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Cover photo courtesy of Alan Kehr, Alan Kehr Anti-Corrosion, LLC

FEATURES

22 **PRACTICAL IN-PLANT EVALUATION OF TWO FBE ABRASION-RESISTANT OVERCOAT SYSTEMS**

By Emre Aksu, Borusan Mannesmann; Alan Kehr, Alan Kehr Anti-Corrosion LLC; and Matt Dabiri, Consultant

In this article, the authors illustrate a comparison between a new flexible version of an abrasion-resistant overcoat (ARO) coating system and two ARO coatings at a total thickness of 20 mils, two single-layer fusion-bonded epoxy (FBE) coatings, and two dual-layer FBE (2LFBE) systems at a thickness of 60 mils.

32 **NEW ADVANCES IN EPOXY COATINGS FOR MARINE MARKETS**

By James McCarthy, PPG Protective and Marine Coatings

Because of its high-performance capabilities, epoxy technology has been a mainstay of the marine coatings market for many years, but this technology also presents problems resulting from its two-component composition. The author describes testing of single-component coatings for marine applications that offer advantages over multi-component coatings such as eliminating pot-life and mix-ratio concerns while satisfying performance requirements.

44 **TRANSFORMING THE SUBJECT MATTER EXPERT INTO AN EDUCATOR: GAINING COMPETITIVE ADVANTAGE BY APPLYING ADULT LEARNING PRINCIPLES**

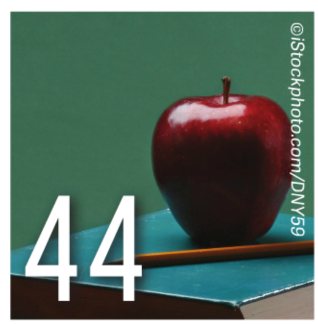
By Amy Gibson, KTA-Tator, Inc.

This article describes what makes adult learners different, the different ways they learn, and how by considering their unique needs, characteristics and learning styles, a more customized education plan can be developed which will support more permanent and successful learning outcomes.

50 **THE EFFECT OF SURFACE PREPARATION ON COATING PERFORMANCE**

By Patrick Cassidy, Elzly Technology Corporation and Paul Slebodnick, James Tagert and James Martin, U.S. Naval Research Lab

This article describes a study of the effect of profile type, profile height, the extent of cleanliness and the amount of chloride contamination on coating performance in an effort to determine the correlation between these factors and to ideally identify whether or not there is a primary surface preparation factor that leads to coating failure.



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DEPARTMENTS

6 Top of the News
SSPC Revises Two Standards

8 The Buzz
Grain Silo Gets 'Despicable' Paint Job

10 Problem Solving Forum
On Approving Work

12 How To...
Ensure Accurate DFT Readings:
10 Important Things to Know

18 Investigating Failure
Protecting Offshore Platforms in the Gulf of Mexico:
Shortcuts = Potential Havoc

FROM THE OFFICES OF SSPC The Society For Protective Coatings

4 SSPC on the Front Line
Measuring Surface Profile:
What's Changed, What's the Same

69 SSPC Organizational Members

ALSO THIS ISSUE

61 Specifiers' Choice Guide
Educational Advertisement

75 SSPC Certified Contractors

76 Service Directory

79 Classifieds

80 Index to Advertisers

80 Calendar

STAFF

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Measuring Surface Profile

WHAT'S CHANGED, WHAT'S THE SAME

In the coatings industry, there are a number of methods and instruments used to measure the surface profile of abrasive blast-cleaned steel. Surface profile is a measurement of the peak-to-valley height of a surface, and it is a major factor in determining a coating's adhesion when applied to steel. Producing a surface profile lower than that specified can lead to adhesion problems, while too great of a profile may lead to pinpoint rusting due to insufficient coating application over the peaks of the profile.

Some methods and equipment for measuring surface profile have been used in the same way for decades, while others have been changed to comply with updated testing standards and advances in technology. It is essential to review the specification carefully to establish which methods of measuring surface profile are to be used before beginning work. As with any other step in the process, it is also important to ensure that the equipment chosen to take these measurements has been tested, calibrated and verified to be in good working order.

ASTM D4417 and SSPC-PA 17

The ASTM International standard ASTM D4417, "Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel," describes three different methods used in the industry to measure surface profile of steel.

- Method A: Comparator
- Method B: Digital Profile Gage
- Method C: Replica Tape

Method A compares an abrasive blast-cleaned surface to a set of discs corresponding to a steel surface that has been blast-cleaned using sand, grit/slag, and steel shot abrasive. Each disc features multiple surface profiles to provide for side-by-side visual or touch comparisons to the actual blast-cleaned surface. This method and the comparator discs used have remained largely unchanged since their introduction.

Methods B and C, however, were revised by ASTM in 2014. For Method B, the digital profile gage is an electronic gage that uses a probe to measure surface profile. Readings are taken by placing the probe firmly onto the blast-cleaned area, allowing the pointed tip to enter a single valley of the steel. The revised Method B states that 10 profile readings shall be taken over each location, and the highest measurement is recorded as the profile for the surface. The previous version of the standard mandated the taking of 10 readings, with the *average* being used as the reading.

This change was brought on partially by the belief that the calculated average of 10 readings is usually less than the profile values obtained when using Method C, as the digital gage records readings from the lowest pits as well as the highest peaks depending on where the inspector places the probe. Recording the highest reading instead of an average shows a better correlation to the results that are produced by Method C.

Photo courtesy of SSPC.

SSPC-PA 17, "Procedure for Determining Conformance to Steel Profile/Surface Roughness/Peak Count Requirements," which was issued in 2012 to create an industry standard for conformance of surface profile readings, requires the 10 readings to be taken from a minimum of three 15-by-15-centimeter (6-by-6-inch) locations. The revised ASTM D4417 now states that SSPC-PA 17 should be employed to verify conformance to the specification. When used in tandem, the ASTM and SSPC standards complement one another, and both standards are now necessary to provide proper inspection and evaluation of the surface profile. ASTM guides the inspector in using the instrumentation, while SSPC instructs what to do (in other words, the where and when) to determine that the profile requirements in the specification are met.

Many of the digital profile gages used for Method B now have the ability to record and store surface profile measurements, which can be uploaded to a mobile device or computer via USB, Bluetooth and/or wireless internet. This can save time and paper on the job site and eliminate the potential for human error in recording measurements manually.

ASTM D4417, Method C uses replica tape, which consists of a layer of crushable plastic microfoam coated onto a polyester film of highly uniform thickness. The tape is compressed against the surface to produce an impression of the surface profile, which is then measured with either an analog or digital spring micrometer. While micrometer technology has advanced, replica tape is one of the industry's older but most tried-and-true pieces of equipment for measuring surface profile.

According to the revised Method C, two readings are to be taken over each location and averaged to get one measurement of the profile of the surface. The previous standard required an average of three tape readings per area instead of two. This was changed based on testing that showed that taking two tape readings was just as sufficient and accurate as taking three. The advantage is a slight reduction in cost of materials and time to perform the test. Again, SSPC-PA 17 is referenced for the measurement area, requiring a minimum of three 15-by-15-centimeter (6-by-6-inch) locations from which to take these measurements.

Portable Stylus Instrument

ASTM D7127, "Measurement of Surface Roughness of Abrasive Blast Cleaned Metal Surfaces Using a Portable Stylus Instrument," also describes a method to determine the surface roughness, or the combined characteristics of surface profile and peak count or density, of a blasted steel surface. The instrument draws a stylus at a constant speed across the surface, and the results can show the differences in roughness produced by blasting with different types of abrasive media. Steel grit is considered "angular" and will produce a high count of sharp peaks and valleys on the surface, while steel shot produces a rounded profile. A higher peak count equates to an increase in surface area, which improves coating adhesion, so grit is usually recommended. The latest update to ASTM D7127 in 2013 contained no major revisions to the process.

Determining Surface Profile on Pitted Steel

Surface profile readings taken on pitted areas of steel can yield false high values, even when using the visual techniques described earlier. If the steel being inspected contains pits, surface profile readings should be obtained from non-pitted areas. If the steel is 100-percent pitted, a non-pitted test panel should be created to receive the same surface preparation as the pitted steel will. The test panel is then measured for profile, and since it is not pitted, a more accurate reading can be obtained from the equipment.

Conclusion

ASTM D4417, Methods B and C, are by far the most popular for measuring surface profile today, as they are the most practical for use in the field and provide quantitative results. Method A is qualitative, purely based on visual evaluation. The portable stylus can be difficult to use in the field and tends to be used in the laboratory. However, some owners do not allow the use of electronic devices due to potential hazards, especially in confined spaces, so replica tape is used as a default. One should always refer to the specification to verify which methods of measuring surface profile are to be used.

For further information, contact Dane Worms, technical services coordinator, SSPC, at dworms@sspc.org or 412-281-2331, ext. 2217. Additional information on ASTM D4417, ASTM D7127 and SSPC PA-17 can be found at www.astm.org and www.sspc.org.

SSPC Revises Two Standards

Two standards — one for the coating of metals and one for qualifying and certifying industrial coating and lining application specialists — have been updated under the direction of SSPC: The Society for Protective Coatings.

SSPC-PA 1, "Shop, Field and Maintenance Coating of Metals," provides basic requirements for best practices for application of industrial and marine protective coatings to coated or uncoated metallic substrates. Written by SSPC's Application Methods Committee (C.3.1), the guide is intended as a reference for specifiers and contractors in regard to the coating application and process control procedures. The scope of this standard includes specific as well as general requirements for the application of liquid coatings applied by brush, spray or roller.

Revisions include the following.

- Editorial and organizational amendments that shorten and streamline the standard itself, with commentary and supplementary information moved into the Notes section.
- An expanded scope that includes coated or uncoated metallic substrates in addition to steel.
- A brief discussion of the importance of a contractor's work plan as a method of project oversight and quality assurance, with supplementary resource information.
- An example of language that may be used to invoke requirements of PA-1.
- The removal of discussion of application requirements for specific types of generic coatings, which is usually addressed more specifically in manufacturers' application instructions.

Additionally, a section has been added to address pre-application requirements, clarifying that the contractor is responsible for documenting resolution of ambiguous or conflicting requirements prior to beginning the application process, verifying that the prepared surface meets project requirements for cleanliness and surface profile prior to coating application and ensuring that ambient conditions comply with project requirements prior to coating application.

SSPC-ACS 1/NACE No. 13, "Industrial Coating and Lining Application Specialist Qualification and Certification," can be used to validate or assess a candidate's or employee's knowledge and skill level based on qualification in a certification program. It was designed for use by personnel involved in developing such education and certification programs.

The standard, written by the 2015 Revision SSPC-ACS 1/NACE No. 13 Committee (C.3.15), recognizes and records in outline form the competency requirements or minimum Body of Knowledge for each qualification level.

Revisions include the following.

- Terminology updates.
- Adjustments to Level I, II and III qualifications requirements, including demonstration of abilities, work experience, training options and exam completion.
- Requirements to maintain qualification status.
- Reduction of levels of competency from six to three, with changes to definitions.
- A streamlined Body of Knowledge with revisions to competency levels that reflect new definitions.
- A non-mandatory appendix providing examples of acceptable training programs.

For further information on these standards, visit www.sspc.org.

$11B Valspar Deal Gets Shareholders' OK

Paint and coatings maker Valspar, based in Minneapolis, received the support of its shareholders on June 29 as they voted to approve the proposed sale of the company to rival The Sherwin-Williams Company.

The vote, which was held during a special shareholders meeting, marks a significant step needed to close the deal — worth an estimated $11.3 billion.

Announced in March, the merger would result in a combined coatings company with annual sales of $15.6 billion, profits of $2.8 billion and 58,000 employees, according to the companies. The deal would increase Sherwin-Williams' global footprint in Asia-Pacific and Europe, the Middle East and Africa (EMEA) and add new capabilities in packaging and coil segments, according to Sherwin-Williams' President and CEO John G. Morikis. The companies anticipate a first quarter 2017 closing.

Before closing, federal antitrust regulators must also approve the proposed transaction. The U.S. Federal Trade Commission has requested additional information and documentary materials from both parties.

John G. Morikis

Gary E. Hendrickson

According to the filing with the U.S. Securities and Exchange Commission, the Valspar vote in favor of the merger was 63.2 million shares, with 1.1 million against. Sherwin-Williams' shareholders do not need to vote on the transaction. The companies' boards of directors previously approved the transaction.

During the special meeting, Valspar shareholders also agreed to a top-level executive compensation clause should the merger close, the *Minneapolis Star Tribune* reported. Valspar's CEO Gary E. Hendrickson is expected to receive severance of roughly $38.1 million in combined cash, equity and benefits, the report stated. The company's chief financial officer, James Muehlbauer, would reportedly receive $11.1 million and Rolf Engh, Valspar's executive vice president and general counsel, would get $5 million in combined compensation.

University of Akron's Corrosion Hub Expands

Photo courtesy of The University of Akron/NCERCAMP.

The University of Akron (UA) celebrated the expansion of facilities and capabilities in its corrosion research center with an open house on June 21.

The National Center for Education and Research on Corrosion and Materials Performance (NCERCAMP), established in 2010 by Congress and the U.S. Department of Defense, is dedicated to helping industry and government agencies improve material performance, mitigate the effects of corrosion and manage risk through research.

The open house event was organized around the theme of "The Fight Against Corrosion," which causes an estimated $423 billion of damage annually in North America alone, according to UA's announcement.

Attendees included representatives from Bendix Commercial Vehicle Systems, Parker Hannifin, the U.S. Army Corps of Engineers and Wright-Patterson Air Force Base, the University noted.

The Center offers programs and services in education and workforce training, research and technology development, as well as outreach and public policy activities. It also boasts a core set of specialized laboratories that support activities ranging from materials performance, structural analysis and advanced material development to product testing and deployment, according to its website.

Following a ribbon-cutting ceremony, attendees, representing government and industry, took tours of the expanded facility, during which UA unveiled its newest labs and capabilities, including the following.

- An X-ray Diffraction Lab that is unique in the U.S., offering a variety of capabilities with easy switching from one type of experiment to another. The lab focuses on thin films, surface structure and materials at high humidity and high temperature.
- A Fatigue Lab featuring two different-sized load frames that allow researchers to determine how fatigue and corrosion impact a wide variety of materials.
- A doubling of the number of salt spray test chambers so that larger numbers of material samples can be tested for corrosion under "natural" conditions.

NCERCAMP complements UA's undergraduate program in corrosion engineering, the only one of its kind in the U.S. The center serves as a strategic partner of the DoD's Office of Corrosion Policy and Oversight. In addition to a formal memorandum of understanding with NACE International, NCERCAMP boasts relationships with organizations such as SSPC and ASM International, which help to maintain industry involvement in the program.

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Photos courtesy of Imgur.

Grain Silo Gets 'Despicable' Paint Job *(June 17)*

The long, flat stretches of road in rural Indiana can lead to driver fatigue, but if you're cruising through Wells County and see a giant minion on the side of the road, don't worry: You're not hallucinating.

The big yellow guy popped up on the farm of Kathy Stark earlier this year, a tribute to her late husband, Jim, who had talked about painting the farm's old grain silo like one of the characters last year, but passed away last fall before the job could be done.

According to media reports, Stark has lived on the farm for 37 years, and last year, she and her husband decided the silo was in desperate need of a fresh coat of paint. It was then that the minion idea came up, in part to entertain the grandkids. And because, let's face it: That silo is shaped exactly like a minion.

According to *The Washington Post*, the piece was a family affair. Stark has a son and daughter who are architects, and they have a cousin who is a welder, the *Post* reports — that's who created the six-foot eyes that pop off the character's face. The 25-foot-tall silo took about 14 gallons of paint to finish, according to reports.

It's become the talk of Wells County and the surrounding environs, of course. Stark told *WANE-TV* that even a nearby senior center took a field trip to see the minion.

The minions were created for the 2010 movie "Despicable Me," released by Universal Pictures and Illumination Entertainment.

PSN TOP 10 *(as of June 30)*

1. PPG Expands Reach with New Acquisition
2. TiO_2: Cause for Concern?
3. Bridge, Scaffolding Fall on Autobahn
4. BASF Grows Coatings Arm in $3.2B Deal
5. Railcar Factory Faces $105K OSHA Bill
6. Swiss Launch Record-Breaking Tunnel
7. Possible Burial Ground Halts Pipeline
8. Heat Wave 'Blows Up' Highways
9. Coast Guard Cadets Analyze Corrosion Rates
10. 2 Injured in AZ Bridge Project

WHAT'S GOT US TALKING

(PaintSquare News *Weekly Poll, June 12–18)*

A pipeline company was recently indicted on criminal charges for knowingly discharging a pollutant into state waters and wildlife charges; one employee faces up to three years in prison if convicted. Are criminal charges appropriate in such a case?

71% Yes, companies and their staffs need to know there are severe consequences for not taking adequate steps to protect the environment.

26% Maybe; financial penalties would be appropriate but not jail time.

3% No, there was no loss of human life.

M. Halliwell: "Willful is willful. Splitting hairs about what chemical, how much, whether it will cause death/disease in humans, animals or plants ... just circumstances for the judge to use in deciding what the punishment is upon conviction. If you knowingly let someone go 100 feet in the air without fall protection and they have a fatal fall, it's willful and chances are you'll get charged. Why should it be less if you knowingly release a chemical into a river that could make thousands sick and/or kill people? Jail time and fines are necessary tools to encourage compliance and punish those who knowingly do this sort of thing."

On Approving Work

IF YOU'RE PERFORMING A QA INSPECTION AS A PART-TIME CONSULTANT AND THE SURFACE IN QUESTION WAS BLASTED AND PAINTED TWO DAYS BEFORE YOU ARRIVED ON-SITE, SHOULD YOU SIGN OFF ON THE WORK IF THE OWNER ASKS YOU TO?

Per Gabrielsson
Freelance Consultations and Inspections
I would say, "You must be kidding!" Then I would charge him for the wasted time spent.

M. Halliwell
Thurber Engineering Ltd.
I had this sort of scenario pop up for me. A contractor called to say that they were going to start the work (cast-in-place piles) that morning and asked if they could get an inspector. An hour later, when we got to the site, six piles were already completed. (They had to have started before they called us.) We flatly refused to sign off on those piles. We had no confirmation of what the piles were cast in, how deep they were, what rebar was placed or information on the concrete. It's impossible to say you witnessed the work and that it is in compliance (i.e., sign off on the work) if it was done without you there.

Daniel Valdivia
IUPAT DC 30 Painters JATF
No, I would not put my name on an inspection that I did not conduct.

Om Prakash Jat
Tech International Sharjah Hamriyah UAE
I will not sign any inspection documents if I did not witness the work.

Adrian Granda
Julio Crespo Perú, s.a.c.
Definitely not. Inspectors who know this issue will not sign off on any document if they did not witness the work.

Jason Hetherington
Corrpro Companies, Inc.
Absolutely not. This is a test of morality. Never sign off on completed work based anything other than what you, as the QA, observed. Taking the direction on this from an owner or the word of the contractor is a recipe for disaster.

Lionel Darre
LDI
The question does not specify to sign "witnessed." I would check the records to be signed and if data are conforming to the specifications, procedures, etc., then I would sign "reviewed."

Per Gabrielsson
Freelance Consultations and Inspections
Lionel, you must have great trust in subcontractors! As mentioned before, I would walk away and tell the project manager to expect my invoice for wasted time.

Rosemary Coutinho
O Pintor Consultoria
I would never sign off on work I didn't witness!

M. Halliwell
Thurber Engineering Ltd.
Lionel, I agree you could review the documentation and sign off on the review of the documentation, but I don't think you'd accept liability and sign off on the work itself when you cannot confirm the work was done properly. There is a big difference there and I think that's what you were trying to get at in the "reviewed" vs. "witnessed" comment. Typically, though, if you "sign off on the work" you are declaring (and in most cases assuming liability) that the work was performed correctly, which implies witnessing it.

Pieter van Riet
Corrocoat SA (Pty) Ltd
If the inspection points that you missed were witness points, you may not sign off on the work as if you inspected it. You will be committing fraud if you do so, at least if you fail to record on the QC records that the work was done unwitnessed. This does not mean that you MUST automatically reject the work and instruct re-blast and recoating. You need to discuss this with the party that appointed you. It is their call to make. There might be severe consequences to the overall project if it is delayed by rework and the project management team might decide to accept the risk of incorrect coating so as not to incur even bigger risk elsewhere. If all the contractual parties to the QCP (the end-user, ECP consultants, paint manufacturer, etc.) are keen to accept the work and move the project forward, you can request a concession from the highest approval authority (usually the engineer). You should do so only after you have interviewed (interrogated) all the crew involved in the surface prep and paint work, thoroughly reviewed the records, assured yourself that there is nothing obviously amiss, considered your and others' experience with this contractor and assured yourself of his honesty and competence, and investigated why the work was started before the inspector had arrived. A concession should be considered only if it was purely due to miscommunication, or misunderstanding and not if there was a risk that it was for nefarious reasons or to hide poor work.

ENSURE ACCURATE DFT READINGS
10 IMPORTANT THINGS TO KNOW

By David Beamish, DeFelsko Corporation

Hand held dry film thickness (DFT) gages are common inspection tools used by applicators and inspectors. With a little care and maintenance, mechanical and electronic instruments can be relied upon to give many years of accurate and dependable service.

Good operation begins with reading the manual. All instruments have subtle operational differences. Record the make, model, serial number and date of purchase inside the manual and highlight maintenance and calibration tips.

1. CAN I CALIBRATE?

There's a good chance someone you know misunderstands the terms "calibration" and "calibration interval." They would be surprised to learn that not only can they not calibrate their gage, but there is usually no requirement for annual recertification either.

ASTM D7091 defines calibration as "the high-level, controlled and documented process of obtaining measurements on traceable calibration standards over the full operating range of the gage, then making the necessary gage adjustments (as required) to correct any out-of-tolerance conditions." It goes on to point out that calibration, "is performed by the equipment manufacturer, their authorized agent or by an accredited calibration laboratory in a controlled environment using a documented process."

A calibration often results in the issuance of a document called a Certificate of Calibration (Fig. 1). This document records actual measurement results and all other information relevant to a successful instrument calibration and clearly shows the traceability to a national standard. Job specifications often require proof of a recent calibration.

Recalibration (or recertification) is periodically required throughout the life cycle of an instrument since the accuracy of most measuring devices degrades with use. A *calibration interval* is the established period between recalibrations of an instrument. As per the requirements of ISO 17025, most manufacturers do not include calibration intervals as part of calibration certificates. Why? Because they don't know how frequently the gage is used, in what environment it is used and how well it is looked after.

If you don't have experience with an instrument, one year is a good starting interval between calibrations. This can be adjusted with experience and regular verification. Customers with new instruments can utilize the instrument purchase date as the beginning of their first calibration interval. The negligible effect of shelf life minimizes the importance of the actual calibration certificate date.

2. IT'S VITAL TO VERIFY

A calibration certificate does not guarantee accuracy will be maintained throughout the calibration interval. Myriad factors detrimentally affect gage operation as soon as you open the box. That is why most standards require regular verification of accuracy.

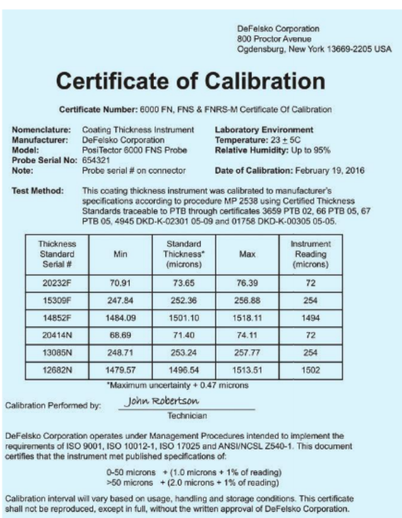
To guard against measuring with an inaccurate gage, accuracy and operation should be verified before each use, typically at the beginning of every work shift. It should be rechecked when large numbers of measurements are being obtained, or if the gage is dropped or suspected of giving erroneous results.

Accuracy checks are performed by measuring traceable reference standards — either shims or coated metal standards. The average of a series of readings should be within the combined tolerances of both the gage and the reference standard (Fig. 2, p. 14).

Traceability is the ability to follow the result of a measurement through an unbroken chain of comparisons all the way back to a fixed international standard that is commonly accepted as correct. The chain typically consists of several appropriate measurement standards, the value of each having greater accuracy and less uncertainty than its subsequent standards.

3. INFLUENTIAL EFFECTS

Most DFT gages are factory calibrated to perform well on flat, smooth carbon steel. Your application may be different. Generally, four conditions affect accuracy and must be corrected for: surface roughness, geometry (curvature, edge effect), composition (metal alloy, magnetic properties, temperature) and mass (thin metal). To prevent these or any other factors from causing gage inaccuracies, check that the



DeFelsko Corporation
800 Proctor Avenue
Ogdensburg, New York 13669-2205 USA

Certificate of Calibration

Certificate Number: 6000 FN, FNS & FNRS-M Certificate Of Calibration

Nomenclature: Coating Thickness Instrument
Manufacturer: DeFelsko Corporation
Model: PosiTector 6000 FNS Probe
Probe Serial No: 654321
Note: Probe serial # on connector

Laboratory Environment
Temperature: 23 ± 5C
Relative Humidity: Up to 95%
Date of Calibration: February 19, 2016

Test Method: This coating thickness instrument was calibrated to manufacturer's specifications according to procedure MP 2538 using Certified Thickness Standards traceable to PTB through certificates 3659 PTB 02, 66 PTB 05, 67 PTB 05, 4945 DKD-K-02301 05-09 and 01758 DKD-K-00305 05-05.

Thickness Standard Serial #	Min	Standard Thickness* (microns)	Max	Instrument Reading (microns)
20232F	70.91	73.65	76.39	72
15309F	247.84	252.36	256.88	254
14852F	1484.09	1501.10	1518.11	1494
20414N	68.69	71.40	74.11	72
13085N	248.71	253.24	257.77	254
12682N	1479.57	1496.54	1513.51	1502

*Maximum uncertainty + 0.47 microns

Calibration Performed by: John Robertson
Technician

DeFelsko Corporation operates under Management Procedures intended to implement the requirements of ISO 9001, ISO 10012-1, ISO 17025 and ANSI/NCSL Z540-1. This document certifies that the instrument met published specifications of:

0-50 microns + (1.0 microns + 1% of reading)
>50 microns + (2.0 microns + 1% of reading)

Calibration interval will vary based on usage, handling and storage conditions. This certificate shall not be reproduced, except in full, without the written approval of DeFelsko Corporation.

Fig. 1: A certificate of calibration.
All figures courtesy of the author.

average of a series of measurements on the uncoated substrate is within the gage tolerance at zero. Alternatively, check the known thickness of a shim placed over that uncoated substrate.

4. EDGE CASES

It used to be that industry standards advised against measuring closer than one or two inches from an edge. Modern probes

What are acceptable results when measuring a 5 mil shim if ...
• the shim tolerance is ±5% and
• the gage accuracy is ±(0.1 mil + 1%)?

shim variable tolerance: 5 mils x 5%	= 0.25 mils
gage variable tolerance: 5 mils x 1%	= 0.05 mils
gage fixed tolerance:	= 0.10 mils
Total tolerance range:	**= 0.40 mils**

The acceptable average of a series of readings should fall between 4.6 and 5.4 mils.

Fig. 2: A sample calculation.

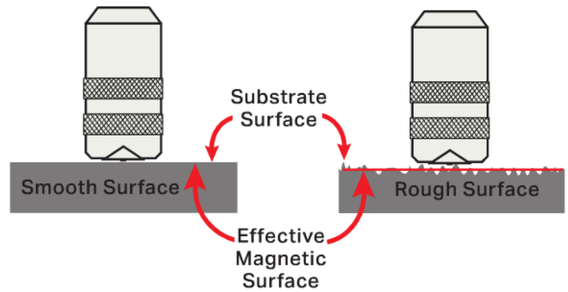


Fig. 3: Surface profile usually results in higher readings.

can usually measure much closer. In fact, their accuracy generally diminishes only when they overhang.

You check this the way you check most other issues — by measuring the uncoated substrate to verify that the average of a series of measurements is within gage tolerance at zero. Stripe coats are often best measured with microprobes designed for the purpose of measuring on small surfaces.

5. ROUGHLY ADJUSTING FOR PROFILE

Steel surfaces are frequently cleaned by abrasive impact prior to the application of protective coatings. Measuring on these surfaces is more complicated than on smooth surfaces. The effect on gage measurements increases with profile depth and also depends on the design of the probe and the thickness of the coating.

Users are taught that this "anchor pattern" can cause gages to read high (Fig. 3). But when it comes to adjusting for this profile it seems every user has a favorite method. Which one is right?

SSPC-PA 2 proposes several solutions depending upon the instrument type and the particular situation. Similar methods are suggested by ASTM D7091 and ISO 19840.

Mechanical pull-off (Type 1) gages have non-linear scales that cannot be adjusted. Therefore, the average of at least 10 bare surface measurements is calculated to

$$\sqrt{1^2 + 5^2} = 5.099 \approx 5\%$$

Fig. 4: The accuracy of an adjusted gage changes from ±1% to ±5% as calculated using a root sum of the squares formula.

generate a base metal reading (BMR). This value is subtracted from future coating thickness readings.

Most electronic (Type 2) gages can be adjusted by the user following the manufacturer's instructions. A common method is to simulate a coating covering the major peaks of the profile. A shim of known thickness is placed over the surface profile and measured. The gage is adjusted to match that shim's thickness.

If access to the uncoated substrate is not possible, ISO 19840 has correction values to subtract from DFT readings over fine, medium and coarse ISO 8503 profile grades.

6. ACCUMULATING ERRORS

Now that we know it is common practice to adjust a gage to the thickness of a shim, it is important to be aware that it can add significant error to future gage readings.

Measuring instruments have stated accuracy or tolerance statements issued by the manufacturer. When you make gage adjustments on shims, resultant gage measurements are less accurate. For example, if the accuracy of a properly calibrated gage is ±1 percent and the shim's thickness is accurate to within ±5 percent, the combined tolerance of the gage and the shim will be slightly greater than ±5 percent, as demonstrated by the formula in Figure 4.

7. INSPECT YOUR PROBE

Once the gage has been put into service, a surprising amount of trouble can be avoided with regular visual examinations of the probe. Look for obvious damage particularly to the measuring surface or to the probe cable. Constant-pressure probes should move up and down freely. Damaged, scratched or worn probes should be tested for accuracy on reference standards and replaced when necessary. Metal filings, dust and paint should be carefully removed with a cloth.

Avoid prolonged exposure to hot surfaces and allow the probe to cool between measurements. Respect rough surfaces by lowering the probe carefully and never drag it sideways unless the probe was designed for that use. Plastic shims of known thickness can be placed onto these surfaces to afford the probe some protection. Subtract the thickness of the shim from the measured thickness and be mindful of the additional measurement tolerance resulting from use of the shim.

Indications that a probe may need service include lower than expected readings (i.e. probe tip wear), higher than expected readings (i.e. foreign material stuck on it) and erratic measurements (i.e. component failure).

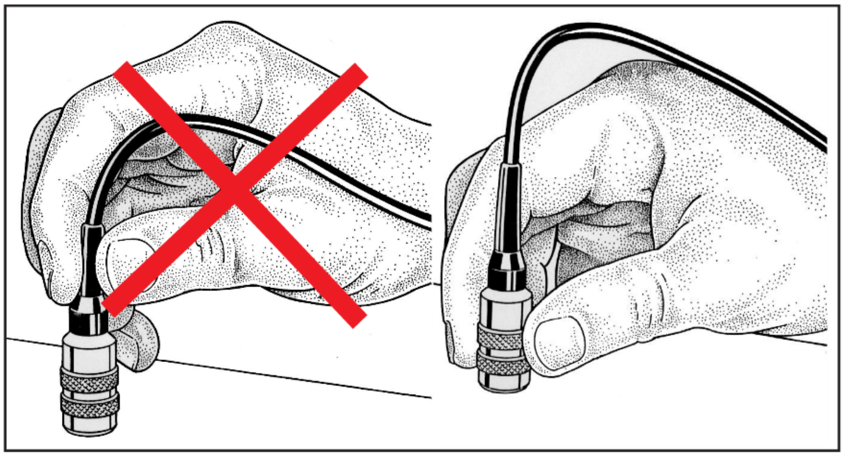


Fig. 5: For best results and longest life, the sliding probe should not be gripped high (left), but instead with your fingers low to the surface (right).

8. HOLDING THE PROBE

Modern instruments are designed to reduce operator influence but you may not know that damage can result from holding the probe improperly.

Gages come in all different shapes and sizes. Get to know the proper way to hold and operate your particular model. The majority of hand-held instruments take one measurement at a time. Lift the probe away from the surface between measurements. Dragging the probe reduces probe life.

Constant pressure mechanisms built into most modern electronic DFT gages ensure the probe settles perpendicular to the surface and eliminates operator pressure from influencing the measurement result. Holding the probe improperly overrides these mechanisms and can reduce the life of the probe. It can cause high readings when the probe is tilted or low readings when the probe is pressed into soft coatings.

9. EVALUATE YOUR ENVIRONMENT

Are readings affected by radio transmitters, residual magnetism from welding operations, large motors or cell phones? You might be surprised by what matters and what doesn't.

DFT instruments that measure over steel operate on a magnetic principle. So it stands to reason that gage accuracy might be adversely affected by variations in the steel's inherent magnetic properties. One of those insidious problems is residual magnetism, magnetism that is left behind in steel after an external magnetic field is removed. Magnetic clamps and plasma cutting are two source examples. Buried pipes will pick up magnetism from the earth's magnetic field over time. The effect is usually not pronounced and can be removed by degaussing. Check its effect on the gage by measuring zero on the uncoated steel (or the thickness of a shim placed on the uncoated steel).

Strong stray magnetic fields produced by electrical equipment can interfere with the operation of instruments that use magnetic principles. Erratic readings can result from measuring on electric motors or measuring near a large motor as it starts up. Strong electromagnetic emissions from radio towers or antennas may also interfere with instrument operation. To minimize the impact from external electromagnetic fields ensure that your DFT instrument comes with a declaration of conformity. The declaration of conformity confirms that the manufacturer has tested the immunity of the instrument against electromagnetic interference (EMI) according to international standards. EN 61326-1:2013 is an example of one such standard.

As you can imagine, these are unlikely edge cases. Verifying gage operation on known reference standards will alleviate most concerns.

10. ONE IS SELDOM ENOUGH

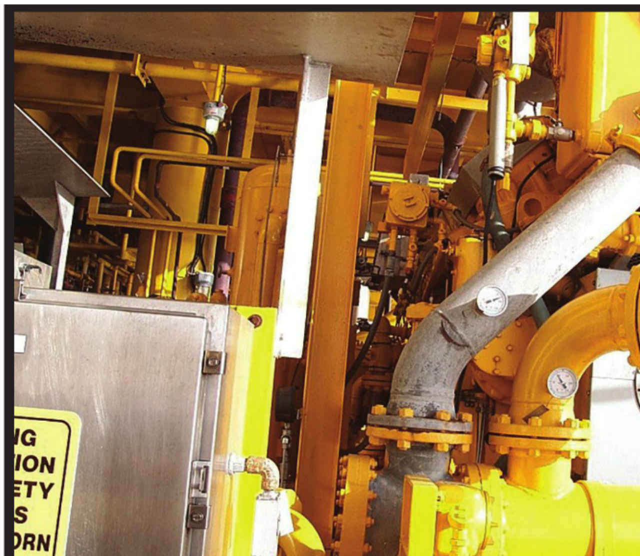
The words "reading" and "measurement" get used synonymously. SSPC-PA 2 makes an interesting distinction by defining a "reading" as a single instrument result and a "measurement" as the average of a series of readings.

A single reading should seldom be trusted whether you are making a thickness determination or adjusting to a shim. Repeated gage readings, even at points close together, often differ due to surface irregularities of the coating and the substrate. Debris on the surface, local emission interferences and improper operator technique are just some of the other things that can detrimentally influence results.

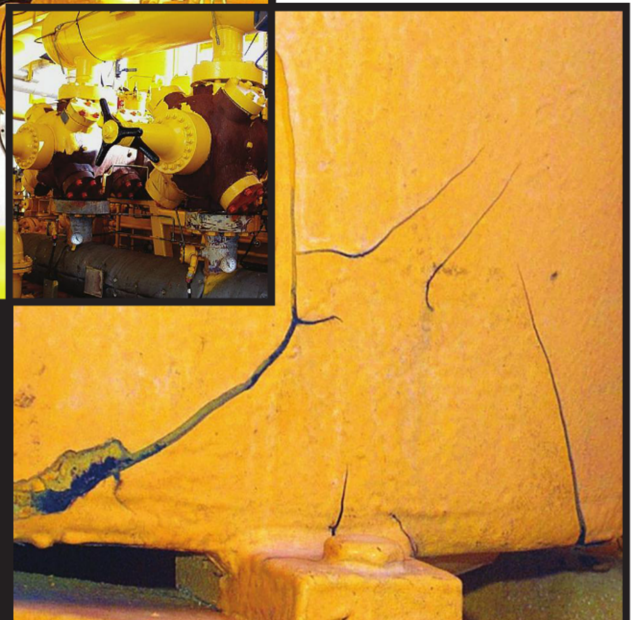
Get the reassurance that statistics provide. Take several readings. Discard any unusually high or low values that are not repeated consistently. The resultant average of the acceptable gage readings is considered to be the coating thickness measurement for that location.

CONCLUSION

Modern instruments compensate for many sources of inaccuracy, but not all. Your best source of DFT measurement knowledge is the manufacturer's instructions backed by their technical support network and industry standards such as those issued by SSPC, NACE, ASTM and ISO.



Photos courtesy of the author.



PROTECTING OFFSHORE PLATFORMS IN THE GULF OF MEXICO: SHORTCUTS = POTENTIAL HAVOC

BY PETER BOCK
CUI SPECIALIST, CONSULTANT

A contractor running a maintenance painting program on offshore oil production platforms in the Gulf of Mexico requires a combination of high levels of skill, endless patience and huge amounts of good luck. Offshore production platforms combine some of the worst corrosion problems of petroleum refineries and ocean-going ship topsides.

A typical offshore oil production platform has an intensely crammed mass of operating machinery running hot, cold or ambient, or cycling between those temperatures. The machinery areas of the structure are completely open to the weather with grating decks above and below, and no sidewalls; an occasional drip pan or blast wall are the only exceptions. Rain, mist, fog, dew, salt spray and the unavoidable fumes and chemical sprays from normal operation all affect coated surfaces. Even the local wildlife is a culprit — seagull droppings are highly alkaline and can do awful things to some types of paint. Because of the closely spaced machinery, moisture and salt tend to gather on surfaces and never be completely removed.

New construction coating specifications for offshore structures and machinery are usually the best available, with excellent surface preparation, coating systems rated for 20-plus years of service life and 100-percent inspection at every stage of the preparation and coating process. But once a structure is installed and operating, there are inevitable breakdowns and routine maintenance operations that tend to damage the original coating. Upgrades are installed, inspections requiring partial tear-down are done, and just day-to-day contact of the crew with painted surfaces tends to have a damaging effect.

On-site maintenance surface preparation and painting is done by expert, specialist crews. If space on the structure permits, the paint crew's portable living quarters, scaffolding, equipment, compressors, blasting abrasive and paint are set on the structure itself. Where there is not enough space, the crew and equipment live on a boat tied off to the structure and "commute" up to their work areas. Working hours are long, daylight and weather permitting, simply because there is nothing else to do on the structure or (worse) on the boat.

Twenty years ago the contractor foreman, the owner's rep and the inspector would get together at sunrise to decide whether that nasty gray rain cloud on the horizon would reach their structure or go elsewhere. Today satellite and radar imagery downloaded to laptops makes the weather prediction a little bit less iffy, but it is still iffy. If the contractor starts work and gets rained out (or fogged out, or the dew point and relative humidity become unacceptable to continue the work) he has lost the man hours, abrasive or paint used, compressor fuel, and the cost of re-doing the lost work — both man hours and supplies. If he has the paint crew sit and wait on the weather, he is losing productivity whether it eventually rains or not. The only time the contractor can be sure is when it is already raining (or fogged-in or the relative humidity is at 98 percent) at sunrise.

Because of the high cost of keeping a crew and their equipment on-site offshore, the tendency is to rush the finish of a project, especially if a period of bad weather is expected. Smaller projects don't always have a full-time inspector, and a roving or spot inspector may be caught between the owner and contractor, who both are more interested in getting the project done and the crew sent back to the shore than in being assured that the project was completed exactly according to specification, good painting practice and SSPC-PA 2.

A major Gulf of Mexico offshore oil production company's standard new construction coating system is an inorganic zinc primer (at 3 mils DFT), a high-build epoxy midcoat (at 6-to-8 mils DFT) and a urethane topcoat (at 2-to-3 mils DFT).

Large areas of the recently applied three-coat maintenance paint failed down to the substrate, exposing bare steel.

Newly applied inorganic zinc coating is a sensitive relatively water-absorbing and relatively slow-drying wet film. With the amount of water (mist, dew and salt spray) in this environment on a typical offshore structure, such a coating is less suitable for spot maintenance primer applications than a solvent-based, quick drying coating material whose wet surface skins and becomes relatively water resistant in a matter of minutes. For this reason, the facility's offshore maintenance system substituted a surface-tolerant epoxy primer (at 3-to-5 mils DFT) for the zinc, but used the same midcoat and topcoat.

About six months after on-site maintenance coating work on a separator unit was completed on one offshore structure, major failures were noted in the coating. The recently applied maintenance coating system was observed to be cracking and lifting at the edges, corners, on weld seams and at many other irregular surfaces.

The initial visual inspection confirmed that cracking and lifting of the coating system occurred mainly along irregularities such as weld seams, steelwork edges and corners, and flange edges. In all areas observed, both failing and non-failing, the coating system was dry and hard and the urethane still showed excellent gloss. Dry film thickness readings taken on adhering areas adjacent to failing areas measured 13-to-25 mils DFT. Paint chips in lifted areas could be removed with a pocket knife; disbonding ranged from near zero to ¼-inch back from the initial crack. Removed chips were hard and dry; DFT measurement of removed chips using a micrometer normally used for replica tape showed DFTs of 12-to-20 mils.

Examination of the edges of disbonded paint chips under 30 times magnification showed six layers of coating: zinc, midcoat, urethane, maintenance primer, midcoat and urethane. The substrate under such removed and lifted areas showed zinc residue on the steel.

Discussion with the field maintenance painting contractor revealed the following: normal maintenance painting work involved spot dry abrasive blasting of all visibly failing or rusting areas to bare steel, spot priming of blasted areas using conventional spray with appropriate overlap into the existing coating,

(Top left) Bare, rusty steel in failed areas showed different levels of inorganic zinc residue.

(Top right) This nonferrous machinery cover showed the same type of coating failure due to poor surface preparation and excessive coating system thickness.

(Bottom left) Many areas had lost the coating system to bare steel; in others, the coating was still in place but disbonded, with rust beneath.

application of a full midcoat for the entire unit, and then a full topcoat, as required by the structure owner.

While the owner and contractor both meant well, the specified maintenance painting process, coupled with the "need for speed" in the offshore maintenance environment created at least three inherent opportunities for premature failure.

- Abrasive blasting fractured the inorganic zinc coating at the edges of blasted areas.
- Spot priming did not adequately tie-in the fractured inorganic zinc.
- Excessive total film thickness in repair coated areas stressed the coating system and caused it to lift and crack along discontinuities and irregularities in the substrate surface.

This was a case where the new construction system's use of inorganic zinc primer caused problems with later on-site maintenance painting. Since the new construction system was already on the structure, care would have to be taken during maintenance painting work not to build in additional problems. Work would have to be done slower and more precisely than is normal for offshore maintenance (for this owner) and more thorough inspection of maintenance work would be required. The following recommendations resolved the problem.

- Use smaller abrasive blast nozzles and precaution in blasting rusted or damaged areas, taking particular care to blast into rusted areas from intact old coating, and to minimize blasting into intact old coating from rusted or failing areas. Featheredge all blasted areas.
- Spot-prime blasted areas using conventional spray, taking additional care to fully wet out all feather edges of old coating. Overlap primer into intact old coating.
- Spot apply midcoat extending just beyond spot primer, taking care not to build excessive millage.
- Apply a full topcoat, taking care not to build excessive millage.
- Inspect at each stage of maintenance painting to assure that the aforementioned specified steps are met and recommended film thicknesses are not exceeded.

Maintenance painting on offshore oil production structures in the Gulf of Mexico presents extremely severe environmental challenges, both for the contractor's surface preparation and coating application, and for the service life of the applied coating system. Very high costs, limited space, poor working conditions and the constant threat of delays from bad weather all conspire against getting a project done exactly according to specification, SSPC-PA 2 and best painting practice. But because of the severity of the environment, minor shortcuts that might not even be noticed long-term in an onshore mild environment project can wreak havoc on an offshore structure.

PRACTICAL IN-PLANT EVALUATION
OF TWO FBE ABRASION-RESISTANT OVERCOAT SYSTEMS

BY EMRE AKSU
BORUSAN MANNESMANN,

ALAN KEHR, ALAN KEHR
ANTI-CORROSION LLC AND

MATT DABIRI, CONSULTANT

Dual-layer fusion-bonded epoxy (FBE) coating systems have been utilized on pipelines for about 20 years because of their damage-resistant properties. These coating systems are composed of two layers (2L); an FBE layer and an outer layer, an abrasion-resistant overcoat (ARO). In these 2LFBE coating systems, the first FBE layer is the anti-corrosion layer and the FBE-ARO layer acts as a shield against external mechanical damage such as abrasion, gouges or holidays sustained during coating application, transportation, pipe-laying construction or handling. This is important because mechanical damage can affect the current requirements of a cathodic protection (CP) system. Single-layer FBE coatings have a lesser ability to withstand damage.

In this study, a new flexible version of an ARO coating system was tested, evaluated and compared to two traditional systems: a single-layer fusion-bonded epoxy (FBE) and a regular dual-layer FBE system (2LFBE). In addition, single-layer and dual-layer systems from two different suppliers were evaluated with the application at similar dry film thicknesses. Finally, thicker coating application was done to learn whether or not there is a benefit to adding more of the ARO material. For evaluation, the most common quality tests were used: cathodic disbondment, hot water soak adhesion, porosity, flexibility and impact resistance. All tests were performed according to Canadian Standard CSA Z245.20 SERIES-14, "Plant-Applied External Coatings for Steel Pipe," unless otherwise noted.

Tests were conducted comparing the performance of different thickness systems (Table 1, p. 24).

- 16 to 20 mils, single-layer FBE from two suppliers.
- 8 to 10 mils, FBE with 8 to 10 mils ARO (2LFBE) from two suppliers.
- 8 to 10 mils FBE with 8 to 10 mils flexible ARO (flexible 2LFBE) from one supplier.
- 14 to 16 mils FBE with 40 to 50 mils ARO (2LFBE) from two suppliers.

COATING PROCESS

All coated test panels were taken from 30-inch mill-applied spiral-weld pipes. During the coating application process, external pipe surfaces were cleaned in two consecutive abrasive blast-cleaning cabinets. In the first cabinet, 100-percent S390 steel shot was used and in the second cabinet, a 50/50-percent mixture of GL25 and GL18 steel grit was used. The surface profile achieved was SSPC-SP 10/NACE No. 2, "Near White Blast Cleaning" (Sa 2 ½) with 70 to 100 µm (~3 to 4 mil) peak-to-valley height and an average peak count of 41 per centimeter (104 per inch). After surface preparation, the pipe was treated with a 6-to-10-percent acid wash then rinsed with water of conductivity below 15 µS

All images courtesy of the authors.

Fig. 1: For this set of tests, a profilometer measured a peak to valley height of 70-to-100 µm (~3 – 4 mil) and an average peak count of 41/cm (104/in).

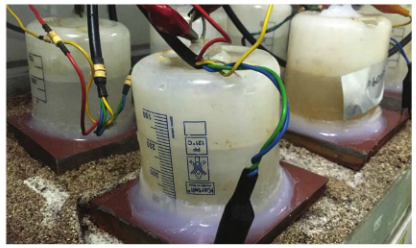


Fig. 2: Both the short- and long-term CD tests were conducted at 65 C (150 F), -3.5 V (calomel reference electrode) and a 3-percent NaCl electrolyte.

per cm. The pipe was then heated per the coating suppliers' recommended temperature, which is approximately 232 C (450 F), followed by FBE and ARO application in consecutive booths. Thicknesses were regulated by the number of electrostatic spray guns. Quenching was adjusted according to the recommended time in the manufacturers' specifications (Fig. 1).

THICKNESS OF EVALUATED SYSTEMS

Thicknesses of the coating systems are normally determined depending on construction terrain and installation procedures. Most often, the 2LFBE system is used for pipeline installation by horizontal directional drill (HDD). Typically, the more likely the damage (based on soil condition), the greater the ARO layer thickness.

The expected lifetime of an effective pipeline coating is directly related to factors such as surface preparation before coating, coating type and coating thickness. The 2LFBE systems have high productivity and relatively low material usage compared to other coating types and, therefore, they provide a positive economic benefit.

THE CATHODIC DISBONDMENT TEST (CDT)

Reduced disbondment allows for reduced cathodic-protection current requirements, which means reduced cost over the lifetime of a pipeline. The potential cost savings makes the disbondment test important. CDT performance of different thickness systems and different suppliers were measured using both short- and long-term tests (Fig. 2).

Table 1: Different Coating Thickness Systems for the Tests

Thickness System	Coating Type	Coating Supplier	FBE Thickness	ARO Thickness
System A1	Single Layer	1	16-20 mils	–
System A2	Single Layer	2	16-20 mils	–
System B1	Dual Layer	1	8-10 mils	8-10 mils
System B1F*	Dual Layer	1	8-10 mils	8-10 mils
System B2	Dual Layer	2	8-10 mils	8-10 mils
System C1	Dual Layer	1	14-16 mils	40-50 mils
System C2	Dual Layer	2	14-16 mils	40-50 mils

*Flexible ARO

Table 2: Average Flexibility Results for Different Mandrels

<table>
<tr><th rowspan="2"></th><th colspan="5">Mandrel Size</th></tr>
<tr><th>1.75°</th><th>2.00°</th><th>2.50°</th><th>3.00°</th><th>3.50°</th></tr>
<tr><td>System A1</td><td colspan="5">Pass</td></tr>
<tr><td>System A2</td><td colspan="5">Pass</td></tr>
<tr><td>System B1</td><td colspan="4">Pass</td><td>Fail</td></tr>
<tr><td>System B1F</td><td colspan="5">Pass</td></tr>
<tr><td>System B2</td><td colspan="4">Pass</td><td>Fail</td></tr>
<tr><td>System C1</td><td>Pass</td><td colspan="4">Fail</td></tr>
<tr><td>System C2</td><td colspan="2">Pass</td><td colspan="3">Fail</td></tr>
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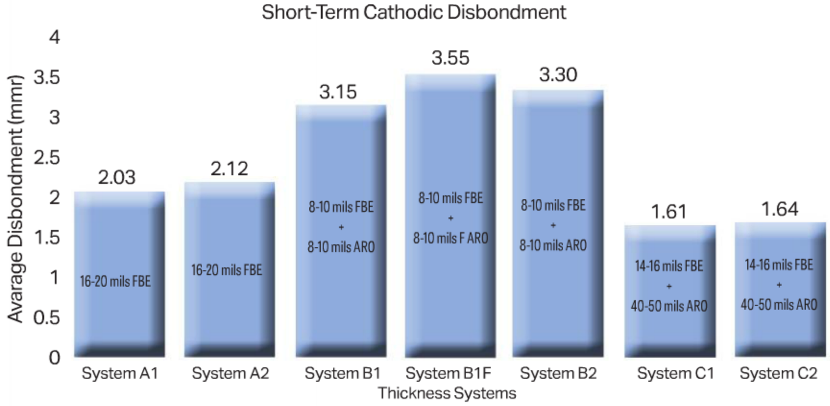

Fig. 3: Short-term cathodic disbondment results.

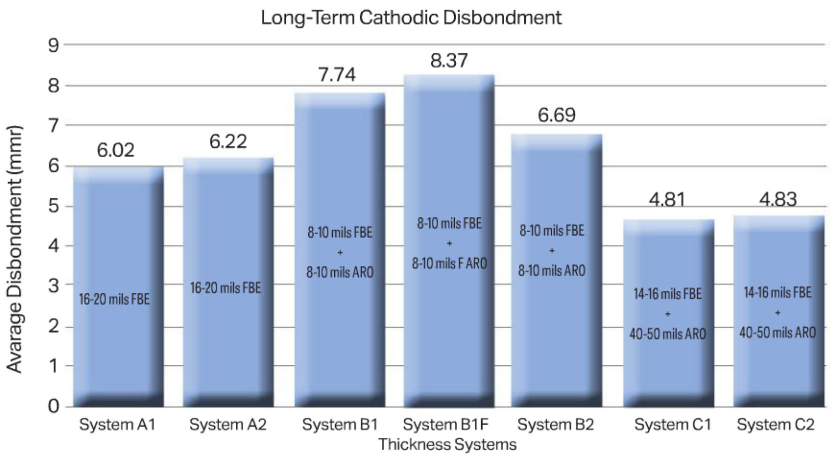

Fig. 4: Long-term cathodic disbondment results.

Short-Term Cathodic Disbondment Testing

In the short-term cathodic disbondment tests, the temperature of 65 C (150 F) was measured with an immersion thermometer in the electrolyte solution, but not touching the coated surface. The applied voltage was -3.5 V measured via calomel (reference) electrode and the solution was 3 percent sodium chloride in deionized water. The initial volume in each test cell was 300 ml and the test duration was 24 hours. The results are shown in Figure 3.

The short-term test showed that thin 2LFBE systems (System B1, System B1F and System B2) have larger short-term cathodic disbondment than single-layer FBE. Thick 2LFBE systems have better results than thin 2LFBE and single-layer FBE systems.

Long-Term Cathodic Disbondment Testing

The test temperature of 65 C was measured with an immersion thermometer in the electrolyte solution as in the short-term disbondment test. The applied voltage was -1.5 V measured via calomel reference electrode and the solution, also 3 percent sodium chloride in deionized water. The initial volume in each test cell was 300 ml and the test duration was 28 days. The results are shown in Figure 4.

The correlation between thickness and average disbondment radius in the long-term tests was similar to the short-term tests. Materials from both suppliers showed comparable relative results for both short- and long-term cathodic disbondment.

Flexibility

The test temperature of -18 C (0 F) for the flexibility testing was achieved in a freezer. Each test set was composed of three samples from a single pipe joint. Tests were performed using different test sets on the mandrels of 1.75, 2.00, 2.50, 3.00 and 3.50 degrees per pipe diameter (PD) and any crack formed on a sample constituted a

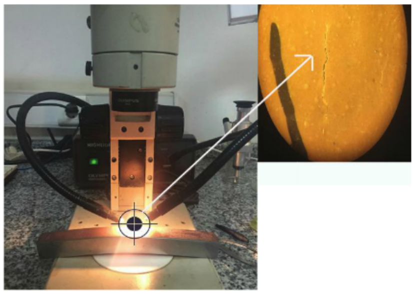

Fig. 5: A crack on a bended sample under 40 times magnification. Any coating crack seen at 40 times magnification constituted a failure.

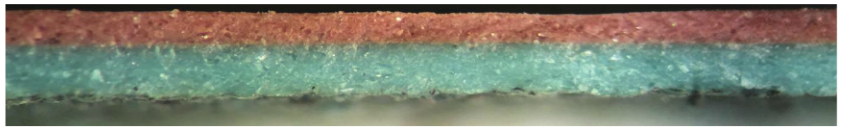

Fig. 6: While the flexible ARO layer showed a low level of porosity, almost none was seen in the remaining samples for either layer.

fail. A 40 times magnification microscope was used to find the cracks (Fig. 5).

Coating flexibility is a major issue because pipes bend during construction. Single-layer FBE coated pipes are more flexible, as seen in Table 2. The flexible-version ARO (System B1F) has greater flexibility compared to the other ARO systems. When the thickness of the ARO layer increases, flexibility decreases.

HOT-WATER SOAK ADHESION (HWS)

The test temperature of 65 C was achieved with a hot-water bath and the test duration was 24 hours. Each test set was composed of three samples from a single joint.

For all coating systems, HWS results were similar with a rating of one on a scale of one to five, with a one showing excellent adhesion and a five with no adhesion to the steel (Table 3).

Table 3: Average Hot Water Soak Adhesion Results

Coating System	Average HWS Results Rating
System A1	1
System A2	1
System B1	1
System B1F	1
System B2	1
System C1	1
System C2	1

POROSITY

To test for porosity, samples were placed in a freezer at -30 C (-22 F) and subsequently bent at a sharp radius to

Table 4: Average Porosity Ratings of Coating Layers

Coating Systems	Coating Supplier	ARO Thickness
System A1	1	–
System A2	1	–
System B1	1	1
System B1F*	1	2
System B2	1	1
System C1	1	1
System C2	1	1

Table 5: Test Averages According to Coating Type

Coating Type	Average Results			
	Short Term CD	Long Term CD	Flexibility	Impact Resistance
Single-Layer FBE	2.1 mm	6.1 mm	Max. 3.50° /PD	3 Joules
Thin 2LFBE	3.2 mm	7.2 mm	Max. 3.00° /PD	7 Joules
Thin Flexible 2LFBE	3.6 mm	8.4 mm	Max. 3.50° /PD	7 Joules
Thick 2LFBE	1.6 mm	4.8 mm	Max. 1.75° /PD	17 Joules

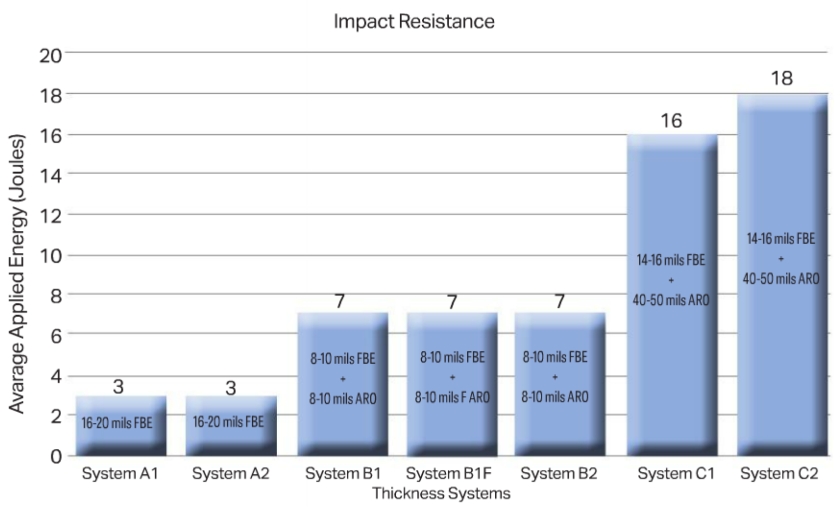

Fig. 7: Average passing impact resistance results.

delaminate the coating from the surface. Coating samples were investigated at 40 times magnification (Fig. 6).

The porosity scale is 1 to 5, 5 representing a very large number of bubbles in the coating. Except for the flexible ARO, all the systems had very low porosity. System A1 had essentially no bubbles and System A2 had a few. The porosity of the flexible ARO was well within all acceptance requirements (Table 4).

IMPACT RESISTANCE

The impact resistance tests were performed according to ASTM G14, "Standard Test Method for Impact Resistance of Pipeline Coatings (Falling Weight Test)." Samples were exposed to a room temperature of 23 C (73 F) for one hour. Impacts were made with increasing force until the coating failed as determined with a holiday detector. The results shown in Figure 7 are based on the impact tests that the coating passed.

Suppliers' performance results were similar for single-layer FBE and thin 2LFBE. Thicker 2LFBE provided higher impact resistance.

CONCLUSIONS

If we compare the results of the tests mentioned for the single-layer systems, 8 to 10 mils of FBE plus 8 to 10 mils of 2LFBE systems with 14 to 16 mils of FBE plus 40 to 50 mils of 2LFBE systems for each of the suppliers, we reach the following conclusions (Table 5).

- CDT results were quite similar for single-layer FBE and thin 2LFBE.
- Thick 2LFBE had the best performance in the CDT.
- Single-layer FBE and the flexible 2LFBE were the most flexible coating types tested.
- Thicker 2LFBE affords lower flexibility.
- The impact resistance of thin 2LFBE was significantly better than with the single-layer FBE.
- As 2LFBE-ARO thickness increases, its impact resistance increases.
- HWS and porosity results were similar for all systems.

The test results revealed that at the same total thicknesses, 2LFBE and single-layer FBE systems showed similar cathodic disbondment, hot-water adhesion resistance and porosity, but the ARO systems showed significantly improved impact resistance. The standard ARO systems had reduced flexibility compared to the FBE. However, at least one supplier offers a flexible version of an ARO coating that, based on these tests, shows promise.

ABOUT THE AUTHORS

Emre Aksu is currently working as coating technology manager of Borusan Mannesmann, a pipe production and coating facility in Gemlik, Turkey. Aksu has eight years of experience in the pipe coating and custom coating industries. He is responsible for the internal and external coating processes. Aksu is currently a NACE Level 2 Coating Inspector.

Alan Kehr is the managing consultant of Alan Kehr Anti-Corrosion, LLC in Lakeway,

Texas, offering worldwide consulting on FBE pipeline and rebar coatings, as well as other services. Kehr has more than 40 years of experience in the pipeline and reinforcing steel coatings industries. He has been active in NACE and was instrumental in standards development for ASTM, ISO and other industry associations.

Matt Dabiri, P.E. has over 38 years of experience in anti-corrosion and protective coatings. His expertise includes the realms of internal down-hole tubular goods coatings, internal and external pipeline coatings and above ground/atmospheric coatings.

Dabiri created and introduced the phrase "abrasion-resistance overcoat" (ARO) and prepared the first specifications for the application process of ARO. He was the first to use thick coating (high mils) of FBE and ARO on large-diameter pipe for road bore, river crossing and HDD.

Dabiri is a longstanding member of NACE and actively contributes to development and revision of international coating standards. He is also currently a co-convener of ISO 21809, charged with the development of nine coating standards. Dabiri holds Bachelor of Science and Master of Science degrees in mechanical engineering.

JPCL

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NEW ADVANCES IN EPOXY COATINGS FOR MARINE MARKETS

BY JAMES MCCARTHY, PPG PROTECTIVE AND MARINE COATINGS

Figures courtesy of PPG unless otherwise noted.

Epoxy coatings are a mainstay of the marine coatings market. Used as intermediate coats over inorganic and organic zinc-rich primers or used as direct-to-metal primers in coating systems, epoxy coatings are widely recognized for their versatility and the excellent corrosion resistance they provide.

One drawback of the current epoxy coating technology is that it requires separate packaging for the epoxy resins and the polyamide or polyamine hardeners because the chemical reaction that occurs when these materials are mixed, which causes the applied film to cure to a dry state, would also cause the bulk material to gel if packaged together. This time limit between mixing and eventual gelation of the mixed materials is termed "pot life," and is typically only several hours for conventional epoxy-polyamide coatings.

Until now, single-pack epoxy coatings have been based on epoxy-ester resins, which are not as robust as true amine-cured epoxy coatings, or based on epoxy resins and latent hardeners, which require a bake cure and are therefore not practical for most marine coating applications. In this article the author will review the features and benefits of a new epoxy coating technology that allows for true epoxy-amine curing in a single-pack product. The author will also compare its performance versus traditional two-component epoxy products and discuss the environmental and convenience benefits of single-pack versus two-component packaging.

THE BACKGROUND

Until around the 1950s, the vast majority of coatings used for substrate protection were single-component or "one-pack" coatings. These coatings were supplied in one can in a ready-to-use condition. Although many different product types existed, the types of products used for heavy-duty protective applications included coatings based on vinyl-chloride copolymers, acrylic and chlorinated rubber polymers, alkyd resins and naturally-derived materials such as coal tar and bitumen. Some of these products, notably the solution-vinyl products, provided excellent water and corrosion resistance as well as resistance to many chemicals. However, these products were low in solids and had very high solvent content, necessitating up to four or more coats to achieve target dry film thicknesses[1]. In addition, the high solvent content has made these products almost obsolete in North America due to volatile organic compounds (VOC) restrictions. Some older single-pack technologies, such as alkyd-based coatings, are still alive and well; however, like newer technologies based on latex emulsions, they do not provide the same high degree of corrosion resistance as did the high VOC solution-vinyl and chlorinated-rubber coatings.

The introduction of epoxy technology in the 1950s addressed the low-solids, low film build disadvantage of the existing single-pack coatings technologies. Epoxy coatings can be formulated at a significantly higher solids content, thus allowing target dry film thicknesses to be met with fewer coats. Then, in the mid-1970s, U.S. regulations limiting VOC content in architectural and industrial maintenance (AIM) coatings were introduced in California as a result of the poor air quality in the city of Los Angeles[2]. Traditional single-pack coatings used at the time could not meet new restrictions on solvent content of paints and coatings and epoxy coatings supplanted the older technology as the go-to products for protective and marine use.

However, epoxy coatings do have some disadvantages. Because these products dry or cure by chemical reaction, the reactive constituents of the finished coating (epoxy resins on the one side and typically amine or amide-functional materials on the other) must be packaged separately and then combined in the proper ratio immediately before application. Mixing the separate components too far in advance of the coating application can result in an unacceptable viscosity increase or even gelling as the reaction proceeds, making the mixed material impossible to apply. This pot life limitation requires careful planning by the coating applicator. Secondly, although most epoxy coatings are packaged with the correct pre-measured mix ratio, oftentimes partial kits are mixed in order to avoid waste when only small amounts of coating are needed (for instance, for minor touch-up work). It is often challenging to maintain a correct mix ratio when partial kits are used, especially in field applications where accurate measurement of weights or volumes can be difficult. A third disadvantage is that the containers currently used to package each component are often only partially filled in order to allow the contents of the one container to be added to the other, which is wasteful and costly.

A novel, single-pack coating utilizing true epoxy-amine reactive functionality has been developed that maintains the performance advantages

Table 1: Rating Guide

Rust per ASTM D610		Blistering per ASTM D714	
		Size	Frequency
10 - None	4 - 10%	10 - None	D - Dense
9 - < 0.03%	3 - 16%	8 - < 1/32"	MD - Medium Dense
8 - < .01%	2 - 33%	6 - < 1/16"	M - Medium
7 - < .03%	1 - 50%	4 - < 1/8"	F - Few
6 - < 1%	0 - 100%	2 - < 1/4"	VF - Very Few
5 - < 3%			

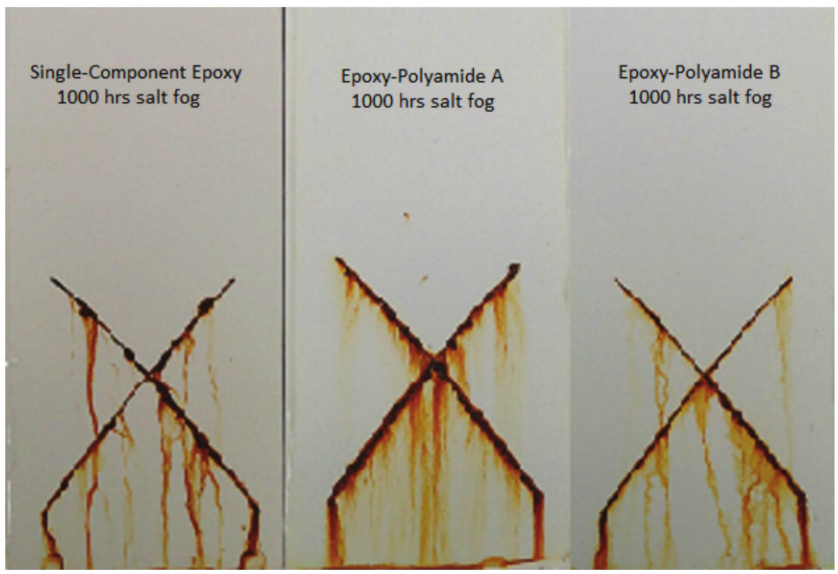

Fig. 1: 1,000 hour salt fog panels before stripping (above) and after stripping (below).

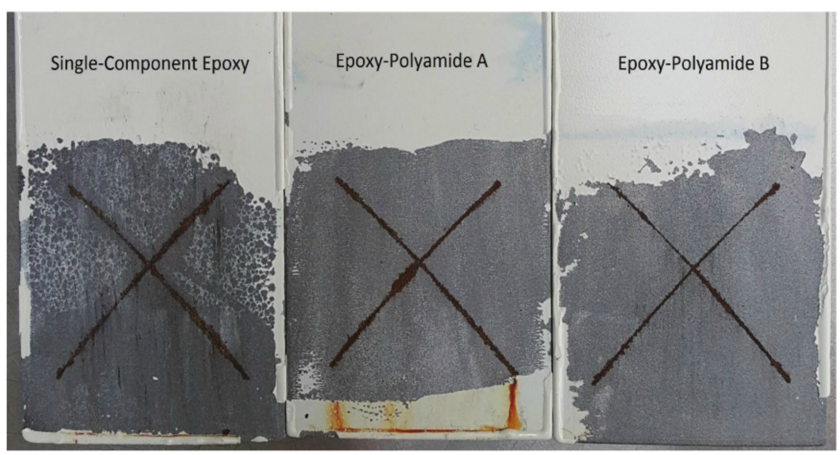

Table 2: Salt Fog Results

Product	Avg. DFT (mils)	Exposure Time (hours)	Unscribed Area		Scribed Area	
			Blistering (D714)	Rust (D610)	Blistering (D714)	Scribe Creep (mm)
Single-pack epoxy	5.1	1,000	10	10	10	0.9
Epoxy-polyamide A*	4.9	1,000	10	10	10	0.5
Epoxy-Polyamide B**	4.9	1,000	10	10	10	1.2
Single-pack epoxy	5.0	2,000	10	10	10	1.2
Epoxy-polyamide A*	5.1	2,000	10	10	10	1.7
Epoxy-polyamide B**	4.8	2,000	10	10	10	1.5
Single-pack epoxy	4.7	3,000	10	10	10	1.5
Epoxy-polyamide A*	4.9	3,000	10	10	10	1.6
Epoxy-polyamide B**	5.2	3,000	10	10	10	1.1

*190 EEW epoxy / 103 AHEW polyamide **500 EEW epoxy / 525 AHEW polyamide

Table 3: Prohesion Test Results

Product	Avg. DFT (mils)	Exposure Time (hours)	Unscribed Area		Scribed Area	
			Blistering (D714)	Rust (D610)	Blistering (D714)	Scribe Creep (mm)
Single-pack epoxy	5.3	1,500	10	10	8F	0.8
Epoxy-polyamide B**	5.5	1,500	10	10	8F	0.7
Single-pack epoxy	5.9	3,000	10	10	8F	1.1
Epoxy-polyamide B**	5.4	3,000	10	10	8F	1.3

*190 EEW epoxy / 103 AHEW polyamide **500 EEW epoxy / 525 AHEW polyamide

Table 4: Condensing Humidity Test Results

Product	Avg. DFT (mils)	Exposure Time (hours)	Unscribed Area	
			Blistering (D714)	Rust (D610)
Single-pack epoxy	5.6	500	10	10
		1,000	10	10
		2,500	10	10
Epoxy-polyamide A*	5.8	500	10	10
		1,000	10	10
		2,500	10	10
Epoxy-polyamide B**	6.1	500	10	10
		1,000	10	10
		2,500	10	10

of two-component epoxy coatings while eliminating the aforementioned disadvantages.

THE TECHNOLOGY

A quick Internet search on the keyword phrases "single-component epoxy" or "one-pack epoxy" will yield results[3], but typically the items identified in such a search are not true amine-cured epoxy coatings. Search results will most likely show acrylic emulsion paints modified with varying amounts of epoxy or epoxy ester-based coatings, both of which are generally recognized as inferior to amine-cured epoxies in terms of corrosion and chemical resistance[4]. Other search results will include epoxy coatings containing latent catalysts that rely on a heat-cure mechanism that is impractical for the marine coatings market. Unlike the technologies described earlier, the new technology is a high-solids, storage-stable coating comprising an epoxy resin, a hydrocarbon compound, a functionalized silicone resin and a ketimine curing agent composed of a polyamine compound and a ketone[5]. All of these materials are derived from commonly available raw materials. Ketimine curing agents are well-known to the epoxy coating formulator community. Ketones will react with primary amines, splitting off water to yield a ketimine. This reaction is reversible: the addition of water to a ketimine will yield the parent amine and ketone. Essentially, these are blocked amines, which in the presence of water will hydrolyze back to the original amine and ketone[6]. These blocked amines are especially useful for extending pot life of high-solids two-pack epoxy coatings, and in theory, these materials should be able to allow the formulator to produce one-pack amine-cured epoxy coatings provided the mixture is kept free from all traces of moisture. Unfortunately, until now, efforts to produce one-pack epoxy coatings based on current ketimine technology have not been successful. It is very difficult to produce formulated coatings that are completely free of water, and even the slight traces of water adsorbed on pigments or picked up from ambient air contact during processing are enough to cause instability and an impractically short shelf life, especially with higher solids (> 60 percent by volume) coatings[7]. This new technology has resolved the problem of limited stability and inordinately short shelf life. Performance of products based on this technology is comparable to that of standard two-component epoxy coatings.

TESTING AND RESULTS

In almost all instances, the most important role of epoxy coatings in the marine coatings market is to provide protection against corrosion. Although other performance and physical properties are

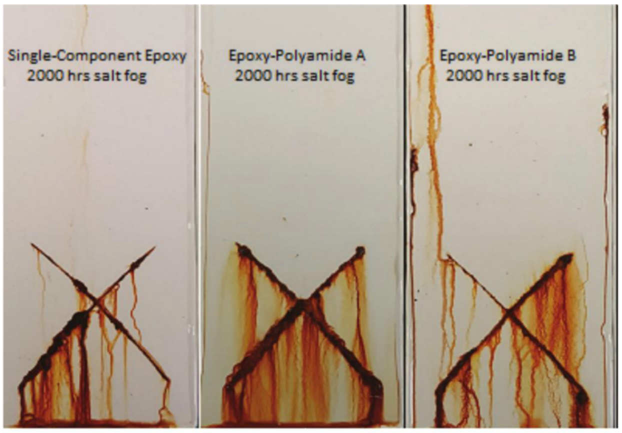

Fig. 2: 2,000 hour salt fog panels before stripping (left) and after stripping (above).

also important, if a coating does not provide corrosion protection, all other properties are of little consequence. There are numerous accelerated corrosion tests and specifications that call out corrosion testing (with pass/fail scribe creep criteria) that can be used in a lab setting to evaluate corrosion resistance. These include ASTM B117 Salt Fog (Standard Practice for Operating Salt Spray [Fog] Apparatus)[8], ISO 12944-6 (Paints and varnishes — Corrosion protection of steel structures by protective paint systems — Part 6: Laboratory performance test methods)[9], ISO 20340 (Paints and varnishes — Performance requirements for protective paint systems for offshore and related structures)[10] and ASTM D5894 Cyclic Prohesion (Standard Practice for Cyclic Salt Fog/UV Exposure of Painted Metal, [Alternating Exposures in a Fog/Dry Cabinet and a UV/Condensation Cabinet])[11]. Although much debate exists regarding the correlation of these accelerated methods to real-world performance, they are useful in generating comparative data in a lab setting. Some of these tests were used to benchmark the performance of the single-pack epoxy technology against two different commercially available two-component epoxy-polyamide controls. The first two-component control is based on 190 epoxy equivalent weight (EEW) liquid epoxy resin and 103 amine hydrogen equivalent weight (AHEW) liquid polyamide resin. The second control is based on 500 EEW solid epoxy resin and 525 AHEW semi-solid polyamide resin.

Materials

The test panels used for evaluating corrosion resistance in the various tests were ASTM A36 cold-rolled steel panels of varying sizes. The panels were abrasive-blasted with steel grit to achieve a 2-to-3-mil angular blast profile, as measured with replica tape. Corrosion testing cabinets were salt-fog cabinets outfitted and programmed in accordance with the requirements of the relevant corrosion

Table 5: Abrasion Resistance Test Results

Product	Avg. Weight Loss (mgs)
Single-pack epoxy	154
Epoxy-polyamide A	108
Epoxy-polyamide B	250

Table 6: Impact Test Results

Product	Direct Impact Resistance (in-lbs)
Single-pack epoxy	36
Epoxy-polyamide A	24
Epoxy-polyamide B	39

Table 7: Adhesion Test Results

Product	Adhesion (psi)
Single-pack epoxy	900
Epoxy-polyamide A	1,000
Epoxy-polyamide B	1,000

test specification and maintained in the testing laboratory's calibration system.

Methods

Coatings were applied to both sides of unprimed steel substrates by hand-held, battery-operated airless spray equipment. For the corrosion testing, one coat of each product was applied to a target dry film thickness of 5 mils. The coatings were allowed to air dry at ambient lab conditions (68-to-72 F, 40-to-50 percent RH) and edges were sealed by dipping after the last coating had reached a dry-through condition. Panels were exposed to each test environment after a total of seven days' cure time. Immediately before exposure, the panels were scribed with an X-scribe (as per the salt fog test protocol) or a 2-inch vertical scribe (as per the cyclic prohesion test protocol) with a scribing tool. At each exposure interval, the test panels were removed from the test cabinet and were evaluated for blistering and rusting in accordance with ASTM D714, "Standard Test Method for Evaluating Degree of Blistering of Paints" and ASTM D610, "Standard Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces." For convenience, a brief summary of the rating scales is shown in Table 1 (p. 33).

The scribe creep values reported are the average of three replicates from three separate test panel series for each product. At the end of an exposure interval, one set of replicates for each product was removed and eventually stripped to measure the scribe creep. As three different sets of test panels were used to generate the scribe creep results at successive exposure intervals, the scribe creep results did not necessarily follow a pattern of increasing creep.

ASTM B117 SALT FOG TEST

For each product under evaluation, three sets, each composed of triplicate panels, were exposed to salt fog per ASTM B117. At 1,000-hour intervals, one set of triplicate panels was removed from the test cabinet and was evaluated for blistering and rusting. After the visual evaluation was completed, the scribe areas were stripped with paint stripper to expose the underlying metal substrate, allowing for accurate scribe creep measurements. Results for the 1,000-hour, 2,000-hour and 3,000-hour exposure intervals are shown in Figures 1, 2 and 3 (pp. 33, 36, 38). All ratings and scribe creep values reported are the average of the three test panels in each set.

The results in Table 2 (p. 34) show that throughout the 3,000-hour exposure period, the single-component epoxy coating exhibited resistance to blistering and rusting similar to that

Fig. 3: 3,000 hour salt fog panels before stripping (left) and after stripping (above).

of the two commercially available epoxy-polyamide coatings used as controls. In fact, no blistering or field rusting was observed on any of the test panels. Likewise, when the scribed areas of the test panels were stripped, the single-component epoxy exhibited scribe creep comparable to that of the two-component epoxy-polyamide controls, a further indication of comparable performance in this test.

ASTM D5894 CYCLIC PROHESION TEST

As with the salt fog testing, for each product under evaluation, three sets, each composed of triplicate panels, were exposed to cyclic salt fog/UV exposure per ASTM D5894. The test cycle consisted of one week in a fluorescent UV/condensation cabinet running a cycle of four hours of UVA exposure and four hours of condensation followed by one week of exposure in a cyclic prohesion cabinet with 0.05 percent sodium chloride and 0.35 percent ammonium sulfate solution and a one hour fog/one hour dry cycle. The total length of time for a complete cycle is 336 hours. In this test, the panel sets were removed at 1,500-hour intervals and were evaluated for blistering and rusting in accordance with ASTM D714, "Standard Test Method for Evaluating Degree of Blistering of Paints" and ASTM D610, "Standard Practice for Evaluating Degree of Rusting on Painted Steel Surfaces." After the visual evaluation was completed, the scribe areas were stripped with paint stripper to expose the underlying metal substrate allowing for accurate scribe creep measurements (Fig. 4). Results for the 1,500-hour (roughly 4.5 cycles) and 3,000-hour (roughly 9 cycles) exposure intervals are shown in Table 3 (p. 34). In this test, only one control was used due to space limitations in the test cabinets. All ratings and scribe creep values reported are the average of the three test panels in each set.

As with the salt fog test results, the results for the cyclic prohesion testing show

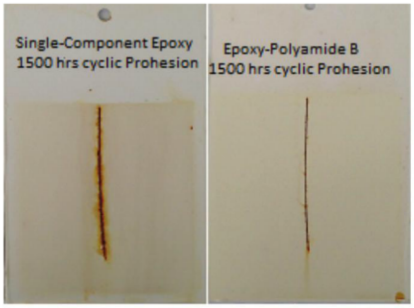

Fig. 4: 1,500 hour cyclic prohesion before stripping (above) and after stripping (below).

that throughout the 3,000-hour exposure period, the single-component epoxy coating showed resistance to blistering and rusting similar to that of the commercially available epoxy-polyamide coating used as the control (Fig. 5, p. 40). Other than the bottom of the 3,000-hour single-component epoxy test panel, which had rusting due to edge effects and low film thickness, no blistering or field rusting was observed in the unscribed area of any of the test panels. The scribes of all test panels did exhibit a few #8-sized blisters immediately adjacent to the scribe. When the scribe areas of the test panels were stripped, the single-component epoxy exhibited scribe creep comparable to that of the two-component epoxy-polyamide control, confirming comparable performance in this test.

ASTM D2247 TESTING WATER RESISTANCE OF COATINGS IN 100=PERCENT RELATIVE HUMIDITY

In this test, the unscribed faces of the test panels were placed over a test chamber containing water heated to 100 F. The backs of the panels were exposed to ambient laboratory conditions, thereby creating a temperature gradient causing condensation of the water vapor on the face of the panel. The panels were evaluated for blistering and rusting per ASTM D714 and ASTM D610. The results are shown in Table 4 (p. 34). Because these panels were not scribed, the same panels were evaluated at each exposure interval.

PHYSICAL PROPERTIES

In addition to corrosion resistance, the ability of a coating to withstand mechanical and physical abuse is important. Corrosion and rust creep emanating from breaks in the coating caused by mechanical damage can significantly shorten the service lifetime of even the most inherently corrosion-resistant coating. Panels were

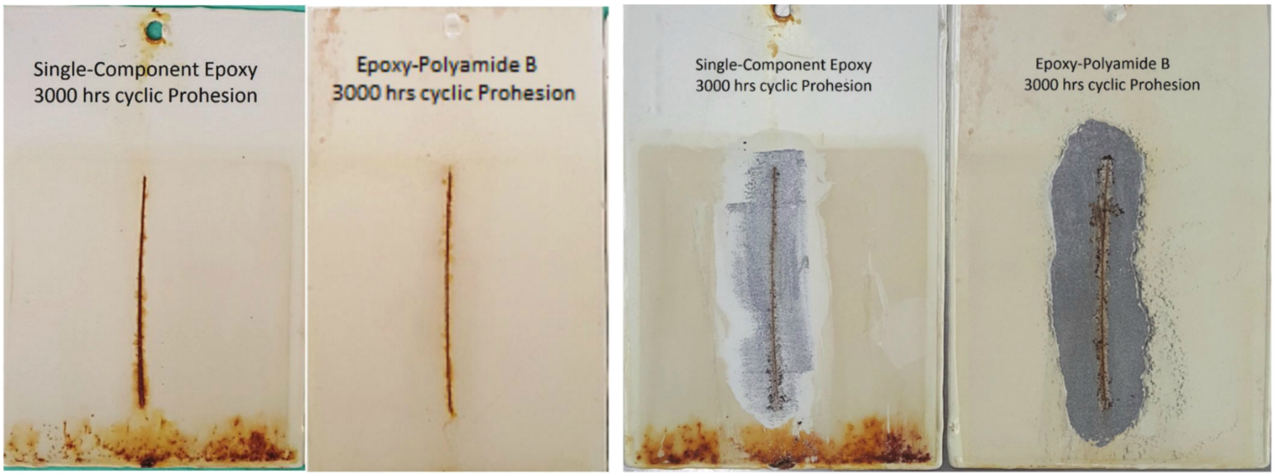

Fig. 5: 3,000 hour cyclic prohesion before stripping (left) and after stripping (right).

prepared to evaluate key physical properties such as abrasion resistance, elongation and hardness development.

Abrasion Resistance

ASTM D4060, "Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser" often referred to as "Taber Abrasion" is a common method used for evaluating the abrasion resistance of organic coatings[11]. With this test method, the coating is applied to a rigid panel and after curing, the surface is abraded by rotating the panel under weighted abrasive wheels for a specified number of rotations, usually 500 or 1,000. Abrasion resistance is calculated as the loss in weight after the prescribed number of rotations. The type of wheel used, the total weight applied to the wheel and the number of rotations are reported, along with the actual weight loss. Results for the single-pack epoxy are compared to the same two commercially available polyamide epoxies. The test was run with CS-17 wheels, a 1,000-gram load and 1,000 wear cycles (Table 5, p. 37).

Film Hardness Development

ASTM D4366, Standard Test Methods for Hardness of Organic Coatings by Pendulum Damping Tests," often referred to as "pendulum hardness" is a common method used for evaluating film hardness of organic coatings[11]. In this test method, a pendulum, which is supported by a fulcrum resting on the surface of the coated panel, is deflected to a certain

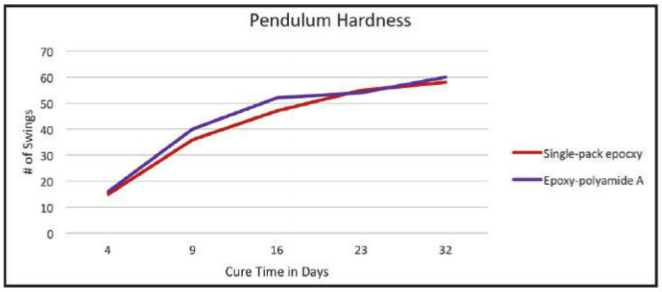

Fig. 6: Pendulum hardness test results.

angle and released. The number of oscillations that occur before the amplitude of the pendulum swing is reduced below a pre-determined angle are recorded. The higher the coating hardness, the lower the damping factor, and hence, the higher the swing count. Comparisons were made of pendulum hardness over time with the single-pack epoxy and the epoxy-polyamide A. Both coatings showed similar hardness development. The results are shown in Figure 6.

Impact Resistance

In many ways, it can be said that all types of failures are due to external forces, since it is the environment to which the coating is exposed that is the primary cause of coating failure[12]. The effects of some forces on protective coatings, such as corrosion potential, are ideally slow and nearly imperceptible over the short term. Obviously, the effects of other external forces such as impact are instantaneous and readily observed. Marine coatings are subjected to impact almost everywhere they are typically used. Tools get dropped on decks and platforms, heavy structural components are dinged during shipping, handling and erection and bulk cargoes such as coal get loaded at high velocity. General-purpose two-component epoxy coatings have adequate impact resistance for most purposes. A comparison of impact resistance test results is shown in Table 6 (p. 37). As can be seen, impact resistance of the single-pack epoxy technology is comparable to two-component products.

Adhesion

The performance properties of the single-component epoxy were compared to the two commercial epoxy-polyamide controls per ASTM D4541, "Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers." In this test, a self-aligning Type IV pressurized tester was utilized. The results are shown in Table 7 (p. 37).

Table 8: Viscosity Increase with Aging at 120 F

Initial	1 wk.	2 wk.	3 wk.	4 wk.	5 wk.	7 wk.	8 wk.	9 wk.	10 wk.	12 wk.
71	71	71	69	68	70	75	78	78	81	83

Table 9: A Comparison of Typical Properties

Product	Volume Solids	VOC (lbs/gal)	# of Components	Mix Ratio	Pot Life (70 F)	Touch Dry (70 F)	Hard Dry (70 F)
Single-pack epoxy	63%	2.6	1	Not applicable	Not applicable	1 hr	8 hrs
Epoxy-polyamide A*	68%	2.6	2	4 to 1	3 hrs	2 hrs	12 hrs
Epoxy-polyamide B**	66%	2.6	2	4 to 1	3 hrs	15 mins	5 hrs

Stability

A common practice for checking stability of coatings is to expose samples in an oven at 120 F to accelerate the effects of aging at room temperature. Samples are taken from the oven and checked for settling, gassing, viscosity increase and other changes in consistency or appearance. The single-component epoxy was tested in this manner, and results are shown in Table 8.

Although some viscosity increase over time is often observed when samples are exposed to elevated temperatures, the viscosity of this particular composition is much more stable than many other prototypes that have been developed and tested. Typically, gelation can occur in as early as four weeks with other compositions[13]. Actual commercial-scale production batches of the single-component epoxy have exhibited stability well in excess of one year, affording the end user sufficient shelf life to make inventory management easy.

Other Properties

A comparison of typical properties of the single-component epoxy against the two-component epoxy coatings is shown in Table 9.

CONCLUSIONS

Single-component coatings offer greater convenience than multi-component coatings. Pot life restrictions and mix ratio requirements are eliminated. Until now, single-pack coatings had limited usefulness in heavy-duty protective and marine applications due to inherent limitations in corrosion resistance associated with common single-pack technologies. A new, single-pack epoxy technology has been developed. This technology delivers reasonable shelf life with a high level of corrosion resistance comparable to that of two-component epoxy-polyamide coatings. Physical properties of the single-pack epoxy technology are comparable to two-component epoxy-polyamide coatings.

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business unit of PPG Industries. A chemical engineer by training, he has over 32 years of product development experience in the heavy-duty marine and protective coatings business. McCarthy's career at PPG Industries began nine years ago within the Technical group, with responsibility for product development and business support for the Americas region.

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TRANSFORMING THE SUBJECT MATTER EXPERT INTO AN EDUCATOR: GAINING COMPETITIVE ADVANTAGE BY APPLYING ADULT LEARNING PRINCIPLES

BY AMY GIBSON, KTA-TATOR, INC.

In recent years, the demand for workplace learning has evolved as a result of accelerated technology, a global marketplace and fluctuating economic trends. Additionally, the average working life of most people has increased by 10-to-15 years, creating a significant skills gap between beginning and seasoned workers. Consistent occupational and technical training has become essential for maintaining competitive, competent employees.

These current workplace challenges have resulted in a movement for lifelong learning. The concept of lifelong learning is a self-directed interest in maintaining and increasing knowledge for sustainability. It is the practice of consciously choosing to improve rather than decline, and to move forward rather than fall behind. Instead of forcefully re-skilling workforce individuals when skillsets become obsolete, lifelong learning supports continuous learning, resulting in a workforce that is prepared to adapt to change. In a time when organizations face certain change, those that are equipped to adapt and thrive will have the competitive advantage in their marketplace.

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THE SUBJECT MATTER EXPERT

Lifelong learning may still be an idealist concept for many organizations that have not transitioned into a culture of education. It is still common for workplaces to provide intermittent training based on the vast knowledge that exists within an organization's subject matter experts (SMEs). SMEs have many valuable assets that can contribute to workforce training. Because they are experts in their field, SMEs already have a deep understanding of training content, industry-related issues and relevant job skills. SMEs also have a wealth of personal experience that enables them to relate to training participants and provide instruction based on real-life field application. SMEs often need minimal time to prepare the technical aspects of course content, and at the onset of the course they have automatic credibility in the eyes of their training participants based on their status. The years of experience and industry expertise that exist in SMEs are very difficult to reproduce in a general teacher or trainer without personal industry knowledge.

With all of these positive attributes considered, it must be recognized that SMEs do not necessarily have the appropriate credentials to train or teach. Most SMEs have no training in instruction techniques or adult learning theory and due to their considerable experience, SMEs also tend to convey more information than is necessary or appropriate for the desired learning outcomes. Without adherence to learning outcomes, an overload of information can be received as irrelevant and confusing.

Unfortunately, the goal of workplace training is oftentimes merely to satisfy an immediate need for compliance with client or industry continuing education requirements or certifications. If compliance is the main priority, learning may be sacrificed for results (i.e., teaching the test). The easiest route to completion takes precedence over knowledge retention, improvement and the ability to apply new skills. In this case, the most accessible SME is the best resource for training, regardless of that individual's ability to facilitate. However, the easiest route does not guarantee a quality learning experience that will develop the workforce and build competitive advantage.

According to the Georgetown University Center on Education and the Workforce, on-the-job and employee training currently makes up about 65 percent of postsecondary education. Employability has become dependent on the development of occupational qualifications and skillsets. Employers that do not embrace this reality and continue to operate using underdeveloped employees will eventually suffer.

THE ADULT LEARNER

In order to improve the effectiveness and successful delivery of workforce training, the learner should be considered. While unloading new information onto employees may be a convenient method of communication, there is no evidence that an opportunity for learning has taken place. To create a competitive and adaptable workforce, the individuals that configure your workforce must be offered valid, reliable and retainable learning experiences.

By incorporating principles of adult learning, workplace training can promote real-world problem solving, participative and cooperative learning experiences, practical implementation of skills learned and enhanced self-worth of employees. In order to apply adult learning principles to workforce training, it is important to understand what distinguishes the adult learner from traditional school-age learners.

ADULT LEARNING PRINCIPLES 101

The term *pedagogy* is often used to describe the practice of teaching; however, the literal meaning of the Greek term *pedagogy* is the teaching of children. The term *andragogy* was popularized by Malcolm Knowles (1913–1997), a champion in adult education advocacy. Andragogy refers specifically to the teaching of adults, stressing the suggestion that adults learn differently than children. Knowles theorized that these differences are based on assumptions that include self-concept, experience, readiness to learn, orientation to learning, motivation to learn and the need to know (Table 1, p. 47). Knowles' andragogy theory is not the only theory on adult learning, but is arguably the most common. These assumptions suggest that adult learners share specific characteristics that should be considered in planning for a successful learning event.

AUTONOMY

Adults benefit from a learning experience that encourages self-directed exploration of the learning materials. Adult learners are accustomed to having control of themselves and their environments and tend to resist situations in which they feel that somebody else's will is being imposed on them. This autonomous existence carries over into a training environment. The adult learner needs to participate and contribute to his or her own learning. Adult learners also prefer to make their own decisions. Adults gather and analyze information before reaching a decision and when an adult is an active participant in the decision-making process, that decision will seem to be more credible.

Autonomy in Action

To foster this self-direction, students should be guided to discovering important questions and answers for themselves. Open-ended questions will encourage thought and discussion. Opportunities for learner participation will provide the learner with a sense of control. Reinforcement and praise of learner contributions builds trust and confidence.

EXPERIENCE

Adult learners enter a learning event with a great deal of experience. Much of the information that is received in a new learning environment will build upon prior knowledge and personal experiences. In an adult learning environment, both the facilitator and the students are responsible for what is taught. Each adult learner brings unique and valuable experience to a new learning environment and adult learners want to be recognized for what they know.

Experience in Action

Adults should be encouraged to participate and share existing knowledge to enhance learning materials. When an adult learner's prior knowledge connects to the new learning material, the material will become more meaningful and permanent for that individual. Group discussions provide a good opportunity for the experienced learner to share knowledge with the group and for peers to have exposure to other personal experiences.

MOTIVATION

Adults do not enter into a new learning environment without a reason. Most adult learners are motivated by a need. This need could represent one of the following.

- A **perceived need** in which an individual feels the learning experience will be of value to him or her. This individual believes that additional training will provide skills or knowledge that will improve his or her skills and performance.
- An **economic need** in which an individual is hoping for financial reward as a result of the learning experience.
- The need for **elevated status** in which an individual feels that the learning experience will make him or her appear more competent with peers.
- A need that is driven by **fear or force** in which an adult learner feels that the learning experience is necessary to avoid negative consequences.

Motivation in Action

Each adult learner is a unique individual with unique motivations. Learning events should be planned to maximize opportunities for satisfying personal and professional goals. Adult learners generally want to be treated respectfully as competent peers of the facilitator. If an individual enters a learning environment with a specific need, that need likely relies on successful completion of the learning event. Adult learners will feel most

Table 1: Assumptions of Andragogy

Self-Concept	As a person matures, his/her self-concept moves from one of being a dependent personality towards one of being self-directed.
Experience	As a person matures, he/she accumulates a growing reservoir of experience that becomes a resource for learning.
Readiness to Learn	As a person matures, his/her readiness to learn becomes oriented to the development task of his/her social roles.
Orientation to Learn	As a person matures, his/her time perspective changes from one of postponed application of knowledge to immediacy of application, causing orientation towards learning to shift from one of subject-centeredness to one of problem-centeredness.
Motivation to Learn	Internal motivation is key as a person matures. Adults are driven by internal motivation and the desire for self-esteem and goal attainment.
Need to Know	Adults need to know the reason for learning something. Adults will invest resources into learning something they deem valuable.

comfortable if they are given one-on-one support, positive reinforcement and multiple opportunities to grasp the material. The adult learner wants to feel competent in the learning environment and confident that he or she will reach a successful outcome.

RELEVANCE

Adults need to know the value of learning and the reason for investing time into learning. Adults tend to be ready to learn what they believe they need to know and will be more receptive and committed to learning if they have an appreciation of the topic and understand why it is important to their lives.

Relevance in Action

Reviewing anticipated learning outcomes before training begins will provide the *why* that will satisfy learners. Learning outcomes should always be specific, measurable and achievable so that upon completion of training, evidence of learning or the absence of learning is apparent.

APPLICATION

Adults expect immediate application of their learning. They need to realize how the training can be used in their lives to benefit them. Adult learners enter a new learning environment with personal responsibilities, complex lives and other priorities. As a result of these circumstances, adult learners want to understand how they can translate their new knowledge

Table 2: Learning Style Exercise

Select the behaviors that most describe your preferences	
I like to read.	
I like having discussions.	
I like to be directly involved.	
I write neatly.	
I prefer quiet.	
I learn by doing.	
I learn by watching.	
I feel distracted by outside noise.	
I am not particularly orderly or neat.	
I like neatness and order.	
I learn by listening.	
I use my hands when talking.	
The color with the majority of selections describes your learning style. [ ] Visual [ ] Auditory [ ] Kinesthetic	

into action immediately upon completion of the training. Adult learning orientation is problem-centered, task-oriented and life-focused.

Application in Action

Opportunities to perform tasks and solve problems that are applicable to real-life situations provide a practical use of the adult learner's time. These training exercises are meaningful to the learner because they will benefit their day-to-day functions. Activities that simulate real-world experiences and are relevant to the learner will be most valued.

LEARNING STYLES

Also important to providing a quality learning experience for the adult learner is recognizing the various learning styles that impact the learning process. Most adults have condition preferences that contribute to the effectiveness of a learning experience. The most commonly recognized learning styles include visual, auditory and kinesthetic. Ideally, a curriculum design should cater to all learning styles, but various tools are available for assessing learners in order to determine the most appropriate learning conditions. Table 2 represents an abbreviated example of a learning style tool.

The Visual Learner

Visual learners use visual senses to receive information. These include looking, seeing, viewing or watching. Images, photos, videos, diagrams, charts, text, written instructions or demonstrations can enhance learning for visual learners.

The Auditory Learner

Auditory learners receive information best by hearing, listening or speaking. These individuals prefer to be talked through a process. Strategies that appeal to auditory learners include discussions, lectures, brainstorming, stories or examples, and Q-and-A sessions.

The Kinesthetic Learner

Kinesthetic learners require a hands-on approach to learning. They learn by doing, trying and experiencing. Strategies that benefit the kinesthetic learner include practicing, workshops, labs, role-playing, note-taking or experiments.

Learning Styles in Action

In order to maximize the opportunity for success of all learners, learning outcomes should be attained with exercises that incorporate all three adult learning styles. For example, a lesson on proper use of a respirator that caters to all learning styles might include 1) instructions recited by the facilitator or by a member in a team setting; 2) a demonstration of donning equipment properly; and 3) an opportunity for each participant to put on the equipment. Not only is the lesson designed to benefit all learning styles, but it also provides reinforcement of the topic by addressing the proper procedure three times. Reinforcement improves the likeliness of comprehension and retention of the learning materials. Addressing various learning styles will increase the opportunity for learning that resonates with a greater number of individual adult learners.

SUMMARY

While many employers are faced with an increased need for training, the learning experiences provided to employees may not be optimizing the opportunity for workforce improvement. By considering the unique needs, characteristics and learning styles of the adult learner, a more customized event can be planned to support more permanent and successful learning outcomes. Change is constant in today's workplace, requiring that employees are up-to-date with current standards and technology and are adaptable to the changing work environment. The quality of skills and industry training should represent an employer's desire to remain competitive and plan for a successful future.

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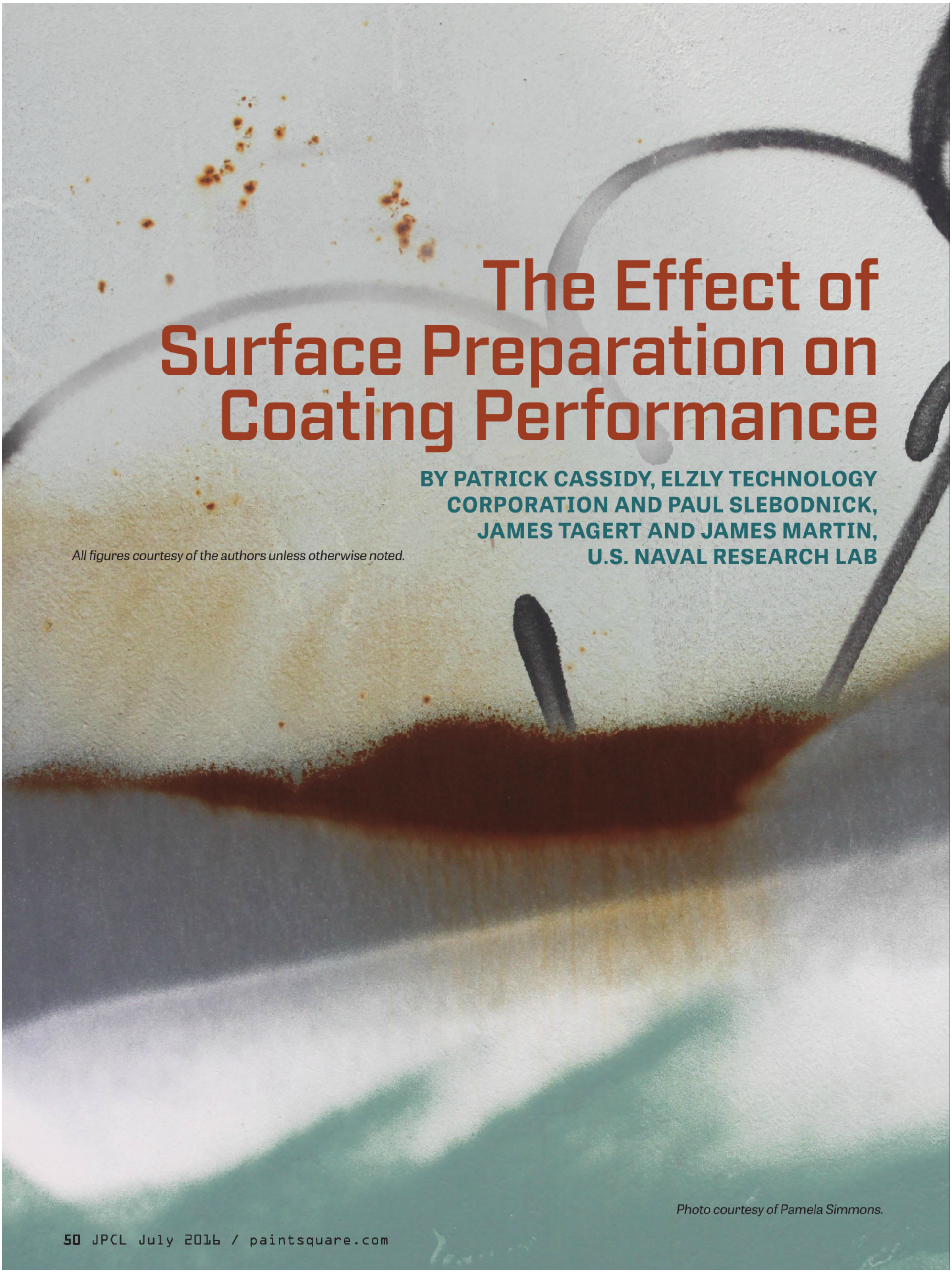

The Effect of Surface Preparation on Coating Performance

BY PATRICK CASSIDY, ELZLY TECHNOLOGY CORPORATION AND PAUL SLEBODNICK, JAMES TAGERT AND JAMES MARTIN, U.S. NAVAL RESEARCH LAB

All figures courtesy of the authors unless otherwise noted.

Photo courtesy of Pamela Simmons.

Prediction of service life for naturally exposed coatings remains problematic. A number of factors can have an effect on coating performance, but none more so than surface preparation, the primary factor that influences how long a coating will last in service. A method of surface preparation must be selected based on coating type, the intended exposure and the desired life cycle. Poor, inadequate or improper surface preparation can lead to premature failure of a coating, sometimes catastrophically.

The U.S. Naval Research Laboratory (NRL) conducted a study of various surface preparation methods to determine their effect on the common topside epoxy primer barrier coatings used by the U.S. Navy. The independent variables that were changed included type of profile (both the extent of cleanliness and the type of tool used), profile height, coating thickness and the amount of chloride contamination

Fig. 1: This images shows the final surface profile types.

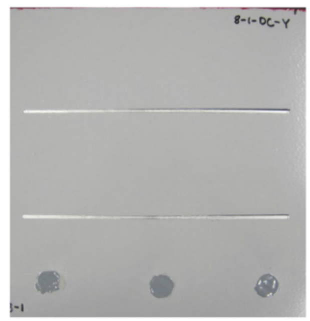

Fig. 2: The final panel for exposure with scribes. Note the touched-up areas.

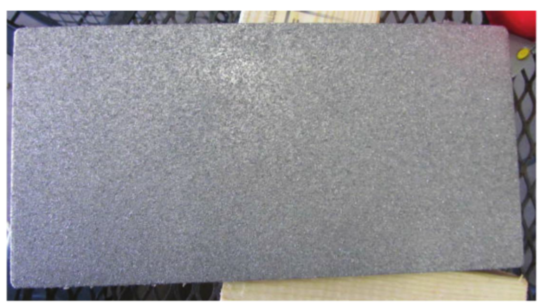

Fig. 3: This image shows the excessive profile height panel.

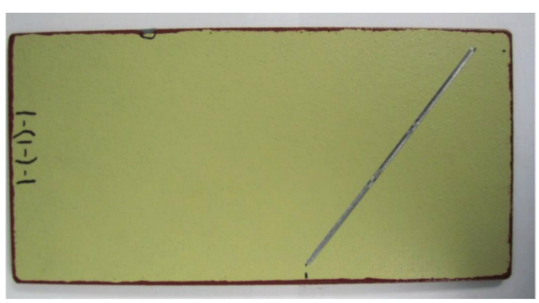

Fig. 4: The final excessive profile height panel ready for exposure.

Fig. 5: Hand tool prepared panel ready for exposure in Ft. Lauderdale, Fla.

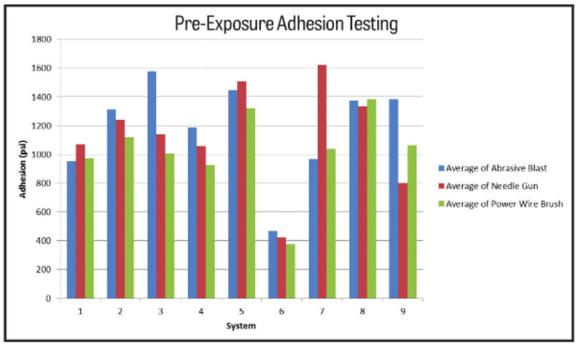

Fig. 6: Pre-exposure adhesion test results.

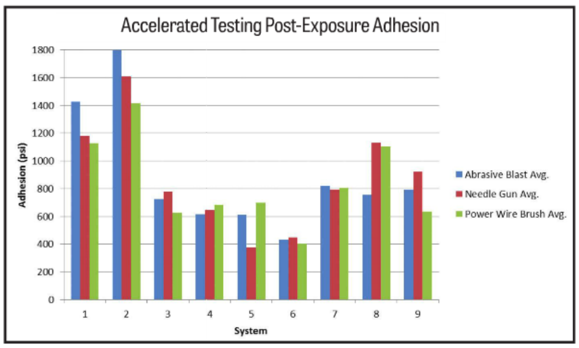

Fig. 7: Post-exposure adhesion results after 1,000 hours as per ASTM B 117.

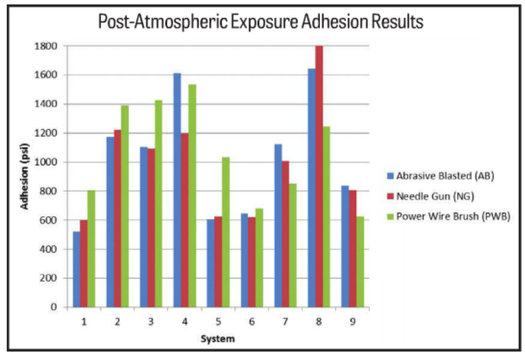

Fig. 8: Post-exposure adhesion results after one year in Key West, Fla.

present. The dependent variable in each case was coating performance, which was evaluated either visually by rust-through, scribe cutback (i.e. scribe creep, the extent of corrosion that undercuts the coating at an intentional holiday), blistering or adhesion of the coating.

TEST APPROACH

The Effect of Profile Type

Three mechanical preparation methods were tested side-by-side on a 12-inch-square steel panel. The panel was sectioned into three equal portions and each portion was prepared by the method indicated in Table 1.

The three different surface preparation methods were intended to simulate field conditions in a laboratory environment. One aspect of field maintenance conditions that the laboratory test panels did not simulate was the presence of aged coatings, corrosion products and soluble salts. The laboratory steel panels used were virgin (SSPC-VIS 1 Condition A) and not pre-conditioned or coated, and the specified SSPC-SP 10/NACE No. 2, Near White Blast achieved a cleanliness level that approached or attained a SSPC-SP 5/NACE No. 1, White Metal Blast level.

The power wire brush surface preparation sample was cleaned to bare metal but not identified as SSPC-SP 11, Power

Table 1: Surface Profile Type

Suface Profile No.	Suface Prep Type	Target Profile Height
1	SSPC-SP 10 Near White Blast Cleaning	2–3 mils
2	SSPC-SP 11 Power Tool Cleaning to Bare Metal (Needle Gun)	1–1.5 mils
3	Power Tool Cleaning to Bare Metal (Power Wire Brush)	0.5–1 mil

Tool Cleaning to Bare Metal, since SP 11 requires a 1 mil minimum profile. Not only were the profiles for each surface preparation method expected to be different, but it was expected that each method would also produce a different type of profile in terms of roughness and angularity, as seen in Figure 1 (p. 51).

Profile measurements were taken on each section of the panel, recorded in accordance with ASTM D4417, Method B with a digital profilometer and were within the specification given.

Nine different coating systems were applied to the panels — five of primer only (two coats of epoxy each) and four of primer and topcoat (two coats of epoxy and one coat of silicone alkyd/polysiloxane). These coating systems were intended to be a sampling of legacy epoxy, high-solids (HS) and ultra-high-solids (UHS) epoxies, the most common topside systems used by the Navy.

All systems were spray-applied in accordance with the manufacturer's instructions and checked for proper dry film thickness (DFT) with a digital coating thickness gage. Each coating system was applied to four replicate panels. Each panel was scribed twice across the face of the panel (Fig. 2, p. 51). Baseline adhesion testing was performed on each section of each panel in accordance with ASTM D4541.

Two panels were exposed to 1,000 hours of ASTM B117 salt fog and two panels were exposed to one year of atmospheric exposure in Key West, Fla. Upon completion of the exposures, the panels were rated for degree of rust-through, blistering, scribe cutback and adhesion using ASTM D610, ASTM D714, ASTM D1654 and ASTM D4541, respectively.

The Effect of Profile Height

Steel panels were procured and abrasive blasted in accordance with SSPC-SP 10. The target profile was 10 mils as measured via ASTM D4417, Method B. This excessive profile and the subsequent coating performance could then be compared to that of the normal profile height from the panels described in the previous section of testing. A sample panel is shown in Figure 3 (p. 51).

To mitigate the effect of the excessive profile height, four coating systems were applied at four different wet film thicknesses (WFTs). Due to the roughness of the profile, the WFT was measured using a witness (control) panel. The four coating systems were all epoxy primers commonly used by the U.S. Navy. The target WFTs over the 10-mil profile were 10 mils, 11 mils, 12 mils and 14 mils. All coatings were spray-applied in accordance with the manufacturer's instructions.

The panels were scribed and exposed in a salt fog cabinet in accordance with ASTM B117 for 1,000 hours (Fig. 4, p. 51). Upon completion of the exposures, the panels were rated for degree of rust- through, blistering and scribe cutback using ASTM D610, ASTM D714, and ASTM D1654, respectively.

The Effect of Contamination

Bare steel panels were exposed to 10 cycles using the GMW14872 Cyclic Corrosion Laboratory Test. The panels were then prepared to SSPC-SP 11 using a power sanding disc with 100-grit sandpaper with a target profile height of 1 mil. The residual contamination was characterized by measuring conductivity on each panel. All panels were coated with the same epoxy primer in accordance with the manufacturer's instructions. Panels were then subjected to either 100 cycles of GMW14872 or six months of natural exposure in Fort Lauderdale, Fla. (Fig. 5, p. 51).

Upon completion of the exposures, the panels were rated for degree of rust-through and blistering using ASTM D610 and ASTM D714, respectively.

RESULTS

The Effect of Profile Type

Adhesion data was taken on each panel before and after exposure over each different type of surface preparation. The results are shown in Figures 6, 7 and 8 (p. 52). All of the systems showed adequate adhesion after exposure. The adhesion tests performed provided no meaningful results pertaining to coating performance other than showing which coatings were the weakest to begin with. For example, System 6 was a silicone alkyd topcoat and its mode of failure was disbondment between the topcoat and primer. There was no correlation between adhesion and type of surface preparation/profile before or after exposure.

Ratings taken on each panel for blistering and rust-through also provided no results pertaining to the difference in performance. However, cutback from the scribe was measured for each coating and surface preparation type and provided meaningful results. Figures 9 and Figure 10 (p. 56) illustrate accelerated exposure and Figures 11 and 12 (p. 56) illustrate atmospheric exposure. Figure 13 (p. 57) shows three sample panels after one year of natural atmospheric exposure on various coating types.

The Effect of Profile Height

The meaningful data collected for the excessive profile panels included rust-through and blistering. Figure 14 (p. 57) shows one coating system set after accelerated exposure. Note that as coating film thickness increased, rust-through and blistering decreased.

The results of the rust-through ratings separated by primer thickness are shown in Figure 15 (p. 58). A rating of 10 is no rust-through. The profile differential is the WFT converted to DFT with the average surface profile height subtracted (-1 mil = 10 mil WFT*90% solids - 10 mil profile). The data and visual inspection both show that as primer film thickness increases above the profile height, rust-through decreases. Blister rating data is shown in Figure 16 (p. 58). This rating number is a composite numerical representation of the ASTM D714 density and size rating that allows the rating to be shown graphically. (A rating of 10 is no blistering.)

The scribe cutback data showed no undercutting of the coating at any film thickness, and thus the data is not shown. Note that in the first part of testing presented, cutback was the primary method of coating failure, with little to no rust-through or blistering, while in this portion of testing, rust-through and blistering were the primary modes of failure and there was little to no cutback observed.

The Effect of Contamination

Panels were rated after exposure for performance by rust-through and blistering. Figure 17 (p. 58) shows the

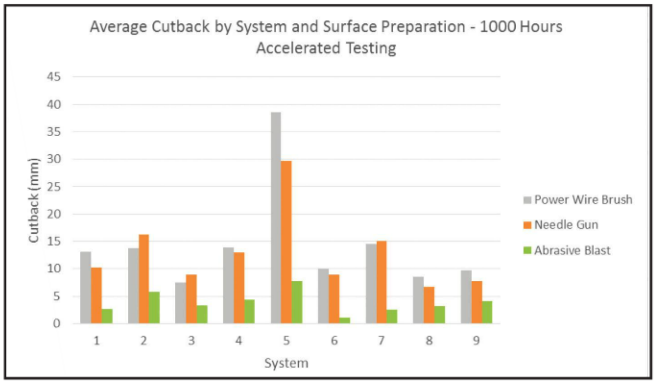

Fig. 9: Cutback data by coating system after 1,000 hours as per ASTM B117.

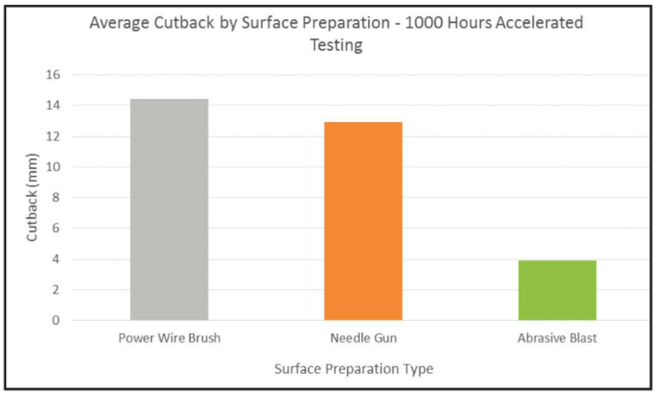

Fig. 10: Cutback data by surface preparation, all coating systems after 1,000 hours as per ASTM B117.

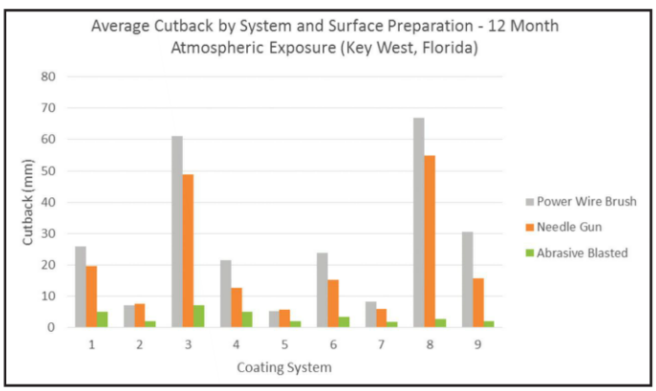

Fig. 11: Cutback data by coating system after one year of natural exposure.

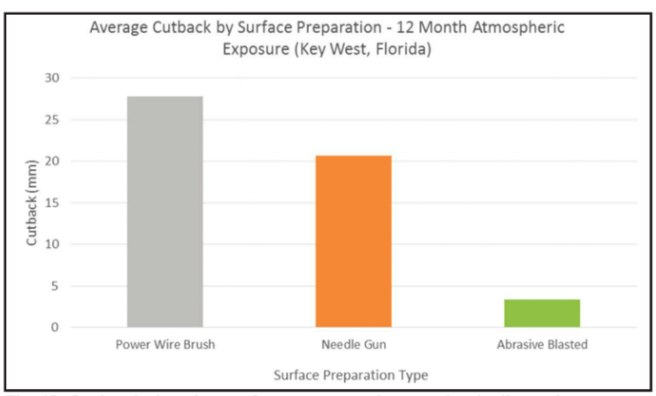

Fig. 12: Cutback data by surface preparation method, all coating systems after one year of natural atmospheric exposure.

average rating of all panels (both accelerated and atmospheric exposure) by conductivity. Conductivity was grouped as either high salts (>70 µS/cm) or low salts (<70 µS/cm) based on the U.S. Navy standard for topside conductivity allowance in Standard Item 009-32. Again, the blister rating number is a composite numerical representation of the ASTM D714 density and size rating that allows the rating to be shown graphically.

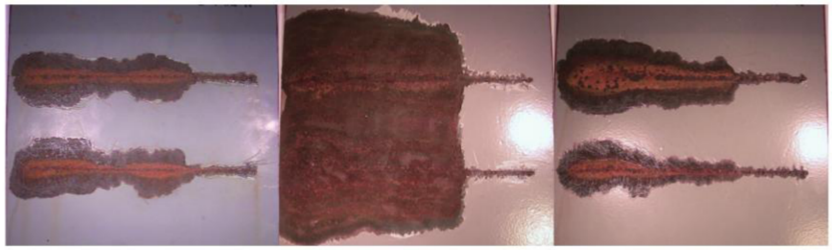

Fig. 13: Three sample panels after removal from one year of natural atmospheric exposure. Surface preparation methods were (left to right) power wire brush, needle gun and abrasive blast. Some coating systems performed better than others over an SSPC-SP 11 surface. Note the massive delamination of the coating over the left two-thirds of the center panel. No trend was recognized as to why this occurred.

CONCLUSIONS

Differences in surface prep type and the extent of cleanliness did not seem to impact adhesion of the coating or the rust-through/ blistering but did affect the cutback performance across all coating systems. Cutback over an abrasive blasted SSPC-SP 10 surface was lower on average than that of a needle gunned, SSPC-SP 11 surface, which in

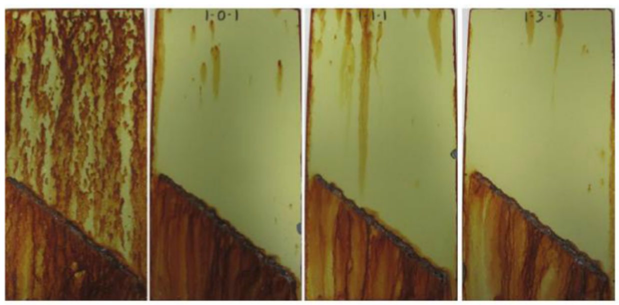

Fig. 14: Excessive profile panels after 1,000 hours as per ASTM B117. Film thickness increases (left to right) at 10 mils WFT, then 11 mils, then 12 mils and on the far right, 14 mils WFT.

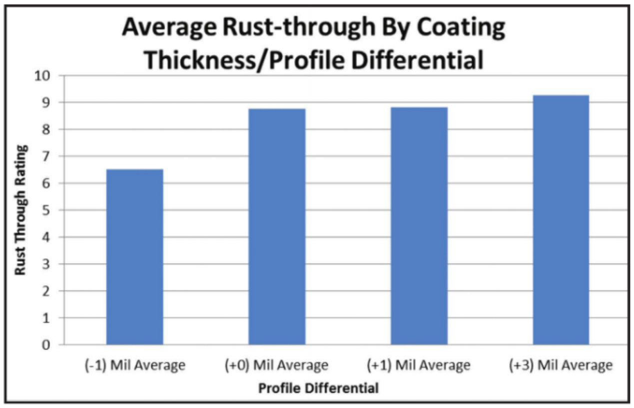

Fig. 15: Average rust-through rating by primer thickness.

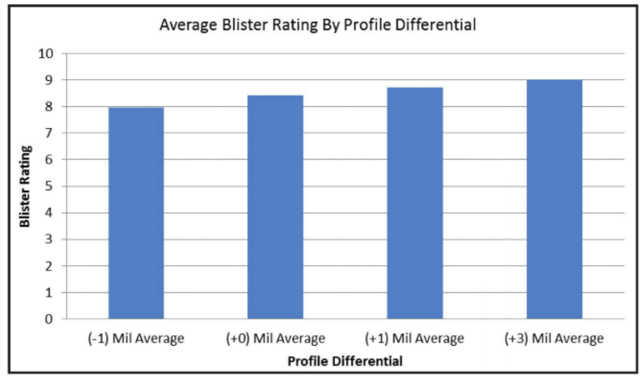

Figure 16: Average blister rating by primer thickness.

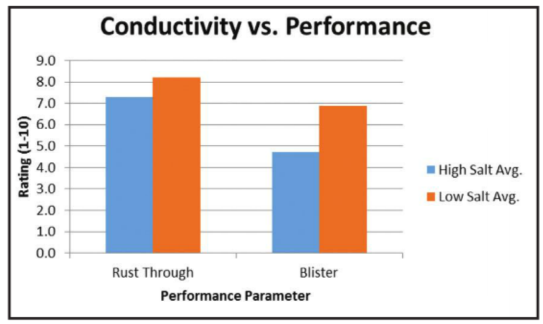

Figure 17: Final results of coating performance for all exposures (100 cycles GMW14872/six months natural atmospheric exposure, Ft. Lauderdale, Fla.).

turn was lower than that of a power wire brushed SSPC-SP 11 surface. It appears that both cleanliness and the profile type (including height and angularity) provide for better cutback prevention. Adhesion performance seems to be primarily influenced by the coating type (and its cohesive strength) and not by the surface preparation variables. Additionally, some individual coating systems tended to perform better than others over different types of surface preparation.

The second portion of testing of excessive profiles showed that a higher profile will even further limit cutback. The abrasive blasted panels with a 10-mil profile height in the second portion of testing outperformed abrasive blasted panels with a 2-to-3-mil profile height from the first portion of testing. However, the risk associated with going to a profile too high is rust-through and blistering of the coating system if not applied at a high enough film thickness. The coating thickness must be applied several mils higher than the height of the surface profile to prevent premature breakdown of the coating. However, this practice, if done incorrectly, may lead to other problems such as solvent entrapment. An effective balance between abrasive blast profile height and coating thickness must be achieved.

Finally, coating performance is affected by chloride contamination. On average, panels with a conductivity above the U.S. Navy acceptable level for topside coatings showed worse overall performance than those with a conductivity level below the acceptable level.

These factors should be taken into account when selecting the proper surface preparation method for a job and should be weighed against the applicable cost of the surface preparation and intended life-cycle requirements.

ABOUT THE AUTHORS

Patrick Cassidy has been working in the corrosion and coatings industry for over eight years and is currently a senior engineer with Elzly Technology Corporation. He has been involved in a diverse number of programs including coatings research, field investigation and application of corrosion control products. He holds a Bachelor of Science degree in mechanical engineering from the University of Virginia. Cassidy

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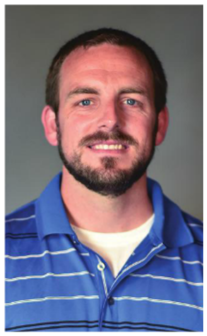
Paul Slebodnick is employed by the Naval Research Laboratory in the Washington D.C., Center for Corrosion Science & Engineering, under the marine engineering Section. He currently leads research programs

in developing technologies for the United States Navy that produce maintenance reductions and reduce Ships Force workload. Slebodnick is responsible for demonstrating new technologies aboard Fleet combatants to determine readiness with in-service evaluation of the technologies prior to transitioning to the Fleet. He also leads Engineering for Research and Development of Tank Coatings under Naval Sea Systems Command, Technical Warrant Holder for Coatings and Corrosion Control — Ships, SEA-05P in Washington D.C.

James Tagert is a materials research engineer working at the Naval Research Laboratory and has over 10 years of experience



working in the coatings industry. He graduated from the University of Maryland in 2004 earning a Bachelor of Science degree in mechanical engineering and is a member of both the American Society of Naval Engineers and National Association of Corrosion Engineers. Tagert has worked at NRL since 2008 supporting U.S. Navy research and engineering programs related to materials science with an emphasis on the development and transition of advanced coating systems.

James Martin has been with the Naval Research Laboratory for over 16 years. He is the head of the Marine Coatings Technology and Systems section Code

6138. Martin is responsible for introducing coatings technology to the Fleet through applied research and development, testing and demonstrations. He has been active in addressing Fleet concerns from both maintenance and new construction with respect to coatings. Martin continues to introduce new technology that will help to reduce the life cycle and ownership costs of today's Fleet.

ACKNOWLEDGMENTS
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