COMPARISON OF SECONDARY SURFACE PREPARATION OVER WATER JETTED SURFACES AND THE EFFECT ON COATING PERFORMANCE

Wayne McGaulley, Staff Engineer
William Shepperson, Staff Engineer
Corrpro Companies, Inc.
1235 Jefferson Davis Highway, Suite 500
Arlington, VA 22202

Fred Berry
Naval Sea Systems Command, Code 05M
1333 Isaac Hull Ave.
Bldg. 197, Stop 5131
Washington, DC 20376-5131

Abstract. Photographs of abrasive blasted and water jetted surfaces taken at microscopic levels have shown that the water jetted surface appears rougher as magnification increases, whereas the abrasive blasted surface appears smoother as magnification increases. The subject paper is a status report of an ongoing Naval Sea Systems Command (NAVSEA) study. The study investigates coating performance over water jetted surfaces with several different secondary surface preparation methods.

BACKGROUND

In recent years, advances in equipment have made water jetting an effective form of surface preparation for use in industry as well as in the US Navy. Currently, water jetting is used by the US Navy to remove non-skid decking material on aircraft carrier flight decks and underwater hull coatings. Current US Navy specifications, such as the Naval Ships Technical Manual (NSTM) Chapter 634, Deck Covering, require a measurable anchor tooth profile of 3 to 4.5 mils. Water jetting at pressures up to 40,000 psi alone cannot impart this profile. It can only reveal an existing profile.

When viewed under magnification, the surface of a water jetted substrate appears rougher than the surface of an abrasive blasted surface. The possibility exists that the increased surface roughness of the water jetted surface may allow increased wetting of coatings on the substrate. By more effectively wetting the surface, coatings can achieve greater adhesion.[1]

On US Navy ships, substrates that do not exhibit a surface profile can be found in various areas, for a variety of reasons. Profiled steel on underwater hulls and in tanks can become corroded, which destroys the angular profile and leaves an irregular topography of pitted steel. On aircraft carrier flight decks, aircraft arresting cables wear away non-skid coatings and polish the underlying steel removing any existing profile. When utilizing water jetting, the resulting surface is not in accordance with the current NSTM Ch. 634 requirement of 3 to 4.5 mils of anchor tooth profile.

The purpose of this study is to investigate the performance of coatings over smooth water jetted surfaces (on a macro level) compared to the performance of surfaces with a measurable anchor tooth profile achieved by secondary mechanical surface preparation methods.

New water jetting technologies, such as next-generation robotic crawlers and improved lance-nozzle designs allow increased productivity for water jetting operations. However, secondary surface preparation to establish a macro profile is slow and costly, thus reducing the feasibility of using water jetting. Therefore, if it can be shown that water jetted surfaces without secondary surface profiling can perform as well or better than those with secondary surface preparation, the US Navy can employ these new water jet technologies on a broader basis for surface preparation, thus reducing costs.

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[1] Weismantel, Guy E., "Paint Handbook," McGraw-Hill, Inc. 1981

INTRODUCTION

In order to fully test the hypothesis that water jetting provides an adequate surface to apply coatings that will perform as well or better than coatings applied over an abrasive blasted surface, the testing must simulate actual field conditions.

Of the conditions that can provide an area where an existing profile has been removed, the flight deck of an aircraft carrier is the worst-case scenario. In the aircraft arresting cable area, aircraft carrier flight deck steel condition is defined by smooth steel with no existing macro-profile. Therefore, testing of all systems was conducted over the worst-case smooth substrate. To simulate this condition, cold-rolled steel was chosen as the substrate. The surface of the cold-rolled steel was a dull shine, with some staining present.

The environmental conditions of an aircraft carrier flight deck consist of moist, salt-laden air and sea spray. Additionally, flight deck coatings are exposed to constant UV radiation during daylight hours. Performance tests must be chosen properly to simulate these conditions. Three performance tests were chosen to best simulate these conditions:

- Atmospheric exposure
- Cathodic disbondment
- Prohesion

The first step in simulating service conditions is the atmospheric exposure test. This provides the most accurate data since panels are subject to a natural marine environment. This test is very time intensive and therefore does not provide immediate results.

Due to the time intensive nature of atmospheric exposure, a procedure that can simulate natural conditions at an accelerated rate called the prohesion test was also used. This test cyclically exposes test specimens to humid salt-laden air, then dry, hot air. This test provides accelerated corrosion results, typically within 2,000 hours of testing, to identify performance differences between surface preparation or materials.

Cathodic disbondment testing provides an additional measure of adhesion. Poorly adhered coatings may blister when the substrate is under cathodic protection. Additionally, if the coating is not performing properly, it may disbond from the substrate in damaged areas when under cathodic protection. The amount of coating that disbonds can be measured directly by scribe cutback and compared to other conditions or coatings.

TECHNICAL APPROACH

Test Matrix. Table 1 summarizes the performance tests and panel conditions that were used in this study. Note that only one panel from each surface preparation method was used for metallography, which is "the study of the structure of metals and alloys by various methods, especially by the optical and electron microscope, and by x-ray diffraction."[2]

Table 1. Test Matrix

	Number of Panels per Coating per Surface Preparation		
Test	Adhesion	Scribe	Uncoated
Atmospheric Exposure	2	2	-
Prohesion	2	2	-
Cathodic Disbondment	-	2	-
Metallography	-	-	1 (per surface prep only)

Procedure. The panel surfaces contained a large amount of oils from the milling process. Panels were degreased by dipping in solvent and wiping.

The primary surface preparation method was Ultra-High Pressure Water Jetting. The operating pressure used for this process was 40,000 psi with a flow rate of 3 gallons per minute. A rotating lance, spinning at 3,000 rpm with a two-jewel, zero-degree, non-cavitating nozzle assembly was used. The jewel orifice size was 0.018 inch.

Six sets of panels received a full cleaning to SSPC-SP 12, WJ-1. Following water jetting, five of the six sets of panels received secondary surface preparation to impart an anchor tooth profile. An additional set of panels received only solvent cleaning, without water jetting, to serve as

[2] "McGraw-Hill Dictionary of Scientific and Technical Terms, Fifth Edition," McGraw-Hill, New York, 1994

a control. Table 2 contains the surface preparation matrix.

Table 2. Surface Preparation Matrix

	Primary Surface Preparation	Secondary Surface Preparation	No. of Panels
1	Water Jetting	None	21
2	Water Jetting	Grind	21
3	Water Jetting	Wire Wheel	21
4	Water Jetting	Grit Blast	21
5	Water Jetting	Shot Blast	21
6	Water Jetting	Roto-Peen	21
7	None	None	21
		Total	147

Following surface preparation, two methods of measuring surface contamination were used to characterize the resulting surface:

- Chloride Measurements
  - Bresle Method
- Conductivity Measurements
  - Modified Bresle Method

The Bresle Method uses a standard extraction fluid and titration to detect only chloride species, whereas the conductivity measurements are made using de-ionized water and a Horiba Twin Cord B-173 Conductivity Meter, which measures the combined conductivity of ionic species present.

Following chloride and conductivity readings, surface profile measurements were made using Testex Press-O-Film replica tape in accordance with ASTM D 4417 "Test Method for Field Measurement of Surface Profile of Blast Cleaned Steel" Method C. Additionally, surface profile was measured using a Mitutoyo SJ-201 Surface Roughness Tester (profilometer). The profilometer provides much more data than replica tape and allows measurements to be made on much smaller profiles, such as smooth surfaces, water jetted surfaces and those that are wire wheel polished. The data provided by the profilometer are as follows:

- Arithmetic mean of profile, R_A
- Maximum peak to valley height, R_Y
- Mean peak to valley height, R_Z
- Mean root square of profile, R_q
- Peak density, R_{PC}

After surface profile measurements were made, panels were coated with accepted US Navy coating systems, outlined below in Table 3.

Table 3. Coating System Matrix

System	1	2
Coating	Standard Epoxy	Non-Skid Primer
Military Specification	MIL-PRF-24441	MIL-PRF-24667
First Coat	F-150, Green	Buff
DFT	2-3 mils	3-4 mils
Second Coat	F-151, Haze Gray	Gray
DFT	2-3 mils	3-4 mils

Prior to further testing, all panels were allowed to cure for a minimum of seven days at 75 °F following application of the topcoat.

Adhesion. After full cure was achieved, adhesion testing commenced. Adhesion testing was done in accordance with ASTM D 4541 "Test Method for Pull-Off Strength of Coatings Using Portable Adhesion-Testers," using a Paddi Jr. portable adhesion tester capable of measuring adhesion up to 4,000 psi. A high strength epoxy adhesive with theoretical bond strength of 4,290 psi at maximum cure was used to adhere the dollies to the coating. Measurements were made on four panels from each surface preparation type per coating system with three readings taken per panel. Areas damaged during adhesion testing were repaired using the proper coating system and allowed to cure for seven days prior to further testing.

Following adhesion testing, panels were placed in a battery of tests to measure performance of the various surface preparation methods in simulated service conditions. These tests are described below.

Atmospheric Testing. Four panels of each surface preparation per coating system were placed in atmospheric testing. This testing is conducted at Corrpro's Atmospheric Test Site in Sea Isle City, New Jersey. Panels were placed at a 45° inclination, facing south. Panels were sprayed with seawater daily at which time they were inspected for significant corrosion changes. Two of the panels received intentional 45° scribes. These panels were evaluated for scribe cutback, general paint failure, and overall rust. The remaining two panels were for adhesion measurements. Formal inspections were performed at regular three-month intervals to evaluate overall performance and measure adhesion.

Prohesion Testing. Accelerated Corrosion testing was performed in general accordance with ASTM G85, "Standard Practice for Modified Salt Spray (Fog) Testing." Test samples were subjected to a standard salt fog exposure, using a 5% NaCl solution, for a period of one-hour. The test samples were then subjected to a one-hour dry-off period, where the exposure chamber is purged of the salt air and heated to 35°C. This cycle was repeated for a total of 2,000 hours. Results from this test are typically a better indicator of performance than traditional salt fog testing (in accordance with ASTM B117).

Four panels of each surface preparation per coating system were placed in prohesion testing. Two of the panels received intentional 45° scribes. These panels were evaluated for scribe cutback, general paint failure, and overall rust. The remaining two panels were for adhesion measurements. Formal inspections were performed every 100 hours for the first 500 hours and every 500 hours for the next 1,500 hours to evaluate overall performance and measure adhesion.

Cathodic Disbondment. Two panels of each surface preparation per coating system were placed in cathodic disbondment testing. Testing was conducted in general accordance with ASTM G 8, "Test Method for Cathodic Disbondment of Pipeline Coatings." Duplicate coated 6-inch by 12-inch by 1/8-inch test panels have a 6-inch scribe made parallel to and centered along the 12-inch panel edge. The test panels were placed in a non-metallic tank and exposed to natural seawater. Seawater flow into the tank was maintained to avoid stagnation.

The test panels were electrically coupled to a centrally located magnesium anode. These panels remain in testing for a minimum of 45 days, with electrical data (galvanic current and on/off potentials) taken weekly. After exposure, the panels were removed from the tank and inspected for blistering and cutback from the scribe. Blistering was rated in accordance with ASTM D 714, and scribe cutback was recorded as the maximum distance from the scribe that the complete coating system could be easily removed using a razor knife.

Metallography. One sample of each type of surface preparation was retained for in-house visual and microscopic evaluation. Samples will also be sent to a laboratory for Scanning Electron Microscopy (SEM) evaluation.

RESULTS AND OBSERVATIONS

Contamination. Chloride and conductivity measurements were made on two panels from each type of surface preparation within the bottom two inches of the panel. Average readings are shown in Table 4 and Figure 1.

Table 4. Contamination Data

Surface Preparation	Average Conductivity	Chlorides*
Solvent Cleaned	13	BDL
Grind	33.5	BDL
Shot Peen	10.5	BDL
Roto-peen	13	BDL
Wire Wheel	26	BDL
Grit Blast	11	BDL
Water Jet	17	BDL

*BDL indicates Below Detectable Levels

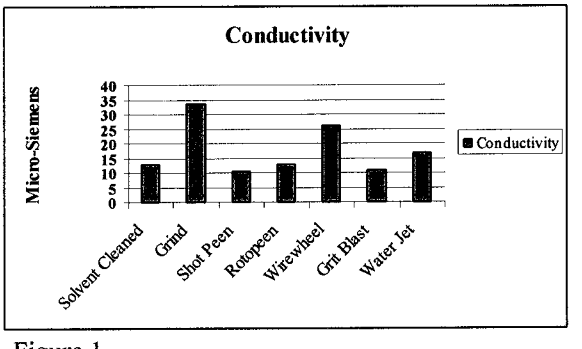

Figure 1

All chloride measurements were below detectable limits. Conductivity readings were within the range of 10-51 micro-siemens per centimeter, with only one reading above 30 micro-siemens per centimeter and the majority of readings below 20 micro-siemens per centimeter. According to NAVSEA Standard Item 009-32, Section 3.6.17.1, the limits on conductivity are 30 micro-siemens per centimeter for immersion service and 70 micro-siemens per centimeter for atmospheric service. Chloride limits are 3 micro-grams per centimeter for immersion service and 5 micro-grams per centimeter for atmospheric service.

Profile Measurements. As shown in Table 5, grit blasting, followed by shot blasting, consistently gave the roughest surfaces on a macro level. Water jetting and solvent cleaning, followed by wire-wheeling, consistently gave the smoothest surfaces on a macro level. Of interest though, is that water jetting and solvent cleaning, followed by wire-wheeling, had the highest R_{pc} (intervals between peak & valley/above & below mean) behavior, by a considerable amount.

Table 5. Profile Data

Surface Preparation	R_A (mils)	R_Y (mils)	R_Z (mils)	R_q (mils)	R_{PC} (peaks /area)	Testex (mils)
Shot Peen	0.27	2.00	1.56	0.35	2.91	2.35
Wire Wheel	0.03	0.29	0.19	0.04	3.03	-
Grinder	0.09	0.80	0.49	0.12	2.04	1.85
Roto-peen	0.09	0.78	0.49	0.13	2.27	1.95
Water Jet	0.01	0.20	0.13	0.02	6.91	-
Grit Blast	0.30	2.16	1.70	0.38	3.32	2.60
Solvent Clean	0.01	0.20	0.12	0.02	6.41	-

The profile data shown in Table 5 does not show any significant difference between the water jetted surface and the solvent cleaned surface. There are, however, scale limitations to the profilometer and the true effects of water jetting on surface topography cannot be determined until metallography is completed.

Adhesion Testing. Prior to being placed into testing, the panels without scribes were tested for coating adhesion.

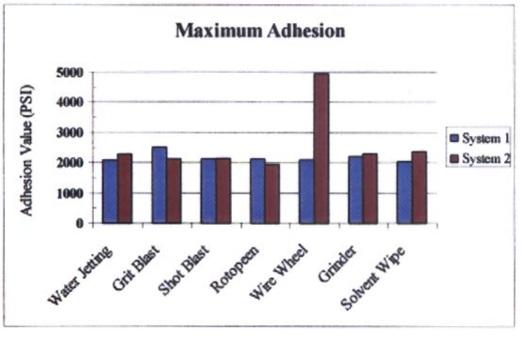

Figure 2

Table 6. Coating Adhesion

	Surface Preparation	Max (PSI)	Min (PSI)
System 1 Standard Epoxy	Water Jetting	2079	1017
	Grit Blast	2528	1303
	Shot Blast	2119	855
	Roto-peen	2119	977
	Wire Wheel	2079	1058
	Grinder	2201	1303
	Solvent Wipe	2038	814
System 2 Non-Skid Primer	Water Jetting	2283	1014
	Grit Blast	2119	936
	Shot Blast	2160	895
	Roto-peen	1956	732
	Wire Wheel	4956	1017*
	Grinder	2283	1303
	Solvent Wipe	2364	732

* Denotes failure to substrate

Results of the adhesion measurements, as shown in Table 3 and Figure 2, indicate that the surface preparation methods are performing at least equally with the exception of the wire wheel, which exhibits an extremely high adhesion of 4,956 psi. The wire wheel surface preparation is also the only one that had a failure to the substrate.

Prohesion Testing. Prohesion testing of the scribed panels was initiated on July 31, 2001. The non-scribed panels were placed into testing on August 20, 2001 following adhesion measurements. At the time of this paper, scribed panels have been in prohesion testing for 500 hours, non-scribed panels have been in prohesion testing for 300 hours. Figures 3 and 4 show the results of prohesion testing to date for scribed and non-scribed panels, respectively. To date, there is no significant difference in the performance of coatings over the various surface preparations. Prohesion testing will be continued until 2,000 hours.

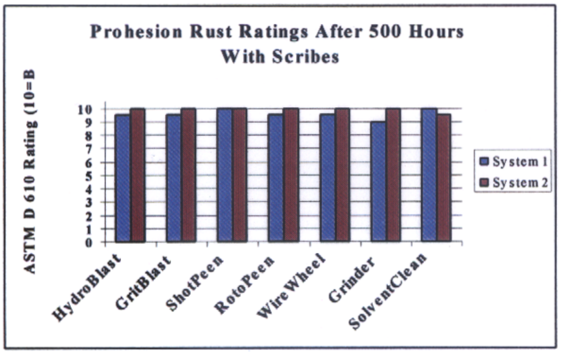

Figure 3

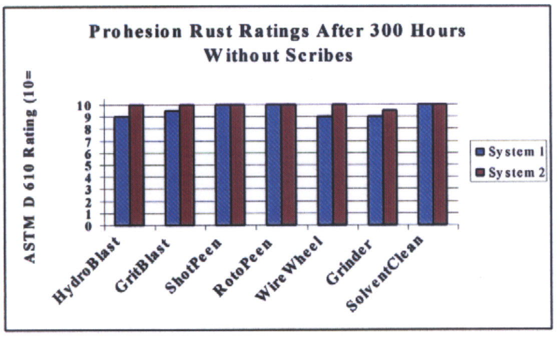

Figure 4

Other Observations. During surface preparation, the wetting characteristics of the surface changed significantly. Prior to water jetting, the water was observed to bead on the surface meaning incomplete wetting was achieved and the substrate had low surface energy. After the surface was water jetted, however, water was observed to spread quickly over the surface, meaning more complete wetting was achieved, thus the surface energy of the substrate was increased. This is demonstrated in Figure 5, shown below.

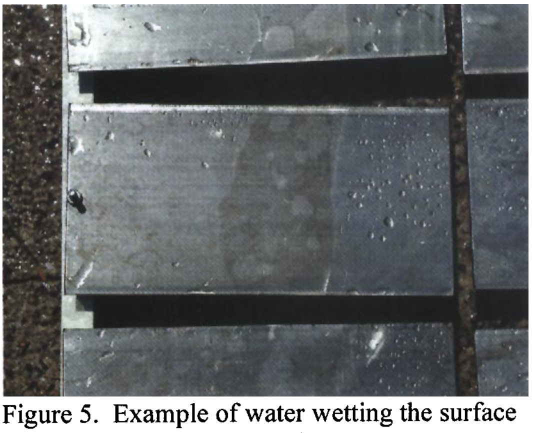

Figure 5. Example of water wetting the surface better after water jetting. The center was water jetted at 40,000 psi with 6 gpm. Left and right of center were only degreased.

CONCLUSIONS

1. Peak density is reduced by surface preparation that implements mechanical deformation of the surface, though without magnification, water jetting does not appear to impart a profile.

2. The effects of water jetting on surface profile were undetectable using either Testex tape or profilometer. Future work in this area will include SEM photographs and metallography of the unpainted surfaces to determine significant differences between the profiles imparted by the surface preparation methods.

3. The data in Table 6 and Figure 2 show no significant difference between the adhesion of coatings to the various surface preparations used. Adhesion values may change following performance testing.

4. Water jetting may affect substrate surface energy. It is not known at this point what this means for coating adhesion, though it does indicate increased wettability of the surface. High wettability results in intimate contact between coating and bare steel, which directly correlates to increased pull-off adhesion.[3]

5. The results reported in this paper are based on the specific parameters of the water jetting equipment used, substrate and coating materials selected, and the tests performed. Using other operating pressures, nozzles designs, different substrates, coating materials, or application under different environmental conditions may dramatically vary the results reported here.

FUTURE WORK

In addition to investigating the initial issue of coating adhesion and performance over water jetting versus other forms of surface preparation, this study will continue to investigate the effects of profile size and density on adhesion as well as its effects on coating performance. This

[3] Baghdachi, Jamil, PhD, "Adhesion Aspects of Polymeric Coatings, Virtual Seminar," Federation of Societies for Coatings Technology, June 14, 2001

will be accomplished through literature searches and additional laboratory research.

One of the goals of this work is to determine which surface characteristics result in the best coating adhesion and coating performance; the absolute roughest (peak/valley values) surface or a surface which, though not as rough, exhibits a higher R_{pc} surface (more peak/valley systems). To accomplish this, results from coating performance testing and adhesion measurements will be analyzed for correlation to surface characteristics.

Currently, panel testing is still in progress and will continue through November 2001 for prohesion and cathodic disbondment testing. Atmospheric exposure testing will continue through July 2002. Results of SEM are expected in November 2001.

If micro-profile is found to influence adhesion and can be controlled, future implications of this ongoing study will require development of a procedure and equipment to measure the surface micro-profile in the field. Accurate field measurements will be necessary if micro-profile of water jetted surfaces is to be considered a quality controlled item such as macro-profile of abrasive blasted surfaces is quality controlled.

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