Retention of MIL-PRF-23236 Type VI Epoxy under UHS Epoxy

Subcontract Agreement 2017-417

Final Report

Rev A – April 15, 2019

Category B - Data developed partially with funding from project participants that was not charged to a government contract and partially with government funding

Unlimited/Approved for Public Release

Revision History:

Revision No.	Date	Description
Rev -	6/30/18	Initial release
Rev A	4/15/2019	Updated test report & modified distribution statement

1.0 Introduction

The complexity of Navy ship construction results in long build cycles in a marine environment. During shipbuilding, a pre-construction primer (PCP) is typically used to protect steel from corrosion. These primers are generally effective for approximately six months. While such a timeframe is suitable for commercial shipbuilding, Navy ship build cycles often last several years. Lack of adequate protection during that time results in corrosion or coating damage that necessitates costly rework. This project investigates the use of supplemental primers to extend corrosion protection during a longer build cycle.

1.1 Objective

The primary objective of this project was to develop the data needed to request Navy approval to apply UHS epoxy over retained MIL-PRF-23236 Type VI epoxy primer in critically coated areas that ultimately receive MIL-PRF-23236 Type VII high solids epoxy in a two coat or single-coat system. This change will also allow:

- Critically coated areas to be protected from corrosion from initial assembly until final paint and construction completion.
- Final UHS systems to be applied in complete, continuous coats, increasing quality of the delivered coating.

2.0 Current State of the Practice

2.1 Coating Application Sequencing During Shipbuilding

Figure 1 schematically illustrates how protective coatings are integrated into the shipbuilding process. The detailed procedure at any particular shipyard may vary, but in general the process begins with steel plate and shapes protected by a thin (0.5-mil) PCP. The plate and shapes are welded together to form panels and the panels are welded together to form units. These units are then outfitted to the greatest possible extent before proceeding to a blast and paint facility. The PCP is damaged during fabrication and outfitting up to the unit stage, but corrosion is minimal in part due to the relatively quick progression of work and the ability to perform most of the work in a somewhat sheltered location.

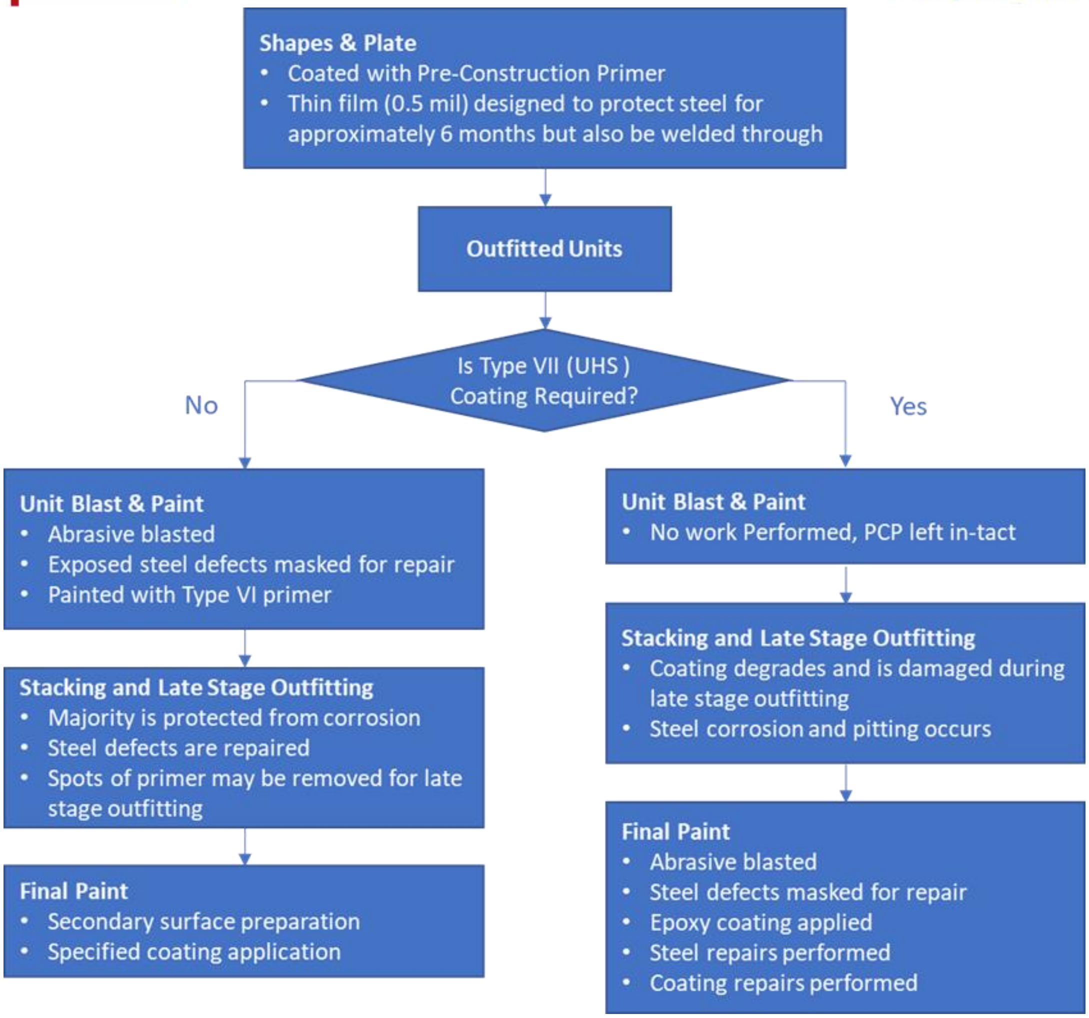


Figure 1. Coating Application Sequencing During Shipbuilding

During the unit blast and paint stage, the abrasive blasting process provides the best opportunity to inspect the steel and identify locations which may require steel repair (most often along welds). These defects may be repaired or masked (so they are not coated) and identified for future repair. Most of the steel is coated with the epoxy primer that will serve as the first coat of the final coating system. However, some spaces may not be coated if the applied coating cannot be retained as the first coat of the final coating system. In these cases, the PCP is left intact to provide as much protection as possible during the remainder of the build process. Figure 2 shows a unit in fabrication with in-tact pre-construction primer. Leaving spaces with PCP through the build process has two major impacts:

1. Increased steel corrosion as the PCP is damaged or breaks down.
2. Emergent hot work is identified late in the build cycle when steel defects are revealed during abrasive blasting. In most cases, defect repair will occur after the

blasted surface is coated, resulting in film weaknesses where spots of power tool cleaned steel are coated.

Figure 2. Degradation of PCP coated surfaces during unit construction.

2.2 Available Coating Systems

A variety of coating systems are used on Navy ships based on the performance requirements for individual spaces. During new construction, the majority of a ships coated steel surfaces will require an epoxy primer meeting one of the following types specified in MIL-PRF-23236.

- Type V - A coating system having a maximum volatile organic compound (VOC) content of 340 grams per liter (2.83 pounds per gallon) of coating. Hazardous air pollutants (HAPs) in the solvent will not exceed VOC levels. Use of pigments that are hazardous to workers or create hazardous waste is restricted to trace levels. May be used in any air quality management district regulating VOC. Dry coating is not a hazardous waste under USEPA regulations.

- Type VI - A coating system having a maximum VOC of 250 grams per liter (2.08 pounds per gallon) of coating. HAPs in the solvent will not exceed VOC levels. Use of pigments that are hazardous to workers or create hazardous waste is restricted. Dry coating is not a hazardous waste under USEPA regulations.
- Type VII - A coating system having a maximum VOC of 150 grams per liter (1.25 pounds per gallon) of coating. HAPs in the solvent will not exceed VOC levels. Use of pigments that are hazardous to workers or create hazardous waste is restricted to trace levels. Dry coating is not a hazardous waste under USEPA regulations. Coatings proposed for qualification testing to this type have no solvent added to either the base resin component or the hardener component.

Type V and Type VI primers are well suited to application at the unit stage. These coatings have features such as long pot life and low viscosity which make them applicator-friendly. They form continuous films at 4-6 mils dry film thickness, which can easily be removed if required for subsequent outfitting or hot work.

MIL-PRF-23236 Type VII (UHS) primers are ***not*** well suited to application at the unit stage. These coatings have a shorter pot life and high viscosity which make them more difficult to apply. They generally end up being applied at dry film thicknesses up to 10 mils, making them difficult to remove if required for subsequent outfitting or hot work. Construction damage to UHS coatings from unplanned work, such as heat straightening, increases rework costs. Figure 3 illustrates the type of damage which occurs to UHS coatings. Repairs at this point produce patchwork coating systems and decrease delivered quality. In addition, the coatings tend to char more extensively than Type VI coatings, increasing the amount of coating damage during hot work. Because of the challenges, spaces requiring UHS coatings are commonly left coated with PCP until late stage outfitting is completed. This results in more steel corrosion as the PCP breaks down and emergent hot work identified during abrasive blasting late in the build cycle.


Figure 3. Hot Work Damage to Type VII (UHS) Epoxy.

3.0 Desired Future Process

Figure 4 illustrates the proposed alternative process for protective coating application. The process allows the Type VII spaces to be treated the same as other steel surfaces. Spaces requiring Type VII coatings would be abrasive blasted earlier in construction and receive a holding coat of MIL-PRF-23236, Type VI primer to protect the steel until late-stage final paint. Figure 5 shows a typical unit after being coated with a Type VI epoxy in the blast and paint hall. Secondary surface preparation would be performed on the primed steel before coating with the specified UHS coating system. Type VI holding primer is preferable to priming with UHS due to material costs, difficulty in preparing and overcoating aged UHS coating systems, and for commonality of painting operations. Any allowance for retention of this Type VI holding coat when sound and intact would reduce blasting operations at late stages, and thus increase productivity. If approved, this process will:

- Allow the shipyard to apply and retain an economical anticorrosive primer at the unit stage to prevent weather related degradation during long construction cycles before the ship is watertight. This paint strategy is feasible because the Type VI primer requires less labor to repair areas damaged by welding and straightening compared to a coat of Type VII epoxy.

- Allow UHS systems to be applied in complete, continuous coats, which would increase quality and make it feasible for newbuild yards to cost-effectively use single-coat UHS systems.
- Align coating processes with pressure testing requirements. Pressure test requirements allow for testing when a maximum of one coat of Type VI primer (or equivalent) is applied on welds. Use of UHS coatings prior to pressure testing often requires welds to be left bare, due to concerns that the thickness of the coating exceeding the thickness of Type VI coating baseline may affect the test result. This results in additional areas that would receive a power tool surface prep and patchwork coating repair rather than a continuous coat. This change would result in continuous Type VI and UHS coats applied throughout these areas over an abrasive blast (SP-10) prep.
- Achieve commonality of painting in early construction stages. All units would be primed in the unit stage with MIL-PRF-23236 Type VI epoxy.
- Increase savings opportunities from retention of PCP by conducting coating operations while the PCP is newer and still in good condition.

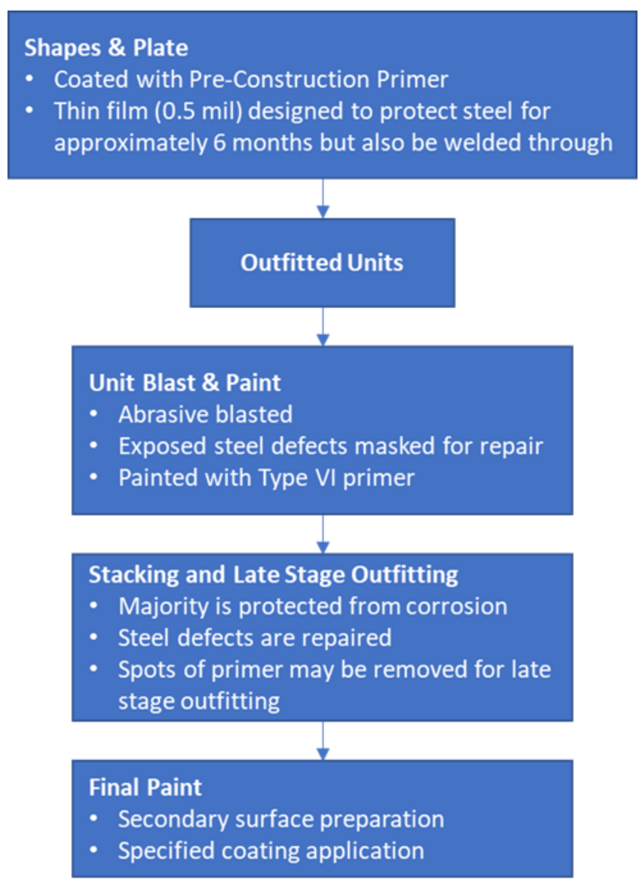


Figure 4. Desired Future Integration of Coating Work Into the Shipbuilding Process.

Figure 5. Unit After Coating with Type VI Primer in Blast and Paint Hall.

4.0 Summary of Test Results

This project developed the data needed to request Navy approval to apply UHS epoxy over retained MIL-PRF-23236 Type VI epoxy primer in critically coated areas that ultimately receive MIL-PRF-23236 Type VII high solids epoxy in a two coat or single coat system. Appendix A provides the complete test report for the project; key results are summarized in this section.

Table 1 through Table 7 summarize the results of seven tests performed on the alternative coating systems. The results are color-coded such that green is indicative of better performance and yellow of lesser performance. The coating systems are grouped such that the currently approved systems are in the top five rows and the proposed alternative systems consisting of a Type VI primer retained under a Type VII coating are the bottom five rows.

For each test, the worst performing coating system is an approved system, thus any of the alternative coating schemes should provide the performance expected by the Navy. In addition, it is worth noting that no one coating system consistently performed best (or worst) in the various tests. The data reflect the reality that coating formulation is a compromise wherein some characteristics are traded off for other characteristics. Similarly, the testing does not present compelling evidence that any given process of secondary surface preparation consistently out-performed another.

Table 1. Summary of Bend Test Results (1-5 rating)

	Coating System			Surface Prep		
	ID	Pre-Weathering	After Weathering	SP-3/SP-11	SP-7/SP-10	SP-14/SP-10
Approved	1	PCP/Interbond 998	Interbond 998	4	4	
	2	PCP	Interbond 998/Interbond 998		4	
	5	PCP	Interline 783			0
	7	PCP	Amercoat 240		2	
	9	PCP	Fast Clad ER			4
Type VII over Type VI	3	PCP/Intergard 264	Interbond 998 (+2 mils)	3	1	
	4	PCP/Intergard 264	Interbond 998/Interbond 998	3	3	
	8	PCP/Amercoat 240	Amercoat 240	3	3	
	11	PCP/SeaGuard 5000 HS	DuraPlate	1	1	
	6	PCP/Intergard 264	Interline 783		0	1
	10	PCP/SeaGuard 5000 HS	Fast Clad ER	4	5	5

Table 2. Summary of Prohesion Undecutting (mm)

	Coating System			Surface Prep		
	ID	Pre-Weathering	After Weathering	SP-3/SP-11	SP-7/SP-10	SP-14/SP-10
Approved	1	PCP/Interbond 998	Interbond 998	1.79	3.04	
	2	PCP	Interbond 998/Interbond 998		6.5	
	5	PCP	Interline 783			0.5
	7	PCP	Amercoat 240		1.69	
	9	PCP	Fast Clad ER			2.6
Type VII over Type VI	3	PCP/Intergard 264	Interbond 998 (+2 mils)	1.54	1.25	
	4	PCP/Intergard 264	Interbond 998/Interbond 998	1.46	1.46	
	8	PCP/Amercoat 240	Amercoat 240	1.48	1.6	
	11	PCP/SeaGuard 5000 HS	DuraPlate	3.54	3.08	
	6	PCP/Intergard 264	Interline 783		1.56	1.92
	10	PCP/SeaGuard 5000 HS	Fast Clad ER	2.96	2.44	2.17

Table 3. Summary of Knife Adhesion Test Results (1-10 rating)

	Coating System			Surface Prep		
	ID	Pre-Weathering	After Weathering	SP-3/SP-11	SP-7/SP-10	SP-14/SP-10
Approved	1	PCP/Interbond 998	Interbond 998	9	8.5	
	2	PCP	Interbond 998/Interbond 998		9.5	
	5	PCP	Interline 783			10
	7	PCP	Amercoat 240		7.5	
	9	PCP	Fast Clad ER			7
Type VII over Type VI	3	PCP/Intergard 264	Interbond 998 (+2 mils)	7.5	8.5	
	4	PCP/Intergard 264	Interbond 998/Interbond 998	8	8.5	
	8	PCP/Amercoat 240	Amercoat 240	8	7.5	
	11	PCP/SeaGuard 5000 HS	DuraPlate	9	8.5	
	6	PCP/Intergard 264	Interline 783		10	10
	10	PCP/SeaGuard 5000 HS	Fast Clad ER	7	7.5	7

Table 4. Summary of Pull Off Adhesion Failure Load (Average psi, regardless of failure location)

	Coating System			Surface Prep		
	ID	Pre-Weathering	After Weathering	SP-3/SP-11	SP-7/SP-10	SP-14/SP-10
Approved	1	PCP/Interbond 998	Interbond 998	2492	2659	
	2	PCP	Interbond 998/Interbond 998		2799	
	5	PCP	Interline 783			1549
	7	PCP	Amercoat 240		1730	
	9	PCP	Fast Clad ER			1485
Type VII over Type VI	3	PCP/Intergard 264	Interbond 998 (+2 mils)	2445	2146	
	4	PCP/Intergard 264	Interbond 998/Interbond 998	2427	2319	
	8	PCP/Amercoat 240	Amercoat 240	2072	1832	
	11	PCP/SeaGuard 5000 HS	DuraPlate	2204	2517	
	6	PCP/Intergard 264	Interline 783		1804	1828
	10	PCP/SeaGuard 5000 HS	Fast Clad ER	1468	1628	1818

Table 5. Summary of Condensing Humidity Results (10 = No Blistering)

	Coating System			Surface Prep		
	ID	Pre-Weathering	After Weathering	SP-3/SP-11	SP-7/SP-10	SP-14/SP-10
Approved	1	PCP/Interbond 998	Interbond 998	10	10	
	2	PCP	Interbond 998/Interbond 998		10	
	5	PCP	Interline 783			10
	7	PCP	Amercoat 240		10	
	9	PCP	Fast Clad ER			10
Type VII over Type VI	3	PCP/Intergard 264	Interbond 998 (+2 mils)	10	10	
	4	PCP/Intergard 264	Interbond 998/Interbond 998	10	10	
	8	PCP/Amercoat 240	Amercoat 240	10	10	
	11	PCP/SeaGuard 5000 HS	DuraPlate	10	10	
	6	PCP/Intergard 264	Interline 783		10	10
	10	PCP/SeaGuard 5000 HS	Fast Clad ER	10	10	10

Table 6. Summary of Cathodic Disbondment (Average undercutting from the holiday, mm)

	Coating System			Surface Prep		
	ID	Pre-Weathering	After Weathering	SP-3/SP-11	SP-7/SP-10	SP-14/SP-10
Approved	1	PCP/Interbond 998	Interbond 998	18.71	33.25	
Approved	2	PCP	Interbond 998/Interbond 998		24.58	
Approved	5	PCP	Interline 783			6.25
Approved	7	PCP	Amercoat 240		100.7	
Approved	9	PCP	Fast Clad ER			18.2
Type VII over Type VI	3	PCP/Intergard 264	Interbond 998 (+2 mils)	10.83	13.08	
Type VII over Type VI	4	PCP/Intergard 264	Interbond 998/Interbond 998	14.33	11.92	
Type VII over Type VI	8	PCP/Amercoat 240	Amercoat 240	13	13.88	
Type VII over Type VI	11	PCP/SeaGuard 5000 HS	DuraPlate	18.71	33.25	
Type VII over Type VI	6	PCP/Intergard 264	Interline 783		3.92	8.08
Type VII over Type VI	10	PCP/SeaGuard 5000 HS	Fast Clad ER	20.21	26.355	19.63

Table 7. Summary of Impact Test Results (Percent Failed at 160 in-lbs)

	Coating System			Surface Prep		
	ID	Pre-Weathering	After Weathering	SP-3/SP-11	SP-7/SP-10	SP-14/SP-10
Approved	1	PCP/Interbond 998	Interbond 998	0%	0%	
Approved	2	PCP	Interbond 998/Interbond 998		17%	
Approved	5	PCP	Interline 783			100%
Approved	7	PCP	Amercoat 240		33%	
Approved	9	PCP	Fast Clad ER			67%
Type VII over Type VI	3	PCP/Intergard 264	Interbond 998 (+2 mils)	17%	17%	
Type VII over Type VI	4	PCP/Intergard 264	Interbond 998/Interbond 998	0%	17%	
Type VII over Type VI	8	PCP/Amercoat 240	Amercoat 240	100%	100%	
Type VII over Type VI	11	PCP/SeaGuard 5000 HS	DuraPlate	0%	17%	
Type VII over Type VI	6	PCP/Intergard 264	Interline 783		17%	33%
Type VII over Type VI	10	PCP/SeaGuard 5000 HS	Fast Clad ER	0%	0%	33%

5.0 Conclusions

The data generated in this study support the following two main conclusions:

1. MIL-PRF-23236, Type VI approved primers retained under MIL-PRF-23236, Type VII primers do not perform materially different than MIL-PRF-23236, Type VII systems.
2. There is no material performance sacrifice associated with any of the three alternative secondary surface preparation techniques evaluated.

6.0 Recommendations

1. Should a shipyard choose to apply epoxy primers in early stages of fabrication, they should be allowed to interchangeably use either Type VI or UHS coatings as the first coat in a system for critical areas such as ballast tanks and bilges. The final coat should be a continuous film of the specified tank lining system to obtain the specified total coating thickness. The flexibility to use either primer material may benefit the shipyard in specific circumstances where a lower VOC product may be necessary.
2. A shipyard should choose the secondary surface preparation process that provides the most cost-effective preparation given various production constraints. Such constraints include, but are not limited to, the extent of coating damage, the size and shape of the space, and accessibility. Generally, sweep abrasive blasting procedures are more productive than power tool cleaning procedures. However, sweep abrasive blasting presents greater accessibility challenges. These logistics should dictate the choice of secondary surface preparation technique.

Appendix A. Test Report

Ingalls Shipbuilding
A Division of Huntington Ingalls Industries

Elzly Technology Corporation

Retention of MIL-PRF-23236 Type VI Epoxy under UHS Epoxy

Subcontract Agreement 2017-417

TEST Report

Rev B – April 15, 2019

Revision History:

Revision No.	Date	Description
-	5/31/18	Initial release does not have completed results from Bend, Prohesion, Cathodic Disbondment, and Condensing Humidity testing.
Rev A	6/30/18	Incorporated complete test results, minor table re-formatting, and an additional test (impact testing).
Rev B	4/15/19	Incorporated two missing panels CD data (10βC1 & 10βC2).

1.0 Introduction

This test report provides details and results of testing performed as part of a National Shipbuilding Research Program funded effort to investigate coating application, exposure conditions, and secondary surface preparation methods for measuring the performance of Ultra High Solids (UHS) epoxy, MIL-PRF-23236 Type VII, applied over MIL-PRF-23236 Type VI that has been aged on steel coupons.

1.1 Objective

The primary objective of this project was to develop the data needed to request Navy approval to apply UHS epoxy over retained MIL-PRF-23236 Type VI epoxy primer in critically coated areas that ultimately receive MIL-PRF-23236 Type VII high solids epoxy in a two coat or single-coat system. This change will also allow UHS systems to be applied in complete, continuous coats, which would increase quality and make it feasible for new build yards to cost-effectively use UHS systems.

1.2 Scope

Test variables can be summarized as follows:
MIL-PRF-23236 Type VI coatings - 3
MIL-PRF-23236 Type VII coatings - 4
Test Article Configurations - 2
Weathering Environments - 1
Surface Defects - 2
Secondary Surface Preparation Scenarios - 3
Coating Performance Test Methods - 5

Figure 1 shows a flowchart of the overall testing plan. Details are discussed below.

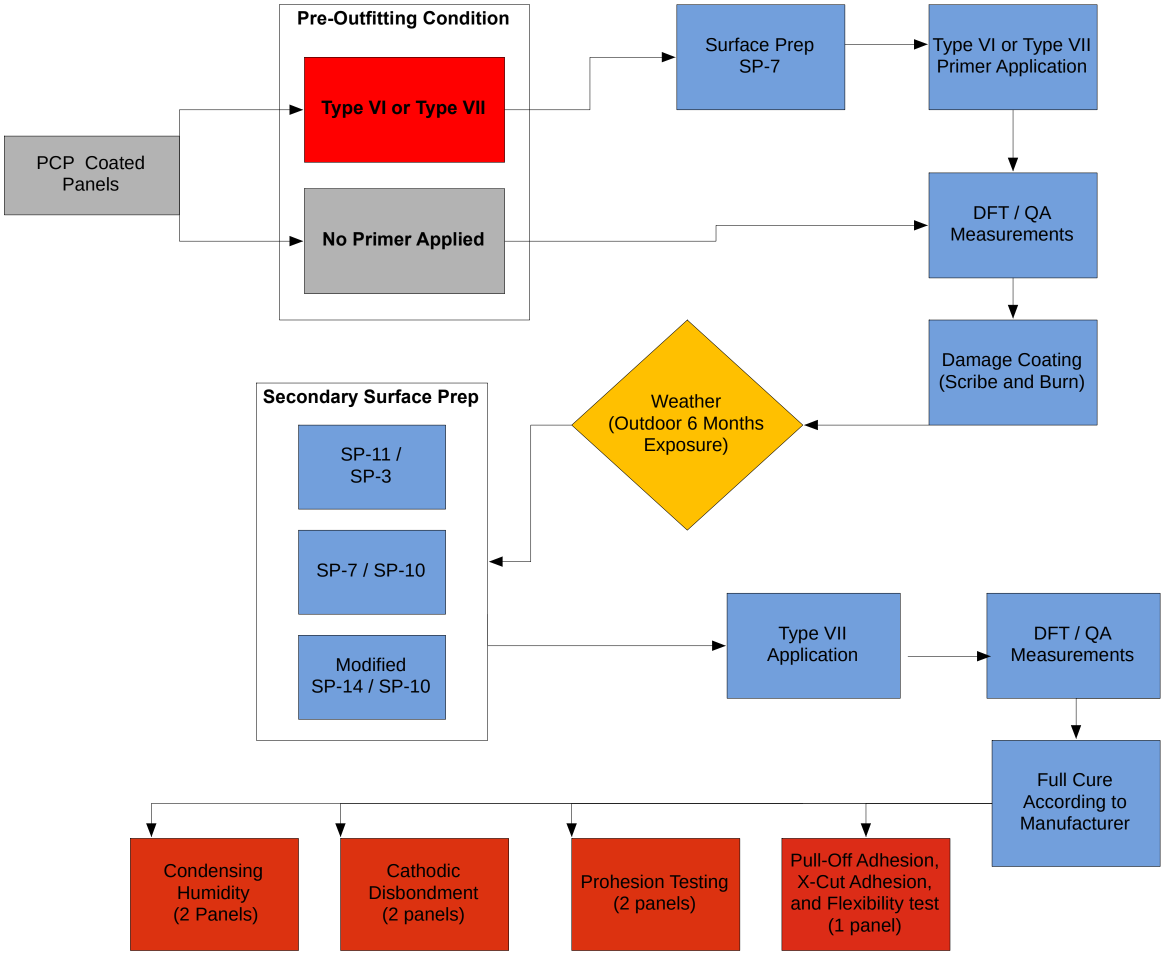


Figure 1. Panel Process Flow Chart

2.0 Coatings

Three Type VI coatings and five Type VII coatings were selected for evaluation as part of this project.
Table 1 identifies the coatings and lists some pertinent characteristics.

Table 1. Summary of Coatings

Product Name	Type	Max VOC	Volume of Solids	Max Overcoat	Dry to Touch
Intergard 264	VI	194	80% +/-3%	8 Weeks	4 hours
SeaGuard 5000 HS	VI	250	73% +/-2%	90 Days	4 hours
Amercoat 240	VI & VII	145	87% +/-2%	6 Months	5 hours
Interbond 998	VII	98	90% +/-2%	28 Days	4 hours
Interline 783	VII	120	95% +/-2%	7 Days	2 hours
Fast Clad ER	VII	85	98% +/-2%	14 Days	1 hour
Dura Plate	VII	280	68% +/-2%	6 Months	2 hours

3.0 Test Article Configurations

3.1 Test Matrix

Table 2 shows the overall test matrix for the project. A set of test plates corresponding to systems 1-11 were prepared. In general, test panels were coated with a pre-outfitting primer prior to an outdoor exposure at HII Pascagoula facilities for six months. Dependent on the system, panels underwent one of three secondary surface preparation scenarios prior to application of a UHS epoxy.

Table 2. Summary Test Matrix

Sample	Qty	1st Coat	Damage	Prep/Repair	2nd Coat	3rd Coat	2nd Coat Mils	3rd Coat Mils	Test
1αA	1	PCP/Interbond 998	Yes	SP-3/SP-11	Interbond 998		6-8		Adhesion
1αB	2	PCP/Interbond 998	Yes	SP-3/SP-11	Interbond 998		6-8		Prohesion
1αC	2	PCP/Interbond 998	No	SP-3	Interbond 998		6-8		Cathodic Disbondment
1αD	2	PCP/Interbond 998	No	SP-3	Interbond 998		6-8		Condensing Humidity
1βA	1	PCP/Interbond 998	Yes	SP-7/SP-10	Interbond 998		6-8		Adhesion
1βB	2	PCP/Interbond 998	Yes	SP-7/SP-10	Interbond 998		6-8		Prohesion
1βC	2	PCP/Interbond 998	No	SP-7	Interbond 998		6-8		Cathodic Disbondment
1βD	2	PCP/Interbond 998	No	SP-7	Interbond 998		6-8		Condensing Humidity
2A	1	PCP	Yes	SP-7/SP-10	Interbond 998	Interbond 998	6-8	6-8	Adhesion
2B	2	PCP	Yes	SP-7/SP-10	Interbond 998	Interbond 998	6-8	6-8	Prohesion
2C	2	PCP	No	SP-7	Interbond 998	Interbond 998	6-8	6-8	Cathodic Disbondment
2D	2	PCP	No	SP-7	Interbond 998	Interbond 998	6-8	6-8	Condensing Humidity
3αA	1	PCP/Intergard 264	Yes	SP-3/SP-11	Interbond 998 (+2 mils)		8-10		Adhesion
3αB	2	PCP/Intergard 264	Yes	SP-3/SP-11	Interbond 998 (+2 mils)		8-10		Prohesion
3αC	2	PCP/Intergard 264	No	SP-3	Interbond 998 (+2 mils)		8-10		Cathodic Disbondment
3αD	2	PCP/Intergard 264	No	SP-3	Interbond 998 (+2 mils)		8-10		Condensing Humidity
3βA	1	PCP/Intergard 264	Yes	SP-7/SP-10	Interbond 998 (+2 mils)		8-10		Adhesion
3βB	2	PCP/Intergard 264	Yes	SP-7/SP-10	Interbond 998 (+2 mils)		8-10		Prohesion
3βC	2	PCP/Intergard 264	No	SP-7	Interbond 998 (+2 mils)		8-10		Cathodic Disbondment
3βD	2	PCP/Intergard 264	No	SP-7	Interbond 998 (+2 mils)		8-10		Condensing Humidity
4αA	1	PCP/Intergard 264	Yes	SP-3/SP-11	Interbond 998	Interbond 998	6-8	6-8	Adhesion
4αB	2	PCP/Intergard 264	Yes	SP-3/SP-11	Interbond 998	Interbond 998	6-8	6-8	Prohesion
4αC	2	PCP/Intergard 264	No	SP-3	Interbond 998	Interbond 998	6-8	6-8	Cathodic Disbondment
4αD	2	PCP/Intergard 264	No	SP-3	Interbond 998	Interbond 998	6-8	6-8	Condensing Humidity
4βA	1	PCP/Intergard 264	Yes	SP-7/SP-10	Interbond 998	Interbond 998	6-8	6-8	Adhesion
4βB	2	PCP/Intergard 264	Yes	SP-7/SP-10	Interbond 998	Interbond 998	6-8	6-8	Prohesion
4βC	2	PCP/Intergard 264	No	SP-7	Interbond 998	Interbond 998	6-8	6-8	Cathodic Disbondment
4βD	2	PCP/Intergard 264	No	SP-7	Interbond 998	Interbond 998	6-8	6-8	Condensing Humidity
5A	1	PCP	Yes	SP-14/SP-10	Interline 783		20-30		Adhesion
5B	2	PCP	Yes	SP-14/SP-10	Interline 783		20-30		Prohesion
5C	2	PCP	No	SP-14	Interline 783		20-30		Cathodic Disbondment
5D	2	PCP	No	SP-14	Interline 783		20-30		Condensing Humidity
6αA	1	PCP/Intergard 264	Yes	SP-7/SP-10	Interline 783		20-30		Adhesion
6αB	2	PCP/Intergard 264	Yes	SP-7/SP-10	Interline 783		20-30		Prohesion
6αC	2	PCP/Intergard 264	No	SP-7	Interline 783		20-30		Cathodic Disbondment
6αD	2	PCP/Intergard 264	No	SP-7	Interline 783		20-30		Condensing Humidity
6βA	1	PCP/Intergard 264	Yes	SP-14/SP-10	Interline 783		20-30		Adhesion
6βB	2	PCP/Intergard 264	Yes	SP-14/SP-10	Interline 783		20-30		Prohesion
6βC	2	PCP/Intergard 264	No	SP-14	Interline 783		20-30		Cathodic Disbondment
6βD	2	PCP/Intergard 264	No	SP-14	Interline 783		20-30		Condensing Humidity
7A	1	PCP	Yes	SP-7/SP-10	Amercoat 240		4 - 12		Adhesion
7B	2	PCP	Yes	SP-7/SP-10	Amercoat 240		4 - 12		Prohesion
7C	2	PCP	No	SP-7	Amercoat 240		4 - 12		Cathodic Disbondment
7D	2	PCP	No	SP-7	Amercoat 240		4 - 12		Condensing Humidity
8αA	1	PCP/Amercoat 240	Yes	SP-3/SP-11	Amercoat 240		4 - 12		Adhesion
8αB	2	PCP/Amercoat 240	Yes	SP-3/SP-11	Amercoat 240		4 - 12		Prohesion
8αC	2	PCP/Amercoat 240	No	SP-3	Amercoat 240		4 - 12		Cathodic Disbondment
8αD	2	PCP/Amercoat 240	No	SP-3	Amercoat 240		4 - 12		Condensing Humidity
8βA	1	PCP/Amercoat 240	Yes	SP-7/SP-10	Amercoat 240		4 - 12		Adhesion
8βB	2	PCP/Amercoat 240	Yes	SP-7/SP-10	Amercoat 240		4 - 12		Prohesion
8βC	2	PCP/Amercoat 240	No	SP-7	Amercoat 240		4 - 12		Cathodic Disbondment
8βD	2	PCP/Amercoat 240	No	SP-7	Amercoat 240		4 - 12		Condensing Humidity
9A	1	PCP	Yes	SP-14/SP-10	Fast Clad ER		18-22		Adhesion
9B	2	PCP	Yes	SP-14/SP-10	Fast Clad ER		18-22		Prohesion
9C	2	PCP	No	SP-14	Fast Clad ER		18-22		Cathodic Disbondment
9D	2	PCP	No	SP-14	Fast Clad ER		18-22		Condensing Humidity
10αA	1	PCP/SeaGuard 5000 HS	Yes	SP-3/SP-11	Fast Clad ER		18-22		Adhesion
10αB	2	PCP/SeaGuard 5000 HS	Yes	SP-3/SP-11	Fast Clad ER		18-22		Prohesion
10αC	2	PCP/SeaGuard 5000 HS	No	SP-3	Fast Clad ER		18-22		Cathodic Disbondment
10αD	2	PCP/SeaGuard 5000 HS	No	SP-3	Fast Clad ER		18-22		Condensing Humidity
10βA	1	PCP/SeaGuard 5000 HS	Yes	SP-7/SP-10	Fast Clad ER		18-22		Adhesion
10βB	2	PCP/SeaGuard 5000 HS	Yes	SP-7/SP-10	Fast Clad ER		18-22		Prohesion
10βC	2	PCP/SeaGuard 5000 HS	No	SP-7	Fast Clad ER		18-22		Cathodic Disbondment
10βD	2	PCP/SeaGuard 5000 HS	No	SP-7	Fast Clad ER		18-22		Condensing Humidity
10γA	1	PCP/SeaGuard 5000 HS	Yes	SP-14/SP-10	Fast Clad ER		18-22		Adhesion
10γB	2	PCP/SeaGuard 5000 HS	Yes	SP-14/SP-10	Fast Clad ER		18-22		Prohesion
10γC	2	PCP/SeaGuard 5000 HS	No	SP-14	Fast Clad ER		18-22		Cathodic Disbondment
10γD	2	PCP/SeaGuard 5000 HS	No	SP-14	Fast Clad ER		18-22		Condensing Humidity
11αA	1	PCP/SeaGuard 5000 HS	Yes	SP-3/SP-11	Dura Plate		18-22		Adhesion
11αB	2	PCP/SeaGuard 5000 HS	Yes	SP-3/SP-11	Dura Plate		18-22		Prohesion
11αC	2	PCP/SeaGuard 5000 HS	No	SP-3	Dura Plate		18-22		Cathodic Disbondment
11αD	2	PCP/SeaGuard 5000 HS	No	SP-3	Dura Plate		18-22		Condensing Humidity
11βA	1	PCP/SeaGuard 5000 HS	Yes	SP-7/SP-10	Dura Plate		18-22		Adhesion
11βB	2	PCP/SeaGuard 5000 HS	Yes	SP-7/SP-10	Dura Plate		18-22		Prohesion
11βC	2	PCP/SeaGuard 5000 HS	No	SP-7	Dura Plate		18-22		Cathodic Disbondment
11βD	2	PCP/SeaGuard 5000 HS	No	SP-7	Dura Plate		18-22		Condensing Humidity

The test plan includes three different secondary surface preparation scenarios after outdoor exposure. For each surface prep scenario per system, seven test panels were required for performance testing. Of these panels, three had defects applied in the pre-outfitting primer prior to outdoor exposure to replicate defects that may occur during the shipbuilding process. Some systems were only tested with one secondary surface preparation scenario while others were tested with two or three alternatives. In total, 19 test conditions were evaluated. Coating manufacturers were consulted to agree upon compatible Type VI/Type VII coatings systems and accompanying secondary surface preparation methods.

The four performance tests that were performed are discussed in detail in Section 4. Table 3 shows the number of panels designated for the four types of performance testing.

Table 3. Test Panel Quantities

	Performance Testing			
	Adhesion & Flexibility	Prohesion Testing	Cathodic Disbondment	Condensing Humidity
Number of Panels per Condition	1	2	2	2
Panel Dimensions and Damage	6x12x1/8" Scribe/burn	6x12x1/8" Scribe/burn	6x12x1/8"	6x12x1/8"

4.0 Test Procedures

4.1 Test Article Preparation

4.1.1 Test Panels

Testing was performed on ABS DH36 low carbon cold rolled steel panels measuring 6-inch by 12-inch by 1/8-inch for the test panel matrix. Panels were provided by Ingalls shipyard and followed the same processes as standard shipyard materials during the building process. Therefore, prior to preconstruction primer (PCP) application, the steel was abrasive blasted to achieve a Society for Protective Coatings (SSPC) surface preparation standard SP-10 (near white metal). The target surface profile was between 2-4 mils. Surface profile was verified via electronic profile gauge on 10% of the test articles.

Following surface preparation, all samples were cleaned to SSPC surface preparation standard SP-1 to remove any leftover dust or contaminants and allowed to air dry. PCP was applied per standard HII Pascagoula facility procedures. The systems that receive MIL-PRF-23236 Type VI coatings received a sweep blast (SP-7) of the PCP prior to Type VI application. Application procedures for the Type VI coatings followed manufacturer recommendations for environmental conditions, mixing ratio, induction time, film thickness, cure time prior to service, etc.

Environmental conditions, such as ambient and surface temperatures, and relative humidity, were recorded in accordance with HII standard practices and product requirements. Dry Film Thickness (DFT) measurements were recorded for every test panel after cure of each coating layer.

4.2 Primer Weathering Environments

Each pre-outfitting primer surface was photographed prior to the weathering process. All test panels were exposed to an outdoor environment for 9 months at the HII Pascagoula facility. After the exposure period, each primer surface was characterized and photo-documented prior to surface preparation.

4.2.1 Scribe / Burn Defect

Prior to outdoor exposure, three panels per each surface preparation scenario per system were given defects to replicate challenges encountered during the ship building process. Near the top of the test panels, a scribe exposing the steel substrate was created in the coating using a grinding disc tool. The scribe was roughly 3-inches long, centered along the width, 3-inches below the top of the panel. The second defect was a burn spot nominally 3-inches by 1.5-inches, centered along the width, roughly 3-inches from the bottom. Figure 2 is a schematic of the defect plan. After defects were created and prior to exposure, each test panel was photo documented. Figure 3 shows panels with and without defects weathering at Ingalls.

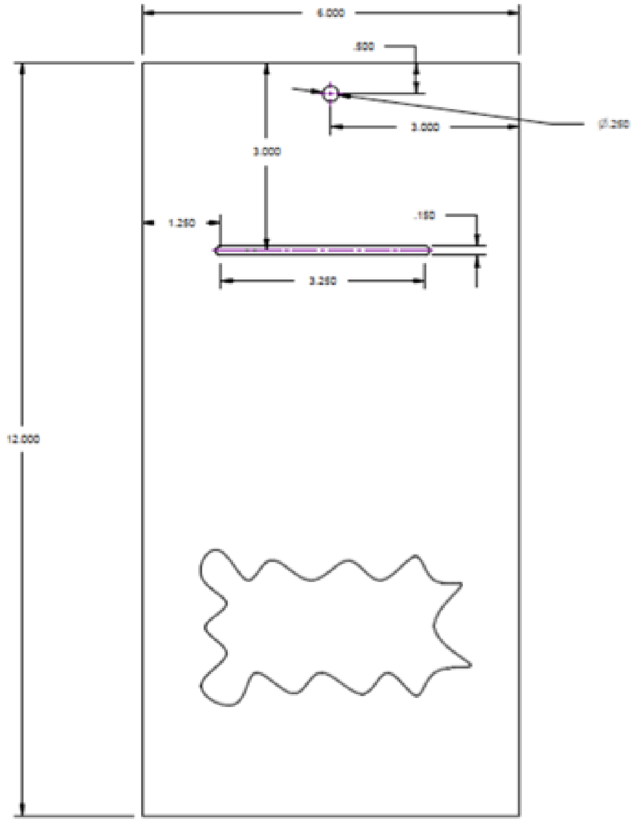


Figure 2. Replicate Panel with Defect Prior to Outdoor Exposure

Figure 3. Panels Weathering

4.3 Secondary Surface Preparation Scenarios

Following outdoor exposure, panels from each system underwent unique surface preparation scenarios as indicated in Table 2 prior to application of UHS epoxies. A description of each surface preparation method is given below. Figure 4 schematically illustrates the surface preparation approach.

- SP-3 (abrade)/SP-11
  - Panels designated for this surface preparation scenario had the entire panel surface abraded to standard SP-3 "Power Tool Cleaning." Panels that were scribed and burnt had SP-11 "Power Tool Cleaning to Bare Metal" performed in the defect areas, and intact coating on the remainder of the panel was abraded. The first image in Figure 4 represents this scenario.

- SP-7/SP-10
    - Panels designated for this surface preparation scenario had the entire panel sweep blasted to SP-7 "Brush-Off Blast Cleaning." Panels that were scribed and burnt had SP-10 "Near-White Blast Cleaning" performed in the defect areas, and intact coating on the remainder of the panel was prepared to SP-7. The second image in Figure 4 shows this scenario.
- Modified SP-14/SP-10
    - Panels designated for this surface preparation scenario had the entire panel prepared to a modified SP-14 "Industrial Blast Cleaning" that is currently used at HII Pascagoula facility. Panels that were scribed and burnt had SP-10 "Near-White Blast Cleaning" performed in the defect areas and intact coating on the remainder of the panel was prepared to the modified SP-14. The last image in Figure 4 shows this scenario.

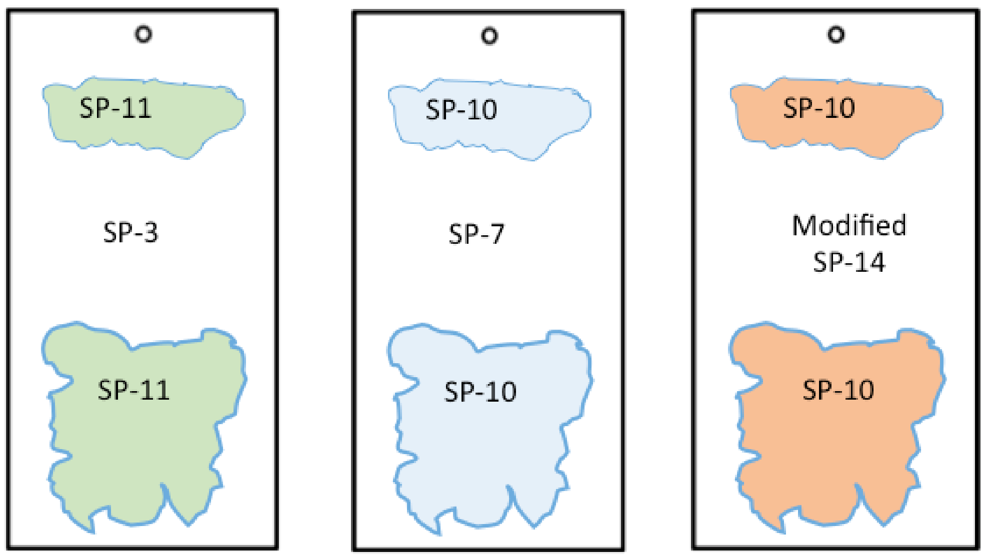


Figure 4. Representative Surface Preparation Panels to be Performed on Defect Panels

After secondary surface preparation, panels were coated with the designated topcoat for that system. Coating DFT was measured in locations similar to the primer measurements after the topcoat had dried sufficiently. Measurements were taken in defect and non-defect areas. After full cure, performance testing was performed on all panels.

4.4 Methods for Characterizing the Secondary Surface Preparations

Current methods of characterizing the coating surface after secondary preparation are limited primarily to visual techniques for remaining coating and the standard techniques for steel surfaces exposed via abrasive blasting or power tool cleaning. Measurements were made after completing secondary surface profile and prior to the designated application of the UHS epoxy.

4.4.1 Visual Inspection

The test panels were visually inspected after surface preparation for conformance with the specified degrees of cleanliness. Special attention was taken to ensure all edges were properly feathered and surfaces were properly abraded to the desired standard. Figure 5 shows panels after the surface preparation during application at Ingalls.

Figure 5. Panels after Surface Preparation

4.4.2 Film Thickness

DFT measurements were recorded on every test panel as the average of three readings on each panel. Readings were taken in areas with intact coating to determine the amount that was removed during the secondary surface preparation process. The DFT data can be found in Appendix A for every panel.

4.4.3 Surface Profile

Panels requiring more extensive surface preparation in the defect areas had the surface profile checked via electronic profile gauge.

4.4.4 Prepared Coating Surface Tension

As an exploratory technique for evaluating the remaining epoxy surface, Dyne marker pens were used to determine the surface tension of the remaining epoxy coating. Dyne marker pens are designed for process control or field use to determine surface tension relative to that of a known fluid. Surface tension measurements were performed on a representative sample of as-applied, weathered (Figure 6), and prepared aged epoxy primers to determine if this may be a feasible test to use in the field.

Figure 6. Dyne Pen on Panels

4.5 Performance Test Methods

4.5.1 Adhesion Testing

After full coating cure, adhesion testing was performed IAW ASTM D6677[1] and ASTM D4541.[2] Adhesion testing was performed on one panel for each condition in the test matrix.

The knife adhesion test was performed using methods described in ASTM D6677 and was rated on the 0 to 10 scale provided in the standard. Reporting included the substrate material and thickness, the coating system and method of cure, the age of the coating at testing, method of preconditioning, the ambient temperature and humidity during testing, the failure ratings of all tests and the failure location (e.g., between coats, substrate, etc.).

Pull-off adhesion was measured in accordance with ASTM D4541, Method E. Briefly, the test involves adhering a test fixture to the coating and pulling it normal to the surface until failure. The failure load and location of failure (i.e., layer of coating or adhesive where the failure occurred) was noted. Note that the interface of interest for this testing was that between the primer and the finish coating. Testing was performed on the as-glued test fixtures, without scoring. Testing was performed to failure or until the upper limit of the adhesion tester was reached. Post-test inspection noted the failure pressure (if any), the location of failure(s), and the percentage of failure observed at each location.

[1] ASTM D6677, Standard Test Method for Evaluating Adhesion by Knife
[2] ASTM D4541, Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers

Each panel was photographed after testing, with photos including the test surfaces of the panel and adhesion dollies.

Eight adhesion tests were performed on each test panel including four tests IAW ASTM D6677 and four tests IAW ASTM D4541. Two adhesion tests of both D6677 and D4541 were performed in the center of the panel where intact primer was prepped. One test of each type was performed in the burn area repair and one was performed in the scribe area repair. Figure 7 illustrates the adhesion test locations relative to the coating defects.

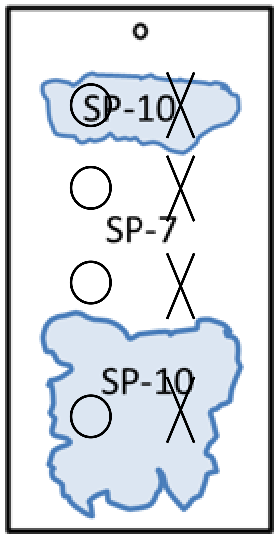


Figure 7. Example of Adhesion Testing Performed on Test Panels

4.5.2 Flexibility Testing

Flexibility was performed on the same panels on which adhesion testing was performed. The panels were bent using a hydraulic press at three increasing angles of deformation (50, 80, and 110 degrees). After each bend, the panels were inspected for cracking and/or delamination from the substrate. Figure 8 shows a representative test panel during test.

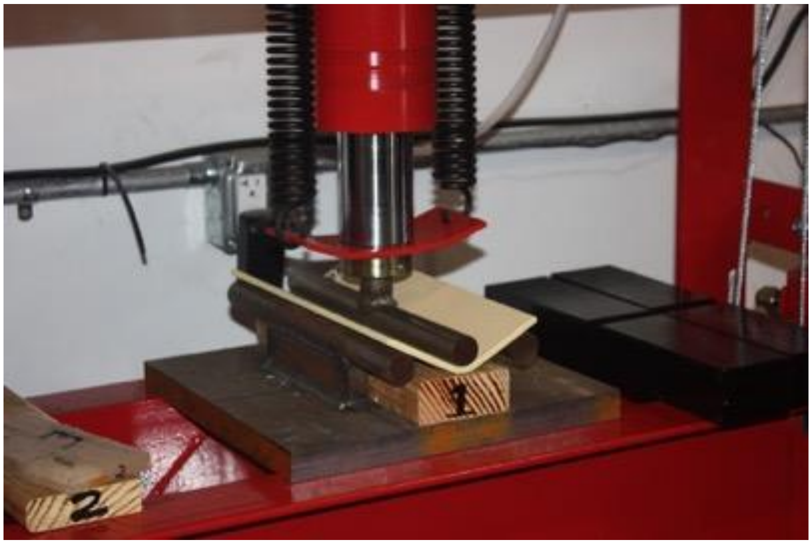


Figure 8. Representative panel in Hydraulic Press

Figure 9 represents the line where panels were bent and where cracking was observed.

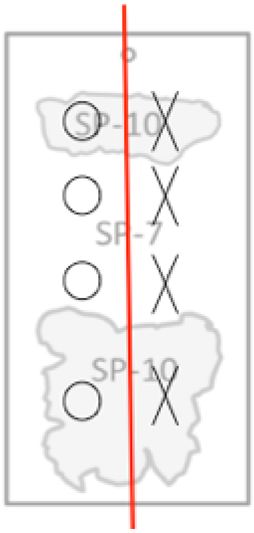


Figure 9. Example of Flexibility Testing location Performed on Panels

4.5.3 Cathodic Protection (CP) Compatibility

This test was performed in general accordance with section 4.5.16 of MIL-PRF-23236D. Duplicate test panels for each condition in the test matrix were electrically connected to a commercial magnesium anode conforming to ASTM G8[3] and had a 0.25-inch (nominal) hole drilled through the coating to the metal at the center of the test panel. Figure 10 shows a representative photo for this test.

[3] ASTM G8, Standard Test Methods for Cathodic Disbonding of Pipeline Coatings

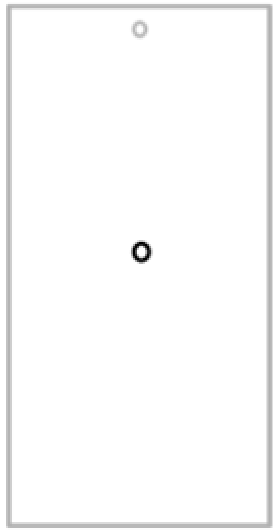


Figure 10. Representative Photo of CP Test Panels

The test panels were installed in a modified ASTM G8 test in such a manner as to separate the test panel from the magnesium anode by 18 inches (nominal) for a period of 74 days. Figure 11 shows the panels in testing. Prior to installation, connection points on the test panels were coated with an epoxy compound for insulation. Periodically over the 74 days, the cathodic protection current, protected potential, and instant "off" potential were measured. The conditions of the tank such as conductivity, pH and temperature were also checked periodically over the test. The water conditions are summarized in Table 4.

Table 4. Cathodic Disbondment Test Water Conditions

Conductivity	pH	Temperature
39-57 mS/cm (avg 45.3 mS/cm)	7.4-8.2 (avg 8.02)	65.2°F to 80.1°F (avg 70.7°F)

At the completion of the testing, each panel was photographed and inspected for peeling, flaking, blistering, dissolving, or other failures. Lifting, peeling, or undercutting around the drilled hole was measured and recorded. Section 3.5 of MIL-PRF-23236D states that undercutting or peeling shall not exceed 4 percent of the area of the test panel and that all undercutting and peeling shall be located within ½-inch of the holiday. However, for the purposes of this test the relative performance of the various coating systems was used to determine suitability of alternative coating scenarios.

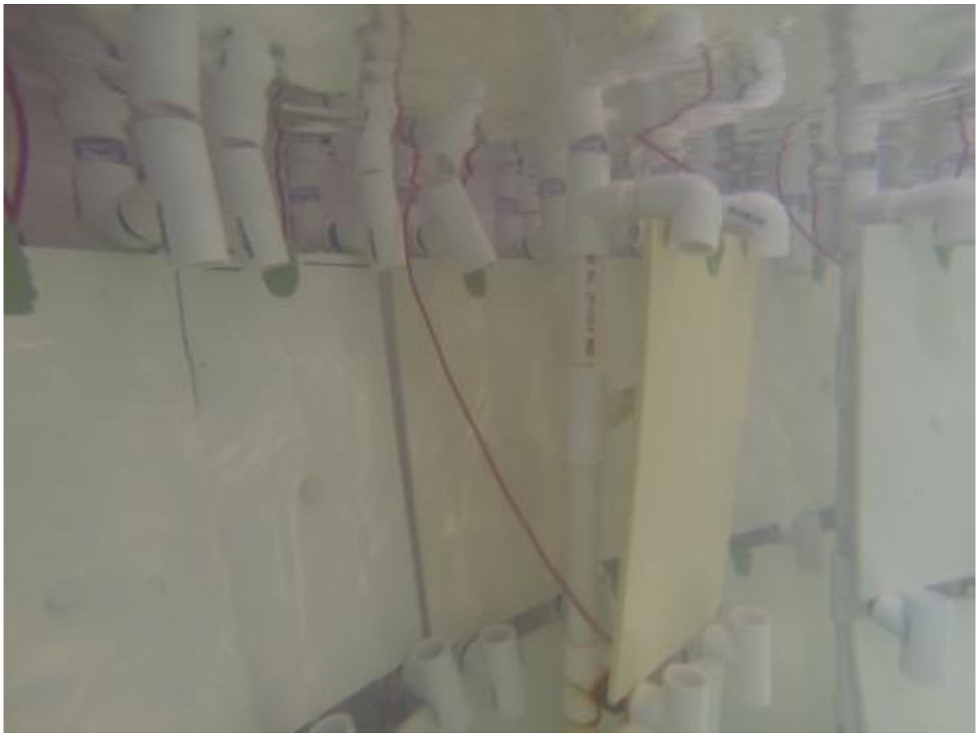


Figure 11. Panels in CD Testing

4.5.4 Prohesion Cycle Testing

Prohesion cycle testing was performed in accordance with ASTM G85[4] Annex A5 on duplicate test panels for each condition in the test matrix. Figure 12 shows panels in testing.

Figure 12. Panels in Prohesion Testing

Prior to testing, a 4-inch scribe was made in the coating system as seen below in Figure 13.

[4] ASTM G85, Standard Practice for Modified Salt Spray (Fog) Testing

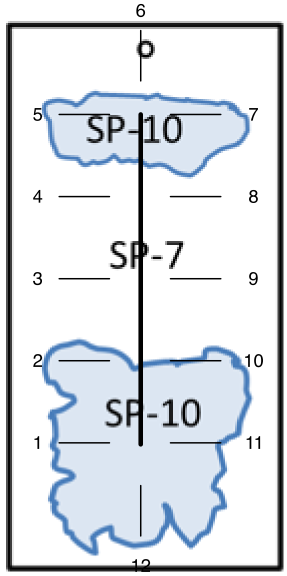


Figure 13. Representative Panel with Testing Locations

Inspections and photographs were made at 100, 300, 500, and 1000 hours. During these inspections, the panels were visually rated as follows:

- Through film corrosion IAW ASTM D610[5]
- Blistering of the coating system determined visually and rated IAW ASTM D714[6]
- Underfilm corrosion (if observed by rusting or blistering initiating from the scribe) was measured to the nearest millimeter every 3/4-inch along the scribe (as shown in Figure 13) for a total of 12 measurements per panel.

4.5.5 Condensing Testing

Duplicate panels for each condition in the test matrix were placed in a condensing cabinet as specified in ASTM D4585[7] for 1,300 hours at 38 °C (100 °F) (Figure 14). The temperature of the water in each tank was monitored periodically throughout each day with the temperatures being recorded daily to ensure that the water was maintained at the designated 38 °C (100 °F). Inspections were performed every 500 hours for blistering, surface imperfections, and signs of edge rusting. The requirement specified in 3.17 of MIL-PRF-23236 states there shall be no pinhole rusting or blistering rated in excess of ASTM D714, blister size number “4 few,” after 2,000 hours of exposure. For the purposes of this test the relative performance of the various coating systems was used to determine suitability of alternative coating scenarios.

[5] ASTM D610, Standard Practice for Evaluating Degree of Rusting on Painted Steel Surfaces
[6] ASTM D714, Standard Test Method for Evaluating Degree of Blistering of Paints
[7] ASTM D4585, Standard Practice for Testing Water Resistance of Coatings Using Controlled Condensation

Figure 14. Panel in Condensing Test

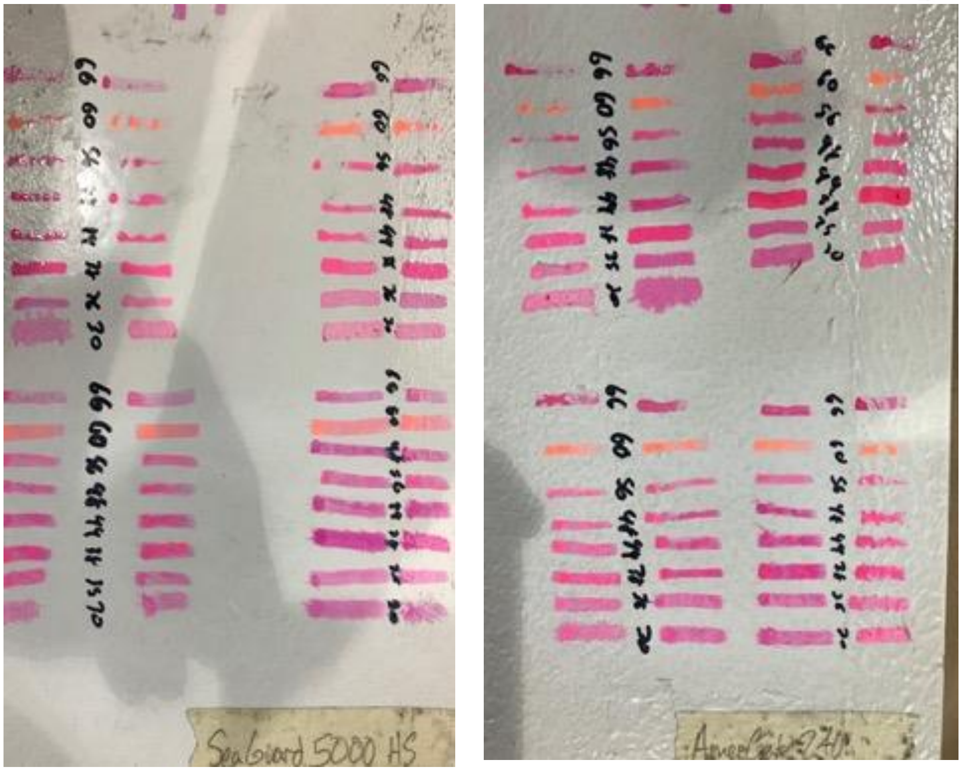
4.5.6 Impact Resistance

While handling the test panels, some were observed to be more brittle and subject to chipping than others. In an attempt to characterize this behavior, the condensing humidity test panels were subjected to testing described in ASTM D2794, Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact). Using the testing apparatus described in ASTM D2794, triplicate impacts were performed on each test panel at maximum height allowed by the guide tube using a 4lb weight (160 in-lbs). A low voltage holiday detector was used to test each impact site for a holiday. Any impact site exhibiting a holiday was marked and all panels were photographed.

5.0 Results

5.1 Prepared Coating Surface Tension

An exploratory technique for evaluating the remaining epoxy surface, Dyne marker pens were used to determine the surface tension of the remaining epoxy coating. Surface tension measurements were performed on a representative sample of panels within 2 to 3 weeks of coating application. Figure 15 shows SeaGuard 5000 HS and Amercoat 240 after testing with Dyne pens. Both had similar tensions of 56-48. After the panels were scuff sanded, a higher surface tension was indicated on both panels.



SeaGuard 5000 HS Amercoat 240

Figure 15. Dyne Pens on Test Panels

Figure 16 shows Interbond 988 and Intergard 264 after testing with Dyne pens. The color of the Interbond 998 made it difficult to identify the tension readings. Interbond had the lowest surface tension of 44-36, while Intergard, Amercoat, and Seaguard had surface tensions in the 56-48 range. Additionally, when panels were scuff sanded both panels indicated an increase in surface tension.

Interbond 998 Intergard 264

Figure 16. Dyne Pens on Test Panels

Dyne pens were brought to application at Ingalls shipyard to be tested on weathered panels. When tested on chalked, weathered surfaces, all coating readings exceeded 66, which is the highest available pen. The surface tension of weathered epoxies is beyond the detection range of commercially available Dyne pens, suggesting that, while they can distinguish a weathered coating from a new coating, they cannot distinguish among weathered coatings.

5.2. Adhesion Testing

Table 5 presents the rating scale from ASTM D6677.[2] Table 6 shows the ratings for each panel. With few exceptions, individual readings were 8 or 10. Each of the systems with a FastClad ER topcoat had at least one rating of “6.”

Table 5. ASTM D6677 X-Cut Adhesion Test Ratings

Rating	Description
10	Coating is extremely difficult to remove; fragments no larger than approximately 0.8 by 0.8 mm (1/32 in. by 1/32 in.) removed with great difficulty.
8	Coating is difficult to remove; chips ranging from approximately 1.6 by 1.6 mm (1/16 by 1/16 in.) to 3.2 by 3.2 mm (1/8 by 1/8 in.) can be removed with difficulty.
6	Coating is somewhat difficult to remove; chips ranging from approximately 3.2 by 3.2 mm (1/8 by 1/8 in.) to 6.3 by 6.3 mm (1/4 by 1/4 in.) can be removed with slight difficulty.
4	Coating is somewhat difficult to remove; chips in excess of 6.3 by 6.3 mm (1/4 by 1/4 in.) can be removed by exerting light pressure with the knife blade.
2	Coating is easily removed; once started with the knife blade, the coating can be grasped with ones fingers and easily peeled to a length of at least 6.3 mm (1/4 in.).
0	Coating can be easily peeled from the substrate to a length greater than 6.3 mm (1/4 in.).

Table 6. Knife Cut Adhesion

Panel #	1st Coat	Prep/Repair	2nd Coat	3rd Coat	1	2	3	4	Average
1aA1	PCP/Interbond 998	SP-3/SP-11	Interbond 998		10	8	8	10	9
1BA1	PCP/Interbond 998	SP-7/SP-10	Interbond 998		10	8	8	8	8.5
2B1	PCP	SP-7/SP-10	Interbond 998		10	10	10	8	9.5
3aA1	PCP/Intergard 264	SP-3/SP-11	Interbond 998 (+2 mils)		8	8	8	6	7.5
3BA1	PCP/Intergard 264	SP-7/SP-10	Interbond 998 (+2 mils)		10	8	8	8	8.5
4aA1	PCP/Intergard 264	SP-3/SP-11	Interbond 998	Interbond 998	8	8	8	8	8
4BB1	PCP/Intergard 264	SP-7/SP-10	Interbond 998	Interbond 998	8	10	8	8	8.5
5A1	PCP	SP-14/SP-10	Interline 783		10	10	10	10	10
6aA1	PCP/Intergard 264	SP-7/SP-10	Interline 783		10	10	10	10	10
6BA1	PCP/Intergard 264	SP-14/SP-10	Interline 783		10	10	10	10	10
7A1	PCP	SP-7/SP-10	Amercoat 240		8	8	6	8	7.5
8aA1	PCP/Amercoat 240	SP-3/SP-11	Amercoat 240		8	8	8	8	8
8BA1	PCP/Amercoat 240	SP-7/SP-10	Amercoat 240		8	6	8	8	7.5
9A1	PCP	SP-14/SP-10	Fast Clad ER		6	6	8	8	7
10aA1	PCP/SeaGuard 5000 HS	SP-3/SP-11	Fast Clad ER		6	8	8	6	7
10BA1	PCP/SeaGuard 5000 HS	SP-7/SP-10	Fast Clad ER		8	8	8	6	7.5
10yA1	PCP/SeaGuard 5000 HS	SP-14/SP-10	Fast Clad ER		6	6	8	8	7
11BA1	PCP/SeaGuard 5000 HS	SP-3/SP-11	Dura Plate		10	8	10	8	9
11aA1	PCP/SeaGuard 5000 HS	SP-7/SP-10	Dura Plate		8	10	10	6	8.5

Table 7 presents the pull-off adhesion data. Appendix B has all photos from each adhesion test performed. All failure loads exceeded 1200 psi and none of the failures were between the aged primer and final lining. Most failures were failures of the adhesive material used to glue on the dollies.

Table 7. Pull-Off Adhesion Data

Panel	1st Coat	Prep/Repair	Finish Coat(s)	Pull 1 Pressure (psi)	Pull 1 Failure Type N/A	Pull 1 Percent %	Pull 2 Pressure (psi)	Pull 2 Failure Type N/A	Pull 2 Percent %	Pull 3 Pressure (psi)	Pull 3 Failure Type N/A	Pull 3 Percent %	Pull 4 Pressure (psi)	Pull 4 Failure Type N/A	Pull 4 Percent %	Average
1αA1	PCP/Interbond 998	SP-3/ SP-11	Interbond 998	2292	Substrate Glue	80 20	2763	Glue	100	3222	Glue	100	1690	Glue Substrate	85 15	2491.75
1βA1	PCP/Interbond 998	SP-7/ SP-10	Interbond 998	2389	Glue Cohesive (Topcoat)	50 50	2742	Glue Cohesive (Topcoat)	80 20	2659	Glue	100	2846	Cohesive (Topcoat) Glue	90 10	2659
2β1	PCP	SP-7/ SP-10	Interbond 998	2494	Cohesive (Topcoat) Glue	95 5	2761	Glue Cohesive (Topcoat)	80 20	3027	Glue	100	2915	Cohesive (Topcoat) Glue	75 25	2799.25
3αA1	PCP/Intergard 264	SP-3/ SP-11	Interbond 998 (+2 mils)	2259	Substrate	100	2636	Adhesive	100	2694	Adhesive Cohesive (Primer) Glue	70 20 10	2191	Substrate Cohesive (Primer) Glue	60 20 20	2445
3βA1	PCP/Intergard 264	SP-7/ SP-10	Interbond 998 (+2 mils)	2712	Glue Substrate	70 30	2001	Substrate Cohesive (Primer)	80 20	1715	Cohesive (Primer)	100	2157	Cohesive (Primer) Cohesive (Topcoat)	70 30	2146.25
4αA1	PCP/Intergard 264	SP-3/ SP-11	Interbond 998/ Interbond 998	1518	Cohesive (Primer)	100	2392	Cohesive (Primer) Glue	80 20	2982	Cohesive (Topcoat) Cohesive (Primer)	75 25	2819	Cohesive (Primer) Cohesive (Topcoat)	85 15	2427.75
4βB2	PCP/Intergard 264	SP-7/ SP-10	Interbond 998/ Interbond 999	2341	Cohesive (Primer)	100	2630	Cohesive (Primer) Glue	90 10	2332	Cohesive (Primer)	100	1974	Cohseive (Primer) Glue	50 50	2319.25
5A1	PCP	SP-14/ SP-10	Interline 783	1725	Glue	100	1401	Glue	100	1829	Glue	100	1243	Glue	100	1549.5
6αA1	PCP/Intergard 264	SP-7/ SP-10	Interline 783	1982	Glue	100	1767	Glue	100	1726	Glue	100	1742	Glue	100	1804.25
6βA1	PCP/Intergard 264	SP-14/ SP-10	Interline 783	1704	Glue	100	2138	Glue Substrate	98 2	1728	Substrate Glue	80 20	1742	Glue	100	1828
7A1	PCP	SP-7/ SP-10	Amercoat 240	1750	Substrate Glue	80 20	2042	Substrate Glue	50 50	1239	Substrate Glue	95 5	1889	Substrate Glue	80 20	1730
8αA1	PCP/Amercoat 240	SP-3/ SP-11	Amercoat 240	1979	Glue Substrate Cohesive (Primer)	60 25 15	2361	Glue Cohesive (Topcoat)	60 40	1923	Cohesive (Topcoat) Glue	70 30	2024	Cohesive (Topcoat) Glue	50 50	2071.75
8βA1	PCP/Amercoat 240	SP-7/ SP-10	Amercoat 240	1582	Glue Cohesive (Topcoat)	95 5	1931	Substrate	100	1606	Substrate Glue	80 20	2210	Cohesive (Topcoat) Substrate Glue	70 20 10	1832.25
9A1	PCP	SP-14/ SP-10	Fast Clad ER	1543	Glue Substrate	80 20	1412	Glue Substrate	90 10	1375	Substrate Glue	60 40	1613	Substrate Glue	60 40	1485.75
10α1	PCP/SeaGuard 5000 HS	SP-3/ SP-11	Fast Clad ER	1583	Cohesive (Topcoat) Glue	75 25	1382	Cohesive (Topcoat) Glue	80 20	1403	Glue Cohesive (Topcoat)	60 40	1503	Cohesive (Topcoat)	100	1467.75
10βA1	PCP/SeaGuard 5000 HS	SP-7/ SP-10	Fast Clad ER	1697	Cohesive (Topcoat) Glue	85 15	1673	Cohesive (Topcoat) Glue	60 40	1564	Glue Cohesive (Topcoat)	70 30	1576	Cohesive (Topcoat) Glue	60 40	1627.5
10γA1	PCP/SeaGuard 5000 HS	SP-14/ SP-10	Fast Clad ER	1861	Cohesive (Topcoat) Glue	50 50	1860	Glue Cohesive (Topcoat)	60 40	1779	Cohesive (Topcoat)	100	1774	Glue Cohesive (Topcoat)	60 40	1818.5
11αA1	PCP/SeaGuard 5000 HS	SP-3/ SP-11	Dura Plate	2116	Substrate Glue	75 25	2359	Glue Cohesive (Topcoat)	80 20	3262	Cohesive (Topcoat)	100	1078	Glue Substrate	60 40	2203.75
11βA1	PCP/SeaGuard 5000 HS	SP-7/ SP-10	Dura Plate	2380	Glue Substrate	75 25	2558	Glue Cohesive (Topcoat)	80 20	2608	Substrate Glue	60 40	2523	Glue Cohseive (Primer) Substrate	80 15 5	2517.25

5.3 Flexibility Testing

At each bending angle, the coating was photographed and inspected for cracking, flaking, and delamination. Appendix B shows a photo of each panel after each angle of deformation. Note that in some cases the X-cut adhesion test (performed prior to the bend) had a localized impact on the bend test performance. The impact can be neglected without impacting the overall observations. Figure 17 shows a representative panel from systems 10 and 5 after being bent 110 degrees. System 10 exhibited excellent adhesion despite the impact of the X-cut test near the bend. Systems 5 and 6 exhibited complete delamination at the bend. Also note that on some systems, there was a noticeable difference in bend test performance on areas cleaned to bare metal versus areas where in-tact primer was overcoated. Figure 18 illustrates this behavior on panel 3βA1. The damaged portions that were repaired (marked by the blue arrows) are more flexible than the areas that were not damaged. This may be influenced by surface preparation, overall coating thickness, or aging of the retained epoxy primer.

Figure 17. Panels 10ϒA1 (left) and 5A1 (right) after bend at 110 degrees

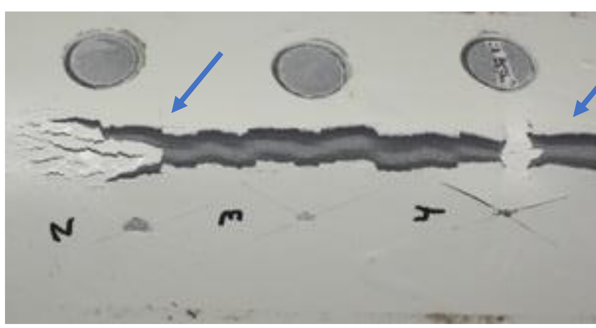


Figure 18. Damaged areas displayed less delamination.

Table 8 shows the inspection rating scale. Table 9 shows the rating for each panel at each angle. The data show that system 10 (PCP/Seaguard 5000 HS topcoated with Fast Clad ER) was the most flexible. This system exhibited cracking but almost no delamination. System 5 (PCP topcoated with Interline 783) and system 6 (PCP/Intergard 264 topcoated with Interline 783) completely disbonded after the first bend (50°).

Table 8. Flexibility Test Rating Scale

Rating	Description
5	No delamination or cracking
4	Cracking along surface
3	Cracking and minor delamination (0 - 25%)
2	Cracking and moderate delamination (25 - 50%)
1	Cracking and major delamination (50 - 75%)
0	Complete delamination across bend (75 - 100%)

Table 9. Flexibility Results

Panel #	1st Coat	Prep/Repair	Finish coat(s)	1 (50°)	2 (80°)	3 (110°)
1aA1	PCP/Interbond 998	SP-3/SP-11	Interbond 998	4	4	4
1BA1	PCP/Interbond 998	SP-7/SP-10	Interbond 998	4	4	4
2B1	PCP	SP-7/SP-10	Interbond 998	4	4	4
3aA1	PCP/Intergard 264	SP-3/SP-11	Interbond 998 (+2 mils)	4	3	3
3BA1	PCP/Intergard 264	SP-7/SP-10	Interbond 998 (+2 mils)	2	1	1
4aA1	PCP/Intergard 264	SP-3/SP-11	Interbond 998/Interbond 998	3	3	2
4BB1	PCP/Intergard 264	SP-7/SP-10	Interbond 998/Interbond 998	3	3	3
5A1	PCP	SP-14/SP-10	Interline 783	0	0	0
6aA1	PCP/Intergard 264	SP-7/SP-10	Interline 783	0	0	0
6BA1	PCP/Intergard 264	SP-14/SP-10	Interline 783	2	1	0
7A1	PCP	SP-7/SP-10	Amercoat 240	3	2	2
8aA1	PCP/Amercoat 240	SP-3/SP-11	Amercoat 240	4	3	3
8BA1	PCP/Amercoat 240	SP-7/SP-10	Amercoat 240	4	3	2
9A1	PCP	SP-14/SP-10	Fast Clad ER	5	4	2
10aA1	PCP/SeaGuard 5000 HS	SP-3/SP-11	Fast Clad ER	4	4	4
10BA1	PCP/SeaGuard 5000 HS	SP-7/SP-10	Fast Clad ER	5	5	5
10yA1	PCP/SeaGuard 5000 HS	SP-14/SP-10	Fast Clad ER	5	5	5
11BA1	PCP/SeaGuard 5000 HS	SP-3/SP-11	Dura Plate	1	1	1
11aA1	PCP/SeaGuard 5000 HS	SP-7/SP-10	Dura Plate	2	1	1

5.4 Cathodic Protection Testing

Appendix C presents photographs of all test panels after destructive evaluation. Table 10 provides a summary of the test data for all panels including the average dry film thickness, coupled potential (E_c vs SCE), average "instant off" potential (E_{oc} vs SCE), average cathodic protection current (mA), and average coating disbondment from the holiday.

Table 10. Summary of Cathodic Disbondment Test Data

Panel	Scenario			DFT (mils)	Avg Eoc (V)	Avg Ec (V)	Avg I (mA)	Final I (mA)	Disbondment (in)
1aC1	PCP/Interbond 998	SP-3	Interbond 998	22.0	-1.116	-1.570	0.00260	0.00144	0.659
1aC2	PCP/Interbond 998	SP-3	Interbond 998	33.1	-1.102	-1.570	0.00132	0.00076	0.814
1BC1	PCP/Interbond 998	SP-7	Interbond 998	29.7	-1.112	-1.570	0.00341	0.00134	2.493
1BC2	PCP/Interbond 998	SP-7	Interbond 998	23.1	-1.107	-1.570	0.00227	0.00085	0.125
2C1	PCP	SP-7	Interbond 998	17.1	-1.212	-1.570	0.00305	0.00247	0.978
2C2	PCP	SP-7	Interbond 998	16.2	-1.183	-1.570	0.00512	0.00431	0.958
3aC1	PCP/Intergard 264	SP-3	Interbond 998 (+2 mils)	37.0	-1.100	-1.570	0.00237	0.00144	0.387
3aC2	PCP/Intergard 264	SP-3	Interbond 998 (+2 mils)	29.0	-1.167	-1.570	0.00284	0.00155	0.466
3BC1	PCP/Intergard 264	SP-7	Interbond 998 (+2 mils)	17.8	-1.115	-1.570	0.00323	0.00193	0.617
3BC2	PCP/Intergard 264	SP-7	Interbond 998 (+2 mils)	32.7	-1.113	-1.570	0.00291	0.00233	0.413
4aC1	PCP/Intergard 264	SP-3	Interbond 998/Interbond 998	24.3	-1.130	-1.570	0.00292	0.00133	0.518
4aC2	PCP/Intergard 264	SP-3	Interbond 998/Interbond 998	34.7	-1.107	-1.570	0.00211	0.00150	0.610
4BC1	PCP/Intergard 264	SP-7	Interbond 998/Interbond 998	29.2	-1.121	-1.570	0.00220	0.00212	0.505
4BC2	PCP/Intergard 264	SP-7	Interbond 998/Interbond 998	28.9	-1.142	-1.570	0.00272	0.00227	0.433
5C1	PCP	SP-14	Interline 783	31.2	-1.138	-1.570	0.00148	0.00075	0.230
5C2	PCP	SP-14	Interline 783	33.6	-1.244	-1.570	0.00339	0.00312	0.262
6aC1	PCP/Intergard 264	SP-7	Interline 783	28.2	-1.106	-1.570	0.00241	0.00055	0.151
6aC2	PCP/Intergard 264	SP-7	Interline 783	34.7	-1.175	-1.570	0.00243	0.00131	0.157
6BC1	PCP/Intergard 264	SP-14	Interline 783	33.6	-1.103	-1.570	0.00224	0.00092	0.302
6BC2	PCP/Intergard 264	SP-14	Interline 783	23.9	-1.100	-1.570	0.00202	0.00115	0.335
7C1	PCP	SP-7	Amercoat 240	8.7	-1.202	-1.570	0.01199	0.01911	4.350
7C2	PCP	SP-7	Amercoat 240	5.9	-1.154	-1.570	0.00721	0.00859	3.579
8aC1	PCP/Amercoat 240	SP-3	Amercoat 240	28.1	-1.111	-1.570	0.00196	0.00156	0.463
8aC2	PCP/Amercoat 240	SP-3	Amercoat 240	18.4	-1.105	-1.570	0.00318	0.00289	0.561
8BC1	PCP/Amercoat 240	SP-7	Amercoat 240	16.4	-1.124	-1.570	0.00432	0.00677	0.472
8BC2	PCP/Amercoat 240	SP-7	Amercoat 240	18.2	-1.110	-1.570	0.00491	0.0047	0.620
9C1	PCP	SP-14	Fast Clad ER	19.3	-1.295	-1.570	0.00364	0.00459	0.735
9C2	PCP	SP-14	Fast Clad ER	25.7	-1.171	-1.570	0.00305	0.00399	0.696
10aC1	PCP/SeaGuard 5000 HS	SP-3	Fast Clad ER	30.9	-1.119	-1.570	0.00223	0.00105	0.935
10aC2	PCP/SeaGuard 5000 HS	SP-3	Fast Clad ER	29.6	-1.113	-1.570	0.00401	0.00429	0.656
10BC1	PCP/SeaGuard 5000 HS	SP-7	Fast Clad ER	28.4	-1.122	-1.598	0.00259	0.00126	1.32
10BC2	PCP/SeaGuard 5000 HS	SP-7	Fast Clad ER	31.8	-1.1803	-1.598	0.00426	0.00188	0.748
10yC1	PCP/SeaGuard 5000 HS	SP-14	Fast Clad ER	17.3	-1.126	-1.570	0.00418	0.00419	0.722
10yC2	PCP/SeaGuard 5000 HS	SP-14	Fast Clad ER	22.1	-1.107	-1.570	0.00327	0.00682	0.823
11aC1	PCP/SeaGuard 5000 HS	SP-7	Dura Plate	38.3	-1.145	-1.570	0.00253	0.00196	0.610
11aC2	PCP/SeaGuard 5000 HS	SP-7	Dura Plate	35.5	-1.140	-1.570	0.00317	0.00380	1.194
11BC1	PCP/SeaGuard 5000 HS	SP-3	Dura Plate	27.4	-1.174	-1.570	0.00288	0.0025	0.597
11BC2	PCP/SeaGuard 5000 HS	SP-3	Dura Plate	33.2	-1.197	-1.570	0.00256	0.00227	0.443

Figure 19 shows the relationship between cathodic disbondment distance and the average measured coating thickness. The data show that disbondment tends to decrease slightly as coating thickness increases from 15 to 40 mils. More importantly the graph highlights three outliers. The two thin coatings with higher disbondment are both from system 7. The third "outlier" was one of the duplicate panels for system 1β. The reason for the disparate performance of the two panels from this system is not readily apparent.

Figure 20 through Figure 22 are boxplots of the cathodic disbondment data grouped by generic systems and secondary surface preparation. The "o" markers indicate outliers. The first and fifth quartiles are represented by the whiskers, the second and fourth quartiles are represented by the box, and the center line represents the median value. The "x" inside the box represents the mathematical average of each data set.

Figure 20 suggests that the systems incorporating a Type VI primer under a Type VII coating may exhibit slightly less risk of cathodic disbondment than the approved coating systems, though the difference is highly influenced by three "outliers" previously mentioned. Figure 21 is a similar plot with the outliers removed. The data suggest that there is no increased risk of cathodic disbondment by allowing Type VII to be applied over retained Type VI epoxy. Figure 22 compares the data by secondary surface preparation method. Note that the analysis eliminated the three previously mentioned outliers (three markers in the "SP-7" data set). The data suggests some increased risk of cathodic disbondment with an SP-7 surface preparation versus SP-3 or SP-14.

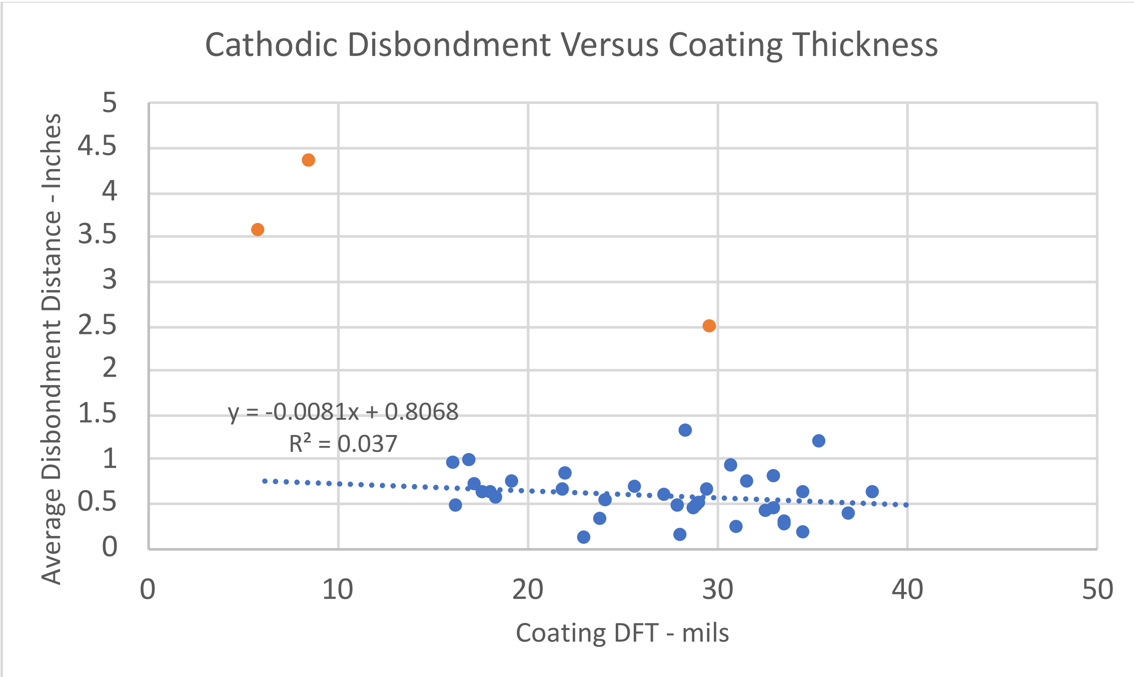


Figure 19. Impact of coating thickness on average disbondment distance.

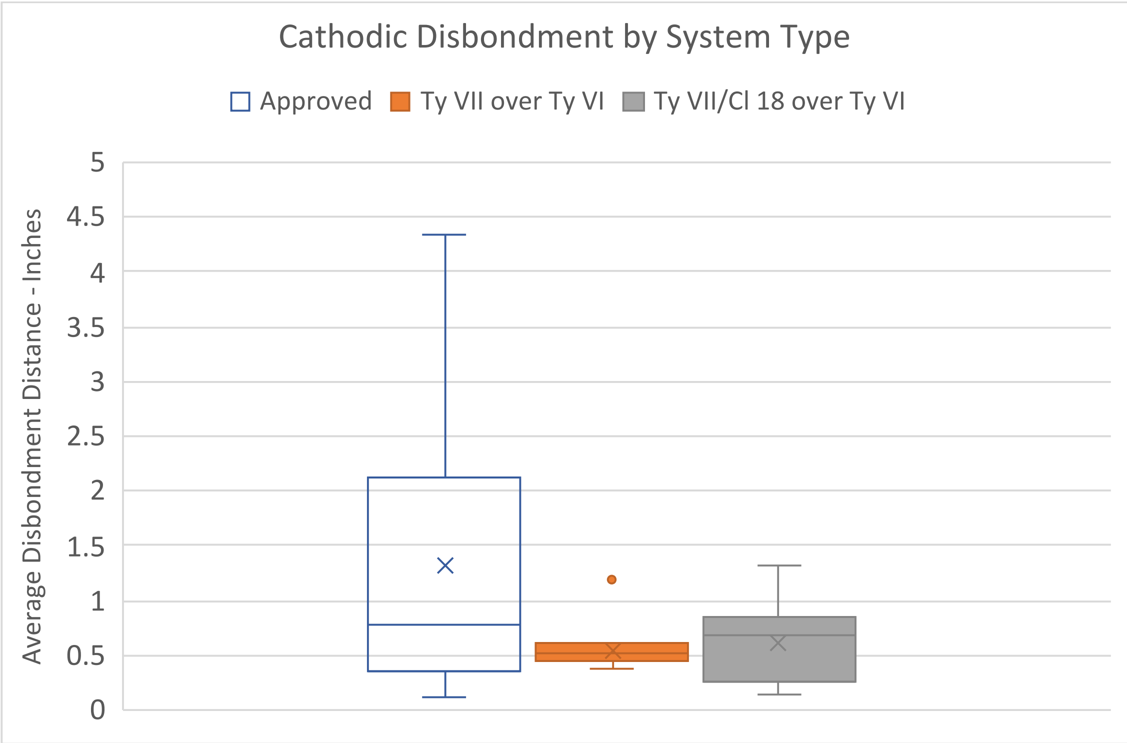


Figure 20. Cathodic disbondment undercutting grouped by system type (e.g., approved versus Type VII over Type VI).

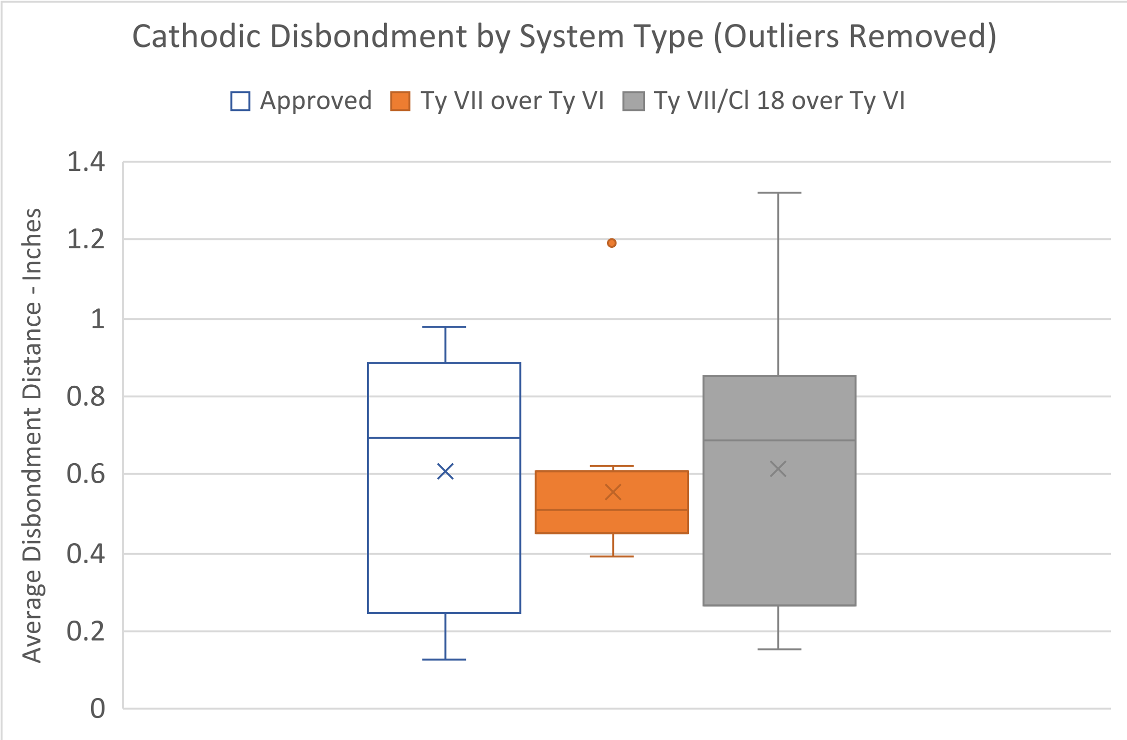


Figure 21. Data from Figure 20 with "outliers" removed.

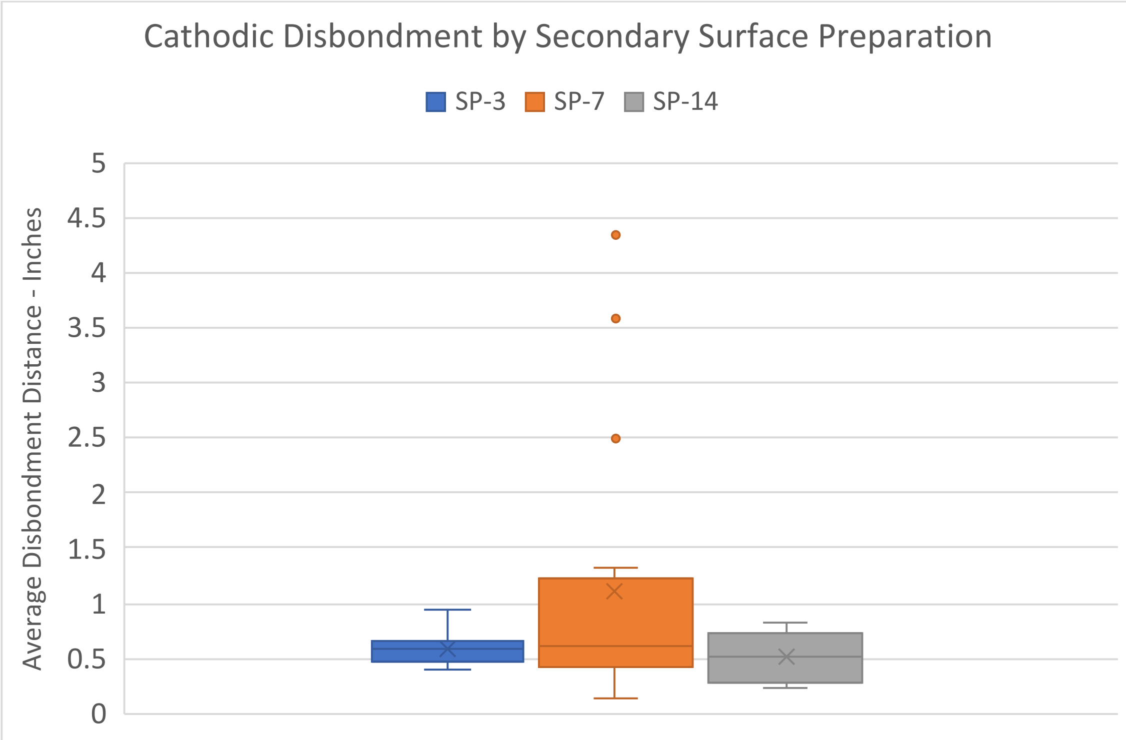


Figure 22. Cathodic disbondment undercutting grouped by secondary surface preparation.

5.5 Prohesion Cycle Testing

Prohesion test panels were inspected and photographed at 100, 300, 500, and 1000 hours. During these inspections, the panels were visually rated as follows:

- Through film corrosion IAW ASTM D610[8]
- Blistering of the coating system determined visually and rated IAW ASTM D714[9]
- Underfilm corrosion

After 1000 hours of exposure testing, very little through film corrosion was seen. The lowest of the ASTM D610 ratings were 8P (0.03-0.1% pinpoint rusting) and most of the panels were rated at a 10. None of the panels exhibited any blistering. Appendix C contains photos of the panels at each inspection cycle and after destructive cutback.

Figure 23 shows the undercutting for each of the test systems through the test period. Inspections at 100, 300, and 500 hours are based on visual indications of undercutting such as coating blisters. Visual inspections for underfilm corrosion

[8] ASTM D610 - "Standard Practice for Evaluating Degree of Rusting on Painted Steel Surfaces."
[9] ASTM D714 - "Standard Test Method for Evaluating Degree of Blistering of Paints."

exhibited undercutting from 0 to 2 millimeters at 500 hours. At 1000 hours, cutback observed after the destructive evaluation was 0.5 to 3.5 millimeters for all but one system. System 2A (PCP/Interbond 998) exhibited 6.5 millimeters of undercutting at the 1000-hour destructive evaluation. Table 11 presents the destructively observed undercutting after 1000 hours of testing.

Checking was observed during the 1,000-hour inspection on the coating systems with Interbond 988 final coat (systems 1α through 4β). Figure 24 and Figure 25 illustrate the range of checking observed during the inspections. There were not any noteworthy concerns during the coating application that could have resulted in checking. Since the checking occurred independent of the primer or surface preparation process, it is not of any concern to the objectives of the test program.

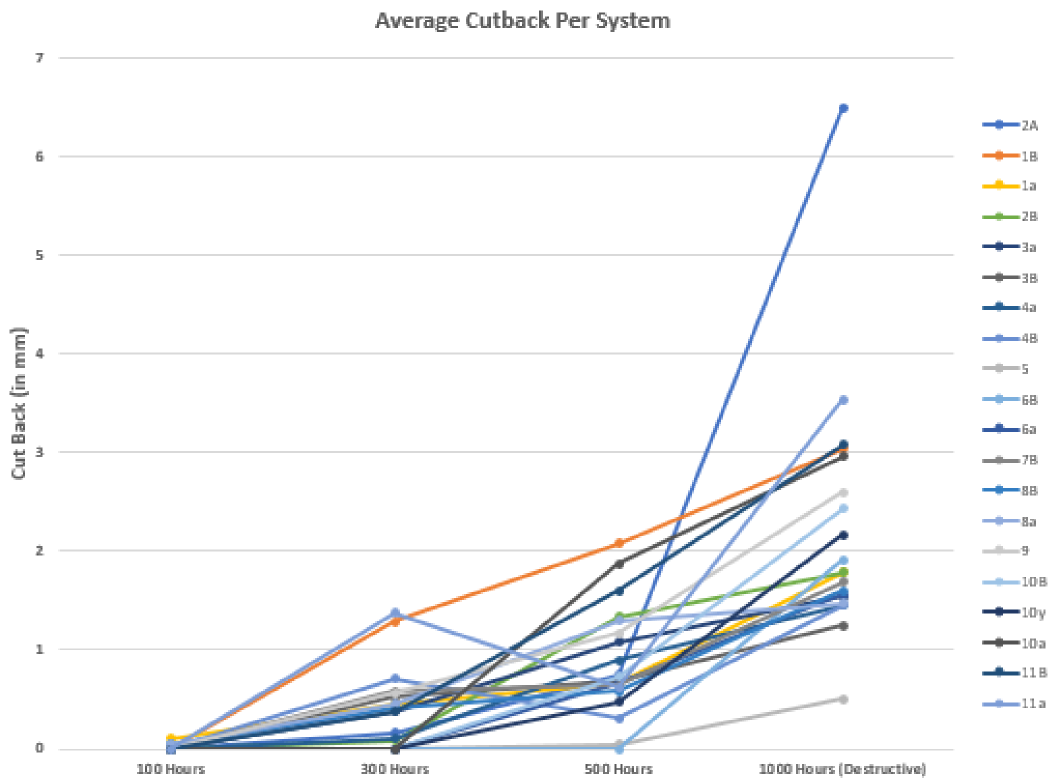


Figure 23. Prohesion Cutback Ratings

Table 11. Average Undercutting Observed after 1000-hour Destructive Inspection

Coating System			Surface Prep		
ID	Pre-Weathering	After Weathering	SP-3/SP-11	SP-7/SP-10	SP-14/SP-10
1	PCP/Interbond 998	Interbond 998	1.79	3.04	
2	PCP	Interbond 998/Interbond 998		6.5	
3	PCP/Intergard 264	Interbond 998 (+2 mils)	1.54	1.25	
4	PCP/Intergard 264	Interbond 998/Interbond 998	1.46	1.46	
5	PCP	Interline 783			0.5
6	PCP/Intergard 264	Interline 783		1.56	1.92
7	PCP	Amercoat 240		1.69	
8	PCP/Amercoat 240	Amercoat 240	1.48	1.6	
9	PCP	Fast Clad ER			2.6
10	PCP/SeaGuard 5000 HS	Fast Clad ER	2.96	2.44	2.17
11	PCP/SeaGuard 5000 HS	DuraPlate	3.54	3.08	

Figure 24. Checking on Interbond 998 Topcoat

Figure 25. Least amount of Checking Displayed on Interbond 998

5.6 Condensing Humidity Exposure

The test is primarily designed to induce osmotic blistering if any soluble materials remain within the finished coating system. No blistering was observed on any of the systems – all panes were rated a "10" for blistering at each inspection interval. A few, very small corrosion spots were observed on panels from systems 5, 6, 7, 8, 10 and 11. However, the corrosion appears to be from steel embedded in the finished coating (the coating was applied in the vicinity of an automated blast booth) rather than a through-film defect.

After the inspection, the exposed face of each test panels was subjected to three impact tests as described in 4.5.6. Appendix E includes photographs of the test panels after condensing humidity and impact testing. Table 12 presents the results of the impact testing as the percent of impact sites exhibiting a coating holiday. The data show that systems 5, 8, and 9 are more susceptible to impact damage than the remaining systems. Interestingly, systems 5 and 9 (Type VII/Class 18 materials) were less susceptible to impact damage when applied over a Type VI primer (systems 6 and 10).

Table 12 - Percent of Impact Sites Exhibiting a Coating Holiday

Coating System			Surface Prep		
ID	Pre-Weathering	After Weathering	SP-3/SP-11	SP-7/SP-10	SP-14/SP-10
1	PCP/Interbond 998	Interbond 998	0%	0%	
2	PCP	Interbond 998/Interbond 998		17%	
3	PCP/Intergard 264	Interbond 998 (+2 mils)	17%	17%	
4	PCP/Intergard 264	Interbond 998/Interbond 998	0%	17%	
5	PCP	Interline 783			100%
6	PCP/Intergard 264	Interline 783		17%	33%
7	PCP	Amercoat 240		33%	
8	PCP/Amercoat 240	Amercoat 240	100%	100%	
9	PCP	Fast Clad ER			67%
10	PCP/SeaGuard 5000 HS	Fast Clad ER	0%	0%	33%
11	PCP/SeaGuard 5000 HS	DuraPlate	0%	17%	

6.0 Conclusions

The testing reported herein demonstrates:

- Dyne Pens will not be suitable for surface characterization in a ship yard.
- There seems to be little difference with applying a MIL-PRF-23236 Type VII coating on top of a retained MIL-PRF-23236 Type VI in regard to corrosion performance.
- There is no clear difference in corrosion resistance found in systems that received a scuffed/ sweep blast/ or SP-14.

7.0 Recommendations

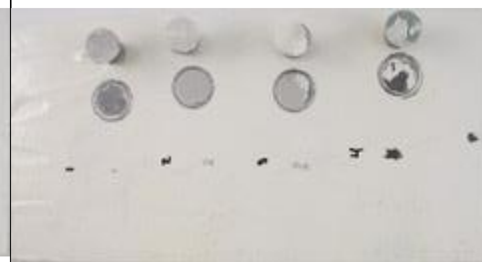
- Use the data provided in this report to support process changes that will improve the cost-effectiveness and quality of shipbuilding by allowing shipbuilders to strategically combine epoxy materials to best integrate painting into the shipbuilding process.

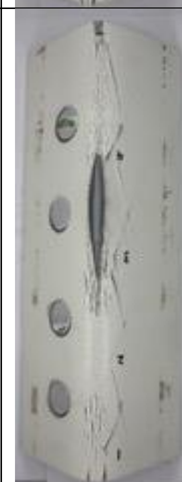
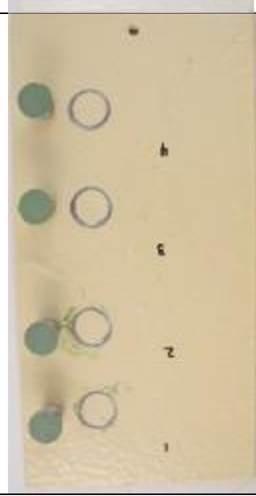
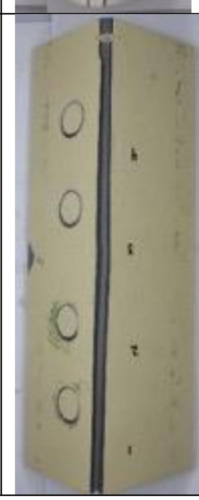
Appendix A. DFT Data

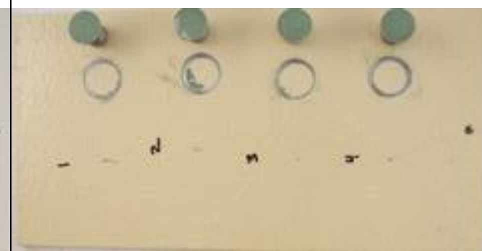
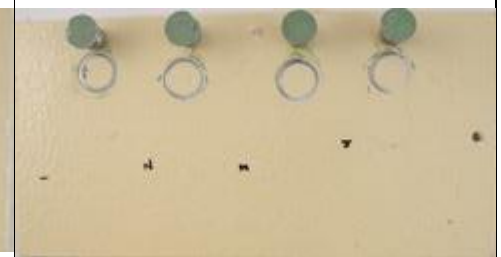
1αA-1	21.2	21.4	21.7	21.43
1αB-1	21.8	22.4	22.0	22.07
1αB-2	22.0	21.4	21.3	21.57
1αC-1	22.6	22.7	20.8	22.03
1αC-2	33.2	32.0	34.2	33.13
1αD-1	31.5	32.0	30.9	31.47
1αD-2	27.0	25.5	25.8	26.10
1βA-1	23.3	23.8	23.9	23.67
1βB-1	31.1	31.5	31.4	31.33
1βB-2	25.9	26.8	26.2	26.30
1βC-1	29.1	29.9	30.2	29.73
1βC-2	33.0	31.4	32.9	32.43
1βD-1	32.4	31.9	32.4	32.23
1βD-2	34.3	34.7	34.8	34.60
2A-1	18.9	19.4	19.1	19.13
2B-1	16.5	15.9	15.1	15.83
2B-2	16.7	15.2	15.0	15.63
2C-1	15.6	17.4	18.3	17.10
2C-2	16.2	15.7	16.8	16.23
2D-1	20.7	19.3	19.4	19.80
2D-2	14.6	15.8	14.9	15.10
3αA-1	27.0	24.5	25.2	25.57
3αB-1	37.7	38.2	39.5	38.47
3αB-2	30.4	31.0	31.1	30.83
3αC-1	37.5	36.1	37.5	37.03
3αC-2	29.7	28.1	29.1	28.97
3αD-1	29.7	25.0	24.6	26.43
3αD-2	29.8	31.2	29.8	30.27
3βA-1	31.8	32.5	32.1	32.13
3βB-1	21.1	24.8	23.2	23.03
3βB-2	19.5	21.5	19.1	20.03
3βC-1	16.9	18.5	18.0	17.80
3βC-2	31.7	32.9	33.4	32.67
3βD-1	27.5	28.0	25.7	27.07
3βD-2	28.9	28.2	29.5	28.87
4αA-1	35.0	33.3	33.5	33.93
4αB-1	36.9	36.5	37.3	36.90
4αB-2	34.4	34.3	32.6	33.77
4αC-1	25.1	24.2	23.5	24.27
4αC-2	32.5	36.9	34.7	34.70
4αD-1	31.6	30.3	30.2	30.70
4αD-2	36.9	37.9	37.8	37.53
4βA-1	24.1	20.5	24.6	23.07
4βB-1	18.1	17.3	25.5	20.30
4βB-2	25.9	25.5	24.0	25.13
4βC-1	29.8	29.3	28.6	29.23
4βC-2	28.1	28.4	30.1	28.87
4βD-1	22.8	24.2	23.2	23.40
4βD-2	19.3	22.4	21.3	21.00
5A-1	34.2	36.8	37.0	36.00
5B-1	38.7	39.0	40.8	39.50
5B-2	38.8	39.1	41.1	39.67
5C-1	30.0	31.7	31.8	31.17
5C-2	33.8	32.9	34.1	33.60
5D-1	36.7	38.7	39.1	38.17
5D-2	33.5	28.0	30.4	30.63
6αA-1	31.5	31.3	31.5	31.43
6αB-1	31.1	34.4	33.1	32.87
6αB-2	33.9	32.7	35.7	34.10
6αC-1	28.0	28.0	28.7	28.23
6αC-2	34.9	35.2	33.9	34.67
6αD-1	38.1	36.8	31.4	35.43
6αD-2	43.5	40.3	40.6	41.47
6βA-1	25.4	24.4	24.8	24.87
6βB-1	24.5	22.5	23.6	23.53
6βB-2	23.3	24.5	22.2	23.33
6βC-1	33.8	33.8	33.3	33.63
6βC-2	25.3	22.3	24.1	23.90
6βD-1	29.4	29.6	30.0	29.67
6βD-2	32.4	30.7	31.6	31.57
7A-1	7.9	8.7	8.8	8.47
7B-1	9.6	8.2	9.9	9.23
7B-2	5.4	5.1	5.1	5.20
7C-1	8.3	10.2	7.6	8.70
7C-2	6.1	6.1	5.5	5.90
7D-1	5.8	7.2	6.0	6.33
7D-2	7.7	7.1	8.1	7.63
8αA-1	14.7	14.6	14.9	14.73
8αB-1	26.7	27.7	26.3	26.90
8αB-2	14.3	13.7	14.2	14.07
8αC-1	29.4	26.8	28.0	28.07
8αC-2	18.7	18.1	18.5	18.43
8αD-1	11.9	11.9	11.4	11.73
8αD-2	26.0	26.5	26.2	26.23
8βA-1	13.4	11.3	12.6	12.43
8βB-1	24.4	23.9	24.1	24.13
8βB-2	12.8	11.1	10.6	11.50
8βC-1	17.0	16.2	16.0	16.40
8βC-2	17.1	18.8	18.7	18.20
8βD-1	14.6	14.9	14.8	14.77
8βD-2	13.8	13.5	13.8	13.70
9A-1	23.4	24.0	24.4	23.93
9B-1	10.2	9.5	9.7	9.80
9B-2	19.6	21.4	20.0	20.33
9C-1	18.7	19.5	19.6	19.27
9C-2	26.1	25.7	25.4	25.73
9D-1	19.2	19.1	18.1	18.80
9D-2	7.5	7.9	7.5	7.63
10αA-1	37.6	38.3	40.3	38.73
10αB-1	46.4	46.4	47.0	46.60
10αB-2	30.4	30.8	29.9	30.37
10αC-1	30.6	31.2	30.8	30.87
10αC-2	29.7	30.2	28.9	29.60
10αD-1	37.6	37.1	37.4	37.37
10αD-2	25.6	25.4	24.8	25.27
10βA-1	29.9	25.7	23.6	26.40
10βB-1	28.6	29.2	29.4	29.07
10βB-2	27.9	27.4	28.2	27.83
10βC-1	24.1	23.6	26.3	24.67
10βC-2	28.2	28.5	28.5	28.40
10βD-1	32.2	31.6	31.5	31.77
10βD-2	32.4	33.1	32.8	32.77
10γA-1	20.0	20.2	19.6	19.93
10γB-1	20.3	19.9	21.2	20.47
10γB-2	23.6	22.3	23.8	23.23
10γC-1	16.6	17.1	18.2	17.30
10γC-2	22.6	21.7	22.0	22.10
10γD-1	19.0	18.9	19.1	19.00
10γD-2	15.4	14.4	14.6	14.80
11αA-1	39.3	39.5	38.8	39.20
11αB-1	32.4	32.5	32.2	32.37
11αB-2	40.1	38.4	39.0	39.17
11αC-1	37.1	38.8	39.0	38.30
11αC-2	35.7	35.1	35.6	35.47
11αD-1	40.6	39.3	39.9	39.93
11αD-2	28.7	28.5	29.2	28.80
11βA-1	29.3	30.2	29.1	29.53
11βB-1	31.7	34.1	33.7	33.17
11βB-2	41.9	41.9	42.3	42.03
11βC-1	27.3	27.4	27.5	27.40
11βC-2	33.1	33.0	33.4	33.17
11βD-1	34.7	34.7	34.6	34.67
11βD-2	39.8	39.1	39.2	39.37

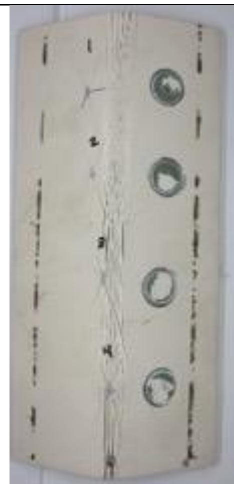
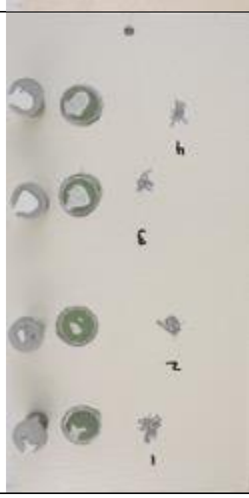
Appendix B. Adhesion and Flexibility Test Photos

Scenario	Adhesion Test Results	Bend 1 (50°)	Bend 2 (80°)	Bend 3 (110°)
1αA1 1st - PCP/Interbond 998 Prep - SP-3/SP-11 2nd - Interbond 998 3rd - N/A				
1βA1 1st - PCP/Interbond 998 Prep - SP-7/SP-10 2nd - Interbond 998 3rd - N/A				

3βA1 1st - PCP/Intergard 264 Prep - SP-7/SP-10 2nd - Interbond 998 (+2mils) 3rd - N/A	**3αA1** 1st - PCP/Intergard 264 Prep - SP-3/SP-11 2nd - Interbond 998 (+2mils) 3rd - N/A	**2B1** 1st - PCP Prep - SP-7/SP-10 2nd - Interbond 998 3rd - Interbond 998
		
		
		
		

4αA1 1st - PCP/Intergard 264 Prep - SP-3/SP-11 2nd - Interbond 998 3rd - Interbond 998				
4βB1 1st - PCP/Intergard 264 Prep - SP-7/SP-10 2nd - Interbond 998 3rd - Interbond 998				
5A1 1st - PCP Prep - SP-14/SP-10 2nd - Interline 783 3rd - N/A			Photo Not Taken	

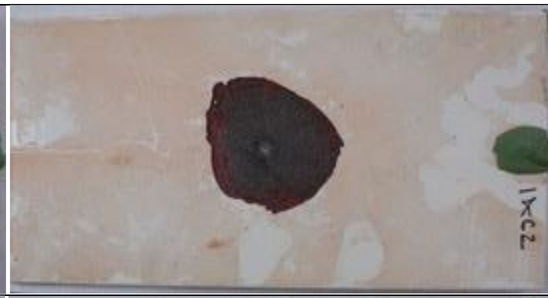
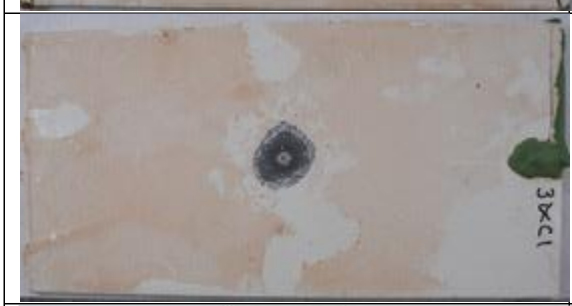
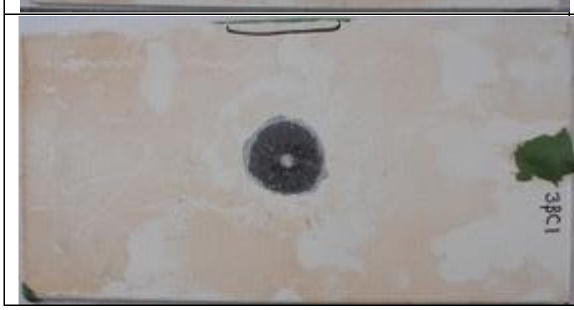
7A1 1^{st} - PCP Prep - SP-7/SP-10 2^{nd} - Amercoat 240 3^{rd} - N/A	**6βA1** 1^{st} - PCP/Intergard 264 Prep - SP-14/SP-10 2^{nd} - Interline 783 3^{rd} - N/A	**6αA1** 1^{st} - PCP/Intergard 264 Prep - SP-7/SP-10 2^{nd} - Interline 783 3^{rd} - N/A
		
		
		
		

8αA1 1^{st} - PCP/Amercoat 240 Prep - SP-3/SP-11 2^{nd} - Amercoat 240 3^{rd} - N/A				
8βA1 1^{st} - PCP/Amercoat 240 Prep - SP-7/SP-10 2^{nd} - Amercoat 240 3^{rd} - N/A				
9A1 1^{st} - PCP Prep - SP-14/SP-10 2^{nd} - Fast Clad ER 3^{rd} - N/A			Photo Not Taken	

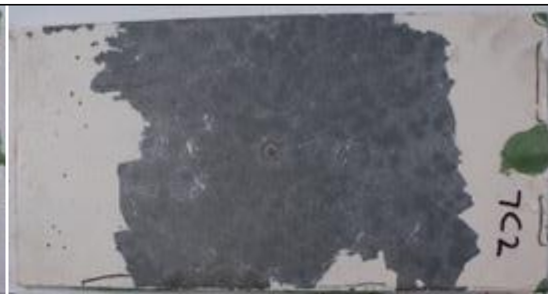
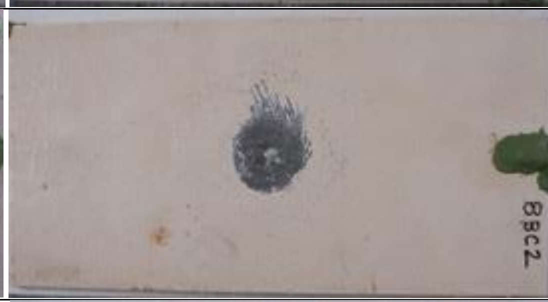
10ϒA1 1st - PCP/Seaguard 5000 HS Prep - SP-14/SP-10 2nd - Fast Clad ER 3rd - N/A	**10βA1** 1st - PCP/Seaguard 5000 HS Prep - SP-7/SP-10 2nd - Fast Clad ER 3rd - N/A	**10αA1** 1st - PCP/Seaguard 5000 HS Prep - SP-3/SP-11 2nd - Fast Clad ER 3rd - N/A
		
		
		
		

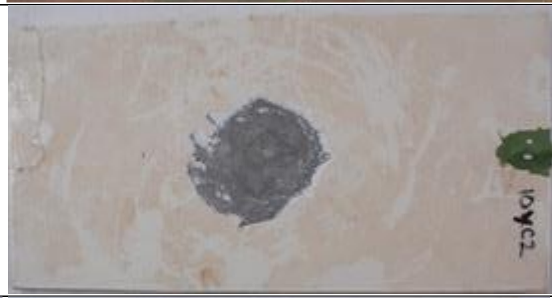
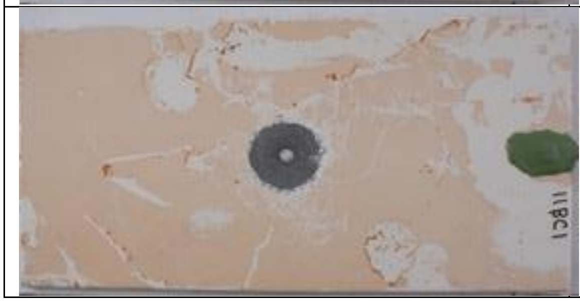
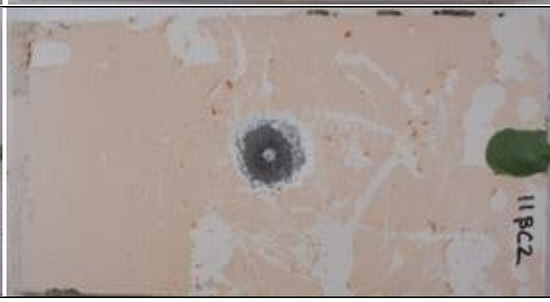
11αA1 1^{st} - PCP Prep - SP-3/SP-11 2^{nd} - Dura Plate 3^{rd} - N/A				
11βA1 1^{st} - PCP Prep - SP-7/SP-10 2^{nd} - Dura Plate 3^{rd} - N/A				

Appendix C. Cathodic Protection Compatibility Test Panels

C1	C2	Panel Scenario
		**<u>1α</u>** 1^{st} - PCP/Interbond 998 Prep - SP-3 2^{nd} - Interbond 998 3^{rd} - N/A
		**<u>1β</u>** 1^{st} - PCP/Interbond 998 Prep - SP-7 2^{nd} - Interbond 998 3^{rd} - N/A
		**<u>2</u>** 1^{st} - PCP Prep - SP-7 2^{nd} - Interbond 998 3^{rd} - Interbond 998
		**<u>3α</u>** 1^{st} - PCP/Intergard 264 Prep - SP-3 2^{nd} - Interbond 998 (+2mils) 3^{rd} - N/A
		**<u>3β</u>** 1^{st} - PCP/Intergard 264 Prep - SP-7 2^{nd} - Interbond 998 (+2mils) 3^{rd} - N/A

		**<u>4α</u>** 1st - PCP/Intergard 264 Prep - SP-3 2nd - Interbond 998 3rd - Interbond 998
		**<u>4β</u>** 1st - PCP/Intergard 264 Prep - SP-7 2nd - Interbond 998 3rd - Interbond 998
		**<u>5</u>** 1st - PCP Prep - SP-14 2nd - Interline 783 3rd - N/A
		**<u>6α</u>** 1st - PCP/Intergard 264 Prep - SP-7 2nd - Interline 783 3rd - N/A
		**<u>6β</u>** 1st - PCP/Intergard 264 Prep - SP-14 2nd - Interline 783 3rd - N/A

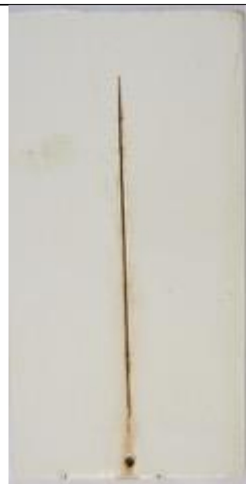
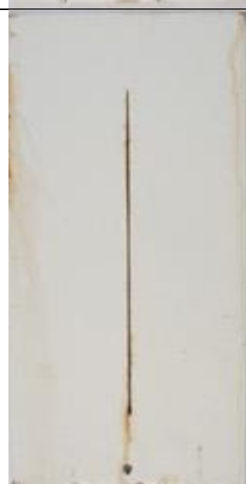
		**7** 1st - PCP Prep - SP-7 2nd - Amercoat 240 3rd - N/A
		**8α** 1st - PCP/Amercoat 240 Prep - SP-3 2nd - Amercoat 240 3rd - N/A
		**8β** 1st - PCP/Amercoat 240 Prep - SP-7 2nd - Amercoat 240 3rd - N/A
		**9** 1st - PCP Prep - SP-14 2nd - Fast Clad ER 3rd - N/A
		**10α** 1st - PCP/Seaguard 5000 HS Prep - SP-3 2nd - Fast Clad ER 3rd - N/A

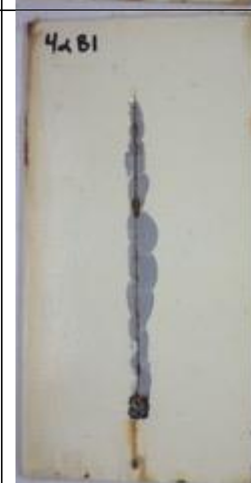
		**10β** 1st - PCP/Seaguard 5000 HS Prep - SP-7 2nd - Fast Clad ER 3rd - N/A
		**10Υ** 1st - PCP/Seaguard 5000 HS Prep - SP-14 2nd - Fast Clad ER 3rd - N/A
		**11α** 1st - PCP Prep - SP-3 2nd - Dura Plate 3rd - N/A
		**11β** 1st - PCP Prep - SP-7 2nd - Dura Plate 3rd - N/A

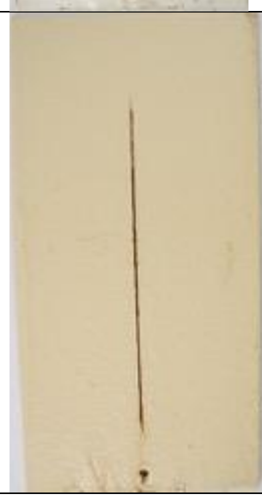
Appendix D. Prohesion Test Photographs

	100hr	300hr	500hr	1000hr	1000hr Destructive
1αB1					
1αB2					
1βB1					

1βB2					
2A1					
2B2					

3αB1					
3αB2					
3βB1					

3βB2					
4αB1					
4αB2					

4βA1					
4βB1					
5B1					

5B2	
6αB1	
6αB2	

6βB1					
6βB2					
7B1					

7B2					
8αB1					
8αB2					

8βB1					
8βB2					
9B1					

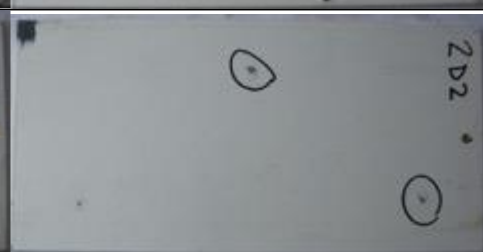
9B2					
10αB1					
10αB2					

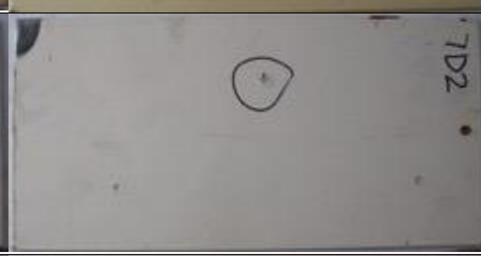
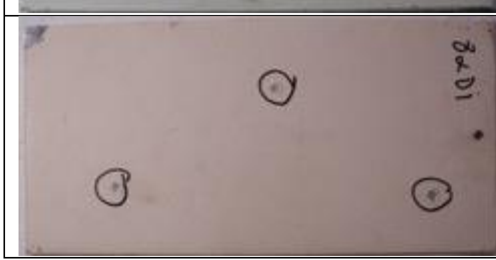
10βB1					
10βB2					
10ϒB1					

10ϒB2					
11αB1					
11αB2					

11βB1					
11βB2					

Appendix E. Condensing Humidity Test Panels After 160 in-lb Impact Test

		**1αD** 1st - PCP/Interbond 998 Prep - SP-3 2nd - Interbond 998 3rd - N/A
		**1βD** 1st - PCP/Interbond 998 Prep - SP-7 2nd - Interbond 998 3rd - N/A
		**2D** 1st - PCP Prep - SP-7 2nd - Interbond 998 3rd - Interbond 998
		**3αD** 1st - PCP/Intergard 264 Prep - SP-3 2nd - Interbond 998 (+2mils) 3rd - N/A
		**3βD** 1st - PCP/Intergard 264 Prep - SP-7 2nd - Interbond 998 (+2mils) 3rd - N/A
		**4αD** 1st - PCP/Intergard 264 Prep - SP-3 2nd - Interbond 998 3rd - Interbond 998

		**4βD** 1st - PCP/Intergard 264 Prep - SP-7 2nd - Interbond 998 3rd - Interbond 998
		**5D** 1st - PCP Prep - SP-14 2nd - Interline 783 3rd - N/A
		**6αD** 1st - PCP/Intergard 264 Prep - SP-7 2nd - Interline 783 3rd - N/A
		**6βD** 1st - PCP/Intergard 264 Prep - SP-14 2nd - Interline 783 3rd - N/A
		**7D** 1st - PCP Prep - SP-7 2nd - Amercoat 240 3rd - N/A
		**8αD** 1st - PCP/Amercoat 240 Prep - SP-3 2nd - Amercoat 240 3rd - N/A

		**<u>8βD</u>** 1st - PCP/Amercoat 240 Prep - SP-7 2nd - Amercoat 240 3rd - N/A
		**<u>9D</u>** 1st - PCP Prep - SP-14 2nd - Fast Clad ER 3rd - N/A
		**<u>10αD</u>** 1st - PCP/Seaguard 5000 HS Prep - SP-3 2nd - Fast Clad ER 3rd - N/A
		**<u>10βD</u>** 1st - PCP/Seaguard 5000 HS Prep - SP-7 2nd - Fast Clad ER 3rd - N/A
		**<u>10ϒD</u>** 1st - PCP/Seaguard 5000 HS Prep - SP-14 2nd - Fast Clad ER 3rd - N/A
		**<u>11αD</u>** 1st - PCP Prep - SP-3 2nd - Dura Plate 3rd - N/A

		**11βD** 1^{st} - PCP Prep - SP-7 2^{nd} - Dura Plate 3^{rd} - N/A