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Effect of Surface Preparation Method on MIL-PRF-24667 Nonskid Performance

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14. ABSTRACT

This report provides the results of MIL-PRF-24667 nonskid coating systems applied to steel substrates that were prepared using various commercial surface preparation methods. The surface preparation methods selected for testing were NACE 2/SSPC-SP 10 using angular mineral grit (SP 10 Grit), NACE 2/SSPC-SP 10 using rounded steel shot (SP 10 Shot), NACE 3/SSPC-SP 6 using angular mineral grit (SP 6 Grit), and NACE/SSPC-SP WJ-2/L using fresh water (UHPWJ). A combination of MIL-PRF-24667 tests and other custom tests developed by the Naval Research Laboratory (NRL) were performed to evaluate the nonskid coatings adhesion and resistance to undercutting corrosion when applied over the various surface conditions. A demonstration was also performed on an active USN ship to compare preparation methods (production rates, surface profile measurements, and in-service performance) on a large scale, over severely weathered (i.e., pitted) steel.

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TABLE OF CONTENTS

1 INTRODUCTION 1
1.1 Background 1
1.2 Objective 2
2 APPROACH 2
2.1 Coatings Selection 2
2.2 Substrate Preparation 3
2.3 Coating Application 8
3 EXPERIMENTAL 9
3.1 Impact Resistance 9
3.2 Peeling Resistance 10
3.3 Accelerated Corrosion Test 11
3.4 Atmospheric Corrosion Test 12
3.5 Shipboard Test 12
4 RESULTS AND DISCUSSION 13
4.1 Impact Resistance 14
4.2 Peeling Resistance 17
4.3 Accelerated Corrosion Test 20
4.4 Atmospheric Corrosion Test 23
4.5 Shipboard Test 28
5 CONCLUSIONS 30
6 REFERENCES 31

TABLE OF FIGURES

Figure 1 – Nonskid removal by UHPWJ on a flight deck 1
Figure 2 – Test panel after salt spray (left) and after UHPWJ (right) to remove rust and chlorides 4
Figure 3 – Images of final surface preparation for test panels 5
Figure 4 – Close-up images of test panel surfaces in areas with and without black staining 5
Figure 5 – Initial condition of DDG missile deck (left) and after UHPWJ (right) to remove nonskid coating 6
Figure 6 – Overview of the DDG missile deck after final surface preparation 7
Figure 7 – Close-up images of each surface condition on the DDG missile deck 8
Figure 8 – Impact sequence for impact resistance test 9
Figure 9 – Peel resistance test setup (left) and test panel after the mandrel bend (right) 10
Figure 10 – Impact sequence for the accelerated corrosion test 11
Figure 11 – Test panel layout for the atmospheric corrosion test 12
Figure 12 – Deck layout for shipboard test on DDG missile deck 13
Figure 13 – As-received impact resistance results for Nonskid A 15
Figure 14 – 15 day immersion impact resistance results for Nonskid A 15
Figure 15 – As-received impact resistance results for Nonskid B 16
Figure 16 – 15 day immersion impact resistance results for Nonskid B 16
Figure 17 – As-received impact resistance results for Nonskid C 16
Figure 18 – 15 day immersion impact resistance results for Nonskid C 16
Figure 19 –As-received impact resistance results for Nonskid D 17
Figure 20 –15 day immersion impact resistance results for Nonskid D 17
Figure 21 – Peel resistance results for Nonskid A 18
Figure 22 – Peel resistance results for Nonskid B 18
Figure 23 – Peel resistance results for Nonskid C 19
Figure 24 – Peel resistance results for Nonskid D 19
Figure 25 – Accelerated corrosion cutback data 20
Figure 26 – Accelerated corrosion test results for Nonskid A 21
Figure 27 – Accelerated corrosion test results for Nonskid B 21
Figure 28 – Accelerated corrosion test results for Nonskid C 22
Figure 29 – Accelerated corrosion test results for Nonskid D 22
Figure 30 – Atmospheric corrosion cutback data for full nonskid system 23
Figure 31 – Atmospheric corrosion cutback data for nonskid primer and a thin color topping 24
Figure 32 – Atmospheric corrosion test panels (1'x2') for Nonskid A (full system) 24
Figure 33 – Atmospheric corrosion test panels (1'x2') for Nonskid A primer with a thin color topping 25
Figure 34 – Atmospheric corrosion test panels (1'x2') for Nonskid B (full system) 25
Figure 35 – Atmospheric corrosion test panels (1'x2') for Nonskid B primer with a thin color topping 26
Figure 36 – Atmospheric corrosion test panels (1'x2') for Nonskid C (full system) 26
Figure 37 – Atmospheric corrosion test panels (1'x2') for Nonskid C primer with a thin color topping 27
Figure 38 – Atmospheric corrosion test panels (1'x2') for Nonskid D (full system) 27
Figure 39 – Atmospheric corrosion test panels (1'x2') for Nonskid D primer with a thin color topping 28
Figure 40 – 19 month follow-up inspection of the shipboard nonskid test on a DDG missile deck 28
Figure 41 – Close-ups of section 1 that received 100% SP10 Grit surface preparation of the deck and appendages 29

Figure 42 – Close-up of section 2 that received 100% SP6 Grit surface preparation of the deck and appendages ... 29
Figure 43 – Close-up of section 3 that received 20% SP10 Grit/80% UPHWJ surface preparation of the deck and power tool cleaning of deck edges and appendages not accessible by UHPWJ ... 30

TABLE OF TABLES

Table 1 – MIL-PRF-24667 nonskid coatings ... 3
Table 2 – Substrate conditioning process ... 3
Table 3 – Abrasive blasting production rates obtained for final surface preparation of test panels ... 4
Table 4 – Test panel surface profile data measured using ASTM D4417 and ASTM 7127 ... 6
Table 5 – DDG missile deck surface profile data measured using ASTM D4417 and ASTM 7127 ... 8
Table 6 – DFT measurements for the epoxy primers ... 9
Table 7 – Test results summary ... 14
Table 8 – Impact resistance test results ... 15

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EFFECT OF SURFACE PREPARATION METHOD ON MIL-PRF-24667 NONSKID PERFORMANCE

1 INTRODUCTION

1.1 Background

MIL-PRF-24667 [1] nonskid coating systems are applied to exterior and interior decks on US Navy (USN) surface ships and aircraft carriers to provide a slip resistant surface for aircraft and people. The coating system is comprised of an epoxy primer applied directly to the steel deck for corrosion protection and a tough nonskid top coat that can withstand mechanical damage caused by aircraft landing gear, safety chains, and the movement of equipment. The nonskid coatings are applied over steel and aluminum decks that are prepared by abrasive blasting, ultra-high pressure waterjet (UHPWJ) cleaning, or power tool cleaning. The type of surface preparation selected is typically dependent on the location on ship where the nonskid system is applied. For example, a flight deck can only be prepared by UHPWJ or abrasive blasting to ensure the nonskid coating system can withstand the rigorous environment of flight deck operations. The most common method of surface preparation across the USN Fleet is UHPWJ according to NACE/SSPC-SP WJ-2 [2] because it does not require expensive containment to protect nearby people and equipment during operation, it efficiently removes the old nonskid coating with minimal clean-up, and cleans the steel by removing chlorides and other contaminants. An example of UHPWJ equipment being used to remove nonskid on a flight deck is provided in Figure 1.

Figure 1 – Nonskid removal by UHPWJ on a flight deck

Surface preparation and nonskid coating requirements for the USN are specified in NAVSEA Standard Item 009-32 [3]. Starting in 2018, an additional requirement was added to Standard Item 009-32 that states "*For flight deck areas, not to include aircraft elevator platform decks, receiving a nonskid system and prepared to NACE/SSPC-SP WJ-2, a minimum of 20 percent of the total area receiving a nonskid system must be abrasively blasted to an NACE 2/SSPC-SP 10 level of cleanliness.*" The requirement was

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added because UHPWJ does not reestablish an angular surface profile, and there was evidence that repeated use of UHPWJ would eventually degrade surface profile from general corrosion, pitting, and mechanical damage of the deck. The degraded surface profile would result in premature nonskid failure and costly repairs. Therefore, the intent of the new 20 percent NACE 2/SSPC-SP 10 [4] requirement in 2018 was to gradually reestablish an angular surface profile by abrasive blasting, targeting the areas of the flight deck most impacted by corrosion, pitting, and mechanical damage, to prolong the service life of flight deck nonskid coatings. To support transition of the new requirement, NAVSEA published additional information on the National Surface Treatment (NST) Center website (www.nstcenter.biz) to help clarify the flight deck surface conditions that require abrasive blasting during nonskid replacement and investigated alternative surface preparation methods, such as NACE 3/SSPC-SP 6 [5], Commercial Blast Cleaning, as a potential lower cost option that could be utilized over a larger percentage of the flight deck at a cost comparable to blasting 20 percent of the deck to NACE 2/SSPC-SP 10.

1.2 Objective

To assess the role of surface preparation, the approach would be to perform testing of MIL-PRF-24667 nonskid coating systems applied to steel substrates that were prepared using various commercial surface preparation methods. The surface preparation methods selected for testing were NACE 2/SSPC-SP 10 using angular mineral grit (SP 10 Grit), NACE 2/SSPC-SP 10 using rounded steel shot (SP 10 Shot), NACE 3/SSPC-SP 6 using angular mineral grit (SP 6 Grit), and NACE/SSPC-SP WJ-2/L using fresh water (UHPWJ). A combination of MIL-PRF-24667 tests and other custom tests developed by the Naval Research Laboratory (NRL) were performed to evaluate the nonskid coatings adhesion and resistance to undercutting corrosion when applied over the various surface conditions. A demonstration was also performed on an active USN ship to compare preparation methods (production rates, surface profile measurements, and in-service performance) on a large scale, over severely weathered (i.e., pitted) steel.

2 APPROACH

2.1 Coatings Selection

Five different nonskid coating systems were selected from the MIL-PRF-24667 qualified products list; the list of nonskid coatings and other technical information is provided in Table 1. Nonskid systems A – D were used for panel testing, and nonskid system E was used for the shipboard demonstration. The nonskid systems consisted of an epoxy primer and nonskid top coat. The minimum coating requirements in 009-32 for a nonskid system is one full coat of primer applied at the manufacturers recommended dry film thickness (DFT), one stripe coat, and one full coat of nonskid applied at the specified coverage rate.

Table 1 – MIL-PRF-24667 nonskid coatings

Nonskid System	MIL-PRF-24667 Type/Composition	# of Coats of Primer	Recommended Primer DFT
A	Type I / Comp D	1	3-9 mils/coat
B	Type I / Comp D	1	4-7 mils/coat
C	Type I / Comp D	2	4-7 mils/coat
D	Type V / Comp G	1	4-7 mils/coat
E	Type I / Comp G	2	3-9 mils/coat

2.2 Substrate Preparation

Ordinary strength Grade A steel test panels were procured for testing. The panel sizes were 6”x6”x0.25” for impact testing, 6”x12”x0.25” for sequential corrosion testing, 2”x12”x0.125” for peeling resistance, and 12”x24”x0.25” for atmospheric corrosion testing. The panels underwent a five step conditioning process to produce weathered/aged steel that is more representative of in-service steel decks prior to the final surface preparation step (step 6). Each step of the panel conditioning process is listed in Table 2.

The steel conditioning process deviates from the test panel requirements of MIL-PRF-24667C, which requires testing over brand new steel that has been cleaned to NACE 2/SSPC-SP 10 (baseline). However, because the qualified coatings have already been proven over a NACE 2/SSPC-SP 10 surface, testing over weathered/aged steel prepared using different methods of surface preparation provides an opportunity to establish a performance gradient for the different surface preparation methods; an example of a test panel after salt spray exposure with a uniformly rusted surface, and after UHPWJ preparation is provided in Figure 2. The initial condition of the test panels was determined using visual standard NACE VIS 7/SSPC-VIS 4 [6]. The initial condition was Condition C with 100% rust, and they were cleaned very thoroughly by UHPWJ with only light flash rust, corresponding to a C WJ-2/L surface condition.

Table 2 – Substrate conditioning process

Step	Process	Purpose
1	Abrasive blast the front face (test surface) with mineral grit and sweep blast the back face	Remove mill scale and prepare for back and edge coating
2	Shot blast the front face	Produce a peened surface, similar to that observed on in-service decks
3	Paint back face and edges	Prevent rusting during pre-weathering
4	Salt spray exposure for 7 days	Weather/rust front face of panels to be more representative of steel condition (i.e. chlorides) observed on in-service decks
5	SSPC-SP WJ-2 front faces	Remove surface rust and chlorides from the surface and reveal the existing profile
6	Final surface preparation	Produce final surface condition using SP10 Grit, SP10 Shot, or SP6 Grit prior to coating application

Figure 2 – Test panel after salt spray (left) and after UHPWJ (right) to remove rust and chlorides

After the test panels were cleaned by UHPWJ, the final surface preparation (step 6) was performed using a blast cabinet. Two different types of blast media were used for final preparation. 36 mesh aluminum oxide (AlOx) was used to produce the SP10 Grit and SP6 Grit surfaces, and a 50/50 blend of S390/S550 steel shot was used to produce the SP10 Shot surfaces.

Dwell time was recorded for each surface preparation method and was the primary factor to discern between SP10 Grit and SP6 Grit, along with the visual standard SSPC-VIS 1 [7]. The dwell time required to produce each surface condition was converted to square feet per hour (sqft/hr) to calculate the production rate; the measured production rates are provided in Table 3.

Images of three 2"x12"x0.125" test panels for each surface condition after final surface preparation are provided in Figure 3. The black staining that developed during the pre-weathering step could not be removed by UHPWJ. The SP10 Shot and SP6 Grit panels had faint shadows of the black staining that remained on the surface, whereas the black staining was mostly removed on the SP10 Grit test panels. Light flash rust also developed on the surface of the test panels after UHPWJ. The flash rust was partially removed when the panels were prepared by SP6 Grit, and completely removed by the SP10 Grit and SP10 Shot surface preparation methods; close-up images of the test panel surfaces are provided in Figure 4.

The images on the left side of Figure 4 were taken in areas of the test panel where there was no black staining. The images on the right side were taken in areas where black staining was present. The close-up images provided an obvious difference in the level of staining and flash rust that remained for each surface condition after final preparation.

Table 3 – Abrasive blasting production rates obtained for final surface preparation of test panels

Surface Preparation	Blast Media	Production Rate
SP10 Grit	36 Mesh AlOx	150-180 sqft/hr
SP10 Shot	S390/S550 Steel Shot	15 sqft/hr
SP6 Grit	36 Mesh AlOx	300-360 sqft/hr
UHPWJ	N/A	N/A

Figure 3 – Images of final surface preparation for test panels

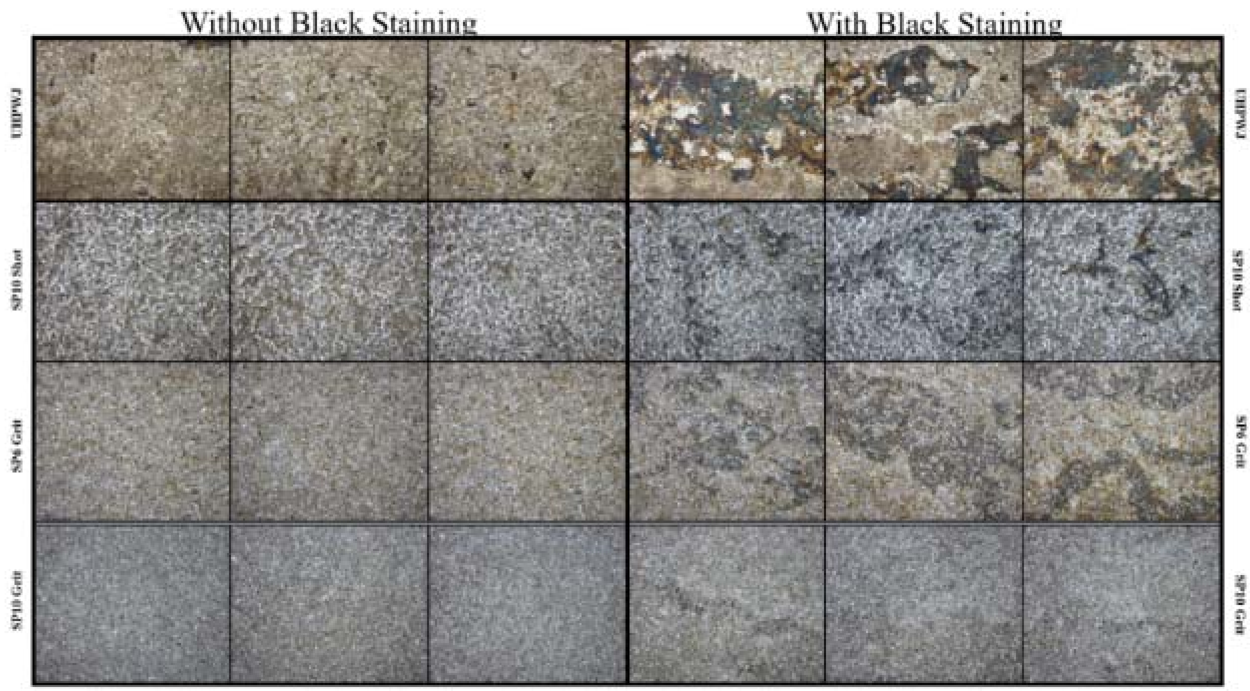


Figure 4 – Close-up images of test panel surfaces in areas with and without black staining

Surface profile measurements were taken in accordance with ASTM D4417 [8] using Method B (needle gauge) and Method C (replica tape) to obtain one-dimensional profile data. Data was also collected using ASTM D7127 [9] (stylus instrument) to obtain two-dimensional profile data; all profile data can be found in Table 4.

The needle gauge measurements listed are an average of ten spot measurements (one spot measurement equals 10 individual gauge readings) that were taken on ten randomly selected panels (one spot measurement per panel). Replica tape measurements are an average of six individual tape readings taken randomly from six different test panels (one tape per panel). Stylus measurements are an average of nine spot measurements taken randomly from nine different test panels (one stylus drag per panel). The profile depth data is consistent for each of the different methods used to measure profile depth. The primary difference in profile is the peak count and angularity, that was additional information resulting from the data using the stylus gauge. The peak count for both SP10 Grit and SP6 Grit are higher than SP10 Shot and UHPWJ. Angularity is also greater for SP10 Grit, SP6 Grit and UHPWJ when compared to SP10 Shot. This correlates with the visual appearance observed in the close-up images in Figure 4, which appears to show a more rounded SP10 Shot surface profile.

Table 4 – Test panel surface profile data measured using ASTM D4417 and ASTM 7127

Surface Preparation	Average Profile Depth (mils)			Average Peak Count (peak/in)	Average Angularity (degrees)
	Needle Gauge	Replica Tape	Stylus (Rt)	Stylus (Rpc)	Stylus (RΔq)
SP10 Grit	2.9	4	3.7	51	26
SP10 Shot	2.7	4.2	3.7	32	19
SP6 Grit	3.4	4	4	44	26
UHPWJ	2.8	4.2	4.5	36	25

The missile deck on a DDG was selected for the shipboard demonstration test. The deck was initially coated with a MIL-PRF-24667 nonskid coating. The nonskid system appeared to be well adhered with very little coating breakdown and rust bleed through. However, it was later revealed that the deck had recently been repainted for aesthetic purposes, which concealed a significant amount of nonskid degradation and rust bleed through. The demonstration area consisted of about 800 square feet divided evenly into three sections for 100% SP10 Grit (section 1), 100% SP6 Grit (section 2), and 80% UHPWJ/20% SP10 Grit (section 3); SP10 Shot was not a surface preparation method tested during the demonstration.

The nonskid coating was removed using a combination of UHPWJ and power tools and revealed a severely pitted and stained steel deck, as seen in Figure 5.

Figure 5 – Initial condition of DDG missile deck (left) and after UHPWJ (right) to remove nonskid coating

After the coatings were removed by UHPWJ, the final surface preparation was performed by using open abrasive blasting and a blend of 16, 24, and 36 mesh aluminum oxide. SSPC-VIS 1 was used to determine the initial condition and degree of cleanliness for sections 1 and 2. The time was also recorded for each section in order to determine a production rate (sqft/hr) for comparison to the laboratory panels:

- Section 1 was 300 square feet and it took 4 hours and 10 minutes to abrasive blast the entire surface to NACE 2/SSPC-SP 10 giving a production rate of 72 sqft/hr. The final condition was determined to be Condition D, SP 10 according to Table 1 of SSPC-VIS 1.
- Section 2 was 270 square feet, and it took 57 minutes to abrasive blast the entire surface to NACE 3/SSPC-SP 6, resulting in a production rate of 284 sqft/hr. The final condition was determined to be Condition D, SP 6.
- Section 3 production times for the 80/20 surface preparation (80% UHPWJ and 20% NACE 2/SSPC-SP 10) were not recorded. NACE VIS 7/SSPC-VIS 4 was used to determine the initial condition and degree of cleaning for the UHPWJ portion. After the final UHPWJ cleaning, the surface was found to be Condition D, WJ-2/L per NACE VIS 7/SSPC-VIS 4, Table 2.

Images of each final surface condition for sections 1, 2, and 3 are provided in Figure 6. Similar to the test panels, there is more black staining associated with the SP6 Grit and UHPWJ surfaces, while only faint shadows in the SP10 Grit surface. The flash rust was heavier in section 3, where UHPWJ was the final surface preparation; close-up images are provided in Figure 7.

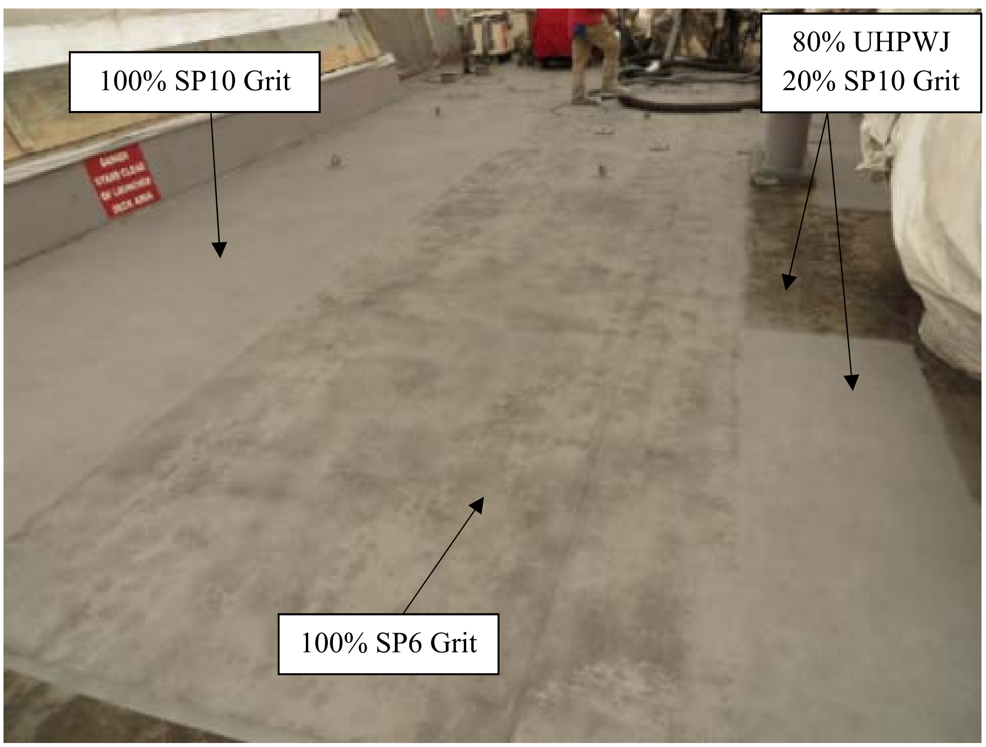


Figure 6 – Overview of the DDG missile deck after final surface preparation

Figure 7 – Close-up images of each surface condition on the DDG missile deck

ASTM D4417 Method B and ASTM D7127 were used for measuring surface profile on the DDG missile deck; the needle gauge and stylus profile measurements provided in Table 5 are each an average of 5 spot measurements per section. Replica tape could not be used because the profile depth exceeded the measurement range of the compressible film of the replica tape.

For the missile deck, there is a significant difference in the profile depth between the sections prepared with abrasive blasting to the section that received UHPWJ only. However, the peak count is also high for the UHPWJ, but peak count is also dependent on profile height, and this is consistent with a trend identified during a previous NRL program that found a deeper profile is accompanied by a lower density of peaks [10].

Table 5 – DDG missile deck surface profile data measured using ASTM D4417 and ASTM 7127

Surface Preparation	Profile Depth (mils)			Peak Count (peak/in)	Angularity (degrees)
	Needle Gauge	Replica Tape	Stylus (Rt)	Stylus (Rpc)	Stylus (RΔq)
Section 1 SP10 Grit	5.7	--	4.7	40.1	48
Section 2 SP6 Grit	6.5	--	4.3	42.3	45
Section 3 UHPWJ	2.8	--	3.1	56	44

2.3 Coating Application

Epoxy primers and nonskid top coats were applied to test plates and the DDG missile deck according to the NAVSEA-reviewed ASTM F718 [11] datasheets. The primers were applied by roller that had a 3/8" nap, while the nonskid coatings were applied using a napless roller with a final spread rate of 25 square feet per gallon.

Primer DFT was measured in accordance with SSPC-PA 2 [12] using a Type 2 gauge; the DFT measurements are provided in Table 6.

The primer DFT for the test plates was the average of 34 spot measurements per coating system (one spot measurement per test plate). The DFT for the DDG missile deck is the average of 15 spot measurements distributed equally over each demonstration section.

During test panel coating application, quarter inch thick masking tape was used on the 6”x12”x0.25” and 12”x24”x0.25” test panels to create a scribe down to bare metal for corrosion testing. Additionally, the peaks of the nonskid created by the napless roller on the 2”x12”x0.125” panels were pressed flat using a tongue depressor, while the nonskid was still wet to create a flat surface for bonding peel tabs that were used for testing peel resistance.

Table 6 – DFT measurements for the epoxy primers

Nonskid System	Substrate	# of Coats of Primer	Target DFT	Actual DFT (range)
A	Test Plate	1	3-9 mils	4.0 mils (5.4-3.0)
B	Test Plate	1	4-7 mils	4.4 mils (5.8-3.2)
C	Test Plate	2	8-14 mils	8.8 mils (10.1-8.6)
D	Test Plate	1	4-7 mils	4.1 mils (6.2-2.8)
E	DDG Section 1	2	6-18 mils	8.5 mils (10.9-6.8)
E	DDG Section 2	2	6-18 mils	9.2 mils (9.6-8.8)
E	DDG Section 3	2	6-18 mils	9.5 mils (11.2-8.7)

3 EXPERIMENTAL

3.1 Impact Resistance

Eight 6”x6”x1/4” steel test panels were prepared for each nonskid system (A-D) to evaluate impact resistance according to MIL-PRF-24667C, Section 3.6/4.5.3: two panels were prepared by SP10 Grit, two panels were prepared by SP10 Shot, two panels were prepared by SP6 Grit, and two panels were prepared by UHPWJ. For each surface condition tested, one panel was impacted with no treatment after coating application, and the other was impacted immediately after being removed from immersion in natural seawater for a period of 15 days.

Impact testing was performed using a device similar to that depicted in ASTM G14 [13], except that a 1.5” thick steel base was used in place of the v-block to secure the sample during impact. Impacts were made using a tup nose with a 5/8” hemispherical head and a tup weight of 4 pounds. Each panel was subjected to 25 impacts by the tup being dropped from a height of 4.0’. Impacts were made in the sequence identified in Figure 8. The impacts formed a 5 by 5 pattern within an area of about 9 square inches; nominally, a 3”x3” grid was created with impacts spaced 3/4” ± 1/16” center-to-center from one another.

2	15	11	7	3
6	19	23	20	16
10	22	25	24	12
14	18	21	17	8
1	5	9	13	4

Figure 8 – Impact sequence for impact resistance test

After the test panel was impacted 25 times, the panel was probed with a sharpened 1” steel chisel using less force than was required to remove coating that had not been impacted. Panels were evaluated by counting the number of impact pairs that were removed down to substrate thus connecting 2 points of impact.

Since the 5 by 5 pattern contains 40 pairs separated by 3/4", for each pair that is connected, the percentage of intact coating is reduced by 2.5%. The requirement for impact resistance of Type I and V nonskid coatings is that 95% of the coating must remain intact. This means that no more than 2 pairs or impacts can be connected after probing with a chisel for a sample to pass.

3.2 Peeling Resistance

Eight 2"x12"x1/8" steel test panels were prepared for each nonskid system (A-D) to evaluate peeling resistance of the nonskid system.

The nonskid peel resistance test is a custom test developed by NRL that uses a 5" mandrel to mechanically bend the nonskid panel that has two 2"x6"x1/8" peel tabs adhered to the nonskid surface using a toughened epoxy adhesive to create a sandwich panel. During the test, the sandwich panel is bent around a mandrel and the peel tabs begin to separate such that the panel/coating stack-up will begin separating at the weakest layer. A picture of the test setup and an example of a bent nonskid panel with the peel tabs separated after the peel resistance test is provided in Figure 9.

Figure 9 – Peel resistance test setup (left) and test panel after the mandrel bend (right)

For this test, two panels were prepared by SP10 Grit, two panels were prepared by SP10 Shot, two panels were prepared by SP6 Grit, and two panels were prepared by UHPWJ. The peel tabs were grit blasted on one side with aluminum oxide to an NACE 1/SSPC-SP 5 [14] surface cleanliness. Scotchweld DP460 epoxy adhesive was uniformly spread across the top nonskid surface of the test panel and the blasted surface of the peel tabs using a tongue depressor. For each nonskid panel, two peel tabs were adhered to the nonskid by placing the glue side down, such that the glue on the peel tab was pressed firmly into the glue on the nonskid panel. The peel tabs were clamped to the nonskid panel using Vise-Grip C clamps and allowed to cure for minimum 24 hours. The edges of the clamped panel were scraped to remove excess glue that was squeezed out during the clamping process.

After the sandwich panels were made, the center of the panel was placed over a 5" mandrel and the panel was bent using an Instron machine with the actuator moving at a rate of 5" per minute. The peel tabs were separated from the nonskid panel and the failure layer was evaluated. Failure at the substrate and primer interface is considered a failure.

3.3 Accelerated Corrosion Test

Eight 6”x12”x1/4” steel test panels were prepared for each nonskid system (A-D) to evaluate accelerated corrosion resistance using a sequential test described in MIL-PRF-24667C section 3.13/4.5.10.1, except resistance to wear (per MIL-PRF-24667, Section 4.5.4) was not performed. Two panels were prepared by SP10 Grit, two panels were prepared by SP10 Shot, two panels were prepared by SP6 Grit, and two panels were prepared by UHPWJ. A 5-3/4” long scribe down to substrate was made using masking tape that was centered vertically on the panels. The test panels were initially weathered in accordance with ASTM G154 [15], Cycle 2 (UV-B) for 400 hours using a QUV Accelerated Weathering Tester. Cycle 2 continuously alternates between 4 hours of UV with a panel temperature of 140 ± 10°F and 4 hours of condensation with a panel temperature of 120 ± 10°F.

Following ASTM G154, the panels were tested in accordance with ASTM B117 [16] for 2000 hours using a Q-FOG Cyclic Corrosion Tester; the ASTM B117 test method uses a 5% sodium chloride solution with a pH between 6.5-7.2. The salt solution was continuously sprayed in the chamber by a fog generator with a deposition rate of 1.0 to 2.0 mL/hour. The chamber temperature was maintained at 95 ± 3°F for the entire test. When the salt fog test was complete, the panels were removed from the chamber, rinsed with clean water to remove salt deposits and carefully examined, then the nonskid system was evaluated for loss of adhesion and corrosion along the scribe.

Following ASTM B117, the panels were impacted using the procedure as described in section 3.1 above, except the impact grid was modified such that only 20 impacts were made with no impact in the scribe area; a diagram of the impact grid is provided in Figure 10. After impacting the panel, the coating was probed using a sharpened 1” steel chisel, and corrosion undercutting was measured along the scribe using ASTM D1654 [17]. The maximum width of corrosion undercutting along the scribe (minus the width of the scribe) was measured and recorded.

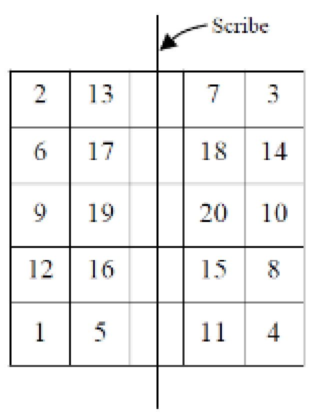


Figure 10 – Impact sequence for the accelerated corrosion test

3.4 Atmospheric Corrosion Test

One 12”x24”x1/4” steel panel was prepared for each nonskid system (A-D) to evaluate the corrosion resistance of panels exposed outdoors. The panels were sprayed with natural seawater daily, every 4 hours for 45 seconds to accelerate corrosion. One additional 12”x24”x1/4” panel was made for each nonskid system that was coated with primer only and a thin weather resistant color topping.

The oversized test panels were divided into four equal 5”x12” sections that were prepared with the four different surface conditions, as shown in Figure 11. A 21” scribe was made using 1/4” masking tape that was centered on the test panel and bisected each 5”x12” test area equally. A 2”x12” section on the edge of each panel was blasted to NACE 2/SSPC-SP 10 to provide space for the scribe to terminate without incurring edge effects. The panels were placed horizontally on a rack that was located on the Mole Pier at the NRL Marine Corrosion Facility, Key West, FL for 1 year. After 1 year, the panels were removed from the rack and the scribes were evaluated in accordance with ASTM D1654 to measure corrosion undercutting.

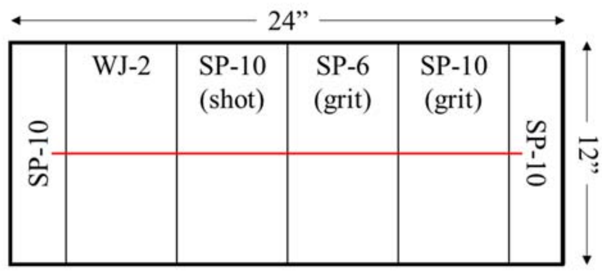


Figure 11 – Test panel layout for the atmospheric corrosion test

3.5 Shipboard Test

An 800 square foot area of a DDG missile deck was used for shipboard testing. The demonstration area was divided into three sections. The existing nonskid coating was initially removed using a combination of UHPWJ and power tools. The final surface preparation was performed using the same processes as the laboratory test panels, except SP10 Shot was not tested.

In Section 1, 100% of the area, including deck edges and appendages, was abrasive blasted to condition SP10 Grit using aluminum oxide. In Section 2, 100% of the area, including deck edges and appendages, was abrasive blasted to condition SP6 Grit using aluminum oxide. In Section 3, 20% of the deck with the greatest amount of pitting and staining was abrasive blasted to condition SP10 Grit using aluminum oxide, while the remaining 80% was cleaned using UHPWJ.

Power tool cleaning was used in areas around the deck edge and appendages where the UHPWJ equipment could not access. Nonskid system E was applied by roller using two full coats of primer. The nonskid was applied by roller. The application was completed on 23 August 2018 and a follow-up inspection was performed on 24 March 2020 (19 months). Visual inspections were performed to document corrosion damage, loss of adhesion, and the overall condition of each section of the demonstration area.

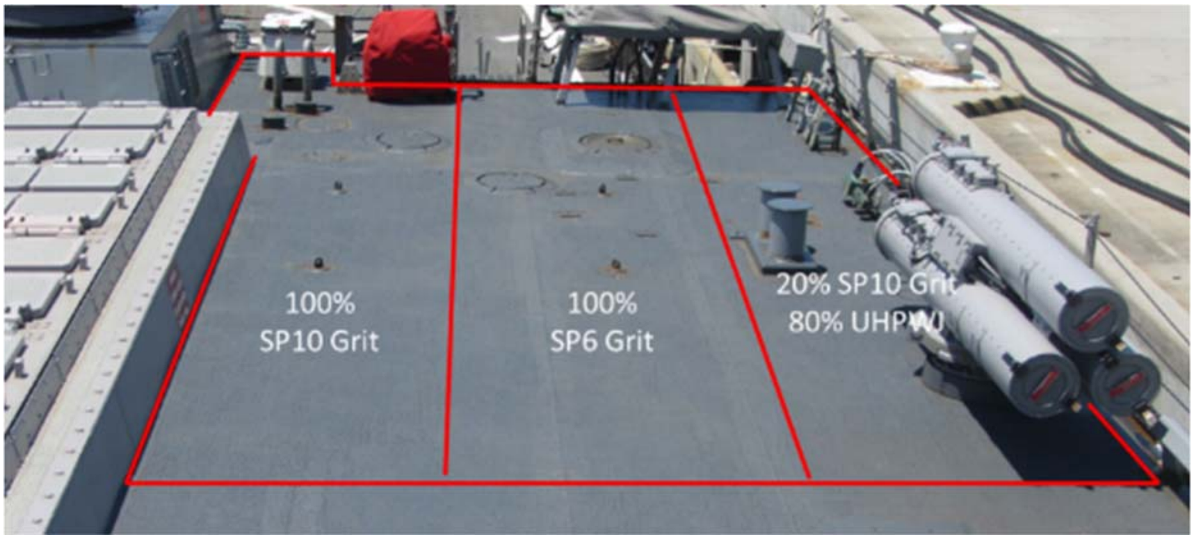


Figure 12 – Deck layout for shipboard test on DDG missile deck

4 RESULTS AND DISCUSSION

Table 7 contains a summary of all the test results. The tests performed and associated pass/fail criteria are in the far left column, and the different surface preparation methods are listed across the top of the table. The table has been color coded to show the best and worst surface preparation methods for each test performed; the best test result is highlighted in dark green, followed by light green, yellow, and the worst is highlighted in red.

In some cases, there were identical test results for the different surface preparation methods, so the same color was used more than once in a given row. The color of the cell does not indicate whether or not the coating/surface prep method met the minimum performance requirement listed in the column on the left; the color coding only provides a visual comparison of the different surface preparation methods.

For example, Nonskid D had approximately 10% adhesive failure at the substrate in the peel resistance test and was highlighted dark green, yet the pass/fail criteria states there shall be no substrate failure, and therefore failed the test. The cell was still highlighted dark green, because the SP10 Grit surface preparation method was the best performing when compared to SP10 Shot, SP6 Grit, and UHPWJ. The worst measured value for each test has also been provided in the cell for further comparison.

Table 7 – Test results summary

		SP10 Grit[1]	SP10 Shot	SP6 Grit	UHPWJ
Impact Resistance (≥ 95%)	Nonskid A	97.5% intact	92.5% intact	95% intact	92.5% intact
	Nonskid B	100% intact	100% intact	100% intact	100% intact
	Nonskid C[2]	100% intact	100% intact	100% intact	100% intact
	Nonskid D	100% intact	82.5% intact	100% intact	100% intact
Peel Resistance (No substrate failure)	Nonskid A	Coh./nonskid	Coh./nonskid	Coh./nonskid	Coh./nonskid
	Nonskid B	Coh./nonskid	Coh./nonskid	Coh./nonskid	Coh./nonskid
	Nonskid C	Coh./nonskid	Coh./nonskid	Coh./nonskid	Coh./nonskid
	Nonskid D	10% adh./substrate	100% adh./substrate	33% adh./substrate	90% adh./substrate
Accelerated[3] (cutback ≤ 9.5mm (3/8"))	Nonskid A	8.5 mm	12 mm	8.5 mm	6 mm
	Nonskid B	7.25 mm	10.5 mm	6.5 mm	7.75 mm
	Nonskid C	7 mm	11 mm	6.5 mm	8 mm
	Nonskid D	12.5 mm	63.5 mm	19 mm	12.75 mm
Atmospheric[4] (cutback ≤ 19mm (3/4"))	Nonskid A	16 mm	16 mm	15 mm	9 mm
	Nonskid B	14.5 mm	27 mm	17 mm	17 mm
	Nonskid C	14 mm	24.5 mm	19.5 mm	17 mm
	Nonskid D	20 mm	30.5 mm	21 mm	29.5 mm
Atmospheric[4] (cutback ≤ 19mm (3/4"))	Primer A	15 mm	24 mm	16 mm	19 mm
	Primer B	12 mm	26 mm	18 mm	18 mm
	Primer C	13 mm	23 mm	16 mm	11 mm
	Primer D	15 mm	24 mm	14 mm	16 mm

NOTES:

[1] - Test panels prepared with SP10 Grit align with requirements set forth in MIL-PRF-24667. Panels prepared to a lesser standard may not meet minimum performance requirements of MIL-PRF-24667.

[2] - Nonskid C contained two coats of primer and there was some delamination between coats, but not to substrate

[3] - Corrosion cutback was assessed after completion of QUV, B117 and impact testing.

[4] - There is no requirement for a 1-year atmospheric corrosion test, therefore 19 mm was arbitrarily set as maximum cutback allowed (twice the amount for accelerated corrosion per MIL-PRF-24667).

4.1 Impact Resistance

The impact resistance test results are provided in Table 8. Pictures of the test panels are provided in Figure 13 – Figure 20. The pass/fail criteria from MIL-PRF-24667 requires nonskid coatings to have a minimum impact resistance of 95% (i.e., no more than two pairs of connected impact sites). Nonskid coatings applied over SP10 Grit performed the best with nearly all test panels having 100% impact resistance. The SP6 Grit and UHPWJ surface preparation methods each had one test panel with less than 95%, however the SP6 Grit panel nonskid failure was between layers of primer and not at the substrate/primer interface, as noted in Figure 17. Nonskid applied over SP10 Shot had the most test panel failures and this is likely due to a lack of angular profile of the shot peened surface.

Table 8 – Impact resistance test results

Nonskid	Condition	SP10 Grit	SP10 Shot	SP6 Grit	UHPWJ
A	As-Received	97.5%	95.0%	100.0%	97.5%
A	15 day immersion	100.0%	92.5%	95.0%	92.5%
B	As-Received	100.0%	100.0%	100.0%	100.0%
B	15 day immersion	100.0%	100.0%	100.0%	100.0%
C	As-Received[1]	100.0%	97.5%	92.5%	100.0%
C	15 day immersion	100.0%	100.0%	100.0%	100.0%
D	As-Received	100.0%	92.5%	100.0%	100.0%
D	15 day immersion	100.0%	82.5%	100.0%	100.0%

NOTES:
[1] – Nonskid C contained two coats of primer. The nonskid failure occurred between primer coats and not at the primer/substrate interface.

Figure 13 – As-received impact resistance results for Nonskid A

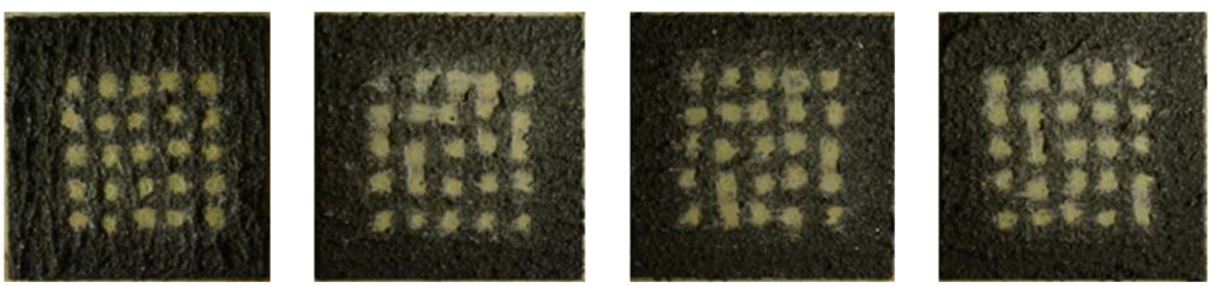
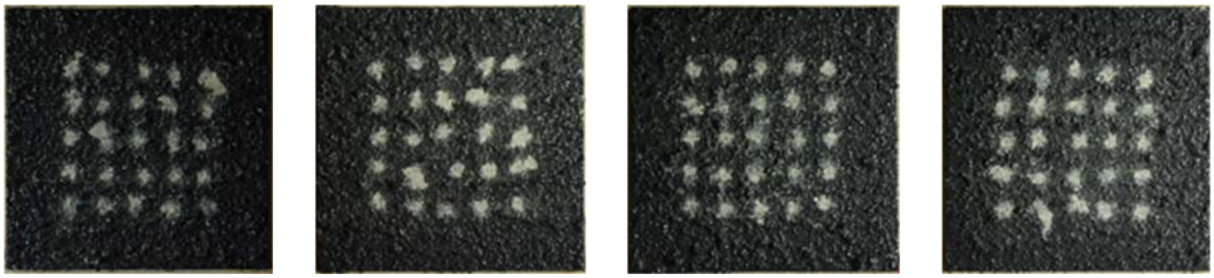
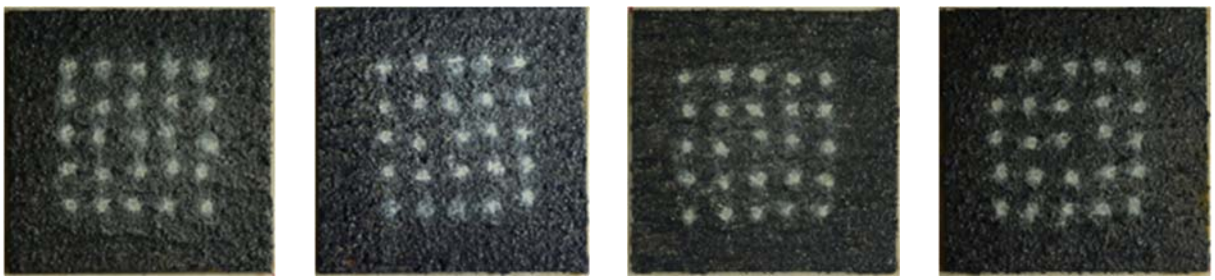


Figure 14 – 15 day immersion impact resistance results for Nonskid A



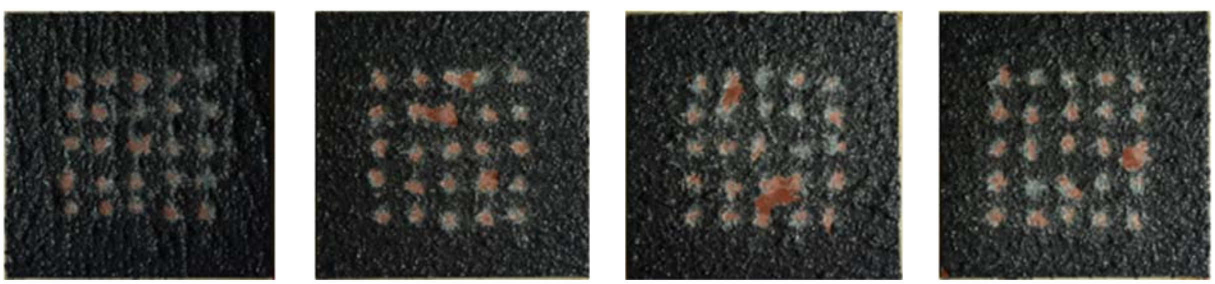
SP10 Grit SP10 Shot SP6 Grit UHPWJ

Figure 15 – As-received impact resistance results for Nonskid B



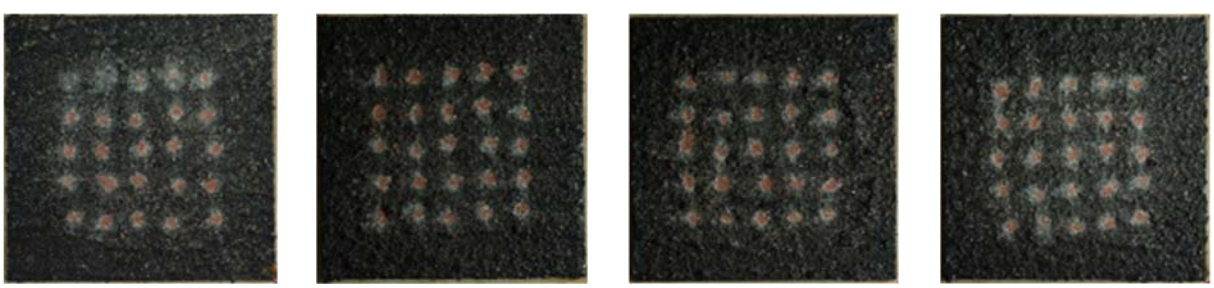
SP10 Grit SP10 Shot SP6 Grit UHPWJ

Figure 16 – 15 day immersion impact resistance results for Nonskid B



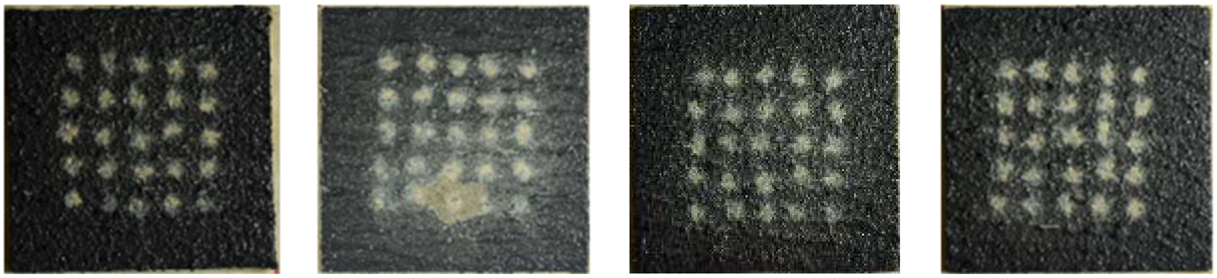
SP10 Grit SP10 Shot SP6 Grit UHPWJ

Figure 17 – As-received impact resistance results for Nonskid C



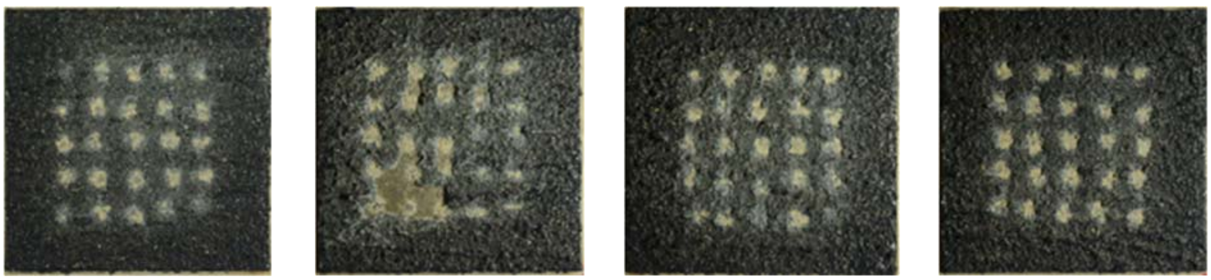
SP10 Grit SP10 Shot SP6 Grit UHPWJ

Figure 18 – 15 day immersion impact resistance results for Nonskid C



SP10 Grit SP10 Shot SP6 Grit UHPWJ

Figure 19 –As-received impact resistance results for Nonskid D



SP10 Grit SP10 Shot SP6 Grit UHPWJ

Figure 20 –15 day immersion impact resistance results for Nonskid D

4.2 Peeling Resistance

Pictures of the peel resistance test panels have been provided in Figure 21 – Figure 24. The pass/fail criteria established was nonskid system shall not delaminate from the substrate when a peeling force was applied using the test setup previously described. Notably, Nonskids A, B, and C were all composition D nonskid coatings, meaning they were formulated with a lightweight aggregate package, such as glass or plastic; whereas Nonskid D was formulated with the traditional Composition G aggregate, aluminum oxide. During the peel test, Nonskids A, B, and C failed cohesively within the nonskid layer of the sandwich panel, and it was noted that there were loose glass and/or plastic particles that could be easily brushed from the nonskid layer that was split in half (i.e., half the nonskid layer remained adhered to the bend panel and the other half remained adhered to the peel tab, as represented in Figure 9).

Because the cohesive strength of the nonskid layers for Nonskids A, B, and C were low, the substrate/primer interface was never stressed to the point that a proper evaluation could be made regarding the adhesion of the nonskid system to the various surface preparation methods. However, for Nonskid D, the cohesive strength of the composition G nonskid was greater, and the substrate/primer interface was stressed, which showed a clear trend regarding adhesion of the nonskid system applied over the various surface preparation methods. For Nonskid D, the nonskid system had the worst adhesion over SP10 Shot, followed by UHPWJ, SP6 Grit and finally SP10 Grit.

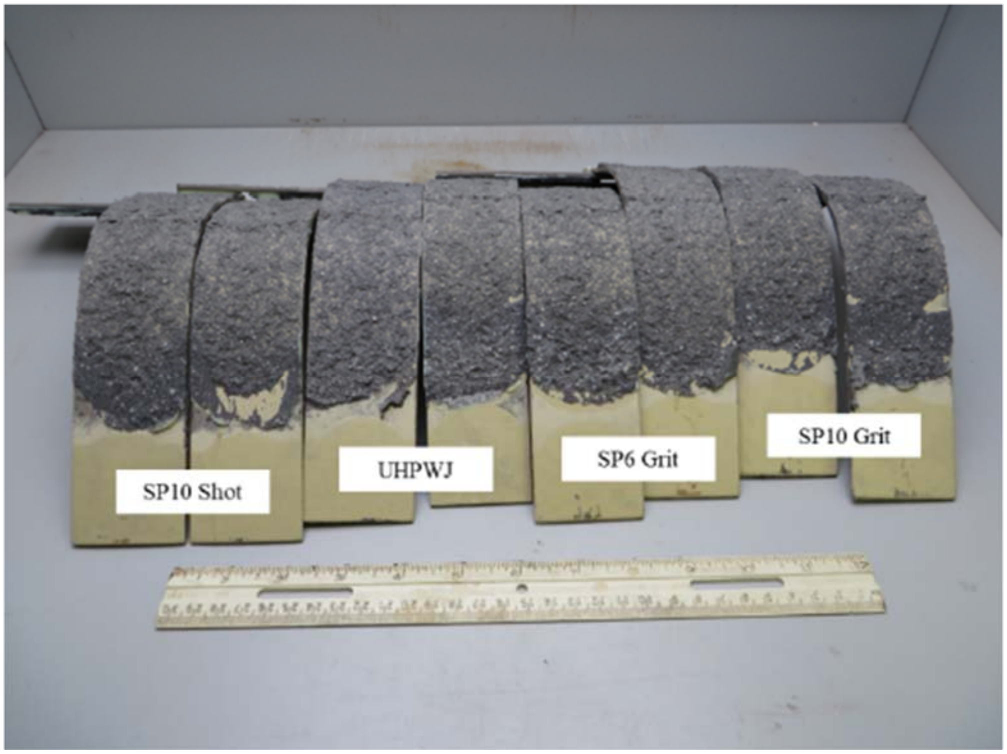


Figure 21 – Peel resistance results for Nonskid A

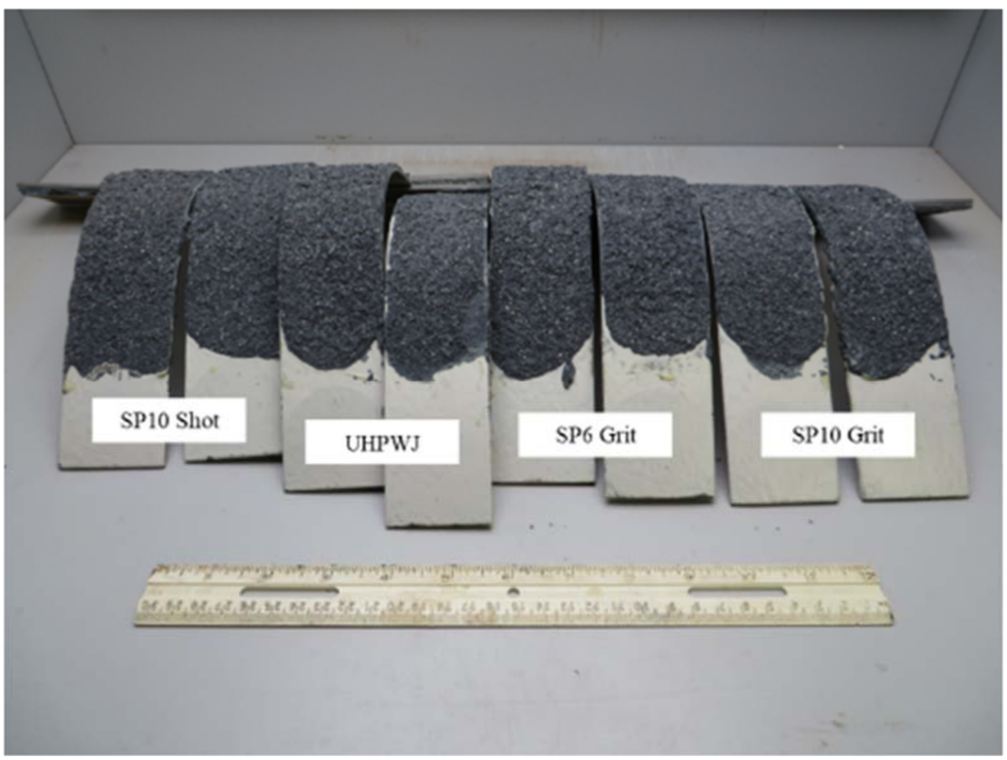


Figure 22 – Peel resistance results for Nonskid B

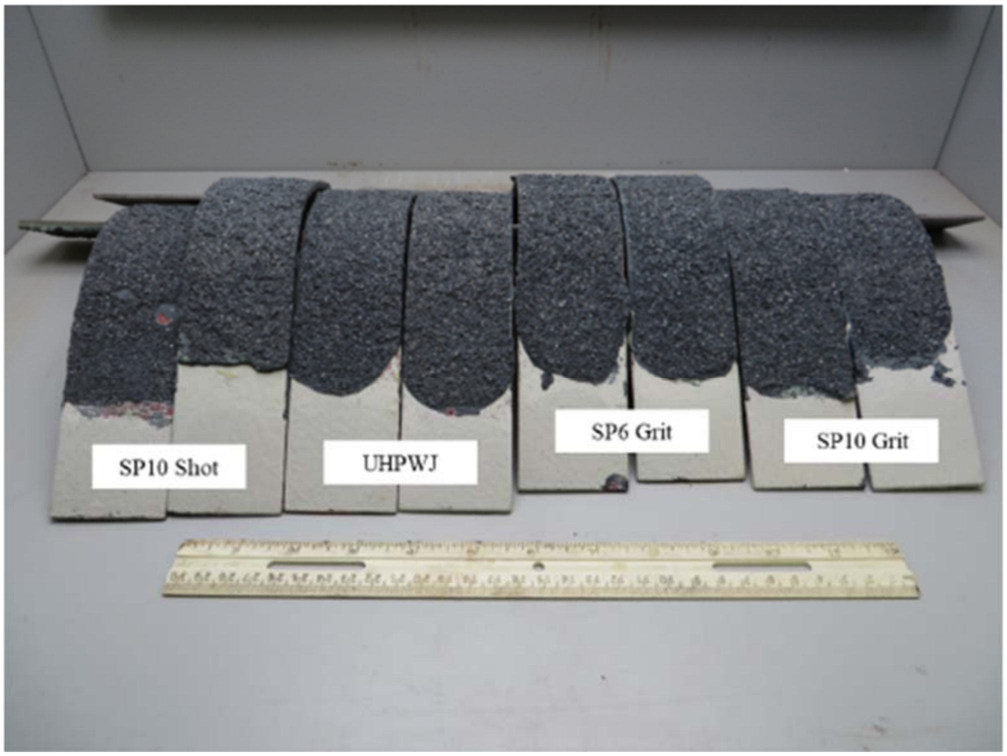


Figure 23 – Peel resistance results for Nonskid C

Figure 24 – Peel resistance results for Nonskid D

4.3 Accelerated Corrosion Test

The cutback data, in Figure 25, is the maximum amount of cutback recorded for the two panels that were tested (minus the width of the original scribe). Pictures of the accelerated corrosion test panels are provided in Figure 26 – Figure 29. The panels were also impacted per the requirements of MIL-PRF-24667; however, the impact resistance did not get evaluated, since the only data of interest from this test was the corrosion cutback.

For each nonskid coating tested, the panels prepared with SP10 shot had the most amount of cutback. For Nonskids A, B, and C, in general, the amount of cutback for SP10 Grit, SP6 Grit, and UHPWJ was the same, and the test panels had approximately 33% less cutback than SP10 Shot panels tested under the same conditions. Nonskid D recorded the most cutback for all surface preparation conditions tested.

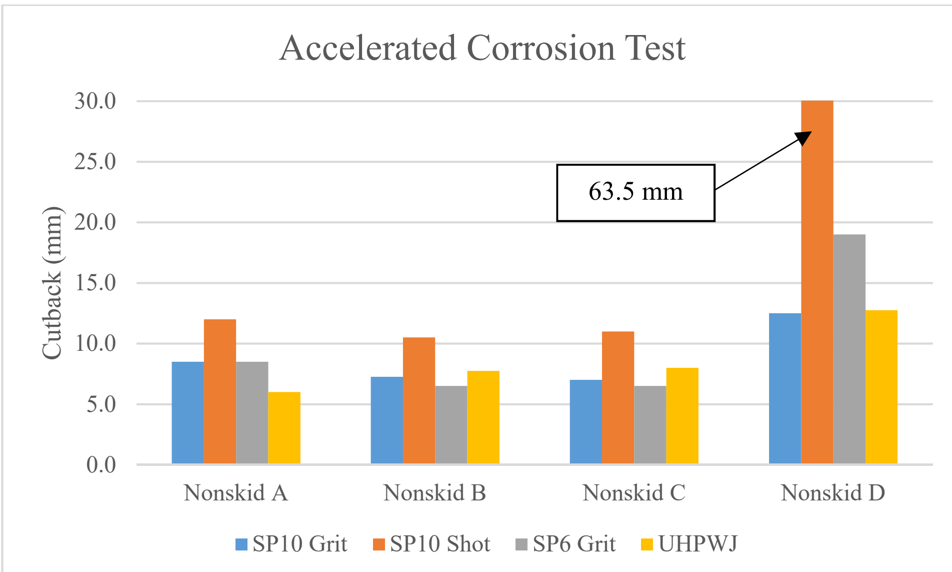


Figure 25 – Accelerated corrosion cutback data

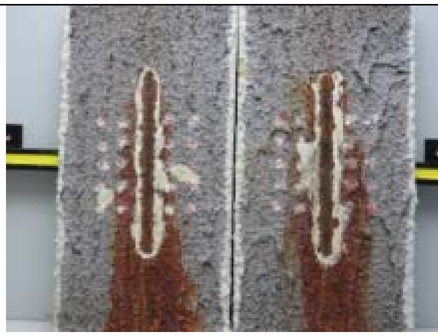
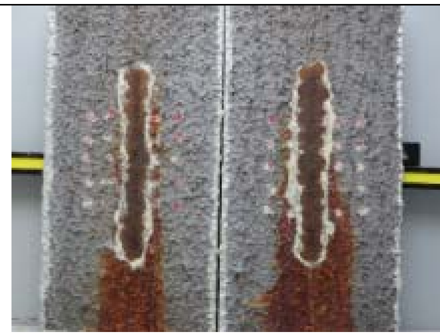
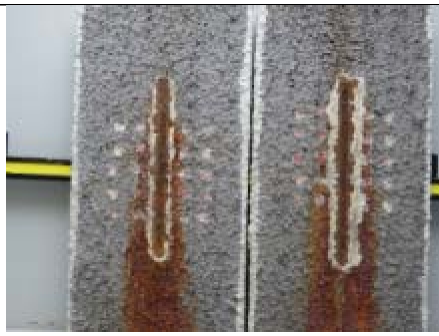
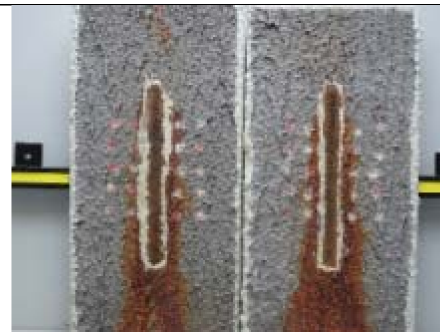
 SP10 Grit	 SP10 Shot
 SP6 Grit	 UHPWJ

Figure 26 – Accelerated corrosion test results for Nonskid A

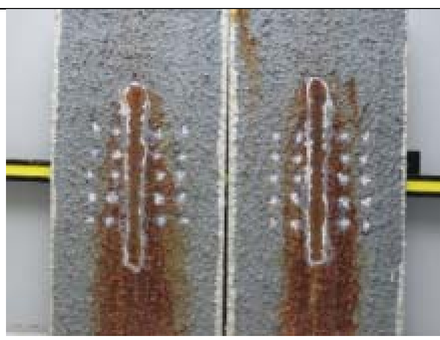
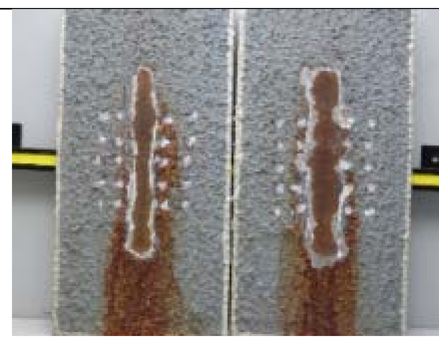
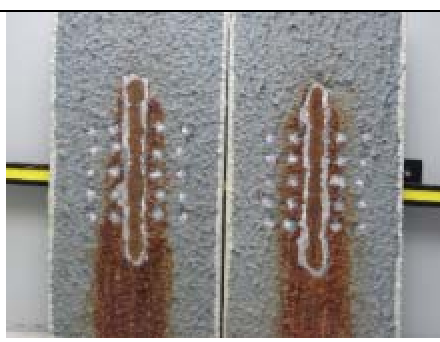
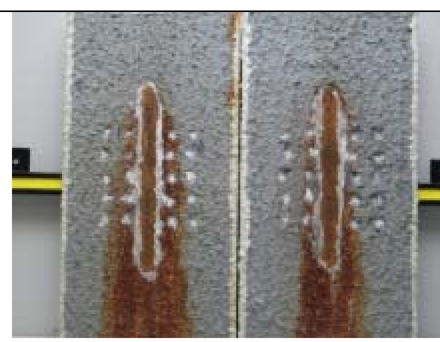
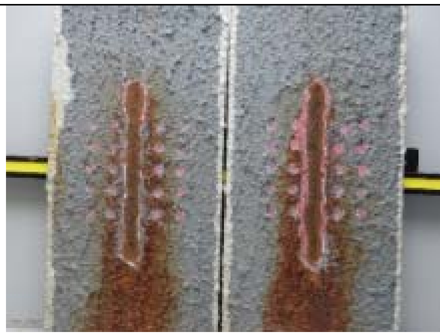
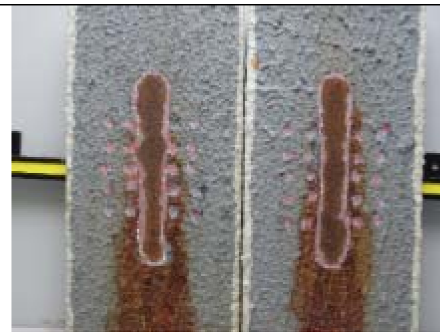
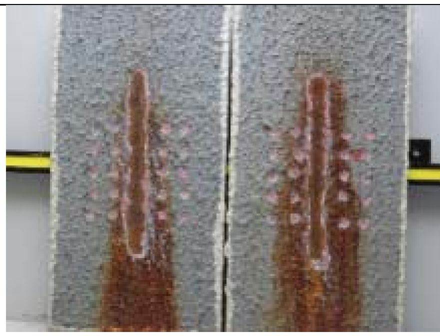
 SP10 Grit	 SP10 Shot
 SP6 Grit	 UHPWJ

Figure 27 – Accelerated corrosion test results for Nonskid B


SP10 Grit


SP10 Shot


SP6 Grit

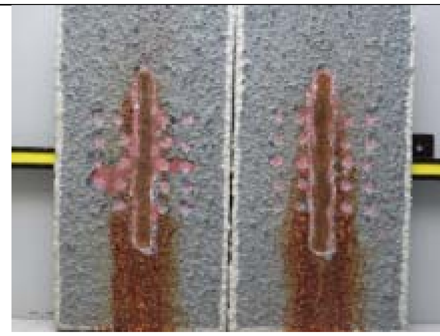
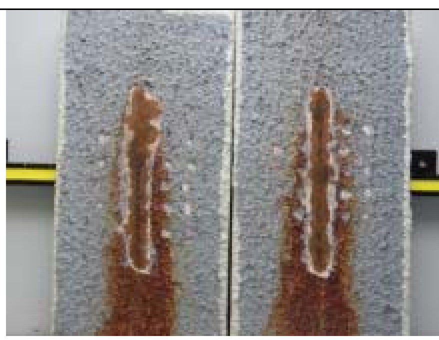
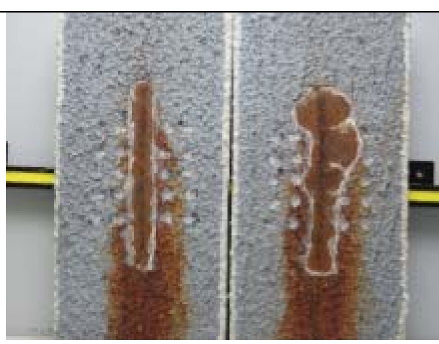

UHPWJ

Figure 28 – Accelerated corrosion test results for Nonskid C


SP10 Grit


SP10 Shot


SP6 Grit

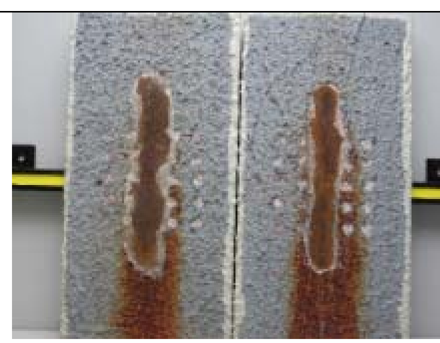

UHPWJ

Figure 29 – Accelerated corrosion test results for Nonskid D

4.4 Atmospheric Corrosion Test

The cutback data for test panels coated with nonskid is provided as a bar chart in Figure 30, and test panels coated with primer only and a thin color topping is provided as a bar chart in Figure 31. The data in both charts are the maximum amount of cutback recorded on the test panels, minus the width of the original scribe, in the given surface preparation zone (as described in Figure 11). Pictures of the accelerated corrosion test panels are provided in Figure 26 – Figure 29.

Similar to the accelerated corrosion cutback data, the sections of the test panels that were prepared by SP10 Shot had the most amount of cutback, except for Nonskid A, which had the same amount as SP10 Grit. The sections of the panels prepared by SP10 Grit, SP6 Grit, and UHPWJ were mostly equal in terms of the amount of cutback measured, with the exception of the UHPWJ area on Nonskid D. The amount of cutback measured on this section was closer to the SP10 Shot area.

The data trends between full nonskid system test panels (Figure 30) and the primer with color topping test panels (Figure 31) were generally consistent as well, meaning the section of the test panel (i.e., SP10 Grit, SP10 Shot, SP6 Grit, or UHPWJ) with the most cutback on the full nonskid system test panels also had the most cutback on the corresponding test panels coated with primer and a thin color topping. The exception to this was the UHPWJ section on Nonskid A/Primer A.

One additional observation was the test panels coated with the nonskid system generally had more cutback than the primer only panels. This may be due to higher stress concentrations applied at the scribe by the thick nonskid topcoat, or seawater may have been retained in the scribe longer since the film thickness of the full nonskid system is greater than the primer only panels.

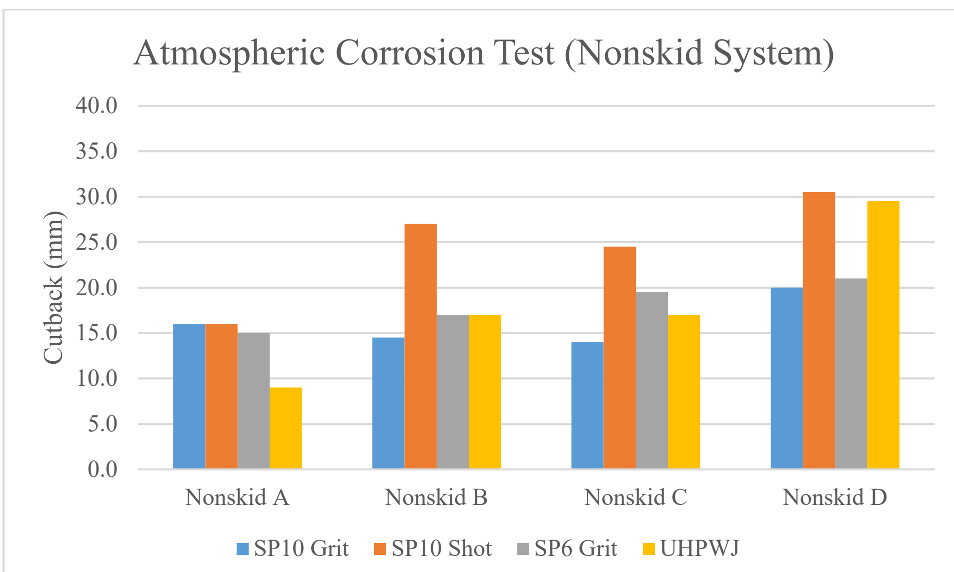


Figure 30 – Atmospheric corrosion cutback data for full nonskid system

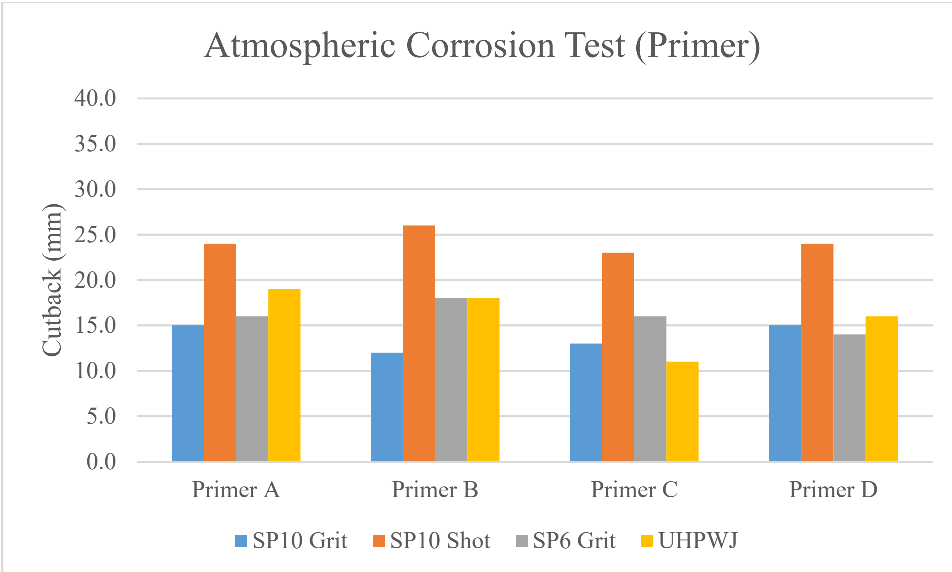


Figure 31 – Atmospheric corrosion cutback data for nonskid primer and a thin color topping

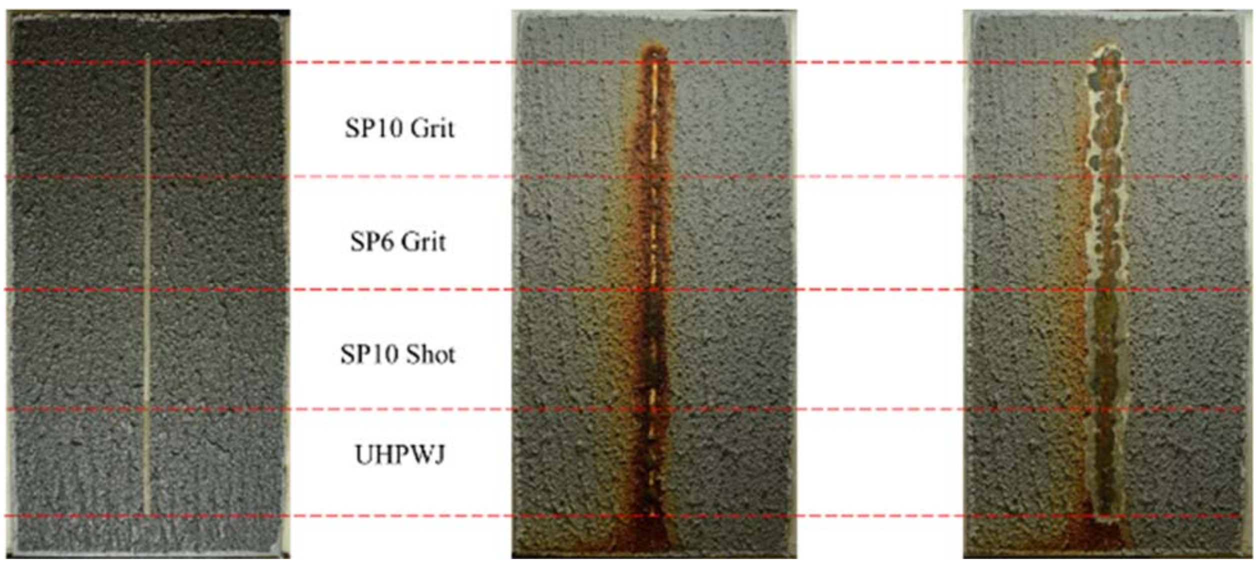


Figure 32 – Atmospheric corrosion test panels (1'x2') for Nonskid A (full system)

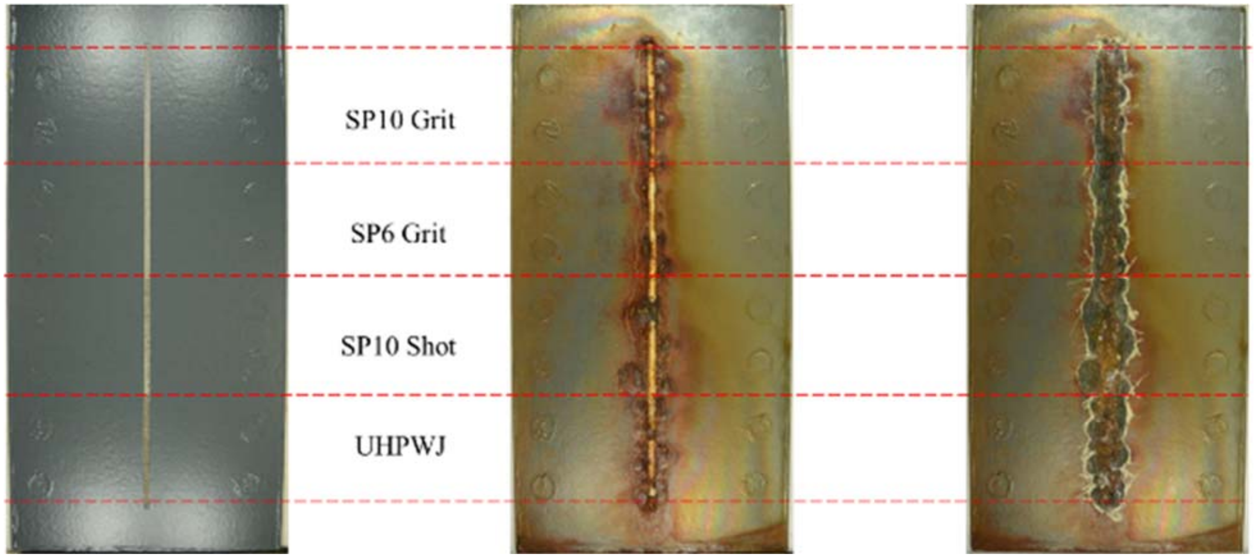


Figure 33 – Atmospheric corrosion test panels (1'x2') for Nonskid A primer with a thin color topping

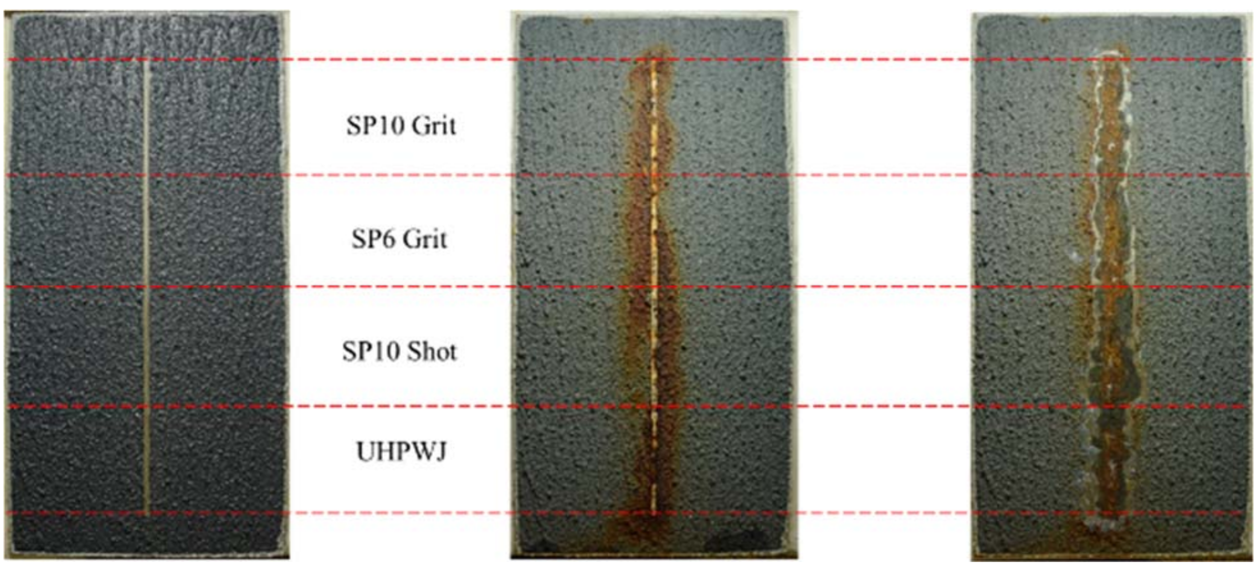


Figure 34 – Atmospheric corrosion test panels (1'x2') for Nonskid B (full system)

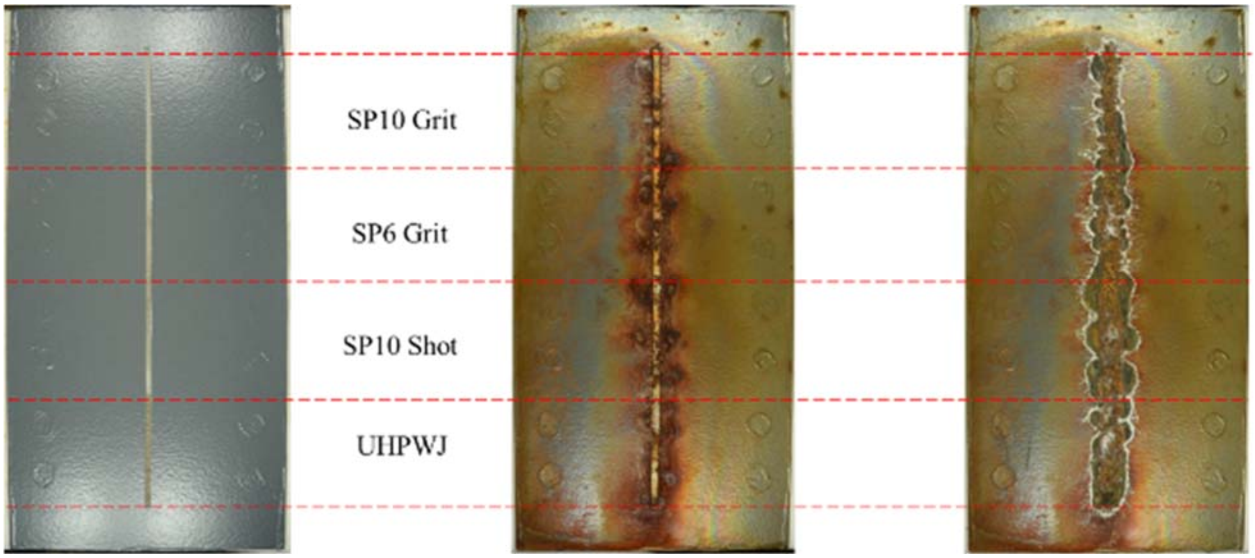


Figure 35 – Atmospheric corrosion test panels (1'x2') for Nonskid B primer with a thin color topping

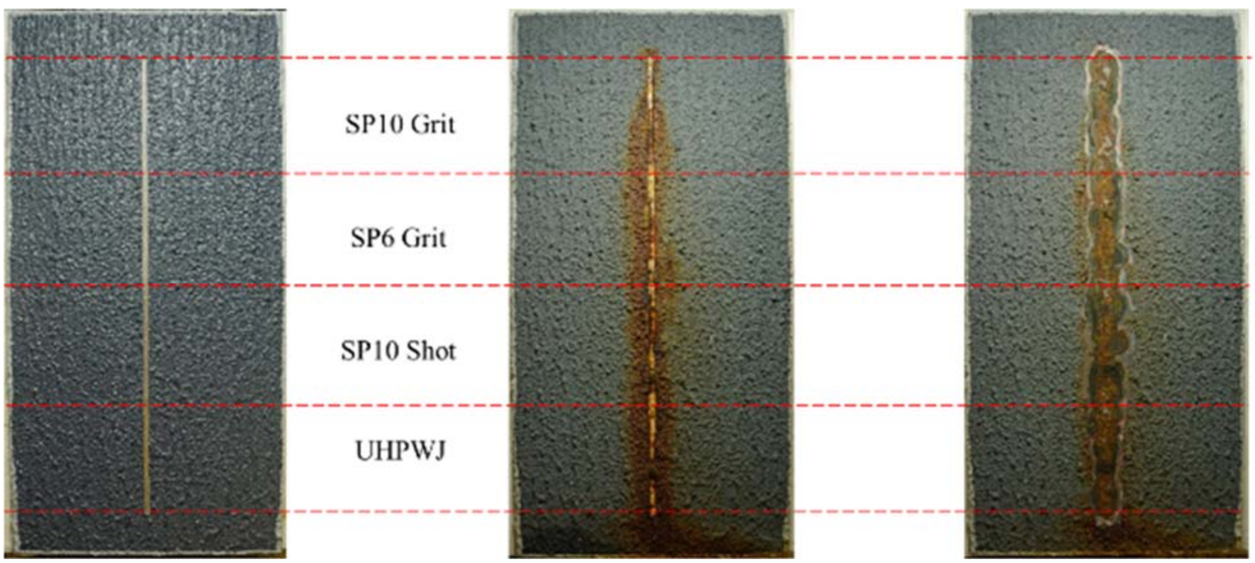


Figure 36 – Atmospheric corrosion test panels (1'x2') for Nonskid C (full system)

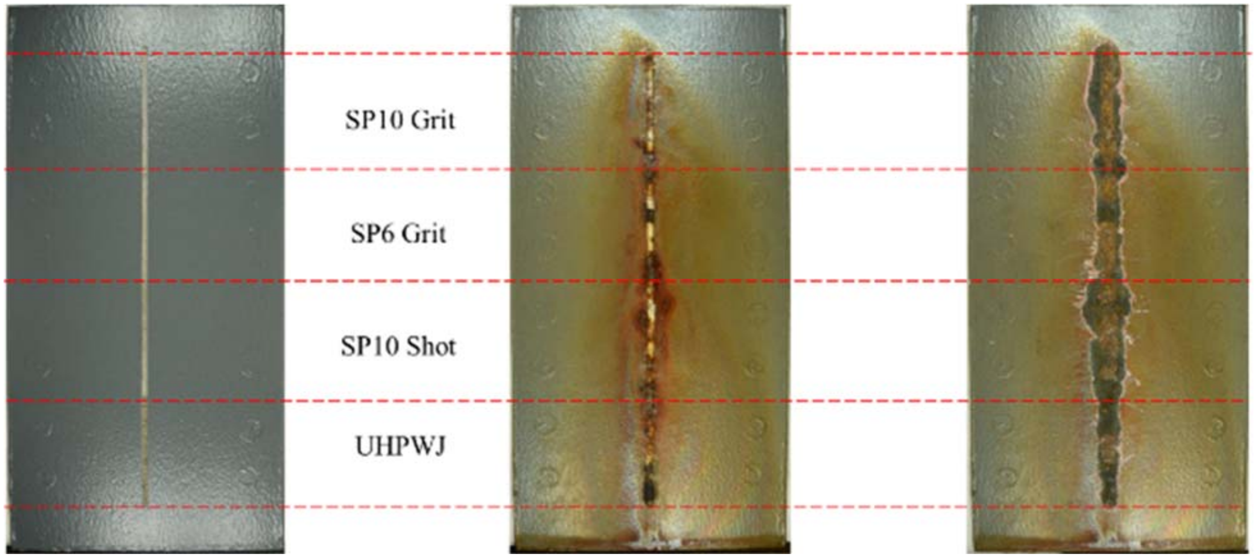


Figure 37 – Atmospheric corrosion test panels (1'x2') for Nonskid C primer with a thin color topping

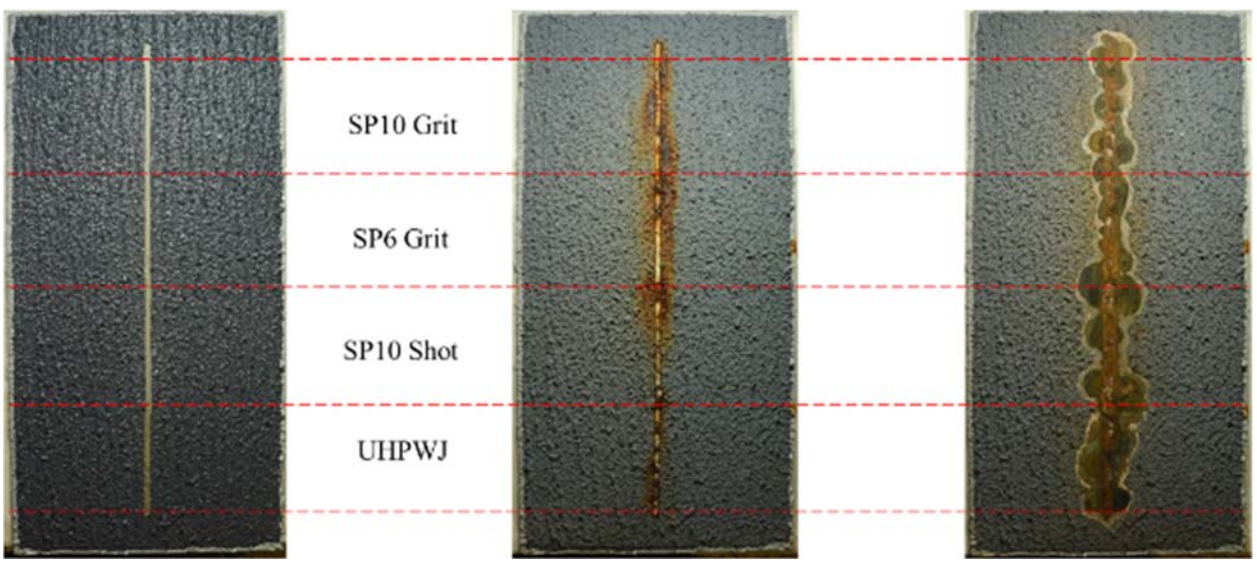


Figure 38 – Atmospheric corrosion test panels (1'x2') for Nonskid D (full system)

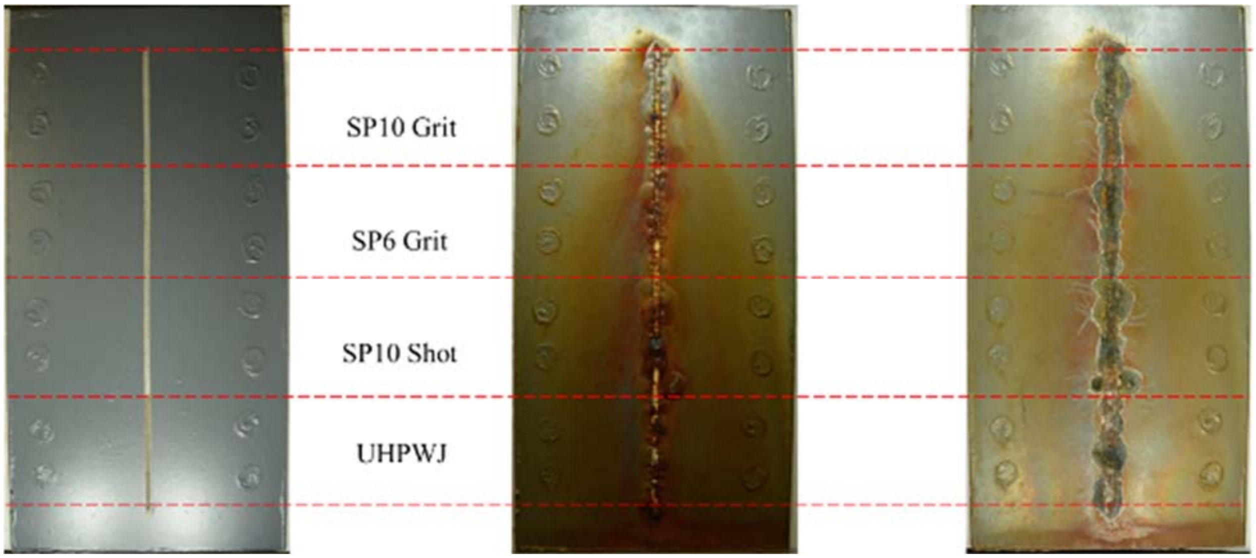


Figure 39 – Atmospheric corrosion test panels (1'x2') for Nonskid D primer with a thin color topping

4.5 Shipboard Test

A follow-up inspection of the demonstration areas on the missile deck of a DDG was performed on 24 March 2020, 19 months after the original installation; an overall picture of the deck condition is provided in Figure 40, and close-ups are provided in Figure 41 – Figure 43. Overall the condition of the deck was very good. All demonstration sections had rust staining from adjacent bulkheads, foundations, or access covers where applicable. Some severe staining and surface rust "build up" was evident in isolated areas; potentially caused by repair work (metal shavings) and poor drainage. It was difficult to evaluate the adhesion of the nonskid coating in the three different sections, but gentle probing did not indicate any nonskid failure, and there was no underlying corrosion or bleed through. Some spot repairs were made in the SP6 Grit section but it was likely caused by mechanical damage that occurred during the shipyard availability.

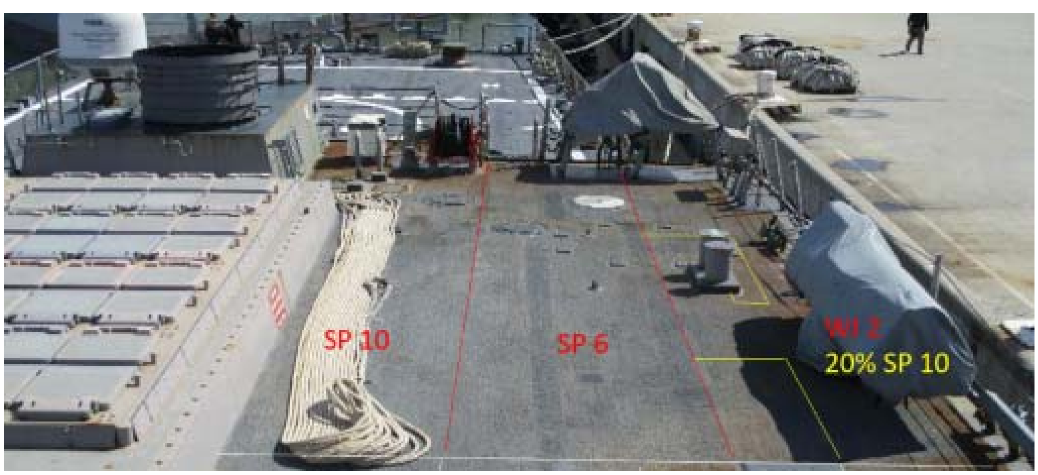


Figure 40 – 19 month follow-up inspection of the shipboard nonskid test on a DDG missile deck

Figure 41 – Close-ups of section 1 that received 100% SP10 Grit surface preparation of the deck and appendages

Figure 42 – Close-up of section 2 that received 100% SP6 Grit surface preparation of the deck and appendages

Figure 43 – Close-up of section 3 that received 20% SP10 Grit/80% UPHWJ surface preparation of the deck and power tool cleaning of deck edges and appendages not accessible by UHPWJ

5 CONCLUSIONS

The following conclusions can be made about the effects of surface preparation on nonskid performance:

- Testing nonskid coating systems over various surface conditions, rather than just NACE 2/SSCP-SP 10, helped distinguish poor performing nonskid systems. For example, Nonskid D performed equal to the other nonskid systems when tested over a substrate blasted with mineral abrasive to a NACE 2/SSPC-SP 10 level of cleanliness; however, when applied over the other surface conditions, it was by far the worst performer of the nonskid systems.
- In a blast cabinet, it took about twice (2x) as long to produce a NACE 2/SSPC-SP 10 level of cleanliness (150-180 sqft/hr) according to the visual standard SSPC-VIS 1 compared to NACE 3/SSPC-SP 6 (300-360 sqft/hr) when using aluminum oxide abrasive.
    - In an industrial environment on a DDG missile deck it took about four times (4x) longer to produce NACE 2/SSPC-SP 10 (72 sqft/hr) compared to NACE 3/SSPC-SP 6 (284 sqft/hr).
- Achieving a NACE 2/SSPC-SP 10 level of cleanliness with steel shot in a blast cabinet was the slowest of the surface preparation methods tested at 15 sqft/hr because the rounded abrasive does not "cut" into the steel and was not effective at removing black corrosion stains or flash rust; this would be akin to a walk-behind wheelabrator machine commonly used in shipyards to prepare deck surfaces.
- All four methods of surface preparation tested produced acceptable surface profile depth on the conditioned test panels; the test panels prepared with aluminum oxide abrasive had slightly higher peak count and angularity.
- The surface profile depth in the two sections of the DDG missile deck that were abrasive blasted with aluminum oxide were about twice as deep (2x) compared to the sections prepared by UHPWJ only.

  - The deeper surface profiles on ship were likely caused by higher blast pressures using the industrial equipment, and the deck steel was approximately 30 years old with significantly more pre-existing corrosion and pitting.
- The only surface conditions to fail the impact resistance test were panels prepared by steel shot and UHPWJ.
- The peel resistance test was not very useful in determining substrate adhesion for Nonskids A, B and C. However, Nonskid D did have some variability with partial adhesion failure for panels prepared with aluminum oxide (SP10 Grit and SP 6 Grit), and complete failure for panels prepared with steel shot and UHPWJ.
- For the atmospheric and accelerated corrosion tests, the test panels prepared with SP10 Grit had the least amount of cutback 50% of the time, SP6 Grit had the least amount of cutback 25% of the time, and UHPWJ had the least amount of cutback 25% of the time as indicated by the dark green cells in Table 7.
- SP10 Shot had the most cutback 100% of the time in the atmospheric and accelerated corrosion tests as indicated by the red and yellow cells in Table 7.
- The MIL-PRF-24667, Type I nonskid installed on the DDG missile deck over surfaces prepared by SP10 Grit, SP6 Grit, and UHPWJ have had equal performance to date.

Overall, preparing steel using mineral abrasive to a cleanliness level of NACE 3/SSPC-SP 6 according to the visual standard SSPC-VIS 1 is a low risk surface preparation option for MIL-PRF-24667 nonskid. For the nonskid systems tested as part of this program, systems applied over SP6 Grit had equivalent adhesion to systems applied over SP10 Grit. Additionally, the corrosion resistance of the nonskid systems applied over SP6 Grit was only slightly worse than SP10 Grit with an average absolute difference of 2.4 mm of cutback between the two surface conditions. Comparatively, test panels prepared by UHPWJ had an average absolute difference of 3.3 mm, while SP10 Shot was 11.4 mm. It was also demonstrated that open abrasive blasting in an industrial environment to NACE 3/SSPC-SP 6 can be up to 4 times (4x) faster than preparing a surface to NACE 2/SSPC-SP 10. Therefore, NAVSEA could update the 009-32 requirement to require more abrasive blasting if a lesser surface preparation standard, such as NACE 3/SSPC-SP 6, is specified. For example, the requirement could be changed to 60% NACE/SSPC-SP WJ-2 and 40% NACE 3/SSPC-SP 6 with minimal cost impact since the production rate of NACE 3/SSPC-SP 6 is higher. One consideration that must be factored in is the cost of environmental containment for open abrasive blasting, unless closed-loop mineral abrasive blast systems become prevalent in the marine industry. Nonskid applied over steel shot presents a higher risk for nonskid undercutting and delamination, especially in areas where the substrate is exposed by mechanical damage.

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