" to 0.007". See Figure 4.6.9.

FIGURE 4.6.9 SEALANT APPLIED TO CORRESPONDING NUTS OF FASTENERS. STRIP OF SEALANT APPLIED TO SURFACE IN BETWEEN

11. The assembly was cured at room temperature for 48 hours.

12. The specific primer or combination of primer and topcoat was applied over the entire area of the test vehicle per manufacturer instructions as shown in Figures 4.6.10 through 4.6.12.

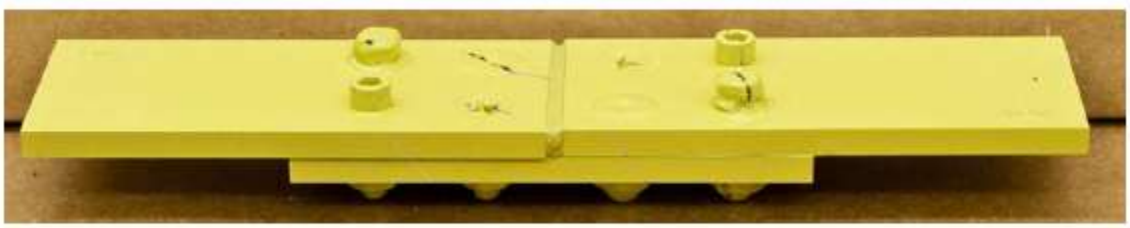


FIGURE 4.6.10 TEST VEHICLE PRIMED WITH AKZO NOBEL AKZO NOBEL 10P20-13/EC-213

FIGURE 4.6.11 TEST VEHICLE PRIMED WITH DEFT 44GN098

FIGURE 4.6.12 TEST VEHICLE WITH PRIMER AND PPG 8211F37886MPY22K TOPCOAT

13. After primer or primer and topcoat system was cured, damage was initiated by scribing the test vehicle surfaces and fasteners. Scribes were generated by an Erichsen Scratch Stylus acc. to Sikkens Model 463 with a 1 mm wide carbon tip. Scribes were made on the sides of the test vehicle in four locations. A scribe was made through the 0.75” by 2.0” brush coated area on the bottom of the bottom plate. In addition, scribes were applied to four fastener heads (two flush heads and two protruding heads) and two nuts on each test vehicle. The other four fastener heads and six nuts on each test vehicle did not get scribed. The scribed areas are portrayed in Figure 4.6.13.

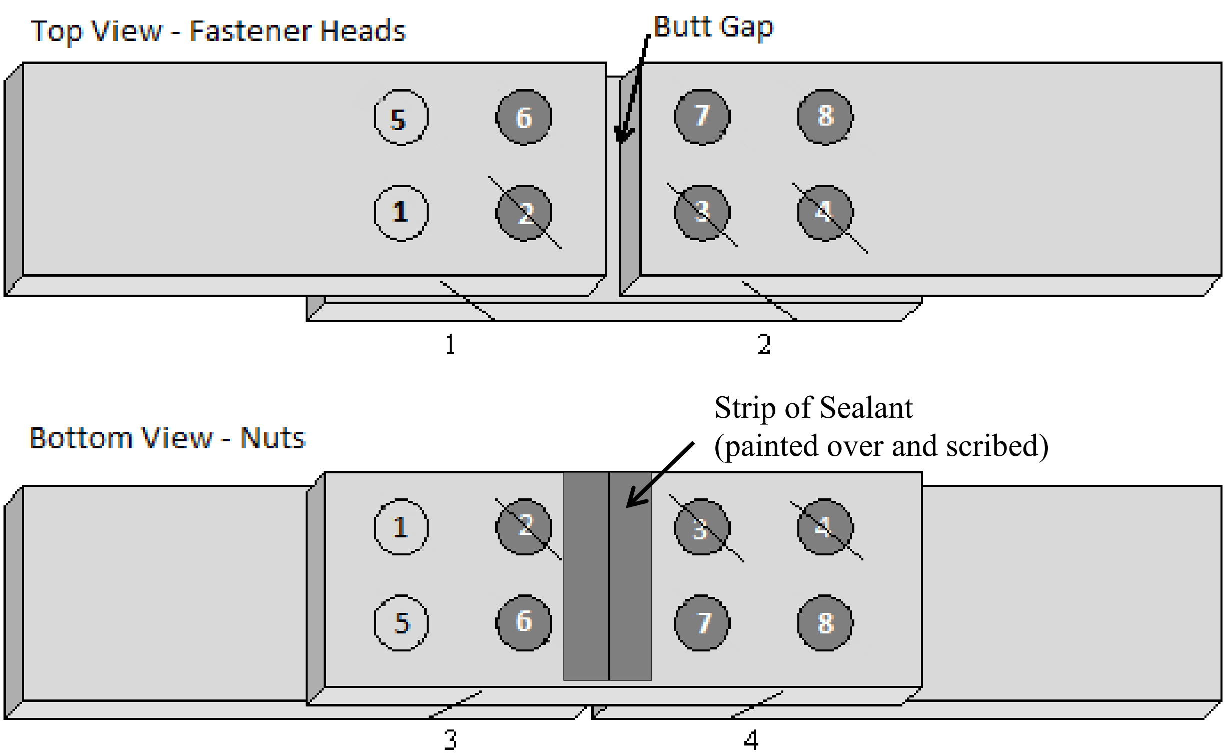


FIGURE 4.6.13 SCRIBED AREAS OF THE TEST VEHICLE

5. TESTING PROCEDURE

5.1. Thermal and Mechanical Pre-conditioning at NAVAIR, Patuxent River, MD

After fabrication, all test vehicles were sent to NAVAIR in Patuxent River, MD to be mechanically and thermally preconditioned to stress the sealant joints. The preconditioning was performed according to MIL-PRF-81733D Section 4.8.9.3.1 Cyclic Loading for Class 1 materials. The test vehicles were soaked at -65 °F for thirty minutes. After the thirty minute soak at -65 °F, the test vehicles were cyclically loaded between 0 and 5,000 lb_f for 250 cycles at the same temperature of -65 °F. The intent of this testing was to simulate several stress applications including: fighter aircraft, cargo aircraft, missiles, ground equipment, and maritime/naval equipment.

After mechanical and thermal preconditioning, the test vehicles were packaged and mailed to Lockheed Martin Aeronautics in Fort Worth, TX to be exposed to SO_2 (sulfur dioxide) salt fog according to ASTM G85 A4 for 1008 hours (6 weeks).

5.2. SO_2 Salt Fog Testing at Lockheed Martin Aeronautics, Fort Worth, TX

5.2.1. Receiving of Test Vehicles

Upon receiving the test vehicles at Lockheed Martin Aeronautics, Fort Worth, many of the test vehicles showed poor adhesion of primer and topcoat. The primed-only test vehicles showed better adhesion to the substrate than the test vehicles that were primed and topcoated. Figures 5.1.1 and 5.1.2 show some examples of poor adhesion of the primer and topcoat to the test vehicles.

FIGURE 5.2.1.1 ADHESION LOSS AROUND GRIP AREAS OF PRIMED-ONLY TEST VEHICLE

FIGURE 5.2.1.2 ADHESION LOSS ON SIDES AND GRIP AREA OF PRIMED AND TOPCOATED TEST VEHICLE

Before exposure to the salt fog, the ends of the test vehicles were taped to prevent excessive corrosion in those areas. Figure 5.2.1.3 shows a taped test vehicle.

FIGURE 5.2.1.3 TEST VEHICLE WITH THE ENDS TAPED BEFORE EXPOSURE TO SO_2 SALT FOG

5.2.2. SO_2 Salt Fog Operating Conditions

SO_2 salt fog testing was performed in accordance with ASTM G85 Annex 4. The process consisted of six-hour cycles in an environmentally controlled chamber. A 5% NaCl solution (aq) was constantly sprayed into the chamber for all six hours of the cycle at a collection rate of 1-2 ml/hr. After the first 5 hours of the cycle, SO_2 gas was introduced into the chamber for 1 hour to complete the cycle. This six-hour cycle was continuously repeated for 1008 hours. The chamber was kept at 95+/- 3 °F and the temperature in the air saturator tower was kept at 117 +/- 2 °F. The pH of the salt fog was kept in the range of 2.5 - 3.2 and was controlled by adjusting the flow rate of SO_2 gas.

Test vehicles were initially oriented with the nuts facing up. The scribed nuts were positioned as the top row as illustrated in Figure 5.2.2.1.

FIGURE 5.2.2.1 TEST VEHICLE ORIENTATION FOR FIRST 168 HRS OF EXPOSURE TO SO_2 SALT FOG

Three days from initial test vehicle exposure to SO_2 salt fog, the conditions inside the salt fog chamber heated up to over 150 °F. A thermocouple inside the chamber failed and caused the water jacket around the chamber to continuously heat up. The test vehicles were exposed to the elevated temperature conditions for 6-12 hours before being moved to another chamber that was operating within ASTM G85 Annex 4 specification. This was the only deviation from ASTM G85 Annex 4 operating guidelines for the entire exposure.

Upon moving the test vehicles to the new chamber, the orientation of the test vehicles was adjusted so that the fastener heads would be facing up to provide a more realistic exposure. The scribed fastener heads were positioned as the top row of fasteners as shown in Figure 5.2.2.2. This orientation was kept for the rest of the exposure.

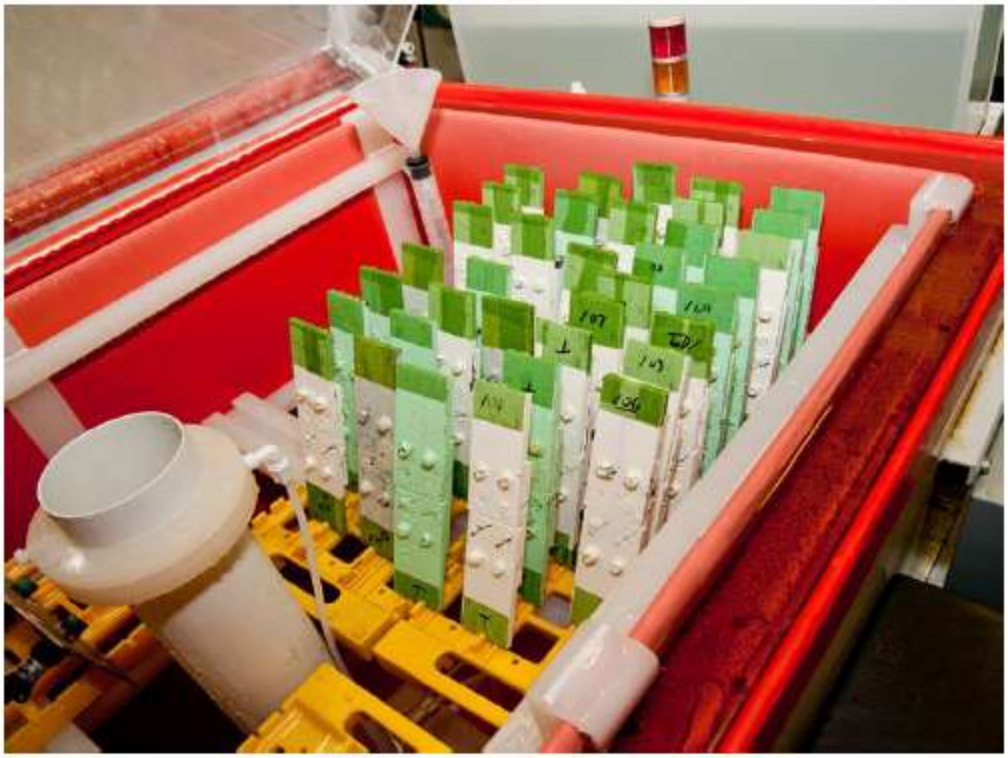


FIGURE 5.2.2.2 TEST VEHICLE ORIENTATION FROM 168 HRS TO 1008 HRS OF EXPOSURE TO SO_2 SALT FOG

5.2.3. Test Vehicle Inspections

Two types of inspections were performed on the text vehicles during their exposure to the salt fog: Non-Destructive and Destructive.

5.2.3.1. Non-Destructive Inspection

Non-destructive inspections were used to examine the outer appearance of the test vehicles and were performed on all of the test vehicles at the following intervals of exposure to the salt fog:

- 168 hours
- 336 hours
- 672 hours
- 1008 hours

For non-destructive inspection, each test vehicle was divided into areas of interest. Each test vehicle was examined and given a numerical value according to the level of corrosion in each area of interst. Table 5.2.3.1.1

and Figure 5.2.3.1.1 describe the areas of interest for non-destructive inspection of each test vehicle.

TABLE 5.2.3.1.1 AREAS OF INTEREST FOR NON-DESTRUCTIVE OBSERVATION OF TEST VEHICLES

Top View - Fastener Heads	
Number	Description
1	Scribed Socket Head with Sealant
2	Non-Scribed Recessed Head w/Sealant
3	Scribed Recessed Head No Sealant
4	Non-Scribed Socket Head No Sealant
5	Scribed Socket Head No Sealant
6	Non-Scribed Recessed Head No Sealant
7	Scribed Recessed Head w/Sealant
8	Non-Scribed Socket Head w/Sealant
NA	Butt Joint
Bottom View - Nuts	
Number	Description
1	Scribed Nut No Sealant
2	Non-Scribed Nut No Sealant
3	Non-Scribed Nut w/Sealant
4	Non-Scribed Nut w/Sealant
5	Scribed Nut w/Sealant
6	Non-Scribed Nut w/Sealant
7	Non-Scribed Nut No Sealant
8	Non-Scribed Nut No Sealant
NA	Strip of Sealant Scribed
Sides	
Number	Description
1	Scribed Side Location
2	Scribed Side Location
3	Scribed Side Location
4	Scribed Side Location

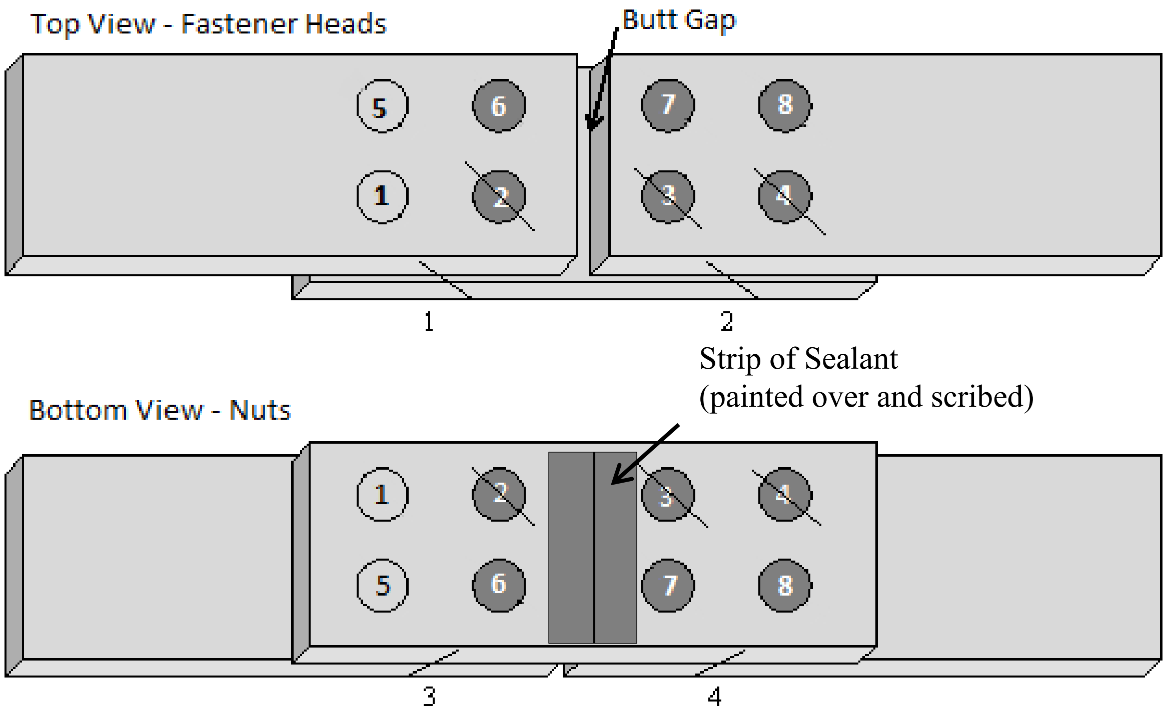


FIGURE 5.2.3.1.1 AREAS OF INTEREST FOR NON-DESTRUCTIVE OBSERVATION OF TEST VEHICLES

Table 5.2.3.1.2 describes the ranking system for non-destructive inspection of the test vehicles.

TABLE 5.2.3.1.2 RATING SYSTEM FOR NON-DESTRUCTIVE INSPECTION OF TEST VEHICLES

Rating	Test Vehicle Observations
5	No observable changes.
4.5	Darkening of scribe line.
4	Slight salt build-up of scribe. No evidence of corrosion.
3.5	Slight evidence of substrate pitting or very small amount of corrosion product limited to the scribe.
3	Slight evidence of substrate pitting or very small amount of corrosion product extending beyond scribe.
2	Evidence of substrate pitting or some corrosion product.
1	Extensive substrate pitting or excessive corrosion product.

5.2.3.2. Destructive Inspection

Destructive inspections involved removing the fasteners, separating the plates of the test vehicles, and stripping the sealant away to examine the inner surfaces that were protected by sealant. The inner surfaces were divided into areas of interest and a rating for the amount of corrosion in each area of interest was recorded. The ratings ranged from 0 – 100 as a percentage of area; 0 representing no corrosion and 100 representing corrosion of the entire area of interest. Destructive inspections were performed on test vehicles after completing 1008 hours of salt fog exposure. Interim test vehicles were destructed at 336 and 672 hours to ensure failures were occurring before the end of the test. Table 5.2.3.2.1 and Figure 5.2.3.2.1 describe the areas of interest for destructive inspection.

TABLE 5.2.3.2.1 AREAS OF INTEREST FOR DESTRUCTIVE OBSERVATION OF TEST VEHICLES

Fastener Holes	
Number	Description
1	Fastener Hole (Barrel Area)
2	Fastener Hole (Barrel Area)
3	Fastener Hole (Barrel Area)
4	Fastener Hole (Barrel Area)
5	Fastener Hole (Barrel Area)
6	Fastener Hole (Barrel Area)
7	Fastener Hole (Barrel Area)
8	Fastener Hole (Barrel Area)
Countersink Areas	
Number	Description
1	Countersink Fastener Hole (countersink area)
2	Countersink Fastener Hole (countersink area)
3	Countersink Fastener Hole (countersink area)
4	Countersink Fastener Hole (countersink area)
Faying Surfaces	
Butt Joint (X-Scribe)	
Butt Joint (Sides)	
Faying Surface	

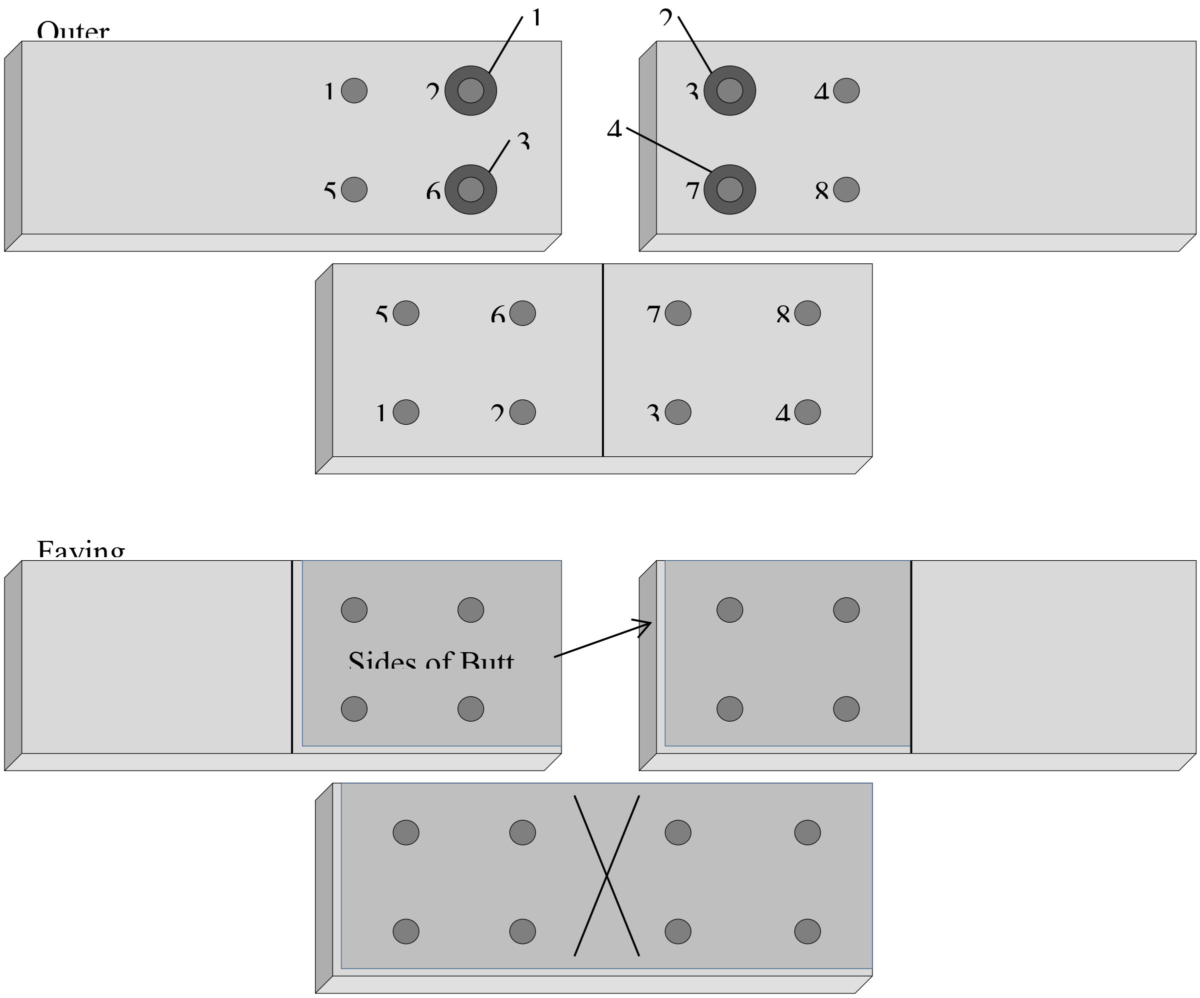


FIGURE 5.2.3.2.1 AREAS OF INTEREST FOR DESTRUCTIVE OBSERVATION OF TEST VEHICLES

6. RESULTS

The results provided in this executive summary only include the SO_2 salt fog testing performed at Lockheed Martin Aeronautics in Fort Worth, TX.

6.1. Non-Destructive Inspection Results

Non-destructive inspection of the test vehicles provided valuable information regarding the outside appearance of the test vehicles. Due to the corrosive environment of the SO_2 salt fog, the secondary finishes of the test vehicles exhibited many areas of lifting, peeling, discoloration, rust, and blisters. These observations were all noted and photos were taken to document the corrosion. Tables 6.1.1 through 6.1.4 present the nondestructive ratings of the test vehicles at 168, 336, 672, and 1008 hours of exposure to the SO_2 salt fog. It should be noted that because the interface of the sealant to the metal could not be examined, some of the lower value ratings may not reflect actual sealant performance.

TABLE 6.1.1 NON-DESTRUCTIVE INSPECTION RATINGS AT 168 HOURS OF EXPOSURE TO SO_2 SALT FOG

Test Vehicle	Hours of Salt Fog	Scribed Socket Head w/Sealant #1	Non-Scribed Recessed Head w/Sealant #2	Scribed Recessed Head No Sealant #3	Non-Scribed Socket Head No Sealant #4	Scribed Socket Head No Sealant #5	Non-Scribed Recessed Head No Sealant #6	Scribed Recessed Head w/Sealant #7	Non-Scribed Socket Head w/Sealant #8	Scribed Nut No Sealant #1	Non-Scribed Nut No Sealant #2	Non-Scribed Nut w/Sealant #3	Non-Scribed Nut w/Sealant #4	Scribed Nut w/Sealant #5	Non-Scribed Nut w/Sealant #6	Non-Scribed Nut No Sealant #7	Non-Scribed Nut No Sealant #8	Scribed Butt Joint	Scribed Side Location #1	Scribed Side Location #2	Scribed Side Location #3	Scribed Side Location #4	Scribed Bottom Plate Surface
1	168	4.5	5	4	5	4	5	4.5	5	4.5	5	5	5	5	5	5	4.5	NC	5	5	5	5	4.5
2	168	5	5	5	4.5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	NC	5	5	5	5	5
3	168	5	5	5	5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	C	5	5	5	5	5
4	168	5	5	5	5	5	5	5	5	4.5	5	5	5	5	5	5	5	C	5	5	5	5	5
5	168	5	5	5	5	5	5	5	5	4.5	5	5	5	5	5	5	5	C	5	5	5	5	5
6	168	5	5	5	5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	C	5	5	5	5	5
7	168	5	5	5	5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	NC	5	5	5	5	5
8	168	5	5	5	4.5	4.5	5	5	5	5	5	5	5	5	5	4.5	4.5	NC	5	5	5	5	5
9	168	5	5	5	5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	NC	5	5	5	5	5
10	168	5	5	5	5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	NC	5	5	5	5	5
11	168	5	5	5	5	4.5	5	4.5	5	4.5	5	5	5	5	5	5	5	NC	5	5	5	5	5
12	168	5	5	5	5	4.5	5	5	5	4.5	5	5	5	5	5	4.5	4.5	NC	5	5	5	5	5
13	168	5	5	5	5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	C	5	5	5	5	5
14	168	4.5	5	4.5	4.5	4.5	5	5	5	4.5	5	5	5	5	5	4.5	4.5	NC	5	5	5	5	5
15	168	5	5	5	5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	NC	5	5	5	5	5
16	168	5	5	5	5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	NC	5	5	5	5	5
17	168	5	5	5	5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	C	5	5	5	5	5
18	168	5	5	5	5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	C	5	5	5	5	5
19	168	5	5	5	5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	C	5	5	5	5	5
20	168	5	5	4.5	5	5	5	5	5	4.5	5	5	5	5	5	4.5	5	C	5	5	5	5	5
21	168	5	5	5	5	4.5	5	5	5	5	5	5	5	5	5	5	5	C	5	5	5	5	5
22	168	5	5	5	5	5	5	5	5	4.5	5	5	5	5	5	5	4.5	NC	5	5	5	5	5
23	168	5	5	5	5	4.5	5	5	5	5	5	5	5	5	5	5	5	C	5	5	5	5	5
24	168	5	5	5	5	4.5	5	5	5	4.5	4.5	5	5	5	5	5	5	NC	5	5	5	5	5
25	168	5	5	5	5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	C	5	5	5	5	5
26	168	5	5	5	5	4.5	5	5	5	4.5	4.5	5	5	5	5	4.5	4.5	NC	5	5	5	5	5
27	168	5	5	5	5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	NC	5	5	5	5	5
28	168	5	5	5	4.5	4.5	5	5	5	4.5	5	5	5	5	5	4.5	4.5	NC	5	5	5	5	5
29	168	5	5	5	5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	NC	5	5	5	5	5
30	168	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	C	5	5	5	5	5
31	168	5	5	5	5	4.5	5	5	5	5	5	5	5	5	5	5	5	C	5	5	5	5	5
32	168	5	5	5	5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	C	5	5	5	5	5
33	168	5	5	5	5	4.5	5	5	5	5	5	5	5	5	5	5	5	NC	5	5	5	5	5
34	168	5	5	5	5	5	5	5	5	5	4.5	5	5	5	5	5	5	C	5	5	5	5	5
35	168	5	5	5	5	4.5	5	4.5	5	5	5	5	5	5	5	5	5	C	5	5	5	5	5
36	168	4.5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	C	5	5	5	5	5
37	168	4.5	5	5	5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	NC	5	5	5	5	5
38	168	5	5	5	5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	C	5	5	5	5	5
39	168	5	5	5	5	4.5	5	5	5	4.5	5	5	5	5	5	5	4.5	NC	5	5	5	5	5
40	168	5	5	5	4.5	4.5	5	5	5	4.5	4.5	5	5	5	5	4.5	4.5	C	5	5	5	5	5
41	168	5	5	5	4.5	5	5	5	5	5	4.5	5	5	5	5	5	4.5	NC	5	5	5	5	5
42	168	5	5	5	5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	C	5	5	5	5	5
43	168	5	5	5	5	4.5	5	5	5	4.5	4.5	5	5	5	5	4.5	5	NC	5	5	5	5	5
44	168	5	5	5	4.5	4.5	5	5	5	4.5	4.5	5	5	5	5	4.5	4.5	NC	5	5	5	5	5

Color Legend
Cracking
Rust
Blistering
Rust & Cracking
Chip

Scribed Butt Joint
NC - Not Cracked
C - Cracked

TABLE 6.1.2 NON-DESTRUCTIVE INSPECTION RATINGS AT 336 HOURS OF EXPOSURE TO SO_2 SALT FOG

Test Vehicle	# Hours of Salt Fog Completed	Scribed Socket Head w/Sealant #1	Non-Scribed Recessed Head w/Sealant #2	Scribed Recessed Head No Sealant #3	Non-Scribed Socket Head No Sealant #4	Scribed Socket Head No Sealant #5	Non-Scribed Recessed Head No Sealant #6	Scribed Recessed Head w/Sealant #7	Non-Scribed Socket Head w/Sealant #8	Scribed Nut No Sealant #1	Non-Scribed Nut No Sealant #2	Non-Scribed Nut w/Sealant #3	Non-Scribed Nut w/Sealant #4	Scribed Nut w/Sealant #5	Non-Scribed Nut w/Sealant #6	Non-Scribed Nut No Sealant #7	Non-Scribed Nut No Sealant #8	Scribed Butt Joint	Scribed Side Location #1	Scribed Side Location #2	Scribed Side Location #3	Scribed Side Location #4	Scribed Bottom Plate Surface
1	336	4.5	5	3.5	5	4	5	3.5	5	4.5	5	5	5	5	5	5	4.5	C	4	4	4	4	4.5
2	336	5	5	5	4.5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	NC	5	5	5	5	5
3	336	5	5	5	5	4.5	5	4	5	4.5	5	5	5	5	5	5	5	C	5	4	5	5	4.5
4	336	5	5	4.5	5	4.5	5	5	5	4.5	5	5	5	5	5	4.5	5	C	5	4	4	4	4.5
5	336	5	5	4	5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	C	5	5	5	5	4.5
6	336	5	5	4.5	5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	C	5	5	5	5	5
7	336	5	5	4.5	5	4.5	5	4.5	5	4.5	5	5	5	5	5	5	5	C	4	4	4	4	4.5
8	336	5	5	4	4.5	4.5	5	5	5	4.5	4.5	5	5	5	5	4.5	4.5	C	4	4	4	4	5
9	336	5	5	4	5	4.5	5	4	5	4.5	5	5	5	5	5	5	5	NC	4	4	4	4	4.5
10	336	5	5	3.5	5	4.5	5	3.5	5	4.5	5	5	5	5	5	4.5	5	C	4	5	5	5	4.5
11	336	5	5	4	5	4.5	4.5	4	5	4.5	5	5	5	5	5	5	5	NC	4	4	4	4	4.5
12	336	5	5	5	4.5	4	5	5	5	4.5	4.5	5	5	5	5	4.5	4.5	C	5	5	5	5	4.5
13	336	5	5	4	5	4.5	5	4.5	5	4.5	5	5	5	5	5	5	5	C	4	4	4	4	4.5
14	336	4.5	5	4.5	4.5	4.5	5	5	5	4.5	4.5	5	5	5	5	4.5	4.5	NC	4	4	5	5	4.5
15	336	5	5	4	4	4.5	5	4	5	4.5	5	5	5	5	5	5	5	C	4	4	4	4	4.5
16	336	5	5	5	5	4.5	5	3	5	4.5	5	5	5	5	5	5	5	C	5	5	5	5	4.5
17	336	5	5	3.5	5	4.5	5	5	5	4.5	5	5	5	5	5	4.5	5	C	3.5	3.5	3.5	3.5	4.5
18	336	5	5	3.5	3	4.5	5	5	5	4.5	5	5	5	5	5	5	5	C	5	5	5	3.5	4.5
19	336	5	5	4	5	4.5	5	3	5	4.5	5	5	5	5	5	5	5	C	4	4	2	4	4.5
20	336	5	5	4.5	5	4.5	5	3	5	4.5	5	5	5	5	5	4.5	5	C	5	5	5	3	4.5
21	336	5	5	3	5	4.5	5	3	5	5	5	5	5	5	5	5	5	C	3	3	3	3	4.5
22	336	5	5	3	5	5	5	3	5	4.5	5	5	5	5	5	5	4.5	C	3.5	5	3.5	3.5	4.5
23	336	5	5	5	4.5	4.5	5	4	5	5	5	5	5	5	5	5	5	C	5	5	5	5	4.5
24	336	5	5	3	4.5	4.5	5	3	5	4.5	4.5	5	5	5	5	5	5	C	3.5	3	3.5	3.5	4.5
25	336	5	5	3	4.5	4.5	5	3.5	5	4.5	5	5	5	5	5	5	5	C	3.5	3	3.5	3.5	5
26	336	5	5	5	4.5	4.5	5	5	5	4.5	4.5	5	5	5	5	4.5	4.5	C	5	3	5	5	4.5
27	336	5	5	5	5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	C	3.5	3.5	3.5	3.5	4.5
28	336	4.5	5	3	4.5	4.5	4.5	3	5	4.5	4.5	4.5	5	5	5	4.5	4.5	C	3.5	3.5	3.5	3.5	4.5
29	336	5	5	3	5	4.5	4.5	3	5	4.5	5	5	5	5	5	5	5	C	3	3	3	3	4.5
30	336	5	5	3	4.5	4.5	5	3	5	4.5	5	5	5	5	5	4.5	5	C	5	5	5	3	4.5
31	336	5	5	3	5	4.5	5	4	5	5	5	5	5	5	5	5	5	C	3.5	3.5	3.5	3.5	4.5
32	336	5	5	3	4.5	4.5	5	3	5	4.5	5	5	5	5	5	5	5	C	3.5	3.5	3.5	3.5	4.5
33	336	5	5	4	5	4.5	5	4	5	4.5	5	5	5	5	5	5	5	C	3.5	3.5	3.5	3.5	4.5
34	336	5	5	3	5	4.5	5	3	5	5	4.5	5	5	5	5	5	5	C	3.5	3.5	3.5	3.5	4.5
35	336	5	5	4	5	4.5	5	4.5	5	5	5	5	5	5	5	5	5	C	3.5	3.5	3.5	3.5	4.5
36	336	4.5	5	3	4.5	5	5	5	4.5	5	5	5	5	5	5	5	5	C	3.5	3.5	5	5	4.5
37	336	4.5	5	5	5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	NC	3.5	3.5	5	5	5
38	336	5	5	3.5	3.5	3	5	4	5	4.5	5	5	5	5	5	5	5	C	5	5	5	5	5
39	336	5	5	3.5	5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	NC	4.5	4.5	5	5	5
40	336	5	5	5	4.5	4.5	5	5	5	4.5	4.5	5	5	5	5	4.5	4.5	C	5	5	5	5	5
41	336	5	5	3	5	4.5	5	3	5	4.5	4.5	5	5	5	5	4.5	4.5	C	3.5	3.5	3.5	3.5	4.5
42	336	5	5	5	5	4.5	5	3	5	4.5	5	5	5	5	5	5	4.5	C	3	3	3	3	4.5
43	336	5	5	3	4.5	4.5	5	3	5	4.5	4.5	5	5	5	5	4.5	5	C	3.5	3.5	3.5	3.5	4.5
44	336	5	5	3.5	4.5	4.5	5	4	5	4.5	4.5	5	5	5	5	4.5	4.5	C	3.5	3.5	3.5	3.5	4.5

Color Legend
Cracking
Blistering & Cracking
Blistering
Blistering & Flaking/Peeling
Rust
Rust & Cracking
Rust & Blistering

Scribed Butt Joint
NC - Not Cracked
C - Cracked

TABLE 6.1.3 NON-DESTRUCTIVE INSPECTION RATINGS AT 672 HOURS OF EXPOSURE TO SO_2 SALT FOG

Test Vehicle	# Hours of Salt Fog Completed	Scribed Socket Head w/Sealant #1	Non-Scribed Recessed Head w/Sealant #2	Scribed Recessed Head No Sealant #3	Non-Scribed Socket Head No Sealant #4	Scribed Socket Head No Sealant #5	Scribed Recessed Head No Sealant #6	Scribed Recessed Head w/Sealant #7	Non-Scribed Socket Head w/Sealant #8	Scribed Nut No Sealant #1	Non-Scribed Nut No Sealant #2	Non-Scribed Nut w/Sealant #3	Non-Scribed Nut w/Sealant #4	Scribed Nut w/Sealant #5	Non-Scribed Nut w/Sealant #6	Non-Scribed Nut No Sealant #7	Non-Scribed Nut No Sealant #8	Scribed Butt Joint	Scribed Side Location #1	Scribed Side Location #2	Scribed Side Location #3	Scribed Side Location #4	Scribed Bottom Plate Surface
1	672	4.5	5	3	5	4	5	3	5	4.5	5	5	5	5	5	5	4.5	C	4	4	4	4	4.5
2	672	5	5	4	4.5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	C	5	5	5	5	4.5
3	672	5	5	5	5	3	5	3	5	4.5	5	5	5	5	5	5	5	C	5	4	5	5	4.5
4	672	5	5	4.5	5	3	5	5	5	3	5	5	5	5	5	4.5	5	C	4.5	4.5	4.5	4.5	4.5
5	672	5	5	4	5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	C	5	5	3.5	4	4.5
6	672	5	5	4.5	5	4.5	5	5	5	4.5	5	5	5	5	5	5	5	C	5	5	3.5	5	5
7	672	4	5	3	5	4	5	3	5	4.5	5	5	5	5	5	5	5	C	3.5	3.5	4	5	4.5
8	672	4.5	5	4	3	3	5	5	5	4.5	4.5	5	5	5	5	4.5	3	C	4	4	4	4	4.5
9	672	5	5	4	5	4.5	5	4	5	4.5	5	5	5	5	5	5	5	NC	4	4	4	4	4.5
10	672	5	5	3.5	5	4.5	5	3.5	5	4.5	5	5	5	5	5	4.5	5	C	4	4	4.5	4.5	4.5
11	672	5	5	3	5	4.5	5	3.5	5	4.5	5	5	5	5	5	5	5	C	4	4	4	4	4
12	672	5	5	5	3	3	4	5	5	4.5	4.5	5	5	5	5	4.5	4.5	C	5	5	5	5	4.5
13	672	5	5	3	5	4.5	5	4.5	5	4.5	5	5	5	5	5	5	5	C	4	4	4	4	4.5
14	672	4.5	5	4.5	3	3	5	5	5	4.5	4.5	5	5	5	5	4.5	4.5	NC	4	4	4	4	4.5
15	672	5	5	4	5	4.5	5	4	5	4.5	5	5	5	5	5	5	5	C	4	4	4	4	4.5
16	672	5	5	5	5	4.5	5	3	5	4.5	5	5	5	5	5	5	5	C	5	5	4.5	4.5	4.5
17	672	5	5	3	5	4.5	5	5	5	4.5	5	5	5	5	5	4.5	5	C	3.5	3.5	3.5	3.5	4
18	672	5	5	3	3	4.5	5	5	5	4.5	5	5	5	5	5	3	5	C	3	3	4.5	3	4.5
19	672	5	5	4	5	3	5	3	5	4.5	5	5	5	5	5	5	5	C	4	3	3	3	4.5
20	672	5	5	4.5	5	3	5	3	5	4.5	5	5	5	5	5	5	3.5	C	4	4	4	4	4.5
21	672	5	5	3	5	4.5	5	3	5	5	5	5	5	5	5	5	5	C	2	3	4	4	4.5
22	672	5	5	3	5	5	5	3	5	4.5	5	5	5	5	5	5	4.5	C	4	3	4.5	4	4.5
23	672	5	5	3	4.5	4.5	5	3	5	5	5	5	5	5	5	5	5	C	4	4	4	4	4.5
24	672	4.5	5	3.5	4.5	3	5	4.5	5	4.5	4.5	5	5	5	5	5	5	C	4	4	3	4.5	4.5
25	672	5	5	3	4.5	4.5	5	3.5	5	4.5	5	5	5	5	5	5	5	C	4	4	4	4	4.5
26	672	5	5	4	4.5	4.5	5	5	5	4.5	4.5	5	5	5	5	4.5	4.5	C	5	4	4	5	3.5
27	672	5	5	4	5	4.5	5	4	5	4.5	5	5	5	5	5	5	5	C	3.5	3.5	3.5	3.5	4.5
28	672	4.5	5	5	3	4.5	5	3	5	4.5	4.5	4.5	5	5	5	4.5	4.5	C	5	5	5	5	4
29	672	5	5	3	5	4.5	5	4.5	5	4.5	5	5	5	5	5	5	5	C	4.5	4.5	4	4	4.5
30	672	5	5	3	4.5	4.5	5	4.5	5	5	5	5	5	5	5	5	4.5	C	5	5	5	5	4.5
31	672	5	5	3	5	4.5	5	4	5	5	4.5	5	5	5	5	5	5	C	4	4	4	4	4.5
32	672	5	5	3	4.5	4.5	5	4.5	5	4.5	4.5	5	5	5	5	5	5	C	4	4	4	3	4.5
33	672	5	5	3	5	4.5	4.5	4.5	5	5	5	5	5	5	5	5	5	C	4	4	4	4	4.5
34	672	5	5	4.5	5	5	5	4	5	5	4.5	5	5	5	5	5	4.5	C	4	4	4	4	4.5
35	672	5	5	4	5	4.5	4.5	4.5	5	4.5	5	5	5	5	5	5	5	C	4.5	4.5	4	4	4.5
36	672	4.5	5	3.5	5	5	5	5	4.5	5	5	5	5	5	5	5	5	C	4	4	4	4	4.5
41	672	5	5	4.5	4.5	3	3	4	5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	C	4	4	4	4	4.5
42	672	5	5	4	4.5	4	4	4.5	4.5	4.5	5	5	5	5	5	5	4.5	C	4	4	4	4	4.5
43	672	4.5	4.5	4.5	3	4	4	4.5	4.5	4.5	4.5	4.5	5	4.5	5	4.5	5	C	4	4	4	4.5	4.5
44	672	5	4.5	5	3	3	3	4.5	4.5	4.5	4.5	5	4.5	4.5	4.5	4.5	4.5	C	5	5	4	4	4

Color Legend
Cracking
Blistering & Cracking
Blistering
Blistering & Flaking/Peeling
Rust
Rust & Cracking
Rust & Blistering
Flaking/Peeling
Rust & Flaking/Peeling
Blistering & Cracking & Rust
Chip
Chip & Cracking

Scribed Butt Joint
NC - Not Cracked
C - Cracked

TABLE 6.1.4 NON-DESTRUCTIVE INSPECTION RATINGS AT 1008 HOURS OF EXPOSURE TO SO_2 SALT FOG

Test Vehicle	# Hours of Salt Fog Completed	Scribed Socket Head w/Sealant #1	Non-Scribed Recessed Head w/Sealant #2	Scribed Recessed Head No Sealant #3	Non-Scribed Socket Head No Sealant #4	Scribed Socket Head No Sealant #5	Non-Scribed Recessed Head No Sealant #6	Scribed Recessed Head w/Sealant #7	Non-Scribed Socket Head w/Sealant #8	Scribed Nut No Sealant #1	Non-Scribed Nut No Sealant #2	Non-Scribed Nut w/Sealant #3	Non-Scribed Nut w/Sealant #4	Scribed Nut w/Sealant #5	Non-Scribed Nut w/Sealant #6	Non-Scribed Nut No Sealant #7	Non-Scribed Nut No Sealant #8	Scribed Butt Joint	Scribed Side Location #1	Scribed Side Location #2	Scribed Side Location #3	Scribed Side Location #4	Scribed Bottom Plate Surface
1	1,008	4.5	5	3.5	5	4.5	5	4	5	4.5	5	5	5	5	5	5	4.5	C	4.5	4.5	4	4	4.5
2	1,008	4.5	4.5	4	4	4	4.5	4.5	4.5	4	4.5	4.5	4.5	4.5	4.5	5	4	C	4	4	4.5	4	4.5
3	1,008	4.5	5	4	5	3	5	4	5	4.5	5	5	5	4.5	4.5	5	5	C	4	4	4.5	4.5	4.5
4	1,008	5	5	4	4.5	3	4	4	4.5	3	5	5	5	4.5	5	4.5	4.5	C	4	4	4	4.5	4.5
5	1,008	4.5	5	3	5	3	5	4	5	3	5	5	4.5	4	5	5	5	C	4	4	3.5	4	4.5
6	1,008	4.5	5	4.5	5	3	5	3.5	5	4.5	3.5	5	5	4.5	5	5	5	C	4.5	4.5	4	4.5	4.5
7	1,008	4.5	5	3	5	3	5	3.5	4.5	4.5	5	5	4.5	4.5	5	5	5	C	4	4	4	4.5	4.5
8	1,008	4	5	3.5	3	3	4	4	4.5	3	3	4.5	4.5	4.5	4.5	3	3	C	4	4	4	4	4.5
9	1,008	4.5	5	4	4.5	3	4	4	5	4.5	5	5	5	4.5	5	5	5	C	4	4	4.5	4.5	4.5
10	1,008	4.5	5	4	4.5	2	4.5	4	4.5	4.5	5	5	4.5	4.5	4.5	4.5	3.5	C	4	4	4	4	4
11	1,008	4.5	5	3	5	4.5	5	4	5	4.5	5	4.5	5	4.5	5	5	5	C	4	4	4	4.5	4.5
12	1,008	4.5	5	4	3	3	3	4	4.5	3	3	4.5	5	4.5	5	4	3.5	C	4	4.5	4.5	4	4.5
13	1,008	4.5	5	3	4.5	3.5	4.5	4	5	4.5	5	5	5	4.5	5	4.5	5	C	4.5	4.5	4	4.5	4.5
14	1,008	4.5	5	4	2	2	4	4	4.5	3	4	4.5	4.5	4.5	4.5	4	3	C	4	4	4	4	4.5
15	1,008	4.5	5	4	5	4.5	5	4.5	5	4	5	5	5	4.5	5	5	5	C	4	4	4.5	4.5	4.5
16	1,008	4.5	5	3.5	5	3	4	4	4.5	4	5	4.5	5	4.5	4.5	5	4.5	C	4	4	4	4	4.5
17	1,008	5	5	4	5	4	5	4.5	5	4	4	5	5	4.5	5	4.5	3.5	C	4	4	4.5	4	4
18	1,008	4.5	5	3	3.5	3	4.5	4.5	5	4	5	4.5	5	4.5	4.5	3	4.5	C	4	4	4	4	4.5
19	1,008	4.5	5	3.5	5	3	5	3.5	5	4.5	5	5	5	4.5	5	5	5	C	4.5	4.5	4	4	4.5
20	1,008	4.5	5	3.5	4.5	3	4	3	4.5	3	4.5	4.5	4.5	4.5	4	3	3	C	4	4	4	4	4.5
21	1,008	4.5	5	4	5	4.5	5	4	4.5	5	4.5	5	5	4.5	5	5	5	C	3.5	4	4	4	4.5
22	1,008	4.5	5	4	4.5	4.5	4.5	4.5	4.5	2.5	4.5	4.5	4.5	4.5	4	4.5	4.5	C	3.5	4	4	4	4.5
23	1,008	4.5	5	3.5	4.5	3.5	5	3.5	5	4.5	5	5	5	4.5	5	5	5	C	4.5	4	4.5	4	4.5
24	1,008	4.5	5	3	3	3	4.5	4	4.5	3	4.5	5	5	4.5	5	5	4	C	4	4	3	4	4.5
25	1,008	4.5	5	4	5	4.5	4.5	4	5	4.5	5	5	5	4.5	5	5	5	C	4	4	4	4	4.5
26	1,008	4.5	3	4	3	3	4.5	4.5	4.5	3	4.5	3	5	5	5	3	3	C	4.5	4	4	4	4
27	1,008	5	5	4	5	4.5	5	4	5	4.5	5	5	5	5	5	5	5	C	4.5	4.5	4.5	4.5	4.5
28	1,008	4.5	5	4	3	3	4	4	4.5	4.5	4.5	4.5	5	5	5	3	3	C	4	4	4	4	4.5
29	1,008	4	5	3	5	4.5	5	4.5	5	4.5	5	5	5	4.5	5	5	5	C	3.5	3.5	3.5	4.5	4.5
30	1,008	4.5	4.5	3	3	3	4.5	4.5	4.5	3	3	4.5	4.5	4.5	4.5	4	4	C	4	4	4	4	4.5
31	1,008	4.5	5	3	5	4.5	4.5	4.5	5	5	4.5	5	5	4.5	5	4	4.5	C	4.5	4.5	4.5	4.5	4.5
32	1,008	4.5	4.5	3	3	3	4	4	4.5	3	3	4.5	4.5	4.5	4	3	3	C	4.5	4	4.5	4.5	4.5
33	1,008	4.5	5	3	5	4.5	4.5	4.5	4.5	5	5	5	5	4	5	5	5	C	3	4.5	4	4.5	4.5
34	1,008	4.5	4.5	4	4.5	3	4.5	4.5	4.5	4.5	3	4.5	4.5	4.5	4.5	4.5	4.5	C	4	4	4	4	4.5
35	1,008	4.5	5	3	5	4.5	4.5	4.5	5	4.5	5	5	5	5	3	5	5	C	4.5	4.5	4.5	4.5	4
36	1,008	4	4.5	4	5	5	4	4	4.5	4.5	5	4.5	4.5	3	4.5	4.5	4.5	C	4	4	4.5	4	4.5

Color Legend
Cracking
Blistering & Cracking
Blistering
Blistering & Flaking/Peeling
Rust
Rust & Cracking
Rust & Blistering
Flaking/Peeling
Rust & Flaking/Peeling
Blistering & Cracking & Rust

Scribed Butt Joint
NC - Not Cracked
C - Cracked

Figures 6.1.1 through 6.1.3 present images of six different test vehicles at each interval of non-destructive inspection. A common sealant was chosen for consistency among these photos. Due to the large amount of photos taken for non-destructive inspection,

this report does not include all non-destructive photos taken of the test vehicles. To request the entire set of photos taken for non-destructive inspection, please contact the author of this report.

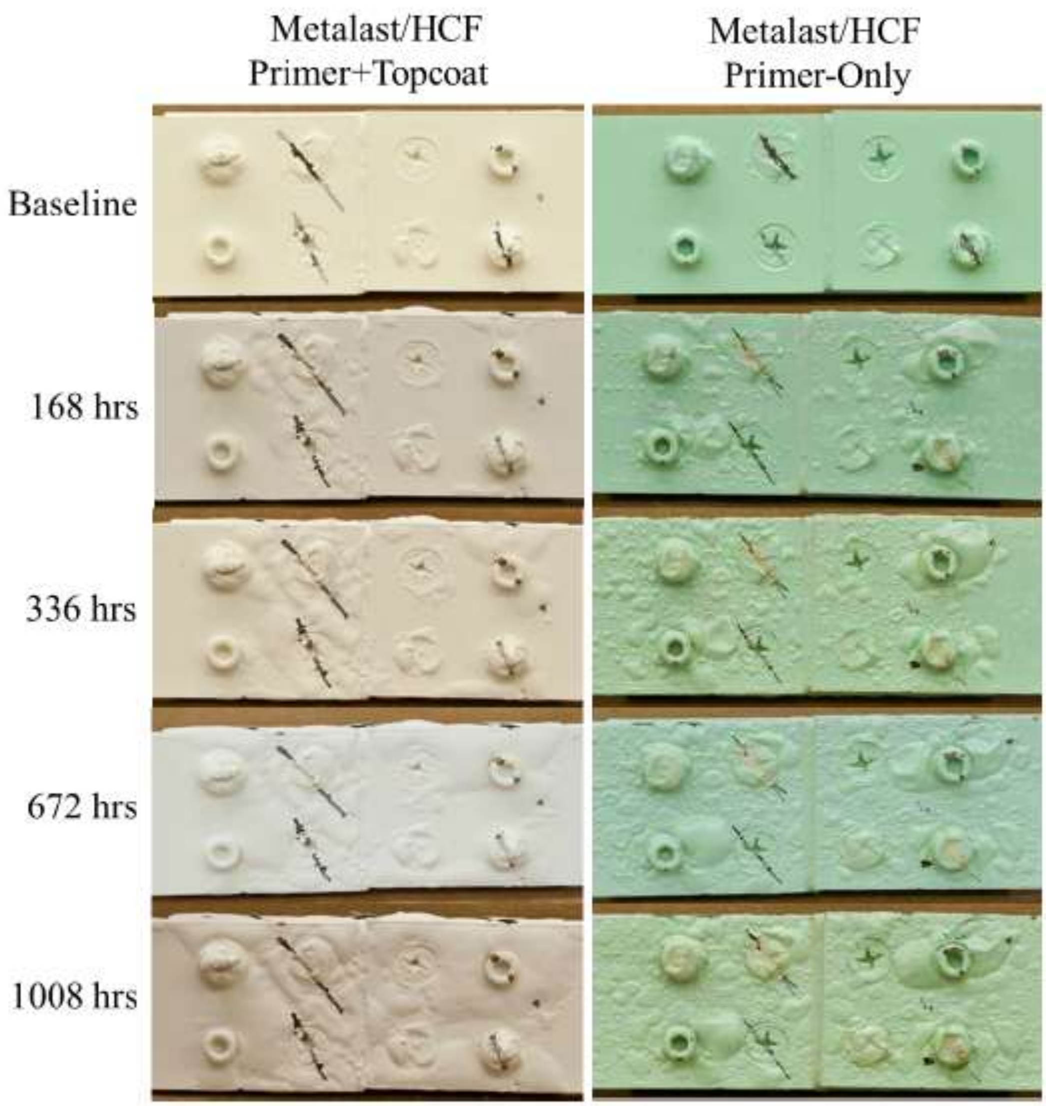


FIGURE 6.1.1 NON-DESTRUCTIVE INSPECTIONS OF 6061-T6 TEST VEHICLES WITH PR-1775

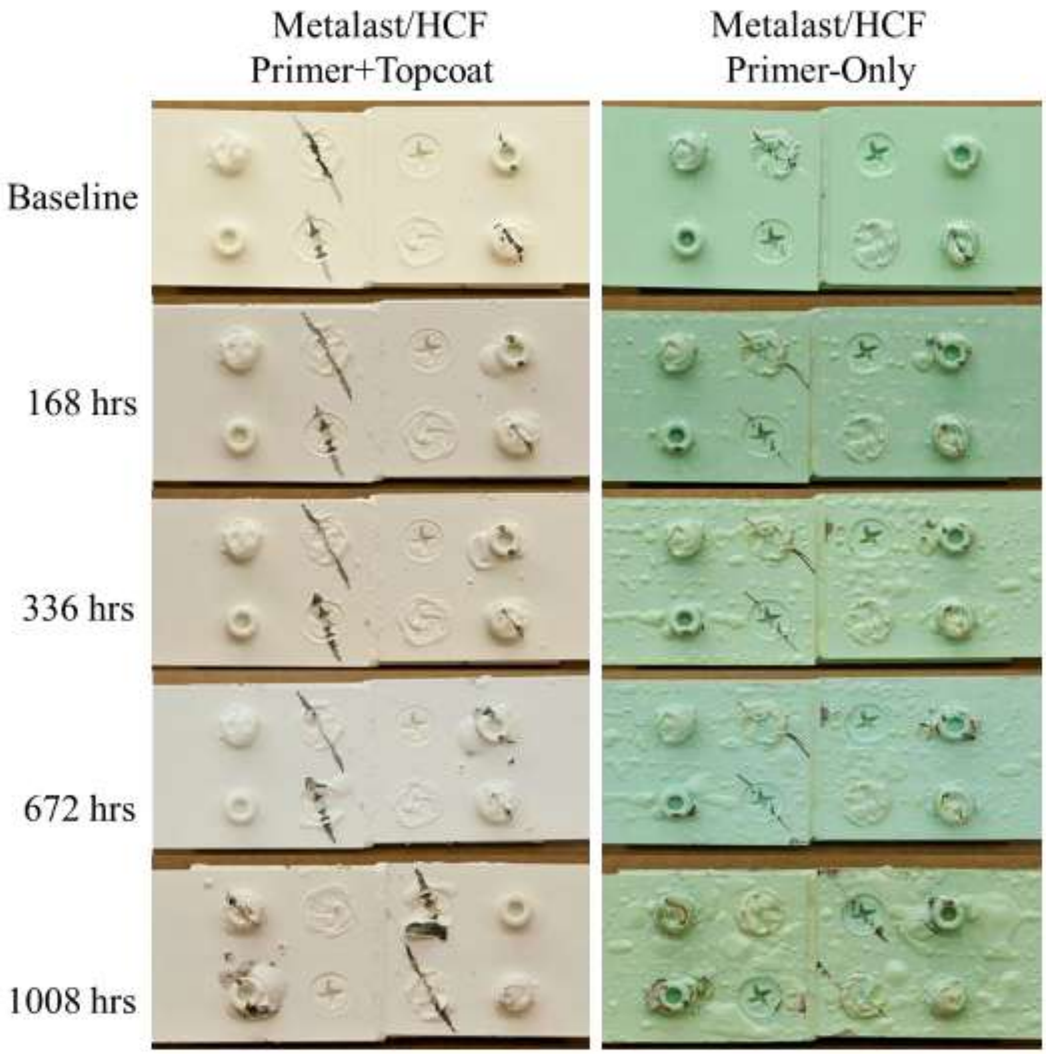


FIGURE 6.1.2 NON-DESTRUCTIVE INSPECTIONS OF 7075-T6 TEST VEHICLES WITH PR-1775

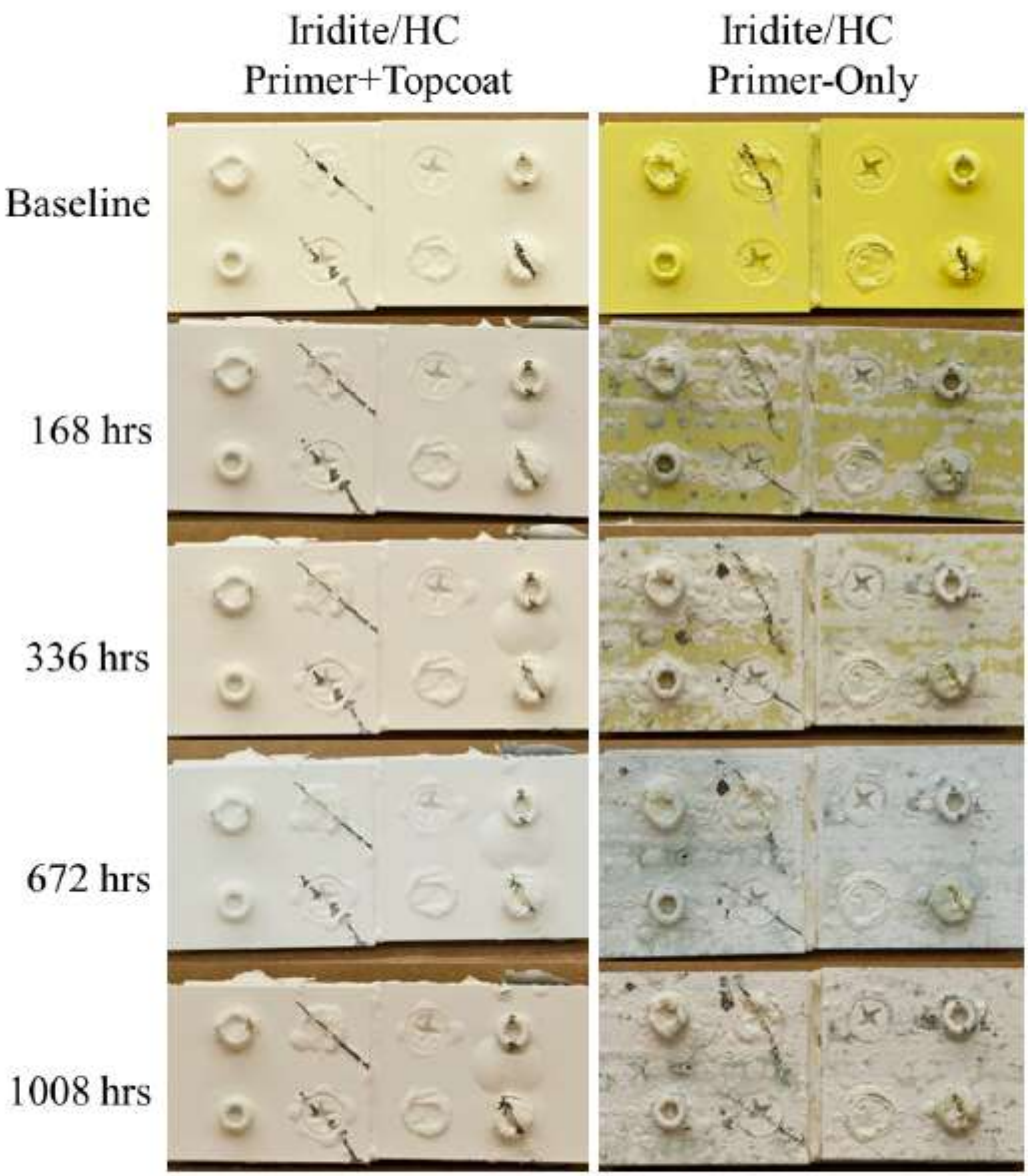


FIGURE 6.1.3 NON-DESTRUCTIVE INSPECTION OF 7075-T6 TEST VEHICLES WITH PR-1775

6.2. Destructive Inspection Results

Table 6.2.1 presents the results and rankings for destructive inspections of all test vehicles exposed to SO_2 salt fog.

TABLE 6.2.1 DESTRUCTIVE INSPECTION RESULTS

Sealant	Conversion Coating	Primer (P) / Topcoat (T)	Test Vehicle	# Hours of Salt Fog Completed	Fastener Hole #1 (Barrel Area)	Fastener Hole #2 (Barrel Area)	Fastener Hole #3 (Barrel Area)	Fastener Hole #4 (Barrel Area)	Fastener Hole #5 (Barrel Area)	Fastener Hole #6 (Barrel Area)	Fastener Hole #7 (Barrel Area)	Fastener Hole #8 (Barrel Area)	Countersink Fastener Hole #1 (countersink area)	Countersink Fastener Hole #2 (countersink area)	Countersink Fastener Hole #3 (countersink area)	Countersink Fastener Hole #4 (countersink area)	Butt Joint (scribe)	Butt Joint (Sides)	Faying Surface
6061 with HCF Primers ↓																			
PS-870	Irridite	P + T	1	1008 hrs	0	0	0	0	0	0	0	0	4	1	3	0	1	0	1
PS-870	Irridite	P	2	1008 hrs	0	0	0	0	0	0	0	0	1	1	1	0	0	0	1
AC-735	Metalast	P + T	3	1008 hrs	0	0	0	3	0	0	0	0	0	2	2	0	5	5	5
AC-735	Metalast	P	4	1008 hrs	0	0	0	0	0	0	0	0	0	10	4	0	4	2	1
AC-735	Irridite	P + T	5	1008 hrs	0	0	0	0	0	0	0	0	1	0	3	0	1	2	1
AC-735	Irridite	P + T	6	1008 hrs	0	0	0	0	0	0	0	0	1	0	10	0	1	0	1
PR-1775	Metalast	P + T	7	1008 hrs	0	0	0	0	0	0	0	0	1	0	6	0	1	2	1
PR-1775	Metalast	P	8	1008 hrs	0	0	0	0	0	0	0	0	0	0	2	0	1	0	1
PR-1775	Irridite	P + T	9	1008 hrs	0	0	0	0	0	0	0	0	2	0	2	0	1	0	2
PR-1775	Irridite	P	10	1008 hrs	0	0	0	0	0	0	0	0	4	1	1	1	1	0	1
PR-2001	Metalast	P + T	11	1008 hrs	0	0	0	0	0	0	0	0	0	1	3	0	10	30	15
PR-2001	Metalast	P	12	1008 hrs	0	0	0	0	0	0	0	0	0	1	1	0	2	5	7
PR-2001	Irridite	P + T	13	1008 hrs	0	0	0	0	0	0	0	0	0	2	5	0	3	5	5
PR-2001	Irridite	P	14	1008 hrs	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2
7075 with HCF Primers ↓																			
PS-870	Irridite	P + T	15	1008 hrs	0	0	0	0	0	0	0	0	80	35	80	0	0	2	1
PS-870	Irridite	P	16	1008 hrs	0	0	0	0	0	0	0	0	50	50	50	40	2	6	2
AC-735	Metalast	P + T	17	1008 hrs	0	30	15	0	20	33	7	5	90	95	100	75	60	90	60
AC-735	Metalast	P	18	1008 hrs	80	70	80	60	10	40	45	40	90	90	60	90	85	80	75
AC-735	Irridite	P + T	19	1008 hrs	0	3	0	0	0	0	0	0	80	50	85	0	0	4	1
AC-735	Irridite	P	20	1008 hrs	0	0	0	0	0	0	0	0	80	80	95	75	0	5	1
PR-1775	Metalast	P + T	21	1008 hrs	0	0	0	0	0	0	0	0	60	35	60	30	2	50	3
PR-1775	Metalast	P	22	1008 hrs	0	0	0	0	0	0	0	0	50	40	45	60	25	85	6
PR-1775	Irridite	P + T	23	1008 hrs	0	0	0	0	0	0	0	0	40	30	30	0	0	4	1
PR-1775	Irridite	P	24	1008 hrs	0	0	0	0	0	0	0	0	40	40	40	25	2	3	2
PR-2001	Metalast	P + T	25	1008 hrs	0	0	0	0	0	0	0	0	35	40	40	30	20	65	20
PR-2001	Metalast	P	26	1008 hrs	30	15	55	25	50	90	40	50	70	90	90	70	90	95	90
PR-2001	Irridite	P + T	27	1008 hrs	0	0	0	0	0	0	0	0	80	15	55	0	1	15	1
PR-2001	Irridite	P	28	1008 hrs	0	0	0	0	6	0	0	0	90	80	80	65	1	4	3
7075 with HC Primers ↓																			
PS-870	Irridite	P + T	29	1008 hrs	0	0	0	0	0	0	0	0	20	15	15	0	1	2	1
PS-870	Irridite	P	30	1008 hrs	0	0	0	0	2	10	0	0	85	85	75	85	3	7	3
AC-735	Irridite	P + T	31	1008 hrs	0	0	0	0	0	0	0	0	90	90	90	0	1	3	1
AC-735	Irridite	P	32	1008 hrs	0	0	0	0	0	0	0	0	90	90	90	85	0	2	2
PR-1775	Irridite	P + T	33	1008 hrs	0	0	0	0	0	0	0	0	40	20	25	0	1	2	2
PR-1775	Irridite	P	34	1008 hrs	0	0	0	0	0	0	0	0	35	25	20	8	1	5	1
PR-2001	Irridite	P + T	35	1008 hrs	0	0	0	0	0	0	0	0	65	50	60	0	2	5	4
PR-2001	Irridite	P	36	1008 hrs	0	0	0	0	0	0	0	0	80	80	85	75	1	5	3
7075 with HCF Primers ↓																			
PS-870	Irridite	P	37	336 hrs	0	0	0	0	0	0	0	0	15	33	33	4	0	2	1
AC-735	Metalast	P	38	336 hrs	0	0	0	3	1	0	0	3	45	40	45	55	20	20	15
PR-1775	Metalast	P	39	336 hrs	0	0	0	0	0	0	0	0	30	25	30	15	3	15	4
PR-2001	Metalast	P	40	336 hrs	0	0	0	5	0	0	0	0	40	45	30	0	8	15	20
7075 with HCF Primers ↓																			
PS-870	Irridite	P	41	672 hrs	0	0	0	5	0	0	0	0	50	55	60	35	2	5	3
AC-735	Metalast	P	42	672 hrs	20	33	60	10	5	35	5	0	100	100	100	80	2	75	44
PR-1775	Metalast	P	43	672 hrs	0	0	0	0	0	0	0	0	50	40	35	40	20	75	20
PR-2001	Metalast	P	44	672 hrs	35	8	12	50	30	5	5	8	40	40	40	40	60	80	70

After rating each area, it was necessary to determine how to best analyze the data to determine sealant performance. Therefore, two categories from the areas of interest were created to analyze the ratings of the test vehicles, Butt Joints and Faying Surfaces, and Countersink Areas. The Butt Joints and Faying Surfaces category summed up all the rankings from the Faying Surfaces in Table 5.2.3.2.1, and the Countersink Areas category summed up all the rankings from the Countersink Areas in Table 5.2.3.2.1. The summations were ranked from least to greatest to determine sealant performance for each category.

The test vehicles were divided into four categories, 6061-T6 aluminum alloy with hex-chrome free (HCF) primer, 7075-T6 aluminum alloy with HCF primer, 7075-T6 aluminum alloy with hex-chrome (HC) primer, and the interim test vehicles that were grouped to provide progression of corrosion with time information. For each of these categories, there were two test vehicles for each sealant and conversion coating combination: one test vehicle with primer-only and one test vehicle with primer and topcoat. The rankings for both the primer-only and primer and topcoat test vehicles were summed to provide one ranking for each sealant and conversion coating combination.

After dividing the ratings into two groups and the test vehicles into four groups, a total of 8 tables were created to analyze the destructive inspection results. Table 6.2.2 presents the data analysis of the destructive inspection results for test vehicles that completed 1008 hours of SO_2 salt fog exposure.

TABLE 6.2.2 DATA ANALYSIS OF DESTRUCTIVE INSPECTION OF TEST VEHCILES THAT COMPLETED 1008 HOURS OF EXPOSURE TO SO_2 SALT FOG

Butt Joints and Faying Surfaces (TVs 1-14)			
6061 with HCF Primer			
Ranking	Sealant	Surf. Prep.	Corrosion
1	PS-870	Iridite	3
	PR-1775	Iridite	5
	PR-1775	Metalast	6
	AC-735	Iridite	6
5	PR-2001	Iridite	16
6	AC-735	Metalast	22
7	PR-2001	Metalast	69

Countersink Areas (TVs 1-14)			
6061 with HCF Primer			
Ranking	Sealant	Surf. Prep.	Corrosion
1	PR-2001	Metalast	6
	PR-2001	Iridite	8
	PR-1775	Metalast	9
4	PR-1775	Iridite	11
	PS-870	Iridite	11
6	AC-735	Iridite	15
7	AC-735	Metalast	18

Butt Joints and Faying Surfaces (TVs 15-28)			
7075 with HCF Primer			
Ranking	Sealant	Surf. Prep.	Corrosion
1	AC-735	Iridite	11
	PR-1775	Iridite	12
	PS-870	Iridite	13
4	PR-2001	Iridite	25
5	PR-1775	Metalast	171
6	PR-2001	Metalast	380
7	AC-735	Metalast	450

Countersink Areas (TVs 15-28)			
7075 with HCF Primer			
Ranking	Sealant	Surf. Prep.	Corrosion
1	PR-1775	Iridite	245
2	PR-1775	Metalast	380
	PS-870	Iridite	385
4	PR-2001	Metalast	465
	PR-2001	Iridite	465
6	AC-735	Iridite	545
7	AC-735	Metalast	690

Butt Joints and Faying Surfaces (TVs 29-36)			
7075 with HC Primer			
Ranking	Sealant	Surf. Prep.	Corrosion
1	AC-735	Iridite	9
2	PR-1775	Iridite	12
3	PS-870	Iridite	17
4	PR-2001	Iridite	20

Countersink Areas (TVs 29-36)			
7075 with HC Primer			
Ranking	Sealant	Surf. Prep.	Corrosion
1	PR-1775	Iridite	173
2	PS-870	Iridite	380
3	PR-2001	Iridite	495
4	AC-735	Iridite	625

Figures 6.2.1 through 6.2.9 illustrate the destructed test vehicles that completed 1008 hours exposure to SO_2 salt fog.

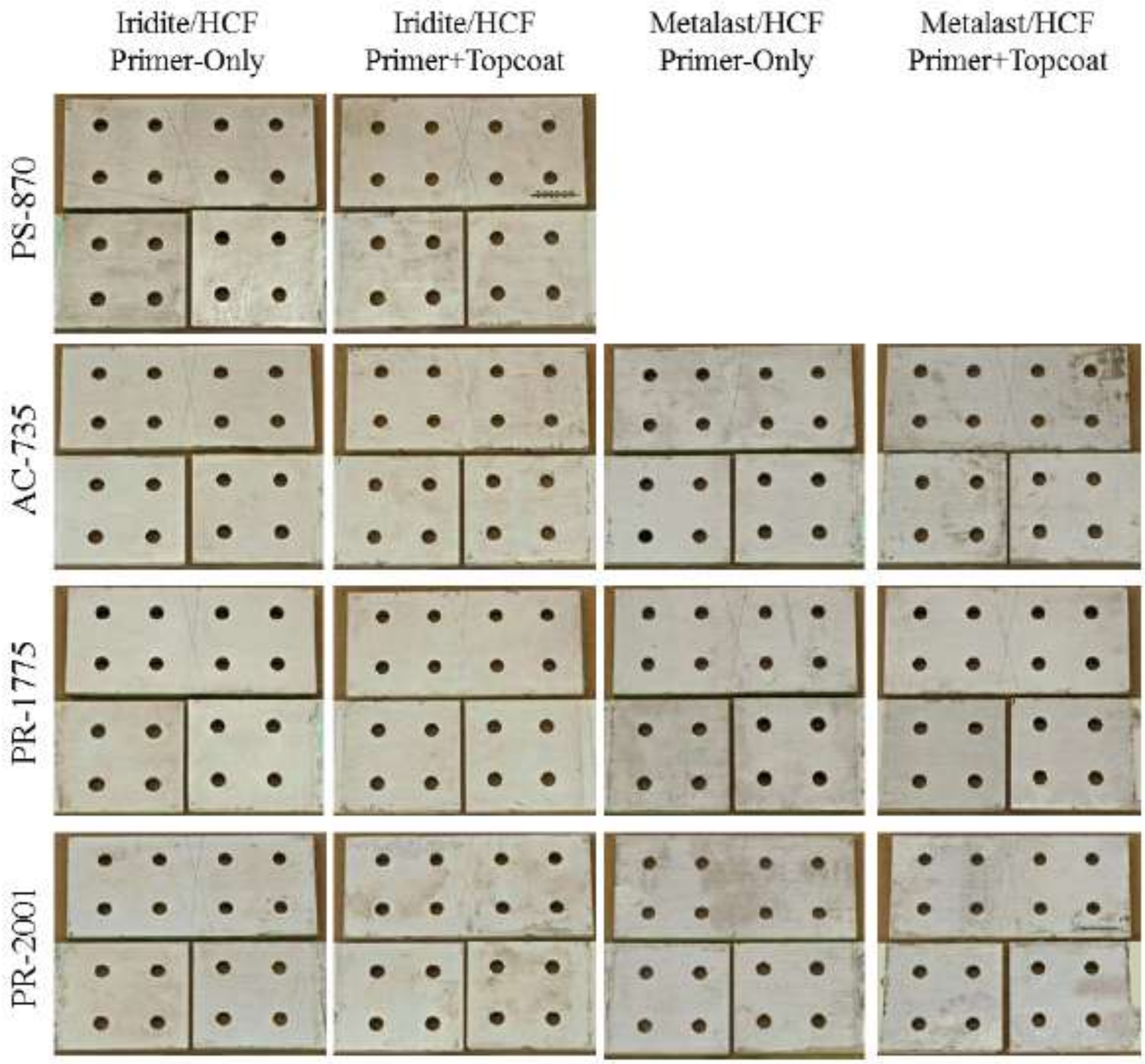


FIGURE 6.2.1 6061-T6 TEST VEHICLE FAYING SURFACES AFTER 1008 HOURS OF EXPOSURE TO SO_2 SALT FOG

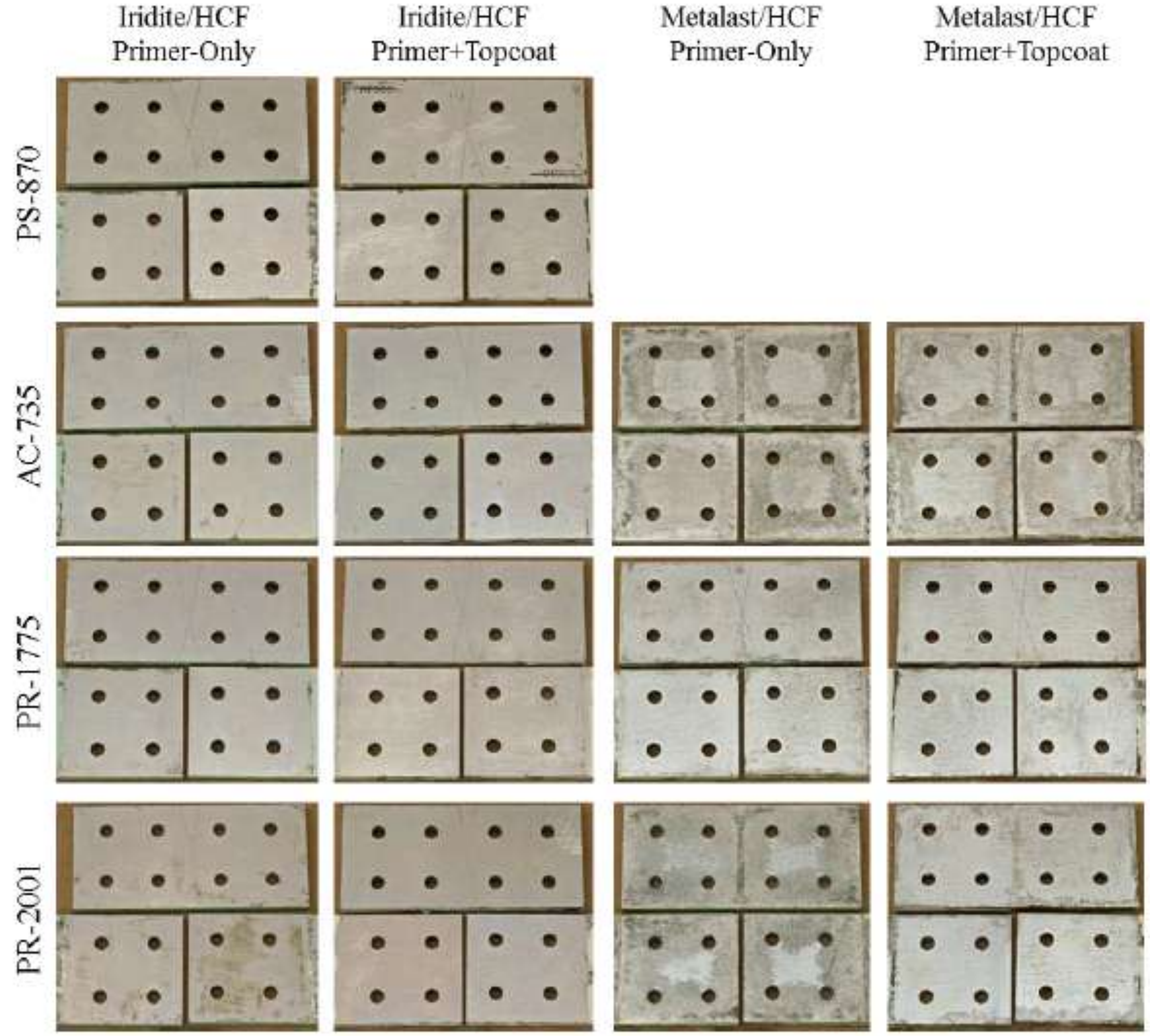


FIGURE 6.2.2 7075-T6 (HCF PRIMER) TEST VEHICLE FAYING SURFACES AFTER 1008 HOURS OF EXPOSURE TO SO_2 SALT FOG

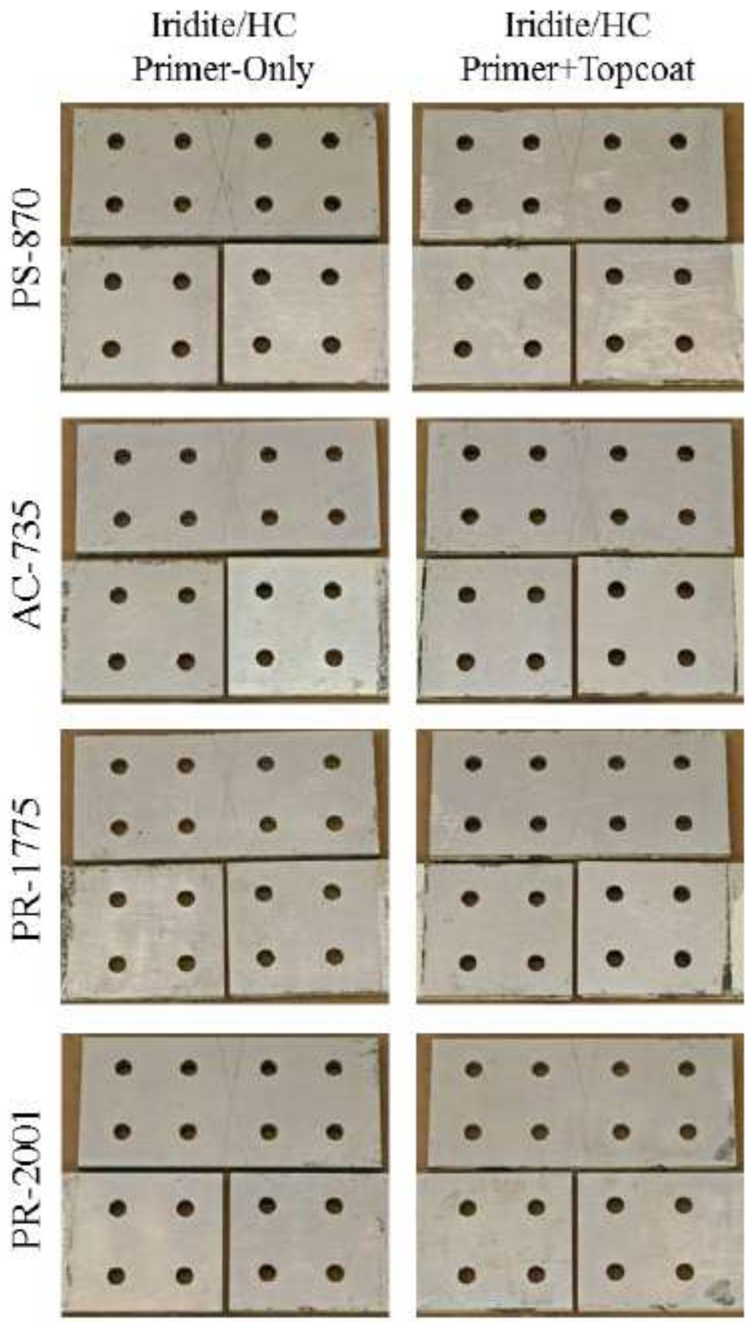


FIGURE 6.2.3 7075-T6 (HC PRIMERS) TEST VEHICLE FAYING SURFACES AFTER 1008 HOURS OF EXPOSURE TO SO_2 SALT FOG

FIGURE 6.2.4 6061-T6 TEST VEHICLE BUTT JOINTS AFTER 1008 HOURS OF EXPOSURE TO SO_2 SALT FOG

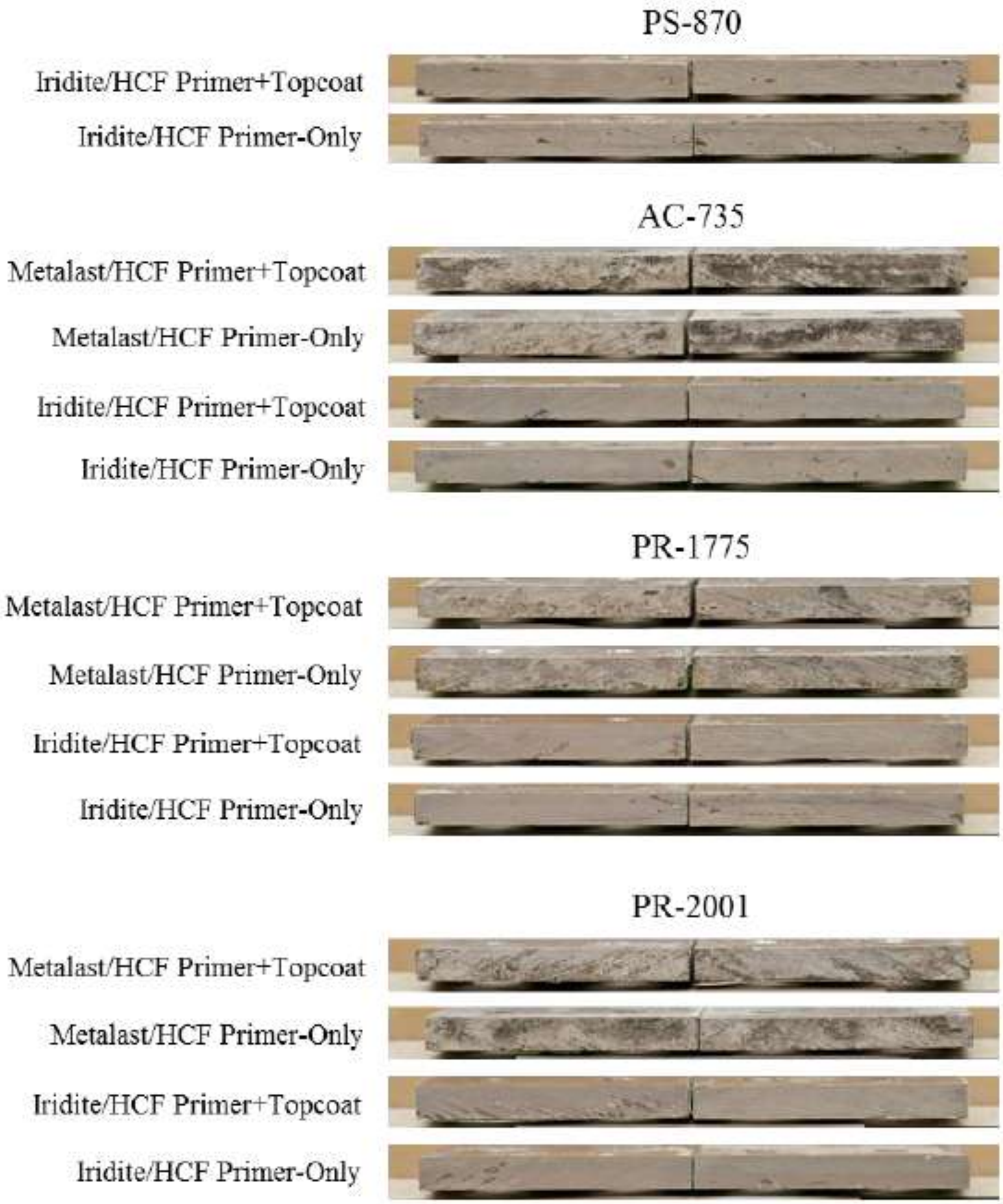


FIGURE 6.2.5 7075-T6 (HCF PRIMERS) TEST VEHICLE BUTT JOINTS AFTER 1008 HOURS OF EXPOSURE TO SO_2 SALT FOG

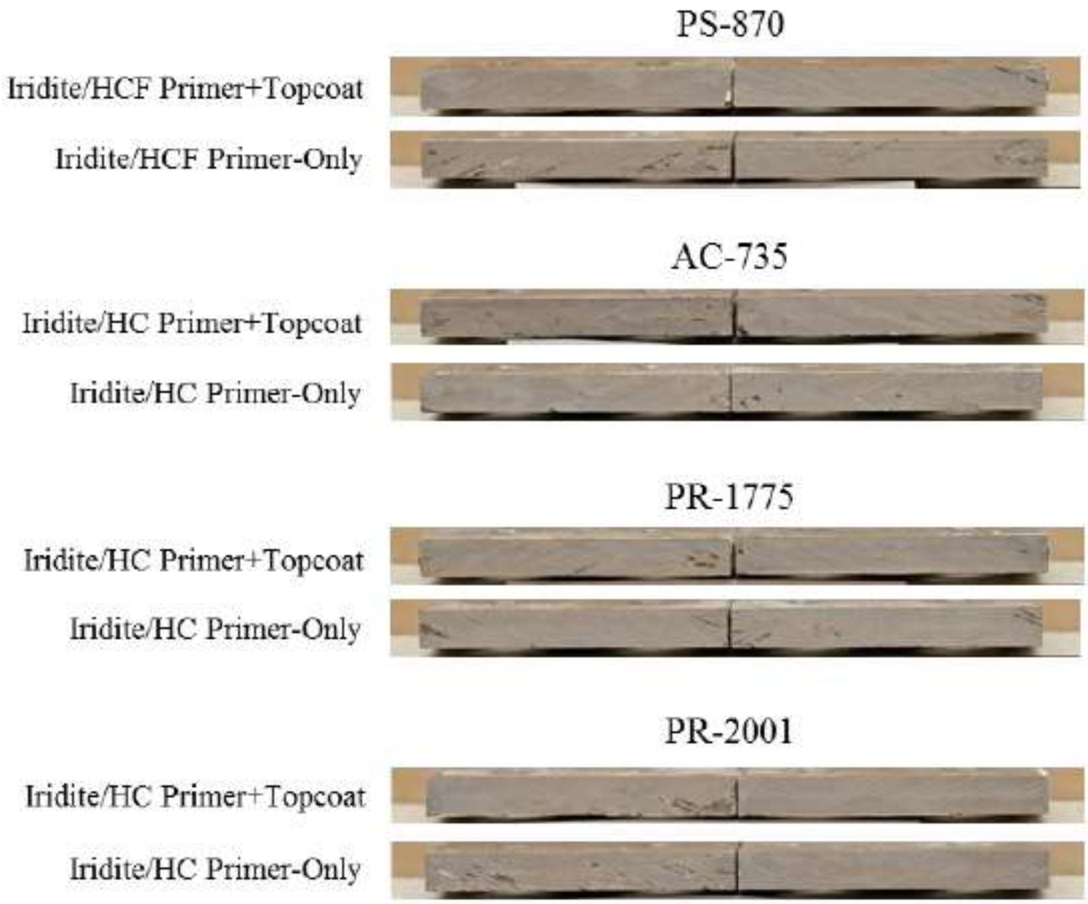


FIGURE 6.2.6 7075-T6 (HC PRIMERS) TEST VEHICLE BUTT JOINTS AFTER 1008 HOURS OF EXPOSURE TO SO_2 SALT FOG

FIGURE 6.2.7 6061-T6 TEST VEHICLE COUNTERSINK AREAS AFTER 1008 HOURS OF EXPOSURE TO SO2 SALT FOG

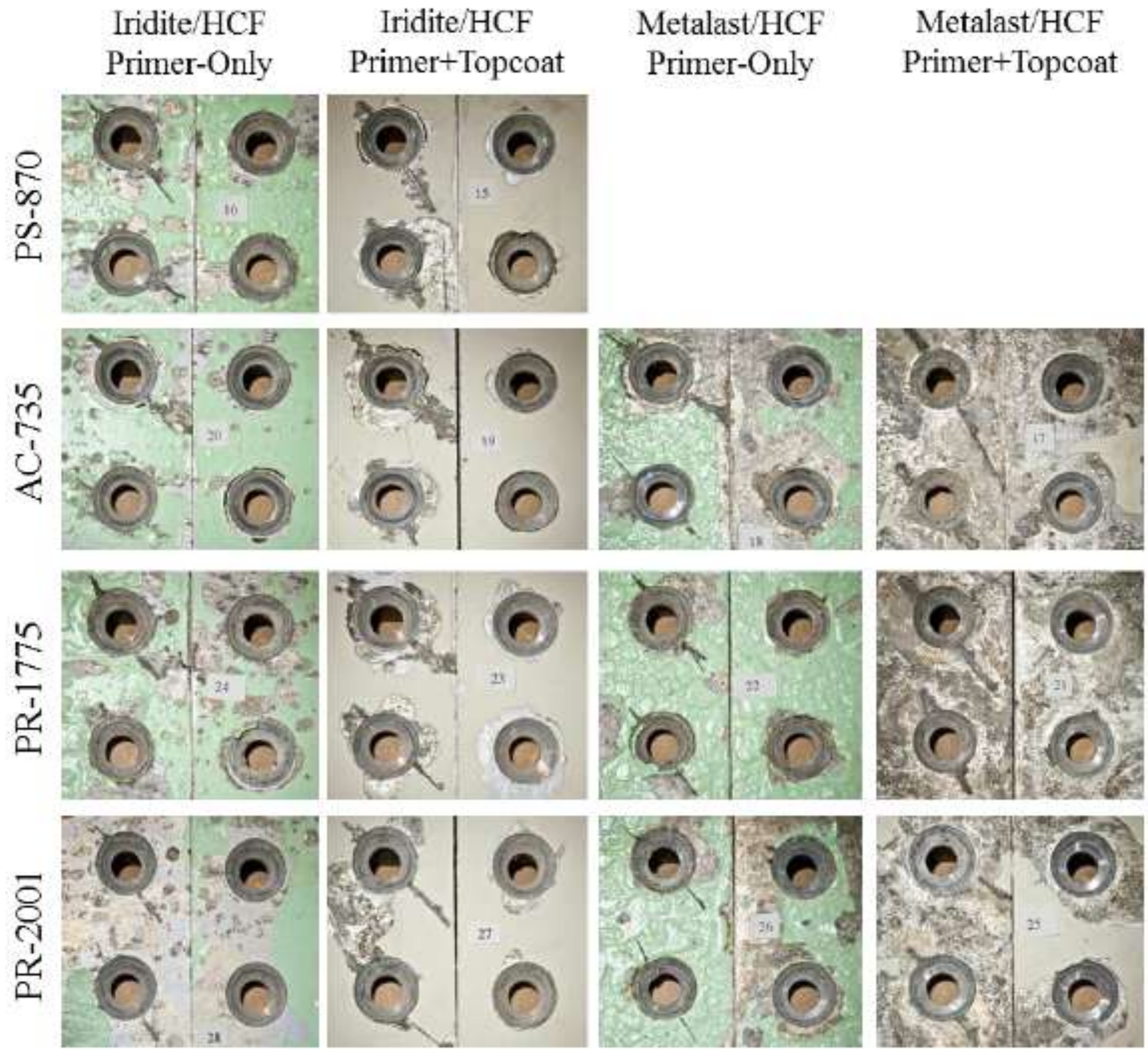


FIGURE 6.2.8 7075-T6 (HCF PRIMERS) TEST VEHICLE COUNTERSINK AREAS AFTER 1008 HOURS OF EXPOSURE TO SO2 SALT FOG

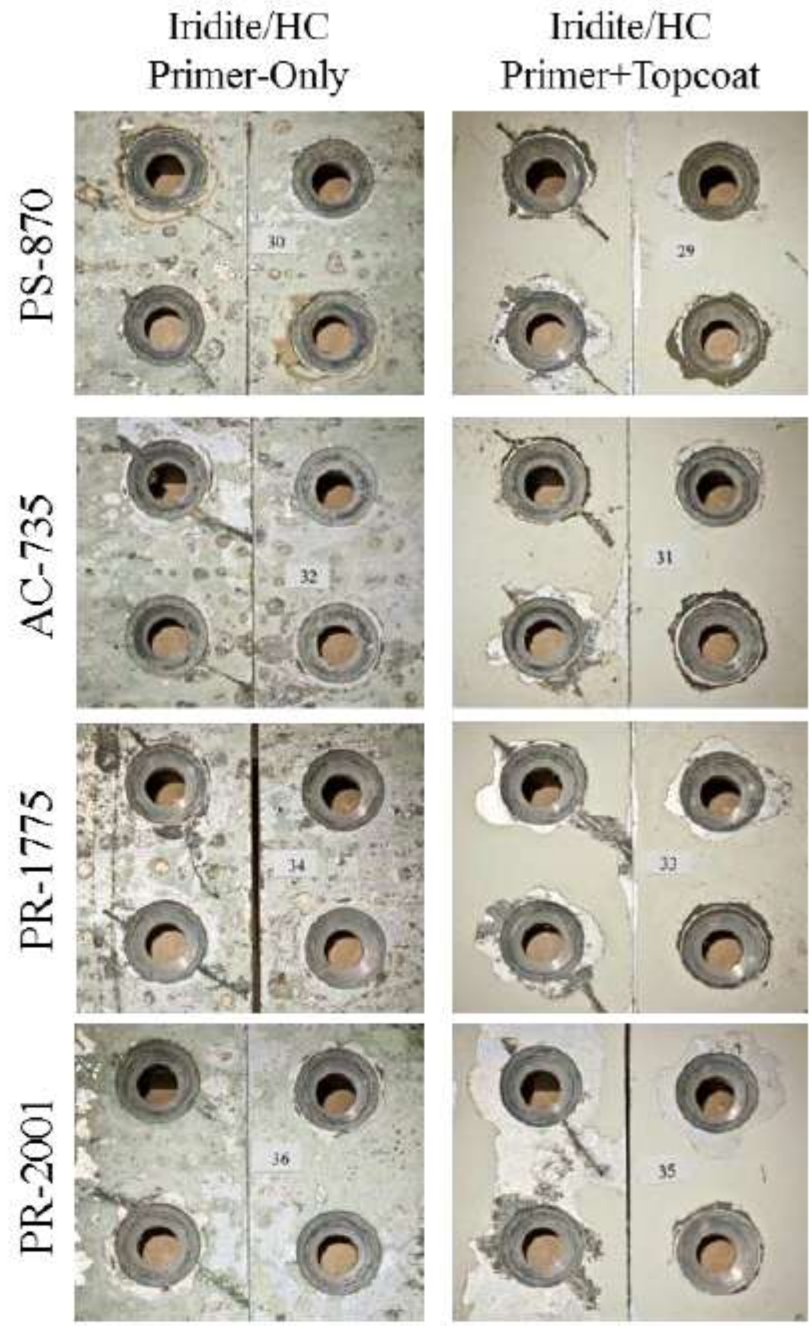


FIGURE 6.2.9 7075-T6 (HC PRIMERS) TEST VEHICLE COUNTERSINK AREAS AFTER 1008 HOURS OF EXPOSURE TO SO2 SALT FOG

Test vehicles that underwent destructive inspection at intervals of 336 and 672 hours of the exposure to so2 salt fog provided data regarding progression of corrosion over time. Table 6.2.3 provides the progression of corrosion over time in the butt joints and faying surfaces of the interim test vehicles.

TABLE 6.2.3 PROGRESSION OF CORROSION IN THE BUTT JOINTS AND FAYING SURFACE

Corrosion Progression in Butt Joints and Faying Surfaces				
Time (hrs)	PS-870 / Iridite / HCF Primer / 7075-T6	PR-1775 / Metalast / HCF Primer / 7075-T6	AC-735 / Metalast / HCF Primer / 7075-T6	PR-2001 / Metalast / HCF Primer / 7075-T6
0	0	0	0	0
336	3	22	55	43
672	10	115	121	210
1008	10	116	240	275

Figure 6.2.10 provides a chart to track the progression of corrosion over time in the butt joints and faying surfaces of the interim test vehicles. It should be noted that the lines between the data points were inserted to make it easier to follow the data for each sealant and are not the result of a regression analysis.

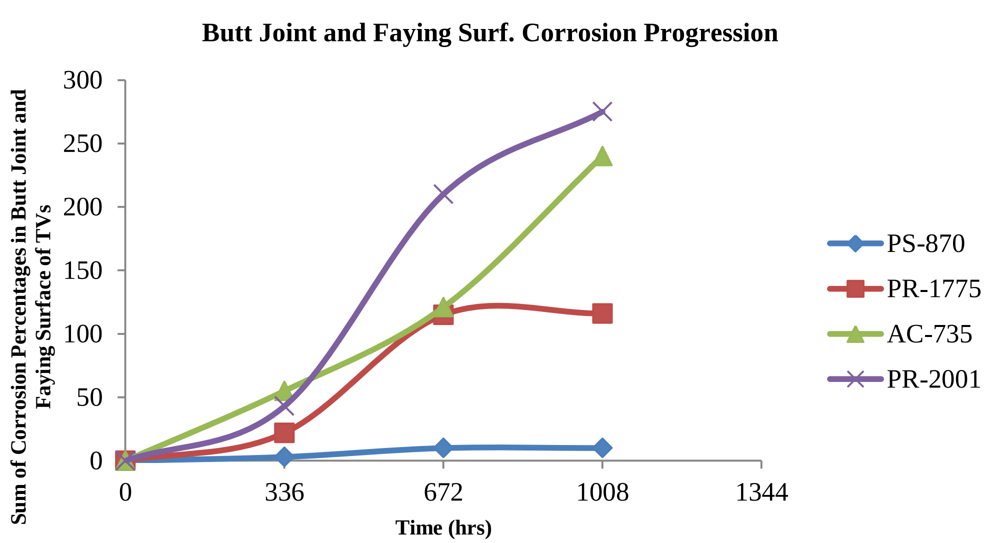


FIGURE 6.2.10 PROGRESSION OF CORROSION IN THE BUTT JOINTS AND FAYING SURFACE

Figures 6.2.11 and 6.2.12 show the faying surfaces and butt joints of the interim test vehicles, respectively.

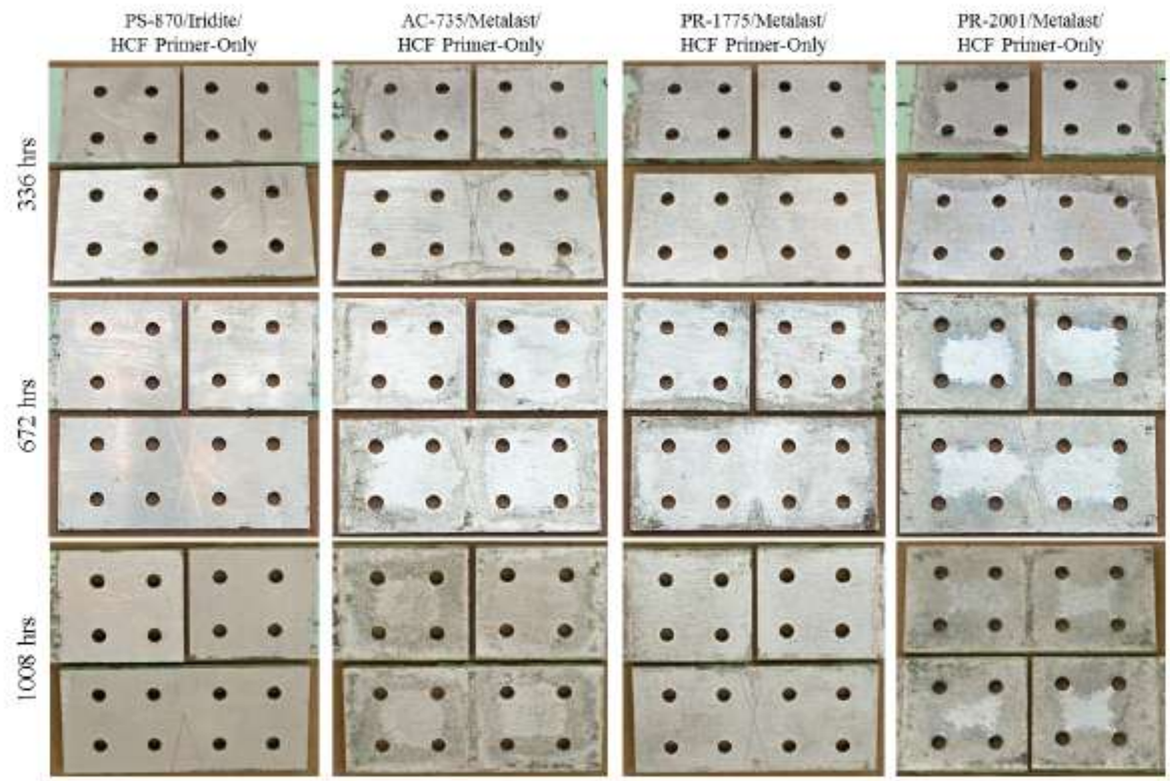


FIGURE 6.2.11 FAYING SURFACES OF 7075-T6 INTERIM TEST VEHICLES AFTER DESTRUCTION

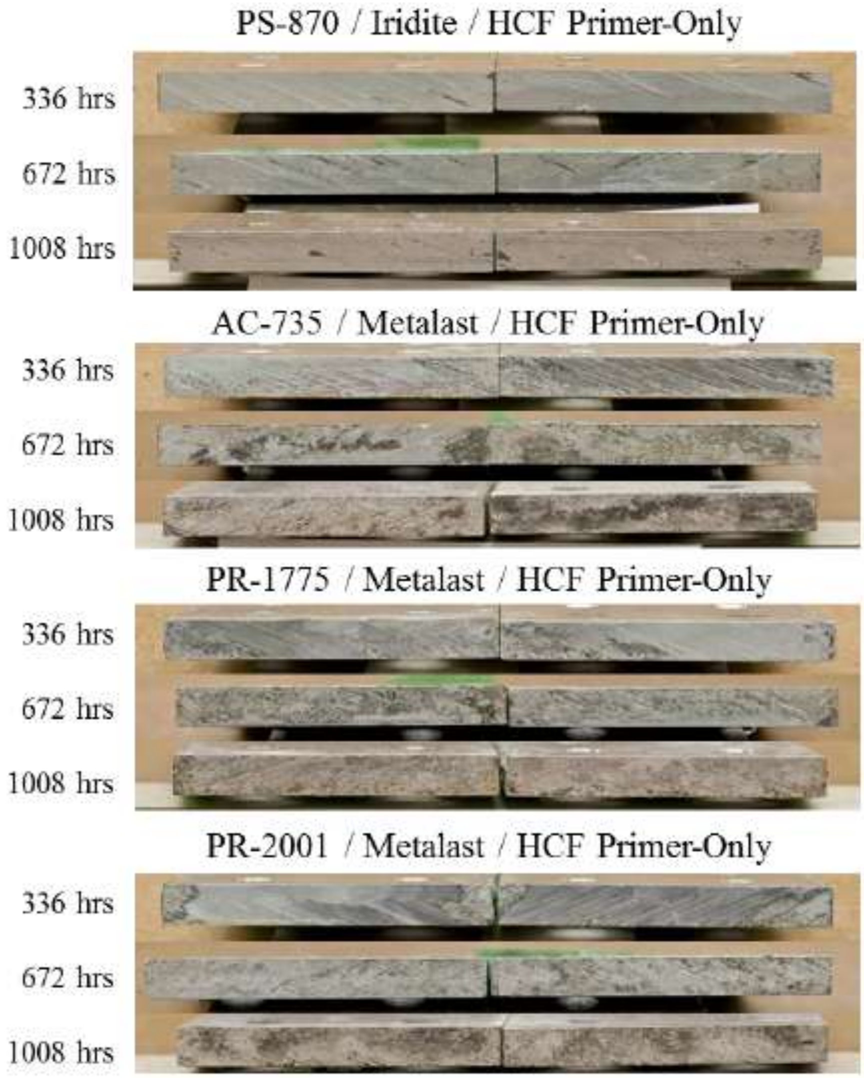


FIGURE 6.2.12 BUTT JOINTS OF 7075-T6 INTERIM TEST VEHICLES AFTER DESTRUCTION

Table 6.2.4 provides the progression of corrosion over time in the butt joints and faying surfaces of the interim test vehicles.

TABLE 6.2.5 PROGRESSION OF CORROSION IN THE COUNTERSINK AREAS ONLY

Corrosion Progression in the Countersink Areas				
Time (hrs)	PS-870 / Iridite / HCF Primer / 7075-T6	PR-1775 / Metalast / HCF Primer / 7075-T6	AC-735 / Metalast / HCF Primer / 7075-T6	PR-2001 / Metalast / HCF Primer / 7075-T6
0	0	0	0	0
336	85	100	185	115
672	200	165	380	160
1008	190	195	330	320

Figure 6.2.13 provides a chart to track the progression of corrosion over time in the countersink areas of the interim test vehicles. It should be noted that the lines between the data points were inserted to make it easier to follow the data for each sealant and are not the result of a regression analysis.

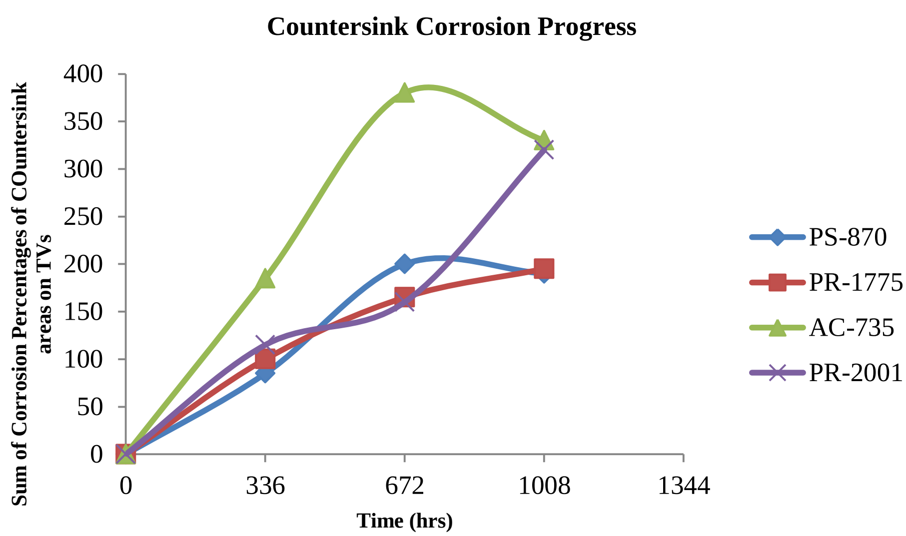


FIGURE 6.2.13 PROGRESSION OF CORROSION IN THE COUNTERSINK AREAS ONLY

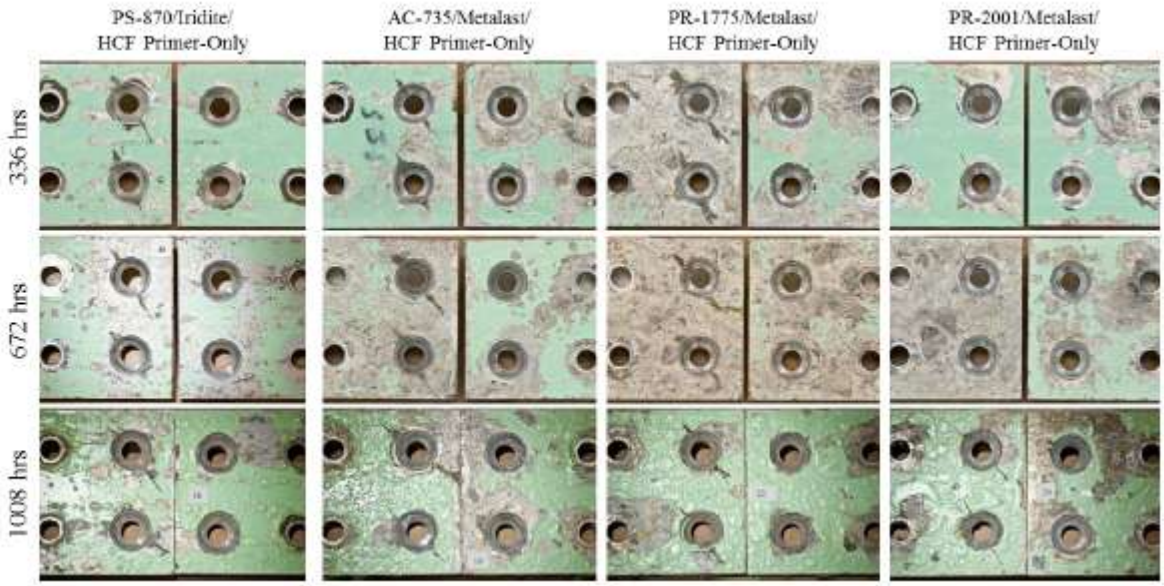


FIGURE 6.2.14 COUNTERSINK HOLES OF 7075-T6 INTERIM TEST VEHICLES AFTER DESTRUCTION

7. CONCLUSIONS

7.1. Non-Destructive Inspection

An important observation was the poor adhesion of the primer to the substrate. The primer seemed to adhere better to the substrate when only primer was used. However, when a topcoat was applied to the primer, the primer adhered much better to the topcoat than to the substrate. On many test vehicles, peeling back of the primer and topcoat was observed near the scribed areas and the areas where grips were attached to apply mechanical cycling. Due to the poor adhesion of the secondary finishes, a greater emphasis of substrate corrosion protection by the conversion coatings, sealants, and metal alloy was observed.

When examining sealant performance, the non-destructive observations proved difficult to determine actual sealant corrosion and moisture inhibition because the sealant-to metal interface could not be observed (i.e. how well the sealant was protecting the area it was sealing off from exposure). The non-destructive ratings were supposed to identify an indicator of the sealant moisture barrier being penetrated. However, the only failures to occur on sealant protected fastener heads for non-destructive observations were on the scribed and countersunk fastener head #7. After examining the ratings and observations of this fastener head during the weeks prior to failure, no common indicator of the moisture barrier being penetrated was found, besides general corrosion on unprotected substrates.

7.2. Destructive Inspection

To determine which sealant performed the best, an analysis of the destructive inspection results was performed and described in Section 6.2 of this report. The ratings provided in the inspection were summed up into two main categories of interest: Butt Joints and Faying Surfaces, and Countersink Areas. Each category provided different information about sealant inhibition. Because of the large amount of surface area that each sealant had to protect for the Butt Joints and Faying Surfaces category, it was regarded as the best indicator of sealant inhibition.

7.2.1. Analysis of Sealant and Conversion Coating Combinations

7.2.1.1. 6061-T6 with Hex-Chrome Free Primers

According to Table 6.2.2, PS-870 with Iridite conversion coating, PR-1775 with Iridite conversion coating, PR-1775 with Metalast conversion coating, and AC- 735 with Iridite conversion coating equally performed as the best combinations for corrosion resistance in the butt joints and faying surfaces. PR-2001 with Iridite conversion coating and AC-735 with Metalast conversion coating were the next best performers. PR-2001 with Metalast conversion coating was the worst performer of this group for providing corrosion resistance in the butt joints and faying surfaces.

According to Table 6.2.2, all sealant and conversion coating combinations provided good corrosion resistance in the countersink areas and performed relatively similar.

7.2.1.2. 7075-T6 with Hex Chrome Free Primer

According to Table 6.2.2, AC-735 with Iridite conversion coating, PR-1775 with Iridite conversion coating, and PS-870 with Iridite conversion coating equally performed as the best combinations for corrosion resistance in the butt joints and faying surfaces. PR-2001 with Iridite conversion coating performed similarly to the first three, but was considered the next best sealant and conversion coating combination. All three sealants paired with Metalast conversion coating performed much worse than the sealants paired with Iridite conversion coating. PR-1775 performed the best of the sealants paired with Metalast conversion coating, followed by PR-2001, followed by AC-735.

According to Table 6.2.2, PR-1775 with Iridite conversion coating was the best combination to provide corrosion resistance in the countersink areas. PR-1775 with Metalast conversion coating and PS-870 with Iridite conversion coating were the next best performers. PR-2001 with Metalast conversion coating and PR-2001 with Iridite conversion coating were the next best performers. PR-2001 protected the countersink areas with the same performance regardless of conversion coating for this group of test vehicles. AC-735 with Iridite conversion coating was the next best performer and AC-735 with Metalast conversion coating was the worst performer in protecting the countersink areas for this group of test vehicles.

7.2.1.3. 7075-T6 with Hex Chrome Primer

According to Table 6.2.2, all sealant and conversion coating combinations provided relatively similar corrosion resistance in the butt joints and faying surfaces.

According to Table 6.2.2, PR-1775 with Iridite conversion coating was the best combination to provide corrosion resistance in the countersink areas. PS-870 with Iridite conversion coating was the next best, followed by PR-2001 with Iridite conversion coating, followed by AC-735 with Iridite conversion coating.

The results of the countersink area ratings for this group of test vehicles match the results of the 7075-T6 test vehicles with hex-chrome free primer. For the purposes of this test, it was concluded that on 7075-T6 aluminum alloy and regardless of Iridite or Metalast conversion coating, PR-1775 is the best sealant to provide corrosion resistance in countersink areas, followed by PS-870, PR-2001, and AC-735.

7.2.1.4. Corrosion Progression

According to Table 6.2.4, PR-1775 with Metalast conversion coating, AC-735 with Metalast conversion coating, and PR-2001 with Metalast conversion coating all provided good corrosion inhibition in the butt joints and faying surfaces for up to two weeks of exposure to SO_2 salt fog. PS-870 with Iridite conversion coating provided good corrosion resistance in the butt joints and faying surfaces for the entire 1008 hours of exposure.

According to Table 6.2.5, none of the sealant and conversion coating combinations provided good corrosion resistance for two weeks of exposure to the SO_2 salt fog in the countersink areas of the test vehicles.

7.2.2. Comparison of Aluminum Alloys

The 6061-T6 aluminum alloy exhibited better corrosion resistance compared to 7075-T6 when similar conversion coatings and sealants were used. This difference in corrosion resistance was especially evident in the countersink areas of the test vehicles.

7.2.3. Comparison of Conversion Coatings

In general, the Iridite 14-2 conversion coating provided better corrosion resistance than the Metalast TCP conversion coating.

7.2.4. Comparison of Secondary Finishes

For similar sealant and conversion coating combinations on 6061-T6 aluminum alloy test vehicles, no major difference was observed between the corrosion resistance of primer-only or primer and topcoated test vehicles.

For similar sealant and conversion coating combinations on 7075-T6 aluminum alloy test vehicles, in general, a primer and topcoat provided more corrosion resistance than a primer-only finish. For the purposes of this test, no difference in corrosion resistance was observed for 7075-T6 test vehicles with hex-chrome free primer-only or hex-chrome primer-only secondary finishes.

Addendum A: Beachfront Corrosion Results

The coupons exposed to a beach environment were manufactured at the same time and manner as those in MPLR-101436 Section 4.5. The coupons discussed here were exposed to a beach environment at the NASA – Beachside Atmospheric Test Facility at Kennedy Space Center, Florida for one year. Table A1 shows the conversion coating and external coating combinations used for these test vehicles.

TABLE A1. TEST VEHICLE DESIGN COMBINATIONS

Test Vehicle Number	Alloy	Sealant	Conversion Coating	Primer/Topcoat	Exposure
45	7075	PS-870	Iridite 14-2	HCF Primer Only	Beachfront
46	7075	AC-735	Metalast TCP	HCF Primer Only	Beachfront
47	7075	PR-1775	Metalast TCP	HCF Primer Only	Beachfront
50	7075	PR-2001	Metalast TCP	HCF Primer Only	Beachfront
49	7075	PS-870	Iridite 14-2	HCF Primer and Topcoat	Beachfront

The nondestructive evaluation of the test vehicles were done similar to MPLR-101436 Paragraph 5.2.1, by providing exterior surface corrosion observations. A summary of the rating scale can be seen in Table A2. Figure A1 shows a cut view of the exterior surfaces around the fasteners that were analyzed, and Table A3 shows the results of the nondestructive evaluation.

TABLE A2. NONDESTRUCTIVE INSPECTION RATING SCALE

Rating	**Test Vehicle Observations**
5	No observable changes.
4.5	Darkening of scribe line.
4	Slight salt build-up of scribe. No evidence of corrosion.
3.5	Slight evidence of substrate pitting or very small amount of corrosion product limited to the scribe.
3	Slight evidence of substrate pitting or very small amount of corrosion product extending beyond scribe.
2	Evidence of substrate pitting or some corrosion product.
1	Extensive substrate pitting or excessive corrosion product.

Test Vehicle 45

Test Vehicle 46

Test Vehicle 47

Test Vehicle 49

Test Vehicle 50

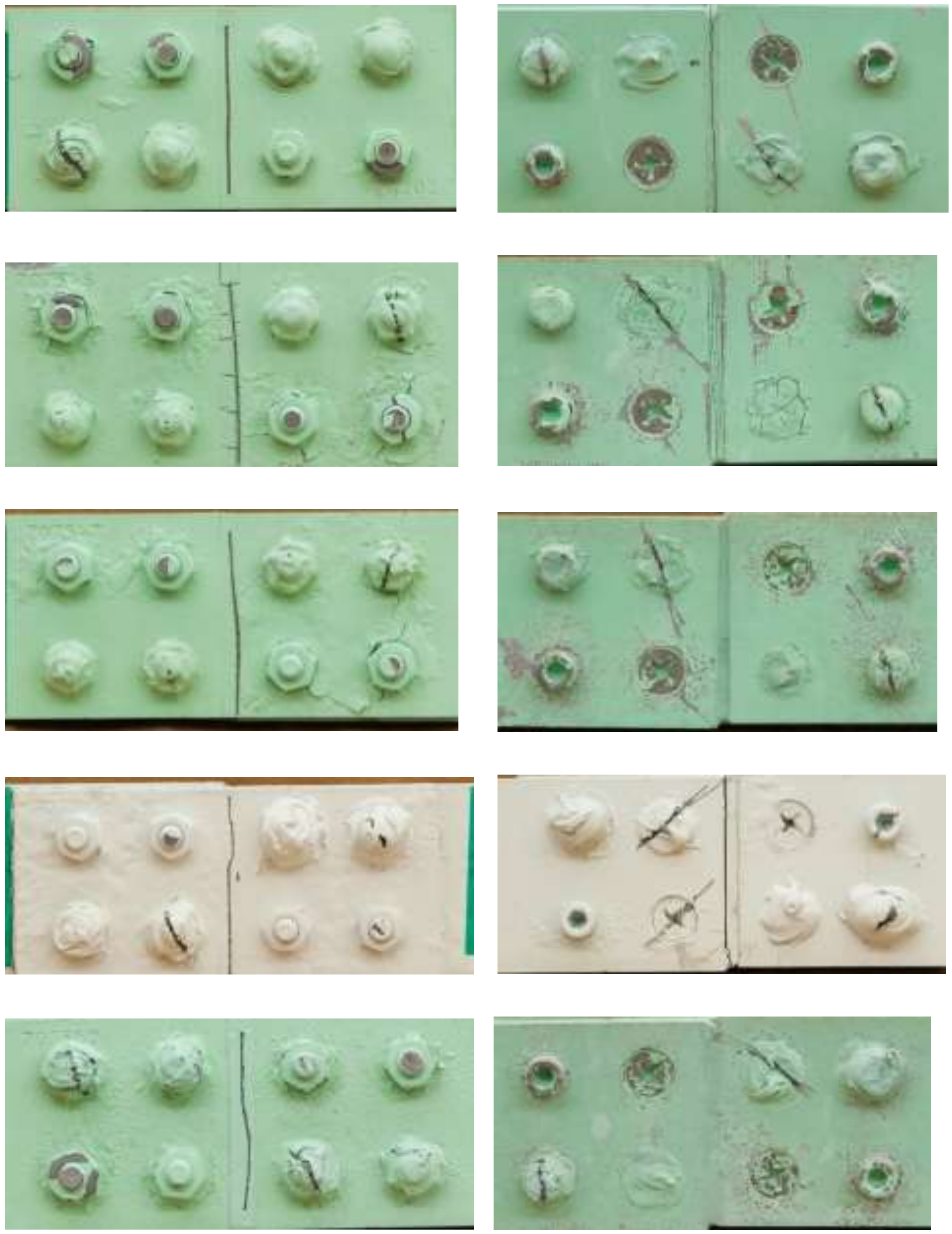


FIGURE A1. SURFACES OF BEACHFRONT COUPONS AFTER EXPORSURE

TABLE A3. NONDESTRUCTIVE RESULTS OF BEACHFRONT COUPONS

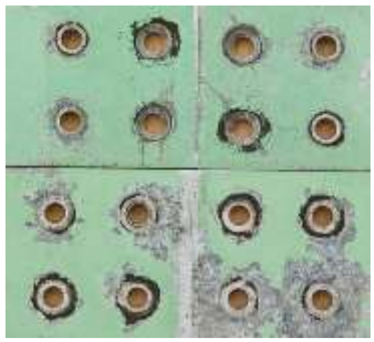
Test Vehicle	Exposure Type	Scribed Socket Head w/Sealant #1	Non-Scribed Recessed Head w/Sealant #2	Scribed Recessed Head No Sealant #3	Non-Scribed Socket Head No Sealant #4	Scribed Socket Head No Sealant #5	Non-Scribed Recessed Head No Sealant #6	Scribed Recessed Head w/Sealant #7	Non-Scribed Socket Head w/Sealant #8	Scribed Nut No Sealant #1	Non-Scribed Nut No Sealant #2	Non-Scribed Nut w/Sealant #3	Non-Scribed Nut w/Sealant #4	Scribed Nut w/Sealant #5	Non-Scribed Nut w/Sealant #6	Non-Scribed Nut No Sealant #7	Non-Scribed Nut No Sealant #8	Scribed Butt Joint	Scribed Side Location #1	Scribed Side Location #2	Scribed Side Location #3	Scribed Side Location #4	Scribed Bottom Plate Surface
45	Beachfront	4	4	4	4	4	4	3	4	4	4	5	5	5	5	4.5	4	4.5	5	5	4.5	4.5	5
46	Beachfront	4	4	4	4	4	4	4	4	3.5	3.5	4	4	4	4	3.5	3.5	3	4.5	4.5	4.5	5	4
47	Beachfront	4	4	3.5	4	4	3.5	3.5	4	3.5	3.5	4	3.5	5	4.5	3.5	3.5	4	5	4.5	4.5	4.5	5
50	Beachfront	4	5	4	4.5	5	3.5	4	5	3.5	3.5	5	4	5	4	4	3.5	3.5	5	5	5	4	5
49	Beachfront	4	4	4	4	4	4	3.5	4	3.5	3.5	4	4	4	3.5	3.5	3.5	4.5	3.5	4	5	5	5

Cracking
Rust
Blistering
Chip
Flaking/Peeling
Rust & Cracking
Rust & Blistering
Rust & Flaking/Peeling
Blistering & Flaking/Peeling
Blistering & Cracking
Blistering & Cracking & Rust
Chip & Cracking

The nondestructive results show that there is only a minor difference between the two types of fasteners used. Also, negligible differences were observed between the fasteners and nuts that had sealant overcoat versus no overcoat, and the fasteners and nuts that were scribed versus unscribed.

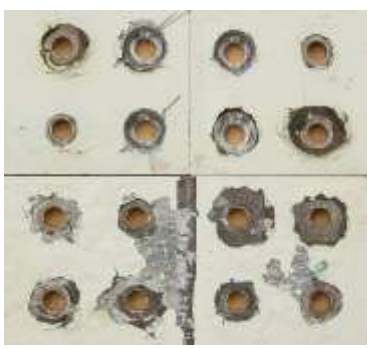
The coupons subjected to beachfront corrosion exposure were disassembled using the Instron and stripped using toluene after their arrival at Lockheed Martin per MPLR-101436 Paragraph 5.2.2. Figures A2 through A4 show views of the coupons after disassembly.

Test Vehicle 45



Test Vehicle 46

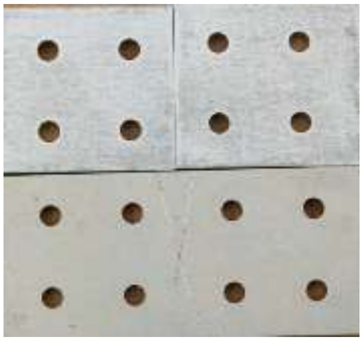
Test Vehicle 47



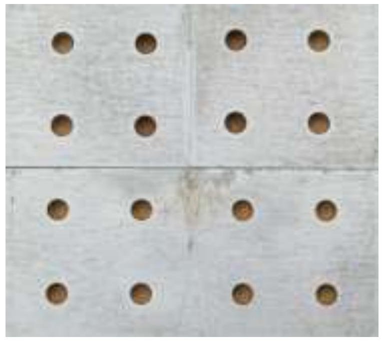
Test Vehicle 49

Test Vehicle 50

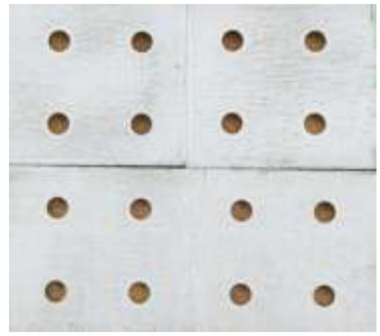
FIGURE A2. TEST VEHICLE EXTERIOR SURFACES POST DISASSEMBLY



Test Vehicle 45

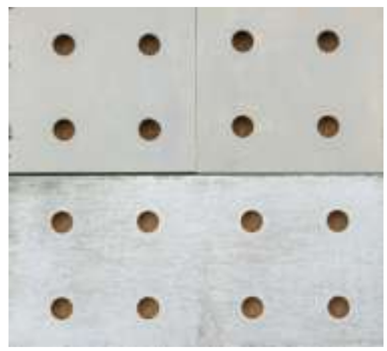


Test Vehicle 46



Test Vehicle 47

Test Vehicle 49



Test Vehicle 50

FIGURE A3. TEST VEHICLE FAYING SURFACES POST DISASSEMBLY

Test Vehicle 45

Test Vehicle 46

Test Vehicle 47

Test Vehicle 49

Test Vehicle 50

FIGURE A4. TEST VEHICLE BUTT JOINT SURFACES POST DISASSEMBLY

For the destructive evaluation, the areas of interest for corrosion observations were the countersink and fastener hole areas, the butt joint and faying surface areas, and the overall test vehicle areas of interest. The test vehicles were examined per Paragraph 5.2.2, which gives each individual area of interest a percent corrosion. The raw data from the beach exposure evaluation are shown in Table A4 along with the intermittent destructive evaluations from the SO_2 salt fog exposure from Table 6.2.1 for comparison purposes.

The countersinks areas were the most vulnerable on each test vehicle and accounted for most of the overall corrosion on all beachfront test vehicles, as seen in Table A4. PS-870 Primer Only and PR-1775 Primer Only test vehicles showed some corrosion within the countersinks, while 3M AC 735 Primer Only, PPG PR-2001, and PS-870 Primer and Topcoat test vehicles corroded much more across all four countersinks.

The faying surfaces across all test vehicles, which is arguably the most important area, showed small amounts of corrosion for all sealants. For the butt joint sides and butt joint scribe areas, the PS-870 Primer Only and PR-1775 Primer Only test vehicles showed minimal corrosion, while AC-735 Primer Only test vehicle had corrosion in the butt scribe and PR-2001 Primer Only and PS-870 Primer and Topcoat test vehicles had corrosion along the butt joint sides.

Overall, the PS-870 Primer Only and PR-1775 Primer Only test vehicles had better corrosion resistance compared to AC-735 Primer Only, PR-2001 Primer Only, and PS-870 Primer and Topcoat test vehicles.

TABLE A4. BEACHFRONT COUPONS COMPARISON

Sealant	Conversion Coating	Primer (P) / Topcoat (T)	Test Vehicle	# Hours of Salt Fog Completed	Fastener Hole #1 (Barrel Area)	Fastener Hole #2 (Barrel Area)	Fastener Hole #3 (Barrel Area)	Fastener Hole #4 (Barrel Area)	Fastener Hole #5 (Barrel Area)	Fastener Hole #6 (Barrel Area)	Fastener Hole #7 (Barrel Area)	Fastener Hole #8 (Barrel Area)	Countersunk Fastener Hole #1 (countersunk area)	Countersunk Fastener Hole #2 (countersunk area)	Countersunk Fastener Hole #3 (countersunk area)	Countersunk Fastener Hole #4 (countersunk area)	Butt Joint (scribe)	Butt Joint (Sides)	Faying Surface
Type of Sealant	7075 with HCF Primers																		
PS 870	Iridite	P	45	Beach	2	0	0	0	0	0	0	0	3	6	13	4	0	1	2
PS-870	Iridite	P	37	336 hrs	0	0	0	0	0	0	0	0	15	33	33	4	0	2	1
PS-870	Iridite	P	41	672 hrs	0	0	0	5	0	0	0	0	50	55	60	35	2	5	3
PS-870	Iridite	P	16	1008 hrs	0	0	0	0	0	0	0	0	50	50	50	40	2	6	2
AC 735	Metalast	P	46	Beach	0	0	0	1	0	0	11	15	24	38	31	27	25	8	7
AC-735	Metalast	P	38	336 hrs	0	0	0	3	1	0	0	3	45	40	45	55	20	20	15
AC-735	Metalast	P	42	672 hrs	20	33	60	10	5	35	5	0	100	100	100	80	2	75	44
AC-735	Metalast	P	18	1008 hrs	80	70	80	60	10	40	45	40	90	90	60	90	85	80	75
PR 1775	Metalast	P	47	Beach	6	0	0	1	0	0	2	0	1	17	19	8	0	2	1
PR-1775	Metalast	P	39	336 hrs	0	0	0	0	0	0	0	0	30	25	30	15	3	15	4
PR-1775	Metalast	P	41	672 hrs	0	0	0	0	0	0	0	0	50	40	35	40	20	75	20
PR-1775	Metalast	P	22	1008 hrs	0	0	0	0	0	0	0	0	50	40	45	60	25	85	6
PR 2001	Metalast	P	50	Beach	0	0	0	0	0	0	0	0	0	58	60	21	2	70	3
PR-2001	Metalast	P	40	336 hrs	0	0	0	3	0	0	0	0	40	45	30	0	8	15	20
PR-2001	Metalast	P	44	672 hrs	15	8	12	30	30	5	5	8	40	40	40	40	60	80	70
PR-2001	Metalast	P	26	1008 hrs	30	15	55	25	30	90	40	50	70	90	90	70	90	95	90
PS 870	Iridite	P + T	49	Beach	0	0	0	0	0	0	0	0	27	42	49	28	1	55	6
PS-870	Iridite	P + T	15	1008 hrs	0	0	0	0	0	0	0	0	80	35	80	0	0	2	1

TABLE A5. DESTRUCTIVE RESULTS OF BEACHFRONT COUPONS COMPARED TO SALT FOG EXPOSURE

Sealant	Conversion Coating	Primer (P) / Topcoat (T)	Test Vehicle	# Hours of Salt Fog Completed	Area of Interest Summary		
					Overall Corrosion	Butt Joints (Side & X) & Faying Surface	Countersinks
PS 870	Iridite	P	45	Beach	0.79	0.5	6.5
PS-870	Iridite	P	37	336 hrs	2.53	1	21.25
PS-870	Iridite	P	41	672 hrs	6.05	3.5	50
PS-870	Iridite	P	16	1008 hrs	5.81	4	47.5
AC 735	Metalast	P	46	Beach	4.88	15.5	30
AC-735	Metalast	P	38	336 hrs	7.16	20	46.25
AC-735	Metalast	P	42	672 hrs	14.47	38.5	95
AC-735	Metalast	P	18	1008 hrs	17.14	82.5	82.5
PR 1775	Metalast	P	47	Beach	1.38	1	11.25
PR-1775	Metalast	P	39	336 hrs	3.70	9	25
PR-1775	Metalast	P	43	672 hrs	9.15	47.5	41.25
PR-1775	Metalast	P	22	1008 hrs	10.71	55	48.75
PR 2001	Metalast	P	50	Beach	7.28	36	34.25
PR-2001	Metalast	P	40	336 hrs	4.36	11.5	28.75
PR-2001	Metalast	P	44	672 hrs	11.11	70	40
PR-2001	Metalast	P	26	1008 hrs	17.78	92.5	80
PS 870	Iridite	P + T	49	Beach	6.79	28	36.5
PS-870	Iridite	P + T	15	1008 hrs	5.68	1	48.75

Note: All coupons were processed with Metalast TCP conversion coating except for the two PS-870 coupons, which used Iridite 14-2. All coupons were made using 7075 aluminum alloy.

Table A5 summarizes the raw test data in Table A4 as a percentage of corroded area. The table compares the areas of interest from the beach exposure test vehicles to the areas of interest from the intermittent destructive test vehicles exposed to SO_2 salt fog per ASTM G85 Annex 4 as percentage of the area of interest corroded. Note that the fastener hole areas were not included in the overall summary of the areas of interest in Table A5 because those areas received such a negligible amount corrosion across all five test vehicles.

Overall, for the beach front exposure test vehicles, PPG PR-1775 Primer Only performed the best of the non-chromated sealants having less than 1.5 % corrosion across all areas of interest, and the second best overall behind PPG PS-870 Primer Only which had less than 1% corrosion. The other non-chromated primers corroded a considerable bit more with AC-735 Primer Only corroding almost 5% on the areas of interest, and PR-2001 Primer Only corroding on more than 7%. PPG PS-870 Primer and

Topcoat did not perform as well as the other PPG PS-870 Primer Only coupon, corroding on more than 6.5 %.

For the conditions of this test, the destructive evaluation of the beach front test vehicles showed comparable performance to the 336 hours samples, as shown in Table A5. PPG PS-870 Primer Only, PPG PR-1775 Primer Only, and 3M AC 735 Primer Only test vehicles performed somewhat better than the 336 hours samples that were subjected to SO_2 salt fog exposure, while PPG PR-2001 Primer Only test vehicle performed slightly worse than its 336 hours SO_2 salt fog counterpart. All test vehicles exposed for 672 hours of SO_2 salt fog had more corrosion than the beachfront exposed test vehicles.

The PS-870 Primer and Topcoat test vehicle had no intermittent destructive test vehicles; however the beachfront test vehicle performed similarly to the 1008 hour SO_2 salt fog exposure test vehicle, except along the butt joint sides which was much more corroded.