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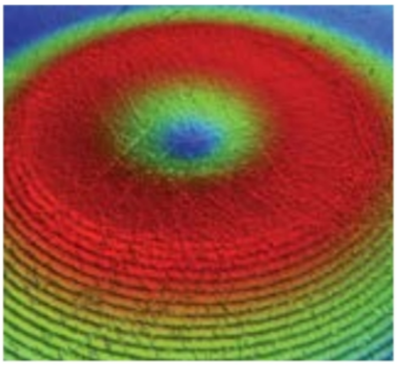
FEATURES



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DEPARTMENTS

ALSO THIS ISSUE

STAFF

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Covestro to Invest $1.7 Billion in Texas Expansion

German-based polymers giant Covestro recently announced that its board approved an investment of 1.5 billion euros ($1.7 billion) to build a new world-scale MDI (methylene diphenyl diisocyanate, a key chemical in polyurethanes) plant in Baytown, Texas. This marks the largest single investment in the history of the company.

Total capacity for the new plant will be 1.1 billion tons of MDI per year, and production is slated to begin in 2024.

"Demand for innovative MDI materials will continue to grow for the foreseeable future and likewise promises attractive capacity utilization rates," said CEO Markus Stellemann. "We have already announced a significant increase in capital expenditures; now it's time to put it into action. With the new MDI train in Baytown, we will further strengthen our global leading position in Polyurethanes, even better serve our customers and create long-term shareholder value."

Photo courtesy of Covestro.

According to the *Houston Chronicle,* Covestro, which spun off from Bayer in 2015, has 30 production sites worldwide and employs more than 16,000 people. The company's Baytown site, built in 1971, is its largest in the U.S. The Baytown plant employs about 1,000 people, and the site expects to add at least another 25 to support expanded operations.

PPG Financials Indicate Slight Increase in Sales

Global coatings supplier PPG released its third-quarter financial report Oct. 18, reporting an increase in net sales, with sales volumes remaining flat and volume growth offset by lower U.S. architectural coatings volumes due to previously announced changes in customer assortment.

Net sales, totaling $3.8 billion for this quarter, were up 1 percent from last year. Sales volumes were flat, with volume growth increasing by 2 percent, but these were offset by the aforementioned lower coatings volumes. Continuing operations net income totaled $368 million, and adjusted net income clocked in at $353 million.

Michael McGarry

"We delivered strong net sales growth in local currencies of more than 3 percent," said Michael McGarry, PPG chairman and chief executive officer. "This growth was driven by higher selling prices and continued strong volume growth from several PPG business units, including aerospace and general industrial coatings."

Segment income for Performance Coatings totaled $331 million, 9 percent lower than 2017's third quarter. Segment income was reportedly down due to lower sales volumes and higher costs for raw materials and logistics.

At $2.3 billion, net sales for PPG's Performance Coatings segment remained flat from the prior year, with sales increasing by 2 percent due to higher selling prices. This was offset by slightly lower sales volumes, however. Net sales were lowered by 2 percent due to unfavorable foreign currency translation, amounting to roughly $45 million.

Aerospace coatings sales volumes saw a low-teen-digit percentage increase due to consistent customer demand across all major regions. Organic sales for automotive refinish coatings saw a mid-single-digit percentage decline thanks to a change in customer order behaviors; both European and U.S. customers currently have a large amount of inventory due to lower end-use market demand. The protective and marine coatings segment also experienced a mid-single-digit percentage sales volume bump.

Organic sales for architectural coatings in the Americas and Asia-Pacific saw a low-single-digit percentage decline, and sales volumes in Latin America experienced a mid-single-digit increase. Company-owned store sales in the U.S. and Canada saw a high-single digit percentage increase.

Industrial coatings segment income was down 25 percent, or $56 million, totaling $169 million; the reduction was attributed to an inflation of raw material and logistics cost, which was somewhat offset by higher selling prices and increased sales volumes. Unfavorable currency translation resulted in a $5 million impact. In the Industrial segment, net sales were roughly $1.5 billion, up 3 percent, or $42 million, compared to last year. Year-over-year sales volumes also saw a 2 percent increase, with selling prices seeing a similar bump at 1 percent. Sales related to acquisitions totaled $30 million, a 2 percent increase from the prior year.

Automotive OEM coatings sales were reportedly flat, but in a better position than overall global automotive OEM industry builds. General industrial coatings sales volumes also experienced solid growth, with both Europe and Latin America experiencing above-market growth. Packaging coatings sales experienced a mid-single-digit percentage increase. Above-industry growth rates were largely attributed to costumers continuing to adopt company technologies.

McGarry noted that PPG expects normal business seasonality in the fourth quarter, along with overall global economic growth remaining positive. With increasing industrial production volatility and inconsistency in emerging region growth rates as the third quarter unfolded, the company expects these trends to continue into the last segment of the year. PPG also expects consistent sales trends moving forward.

SHERWIN-WILLIAMS REPORTS STEADY SALES INCREASES

Consolidated net sales were up in the third quarter of 2018 for The Sherwin-Williams Company, a 5 percent increase over the same quarter in 2017, totaling $4.73 billion. The uptick was largely attributed to higher paint sales volume in the Americas and consumer brands groups, along with selling price increases.

Diluted net income per share also saw an increase from 2017's $3.33 per share to $3.72 per share. Each share included charges of $1.09 and $.87 from the costs associated with California litigation and acquisition.

According to Sherwin, the pre-tax charge for the $136.1 million California litigation is one-third of the lead abatement fund.

Sherwin also reported a 5-percent increase in net sales for the Americas group, totaling $2.67 billion for the quarter. This was largely due to higher architectural paint sales volumes across end market segments as well as selling price increases. Net sales from company stores in the U.S. and Canada increased 5.2 percent this quarter. Segment profit also increased by $52.2 million to $577.7 million.

Consumer Brand Group net sales also experienced an uptick, increasing 6.5 percent to $770.5 million for the third quarter. A new customer program and selling price increases are responsible for the segment's positive trend, though this was slightly offset by lower volume sales to some of the group's retail customers.

John G. Morikis

The new revenue standard also reduced group net sales by 4.7 percent, with segment profit increasing to $83.9 million from last year's $70.4 million due to selling price increases and reduced impacts of purchase accounting. This was offset by the increased costs of raw materials and the incremental supply chain, both of which occurred due to the demand of the new customer program.

The Performance Coating segment reported a 4.2 percent increase in net sales, totaling $1.29 billion for the quarter. The third-quarter uptick was attributed to selling price increases along with the continuation of the trend of demand in most of Sherwin's North American businesses.

Currency translation rate changes also decreased segment net sales by 1.1 percent. Segment profit also partook in the generally positive trend, clocking in at $104.9 million, up from 2017's $59.6 million due to reduced impact of purchase accounting and selling price increases, also offset by the costs of raw materials. In terms of percent to net external sales, segment profit increase from 4.8 percent last year to 8.1 percent this year.

John G. Morikis, the company's chairman, president and chief executive officer noted that in the fourth quarter, the company anticipates that consolidated net sales will increase a mid-single-digit percentage in comparison with last year's results from the same period.

"For the full year 2018, we expect our consolidated net sales will increase by a high teen percentage, including incremental Valspar sales of $1.85 billion for the first five months of 2018, compared to the full year 2017," Morikis noted.

PAINTSQUARE COMMENTS

SvetlanaSF / Getty Images

In Response to "Waterjetting & Surface-Tolerant Coatings: UHP on the Luís I Bridge in Porto, Portugal" *(JPCL October 2018)*

Author Joao Azevedo examined the successful use of UHP waterjetting and application of an ultra-high-solids, damp-surface-tolerant epoxy on the 130-year-old Luís I Bridge in northern Portugal.

Wan Mohamad Nor Wan Abdul Rahman:
"Great article, Joao. It's enlightened our knowledge about the usage of UHP."

Regis Doucette:
"I enjoyed the presentation and wonder about the accidental covering up of active corrosion cells with your reference to imperfect protection around the bolt heads and connections. I understand your emphasis on the metrics of a small percentage of surface area, but structure-critical areas are a small percentage in the same way that our eyes and ears are a small percentage of our own bodies' surface area. Bolts and connections are more important and may require a different approach to protective coatings such as the inclusion of a chemical treatment for corrosion mitigation."

Gordon Kuljian:
"Great success story after 15 years. Maybe only one spot touch-up of the bridge before your 30-year report!"

Joao Azevedo:
"Thank you everyone so kind to comment so far. Regis, your comment [is] well taken, and agree bolts and connections are critical. On the Luís I Bridge, a very small proportion of such critical areas showed imperfections, as good discipline was in place [during] stripe coating. Also, routine touch-up maintenance can spot such defects and correct them before rust creeping takes effect. This being said, other corrosion mitigation processes may be used as you mentioned."

jerom400 / Getty Images

In Response to "Research Betters Blast Media Collection"
(PaintSquare News, Oct. 23)

New research, completed by Michael Clarke, a mechanical engineer at the Fleet Readiness Center Southeast in Jacksonville, Florida, recently revealed that more blasting media could be reclaimed with a reduction in cross-draft velocity in blasting booths.

Doan Thang:
"Abrasive lost to the dust collector and cross-draft velocity of the blast room are different issues. If you have a well-designed suction hood or pre-separator, usable abrasive can be stopped and collected before going to [the] dust collector. Cross-draft velocity should be as big as possible to increase the visibility of the blaster, but the consequence is a bigger investment and operating cost. Moreover, push-pull technology is a good way to increase cross-draft velocity and minimize total air volume of the dust collector."

Joe McGreal:
"In most blast room designs, a deflector or baffle is installed in front of the dust collector exit port to reduce the flying abrasive's opportunity to get caught in the high velocity of exiting air. Well-designed blast rooms have expansion chambers in the ventilation system, prior to the dust collector to capture any usable blast media and large particle separation to lower the burden on the dust collector to manage all the debris. Regardless, good visibility increases productivity and safety."

Problem Solving Forum

paintsquare.com/psf

What is the best way to achieve proper surface preparation in areas with limited access, such as interior box beams on bridges?

Mike Winter:
"Don't design bridges with box beams to start with! Engineers need to be educated on how to design structures in a manner that is consistent with achieving long-term corrosion control, which includes understanding the limitations of surface preparation and paint application in maintenance situations."

Trevor Neale:
"I agree with Mike that there continues to be a major disconnect between corrosion specialists and structural steel engineers. I would have thought, with current computer technology, that factors could be included to allow sufficient access to the all the surfaces to ensure long-term preservation."

Jerrod Monaghan:
"The solution couldn't be easier … use cathodic protection by metalizing the areas you can reach and let chemistry do the work for you. The metalizing will protect the areas with limited access better than any other product, means or methods known to man, because we can't change the reactivity of noble metals no matter how hard we try! Coating manufactures have spent billions of dollars and many of us spent our entire careers trying to solve this riddle. In the end, it's as easy as putting zinc on the steel!"

Sukhmander Singh:
"One can only minimize corrosion inside the box by passing all the steel, before fabrication, through a preservation line using a weldable primer."

Luis Tapia:
"Appropiate design is the first step. If that was not possible or considered, use vapor-phase corrosion inhibitors (VCI) and program their maintenance."

PAINT POLL

paintqsuare.com/poll

Photo courtesy of NTSB / Florida International University.

Earlier this month, a judge stopped the release of records related to the Florida International University bridge collapse. Do you think this was the best choice to protect the investigation?

Yes 49% No 49% Other 2%

Erik Andreassen:
"Who is covering for who? All the facts have to be on the table to complete the investigation. The cannot be a firm and honest result if the facts are not known."

Michael Halliwell:
"I can understand that there may be some reasons why the information would be withheld in the short term from those not directly involved in the case (i.e., not wanting to bias a potential jury pool by releasing information to the press … especially in a high-profile case), but when this hits trial, everything needs to be out in the open for transparency's sake … otherwise you run the serious risk of the appearance of a cover-up."

PAINTSQUARE NEWS TOP 10

paintsquare.com/news, Oct. 8–Nov. 4

1. World's Longest Sea-Crossing Bridge Opens
2. Sherwin-Williams Reports Steady Sales Increases
3. Judge Blocks Release of FIU Bridge Records
4. Environmental Rules Waived for TX Border Wall
5. AkzoNobel Q3 Financials Indicate Revenue Dip
6. Bridge Collapses During TX Flooding
7. EU Concerned Over Croatia Bridge Project
8. None Injured in BC Pipeline Explosion
9. LA Bridge Closed After Crane Barge Impact
10. PPG Financials Indicate Slight Increase in Sales

Adhesion Testing: How Much Is Sufficient?

BY DAVID TORDONATO, PH.D., P.E.; U.S. BUREAU OF RECLAMATION

Pull-off adhesion testing of coatings is commonly used for product trials and qualification as well as quality control and quality assurance. However, initial adhesion values do not necessarily correlate with service life of coatings or their corrosion protection performance in real life. In this study, adhesion of several product chemistries to steel before and after immersion exposure was examined. Results are presented within the context of laboratory corrosion testing to investigate the significance of adhesion testing in modern lining systems.

BACKGROUND

In the coatings industry, adhesion is measured by the degree of difficulty to remove a coating from a substrate. It is preferable for the adhesion of the coating to the substrate to be greater than the cohesive strength of the coating. Water and ions can disrupt adhesion, resulting in blistering, undercutting and delamination. Retaining strong adhesion to the substrate upon exposure to the service condition is one of the key requirements in providing a long service life[1]. One cannot obtain coating longevity without superior adhesion that resists hydrolysis over time.

Adhesion is created through mechanical and chemical forces. Mechanical interlocking results in frictional forces, which are increased by the presence of a surface profile[2]. Several references describe the effects of surface roughness and peak count on adhesion[3-6]. Chemical bonding is also enhanced by the increased surface area of a textured substrate and requires a clean surface free of contamination. Bonding requires that the coating comes into close contact with the substrate and wets out or flows into the profile. Therefore, the coating viscosity, surface tension and volume changes that take place during cure control the ability of the coating to wet the substrate and flow into the profile to form strong adhesion. Incomplete wetting of the profile valleys can significantly affect adhesion.

Chemical forces can result from primary bonds (covalent) or secondary bonds (ionic or hydrogen bonding; dipole interactions or van der Waals forces)[2]. Adhesion of organic coatings depends upon the quantity and type of polar interactions with the metal substrate. Most organic coatings do not contain chemistries that can form covalent bonding to metal oxides; instead, they rely mostly on hydrogen bonding[1]. Hydrogen bonds are weak chemical bonds, which can be displaced by polar water molecules. Therefore, wet adhesion values are lower than dry adhesion values in most coatings[7, 8]. Some functionality groups such as carboxylic acid and phosphoric acid have an affinity towards metal hydroxides (weak acid/weak base interactions) and tend to have improved wet adhesion due to these attractive forces, but most coatings do not contain these functionalities[7].

Wet adhesion testing may be more valuable than conducting dry adhesion, yet there is no industrial standard specifically for wet adhesion testing. Quantitative adhesion is difficult to measure for traditional linings due to variability in testing and mode of cohesive failures versus adhesive failures. There are many technical papers discussing various techniques to conduct wet adhesion testing, including ASTM D3359, ASTM D4541 and ASTM D6677, but only ASTM D6677 references wet adhesion in the keywords of the standard[9-12].

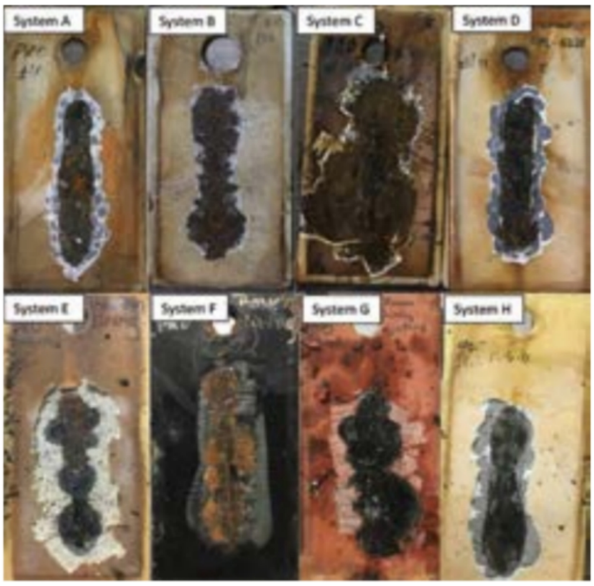

Fig. 1: Samples after 30 weeks (5,040 hours) of prohesion testing. Figures courtesy of U.S. Bureau of Reclamation.

Table 1: General Description of Lining Systems Tested.

System	Generic Description	% Solids	# of Coats	Measured Total DFT*
Control	Vinyl Resin Corps of Engineers System V766E	20	6	12
A	Abrasion resistant, flake-filled, novolac epoxy	100	2	36
B	Polysulfide modified epoxy	100	1	14
C	High-build aromatic polyurethane	100	1	36
D	UV stabilized abrasion resistant epoxy	100	1	45
E	Novolac epoxy/Polyurethane Hybrid	100	1	40
F	Novolac epoxy/Polyurea Hybrid	100	1	27
G	High-solids epoxy	88	1	30
H	High-build epoxy	100	1	37

**Average spot reading, measured using an electronic magnetic DFT gauge.*

It has been shown that good dry adhesion does not equate to good wet adhesion[9]. The same polar functionality that forms strong bonds in dry conditions can be displaced by water, resulting in poor wet adhesion[10]. It has also been shown that loss of adhesion in wet conditions can be recovered, but not to 100 percent of the original dry adhesion values[11, 12].

Undercutting (rust creep) is another metric used to gauge the performance of coatings. Organic coatings (non-zinc-rich primers) typically have poor rust creep resistance because at defects, the adhesion mechanism is readily displaced by water, which allows oxidation to take place and propagate under the coating[1]. Inorganic zinc, galvanized coatings and organic zinc-rich primers typically arrest undercutting due to sacrificial pigments or metals.

TESTING METHODOLOGY

The lining materials for this study were applied by the manufacturer, to whom Reclamation had provided 3-inch-by-6-inch-by-1/8-inch steel panels. Surface preparation and application was performed in accordance with the manufacturer's product data sheet. Several product chemistries marketed for use in immersion service were investigated as part of Reclamation's efforts to identify replacements for solution vinyl resins (Table 1, p. 11). Hence, all materials were compared to vinyl resin paint performance.

Each product was exposed to water immersion and cyclic weathering. Adhesion testing was conducted prior to exposure and only on samples exposed to dilute Harrison water immersion service for one year. Table 2 details the test matrix that was used for the corrosion testing of each system.

The tests included the following.

- "HAR": Sustained immersion in a dilute Harrison's solution (DHS) at room temperature (modified ASTM D870).
- "DI": Sustained immersion in deionized water

Table 2: Test Matrix for Accelerated Weathering.

Immersion Exposure		Cyclic Exposure		Pull-Off Adhesion		Knife Adhesion
Dilute Harrison (HAR)[1]	Deionized Water (DI)[2]	Prohesion (PRO)3	Immersion + Salt Fog[4] + QUV[5] (BOR)[6]	Initial ASTM D4541	Post Immersion (wet) ASTM D4541	Post Immersion (wet) ASTM D6677
2/2	2/2	2/1	2/1	3"x6"x1/8" coupon	HAR samples only	HAR samples only

The number of test panels is indicated for each as "scribed / unscribed."
1. ASTM D870: Harrison's Solution is water with 0.5 g/L NaCl, 3.5 g/L $(NH_4)_2SO_4$, testing performed at room temperature
2. ASTM D870: DI water, testing performed at room temperature
3. ASTM D5894: 1 week alternating exposure schedule in a repeating order: QUV, FOG
4. FOG test: ASTM G85 Annex A5: 1 hr fog at ambient using DHS solution, 1 hr dry-off at 35 C.
5. QUV test: ASTM D 4587: Test condition "B" 4 h UV/60 C followed by 4 h Condensation/50C
6. 1 week alternating exposure schedule in a repeating order: QUV, FOG, HAR, FOG

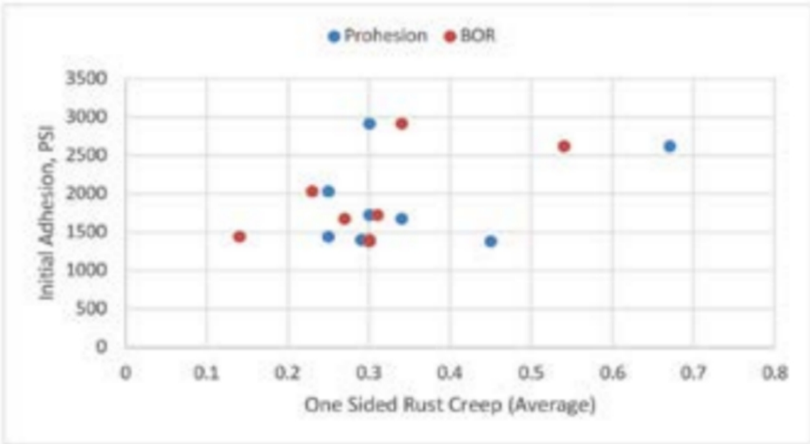

Fig 2: Adhesion versus rust creep for eight lining systems tested.

Table 3: Rust Creep Measured on Scribed Panels After 30 Weeks of Testing.

System	Exposure Condition											
	HAR (30 weeks)			DI (30 weeks)			PRO (30 weeks)			BOR (30 weeks)		
	Max Creep (in)	Rating	Rank	Max Creep (in)	Rating	Rank	Max Creep (in)	Rating	Rank	Max Creep (in)	Rating	Rank
Control (Vinyl)	0.11	Good	5	0.11	Good	4	0.43	Fair	7	0.35	Fair	8
A	0	Excel.	1	0.16	Fair	6	0.30	Fair	4	0.31	Fair	6
B	0	Excel.	1	0.25	Fair	9	0.34	Fair	6	0.27	Fair	3
C	0.63	Poor	1	0.11	Good	4	0.67	Poor	9	0.54	Poor	9
D	0	Excel.	1	0.21	Fair	8	0.30	Fair	4	0.34	Fair	7
E	0.11	Good	5	0.09	Good	3	0.25	Good	1	0.14	Good	1
F	0.16	Fair	7	0.08	Good	1	0.29	Fair	3	0.30	Fair	4
G	0.18	Fair	8	0.08	Good	1	0.45	Fair	8	0.30	Fair	4
H	0.09	Good	4	0.17	Fair	7	0.25	Good	1	0.23	Good	2

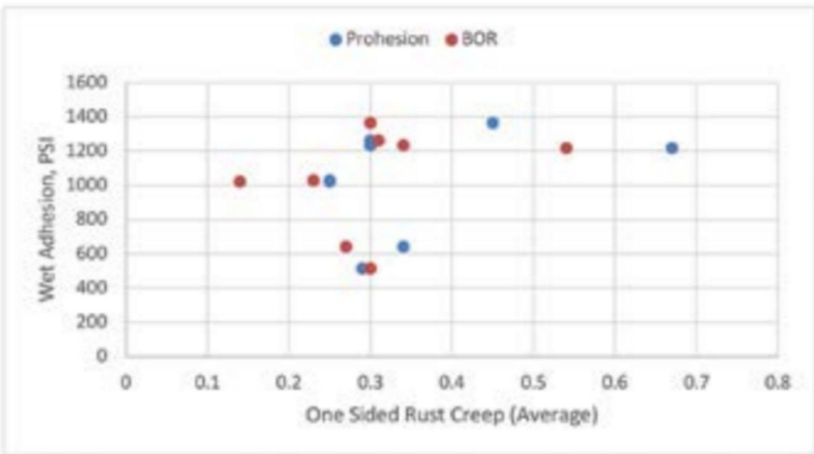

Fig. 3: Wet adhesion versus rust creep for eight lining systems tested.

at room temperature (ASTM D870).

- "PRO": Prohesion cyclic testing (based on ASTM D5894); one week alternating exposure schedule in a repeating order between UV test cabinet and salt fog machine.
- "BOR": Modified prohesion cyclic testing; one week alternating exposure schedule in a repeating order between UV test cabinet, salt fog machine, HAR immersion, salt fog machine.
- Adhesion testing: Pull-off testing performed using a manually operated, hydraulic, digital adhesion tester (ASTM D4541).
- Wet pull-off adhesion testing: Pull-off testing using a manually operated, hydraulic, digital adhesion tester (modified ASTM D4541).
- Knife adhesion testing: Knife adhesion testing on panels following at least 30 weeks in immersion (ASTM D6677).

The BOR test is a modified prohesion test intended to simulate the effects of a fluctuating immersion environment. Panels are rotated every week in the following order: QUV-FOG-HAR-FOG. Panels were scribed vertically with a rotary tool as noted in Table 2. The scribes exposed the bare substrate at approximately 2 mm in width and 3 inches in length. Panels in the PRO and BOR tests were exposed for 30 weeks (5,040 hours).

Panel evaluation proceeded following the exposure period according to ASTM D1654 (Table 3). Coatings were stripped from the panel near the scribe area to expose the underlying white metal at the interface. The "one-sided" rust creep for each panel was determined by measuring with a caliper after coating removal. For immersion samples, the maximum value was measured and reported. For cyclic testing, the full width of the rust area was measured on each panel at six predetermined locations along the scribe, averaged, adjusted for the scribe width and divided by two.

Pull-off adhesion testing was performed using a manually operated hydraulic testing unit on panels initially and after prolonged immersion in HAR for at least 30 weeks. For the wet adhesion test, the panels were removed from the Harrison's solution and dried, and dollies were glued down using an epoxy adhesive. The panel was then placed in 100-percent humidity for 24 hours while the adhesive cured prior to pull-off testing. Glue failures were not included in the test scoring, except for vinyl resin, which were all glue failures.

RESULTS AND DISCUSSION

The results of the corrosion testing are shown in Table 3 and Figure 1 (p. 11). Table 4 (p. 16) summarizes the adhesion data collected and shows the percent change between initial adhesion and wet adhesion. The corrosion performance for each product is presented in terms of rust creep as well as a subjective rating (excellent, good, fair or poor) and a numerical ranking for each exposure.

The best performing product for undercutting resistance was System E, a 100-percent-solids

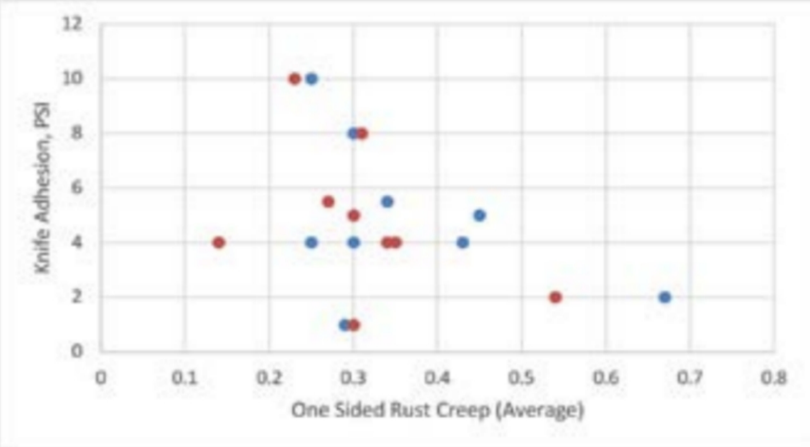

Fig. 4: Knife adhesion versus rust creep for nine lining systems tested (BOR and prohesion testing).

novolac epoxy/polyurethane hybrid material which ranked first in rust creep performance for both BOR and PRO testing with an average rust creep of 0.14 and 0.25 inches, respectively. System E also performed well in HAR and DI steady state immersion testing. The worst performing product for undercutting resistance was System C, a 100-percent-solids, high-build aromatic polyurethane which ranked last in HAR immersion, PRO and BOR testing with an average rust creep of 0.63, 0.67, and 0.54 inches, respectively. System C had the highest initial adhesion.

Figures 2 and 3 (pp. 12-13) show initial adhesion and wet adhesion versus rust creep following 30 weeks of BOR or prohesion testing. None of the figures show any correlation between adhesion and rust creep performance. Note that vinyl is not included because the pull-off testing produced glue failures in this case. It is possible that a study which controlled for coating chemistry and other factors might reveal some effects of adhesion on performance. Obviously, adhesion is a crucial component for any coating's performance, but the optimal amount of adhesion (initial or wet) remains unclear.

Likewise, the percent change in pull-off adhesion does not appear to be a strong predictor of undercutting performance. Table 4 shows that eight out of the nine coatings tested lost pull-off adhesion values when exposed to water immersion for seven months. System E was ranked best for undercutting resistance, but had a 29 percent change between dry and wet adhesion and had poor knife adhesion. On the other hand, System G changed only 1 percent between dry and wet adhesion and had fair undercutting resistance. Systems B, C, D, F and H each had significant change between dry and wet adhesion.

Knife adhesion was performed to determine the correltion with undercutting performance. Figure 4 shows knife adhesion versus rust creep performance in PRO and BOR testing. There is no obvious correlation between these two tests. It is worth considering the influences of a coating's rigidity on test performance, as ASTM scoring is highest when the coating is removed as small chips versus easily peeling off in large strips. In addition to weakening the chemical bond between coating and substrate, immersion may also alter a coating's physical properties, possibly decreasing rigidity and therefore test performance. As a result, it's possible that a significant decrease between initial and wet adhesion could translate to a coating with poor knife adhesion performance (or vice versa). However, there was no correlation between percent change in pull-off adhesion and knife adhesion. System G experienced no change between initial and wet adhesion and had only fair knife adhesion performance, whereas systems B, C, D, F and H each had significant decreases in adhesion and a knife adhesion performance ranging from poor to excellent.

As an additional point of discussion, the vinyl control has excellent longevity in field applications, but performed just fair in knife adhesion (likely due to its plasticity). While elongation data was not available for all products tested, it is suspected that ductility is an important factor due to the tendency of ductile materials to peel rather than chip during removal.

Because adhesion is shown to decrease significantly during immersion service, it is reasonable to hypothesize that high wet adhesion is correlated with good undercutting performance. However, wet adhesion test methodology warrants the following additional considerations.

- The dolly adhesive is applied to a water-saturated coating surface and may not perform as well as a saturated coating. The current study excluded glue failures from scoring.
- Water can evaporate out of the coating as the adhesive is curing, thus allowing some chemical adhesion to recover. The current study mitigated for this by allowing the glue to cure in a 100-percent humidity environment.
- Water absorption may affect a coating's mechanical properties and alter the failure mode.

For these reasons, a testing standard is needed for wet adhesion to ensure consistency.

CONCLUSIONS

This study found no correlation between any type of adhesion measurement to undercutting resistance during immersion or cyclic testing. The best-performing lining systems failed with a mix of adhesive and cohesive failure after prolonged immersion, whereas the worst performer experienced 100-percent adhesion failure to the substrate after prolonged immersion. It is important to note that rust creep is only one aspect of lining performance and other factors such as barrier performance and durability play an important role in determining longevity.

Additional work is needed to systematically study the dependence of undercutting performance on adhesion and individual mechanical properties, while controlling for other factors such as product chemistry. If adhesion is not determined to be a strong predictor of rust creep resistance, it is worth additional investigation to identify coating properties (or combinations of properties) that may be utilized instead. There is also a need to refine and standardize the methodology for performing wet adhesion testing.

ABOUT THE AUTHOR

David Tordonato is a materials engineer with the U.S. Bureau of Reclamation and a member of its Rope Access Team, which performs inspections and work on the inaccessible features of Reclamation structures. He holds B.S. and M.S. degrees in mechanical engineering from Virginia Tech and a Ph.D. in materials and metallurgical engineering from the Colorado School of Mines. He is an SPPC Protective Coatings Specialist, a NACE Coating Inspector and Cathodic Protection Technologist, and an AWS Certified Weld Inspector (CWI).

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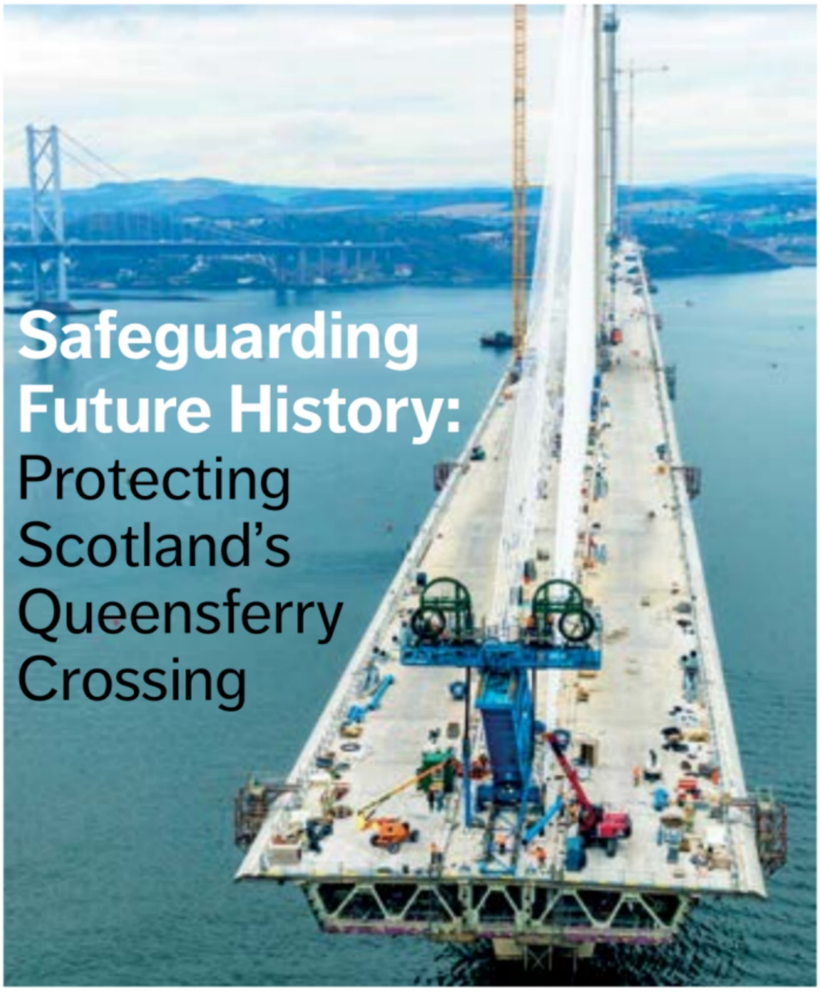
Table 4: Wet Adhesion Testing Data.

System	Dry Adhesion Average	Wet Adhesion Average	Percent Change Dry/Wet	Knife Adhesion	Degree of Undercutting HAR	Tensile Strength (psi) MFR Data
Control	870 +/- 165 100% Glue	770+/-55 100% Glue	11%	4	0.11	6,700
A	1,724 +/- 98 25/75 adh/coh	1,261 +/- 24 5/60/35 g/adh/coh	27%	8	0	8,000
B	1,677 +/- 96 100% coh	643 +/-61 100% coh	62%	5.5	0	>600*
C	2,620 +/- 246 40/60 adh/coh	1,220* 100% adh	54%	2	0.63	3800
D	2,917* 100% adh	1,233 +/- 229 100% adh	68%	4	0	13,100
E	1,446 +/- 255 100% coh	1,023 +/- 87 60/40 adh/coh	29%	4	0.11	2,080 (40% elongation)
F	1,401* 5/10/85 g/adh/coh	515 100% adh	63%	1	0.16	2,110 (70% elongation)
G	1,384* 100% coh	1,366 5/95 adh/coh	1%	5	0.18	N/A
H	2,034 +/- 261 40/20/40 g/adh/coh	1,029 +/- 166 85/15 Adh/coh	49%	10	0.09	7,600 (3.5% elongation)

** Signifies a single data point with other data points omitted due to glue failure.*

Safeguarding Future History: Protecting Scotland's Queensferry Crossing

BY ROBERT WONG, HEMPEL A/S



(Above): The Queensferry Crossing was constructed to alleviate traffic on the adjacent Forth Road Bridge. Photo courtesy of Transport Scotland.

Spanning an impressive 1.7 miles (2.7 kilometers), the new Queensferry Crossing in eastern Scotland is the longest three-tower, cable-stayed bridge in the world, according to *Guinness World Records*. Opened in 2017, it crosses the Firth of Forth alongside the historic Forth Road Bridge. Constructed to alleviate traffic on the older bridge, which was built in 1964, the design of the new Queensferry structure was specifically calculated to provide extra strength and stiffness, making it both beautiful to the eye and durable enough to withstand an expected 120-year lifespan.

Much of the 35,000 tons of steel used in the Queensferry Crossing was manufactured in China and then transported to the construction site by sea. Thus, two key factors played a role when specifying the right coating solutions. First, it was imperative that the coating system chosen would be tough enough to withstand the impact and exposure during the 4,785-mile (7,700-kilometer) journey from China to Scotland. Second, it had to be robust enough to protect the bridge from the unforgiving Scottish climate and coastal conditions for future years. With steady precipitation and sometimes subfreezing temperatures along the coastal setting, high-quality coating solutions were critical to the success of the project.

The coating manufacturer, who had provided coatings on four of the world's ten largest cable-stayed bridges at that point, recommended an assortment of coating solutions for the Queensferry Crossing to tackle the

The newly built Queensferry Crossing spans the Firth of Forth in eastern Scotland, connecting the cities of Edinburgh and Fife. Photos courtesy of Hempel A/S unless otherwise specified.

The new bridge was constructed with both concrete and steel, which was shop-coated with heavy-duty coatings by the steel manufacturer in China before being shipped to the construction site.

corrosive challenges of each individual section.

Portions of the bridge feature structural trapezoidal box girders, designed with a number of hollow void spaces for inspectors, maintenance staff and other personnel to enter and navigate the interior sections of the bridge. Therefore, coating sytems for both interior and exterior surfaces needed to be considered. For the exterior that is exposed to the harsh elements, a weather-resistant zinc-rich epoxy primer was chosen, offering cathodic protection against local mechanical damage; followed by a two-component polyamide adduct-cured epoxy, which combines a relatively high-volume solids content with a short drying time; and a two-component semi-gloss acrylic polyurethane topcoat, offering a high-build finish coat for protection of structural steel in corrosive environments.

The three-towered cable-stayed bridge spans 1.7 miles, making it the longest of its type in the world.

For the interior steel, the two-component polyamide adduct-cured epoxy was selected. For the connection joints, a two-component, solvent-borne, self-curing, inorganic zinc silicate was specified to provide the necessary abrasion and slip resistance.

The Queensferry Crossing's coating system is expected to protect the broidge for decades of the structure's projected 120-year lifespan.

Coatings were shop-applied at the steel fabrication shop after the steel was abrasive blast-cleaned to Sa 2 ½, "Very Thorough Blast Cleaning" (ISO 8501). After shipping and construction, field touch-up was performed to repair weld zones and any mechanical damage due to transport. Over 600,000 liters of coatings were supplied for this project. The success of this high-profile project hinged on more than just the choice of coatings and included the close collaboration and coordination between the main contractor, the steel supplier and fabrication contractor and the coatings manufacturer at different locations around the world. The manufacturer's representative worked with both the steel fabricator and the main contractor's advisory engineering team in the U.K. during the specification process to ensure the coating systems were up to the task.

The manufacturer's technical service team provided on-site supervision at both the steelyard in China and the construction site in the U.K., watching over the application process to ensure the coatings were applied accurately and efficiently.

The iconic Queensferry Crossing was officially opened in the summer of 2017, with all parties involved confident in reliable corrosion protection. A projected 24 million vehicles will utilize the Crossing each year, while its sister Forth Road Bridge will continue to serve cyclists, pedestrians and buses.

ABOUT THE AUTHOR

Robert Wong is group director, head of Protective and Industrial with Hempel A/S. He has over 30 years of experience in the coatings industry.

Clubphoto / Getty Images

HULL FOULING PROTECTION COATINGS AND THE TRANSFER OF INVASIVE AQUATIC SPECIES

BY *JPCL* STAFF

Fouling (or more accurately, biofouling) of vessels occurs naturally in the marine environment. This fouling accumulates over time and if not controlled, can negatively impact a vessel's performance. Biofouling consists of microscopic organisms (slime) and plant (algae) and animal (barnacles) species. As well as impacting a vessel's efficiency, fouling can also be transported from one geographic area to another, and in some cases, where they are not normally found.

The transport of goods by sea is a very environmentally friendly and cost-effective method compared to alternatives. However, it can bring with it problems through accidental transport of non-indigenous marine aquatic species. Transport of these species can be due to marine fouling on the hulls of poorly protected vessels, or from ballast water taken on in one geographical area and discharged at another, as occurred with the zebra mussel infestation of the Great Lakes in North America in the 1980s. Similarly, the increase in popularity of cruise ships — with passengers and tour operators becoming more adventurous — and the increased access to arctic shipping routes means that no areas of the globe are off-limits, including very environmentally sensitive marine areas such as Antarctica, which is now more regularly visited.

As an aside, a further threat to local ecology could come from the release of the toxic biocides used in hull coatings to prevent fouling, although this has been largely reduced thanks to regulation by the International Maritime Organization (IMO), as in 2008, the International Convention on the Control of Harmful Antifouling Systems on Ships (AFS Convention) came into force. This specifically prohibited the use of harmful organotin compounds in antifouling paints used on ships' hulls and established a mechanism to prevent the future use of other potentially harmful substances in antifouling systems. In addition, the coating industry has responded by introducing technologies with "low" or "no" biocide content.

The threat from ballast water discharge has now been addressed by the BWT convention (2004), which requires that most vessels be equipped with a ballast water treatment system to ensure that any discharged water is free from marine organisms. For ships' hulls, there is still much to do, particularly as recent concerns have been raised that, in fact, more invasive aquatic species (IAS) are being transported on ships' hulls than via ballast water discharge.

HULL COATINGS

Hull coatings are designed to prevent or reduce marine fouling of the ship's hull to lessen drag on the vessel, increase fuel efficiency and provide a secondary effect of reducing excessive emissions. IMO recognizes the need for operational efficiencies and requires that vessels have a Ship Energy Efficiency Management plan in place, for which development guidelines were published in 2016. This then raised the question of the performance of the different types of hull coatings and their effectiveness in controlling marine fouling (and thus reducing emissions).

There are basically two main generic types of high-performance hull coatings: "self-polishing" biocide-containing coatings; and "low surface energy," or more accurately, fouling-release coatings, which reduce the ability of fouling to adhere to a vessel and promote its removal when a ship is underway.

The self-polishing systems are primarily based on acrylate technology, either metal (copper or zinc acrylate) or silyl acrylate, with copper oxide as the main biocide (often supplemented by organic co-biocides). Recently, a biocide-free polishing coating has also become available from one global supplier.

The fouling-release coatings can also be generally split into two technologies: "soft" products based on silicone elastomers, or fluoropolymers and "hard" products, based on different resin technologies, such as glass-flake vinyl ester or solvent-free epoxy. In addition, hydrophilic (water-loving) polymers are being used to create a low-friction, very smooth and slippery surface upon immersion. These proprietary coatings react with seawater to produce a surface active zone that allows the constant release of the optimum amount of biocide over time to prevent fouling settlement. These premium hull coatings are available from all the major suppliers, albeit with slight differences between each product in terms of application and performance claims. The correct choice of hull coating for a given vessel depends on a number of parameters, including vessel type, service speed, trading pattern and whether a new-build or maintenance.

GLOBAL REGULATION

The United Nations Convention on the Law of the Sea (UNCLOS) provides a global framework by requiring that countries work to prevent or reduce pollution of the marine environment, including the accidental introduction of harmful or alien species to a specific area of the marine environment. To this end, IMO has been leading the global effort. In 2011 they published Biofouling Guidelines for the control and management of ships' biofouling to minimize the transfer of IAS. They identify the types of performance measures that could assist in evaluating the different recommendations in the guidelines.

In addition, in Europe, the European Union's Marine Strategy Framework Directive (MSFD) requires that Member States take measures to achieve or maintain "good environmental status" by 2020. Also, "Target 5" of the European Biodiversity Strategy states that by 2020, invasive alien species and their transport mechanisms be identified and prioritized, and that the transport of the highest-risk species is managed to prevent the introduction of new IAS.

ASSESSING BIOFOULING ON VESSELS

The type and amount of biofouling on a vessel's hull depends on many factors, including the performance of the specific underwater hull coating and where the vessel has been trading. The IMO guidelines for biofouling have been in place for seven years for vessels greater than 300 gross tons and the IMO Member States and local government authorities are required to regularly review and update their requirements and enforcement regimes. However, the State of California and New Zealand have published stricter specific requirements for their respective jurisdictions.

Praiwun / Getty Images

In California, beginning January 1 of this year, requirements became effective after a vessel's first regularly scheduled dry-dock or after delivery, and include the development and maintenance of a biofouling management plan and mandatory biofouling management of the vessel's wetted surfaces. From May 1 of this year, New Zealand requires that all commercial and recreational vessels arriving there meet the clean-hull threshold, as defined in the Craft Risk Management Standard (CRMS) which is based on the IMO guidelines. For most vessels, the definition of a clean hull means no biofouling apart from a slime layer, but fast turnaround vessels only visiting designated ports (places of first arrival) are permitted a limited amount of biofouling.

Port authorities can now refuse entry into port if a vessel is found to have severe fouling of the hull, but to visually check every vessel would be very time-consuming and expensive and cause delay. Thus, an alternative approach has been proposed that identifies the risk of a vessel being fouled on arrival to the port limits (or before then) based on its previous trading pattern and the biofouling management plan used to control fouling. The system allows port authorities to prioritize high-risk vessels before they arrive at the port, while potentially also allowing vessel owners to manage their fouling risk. This could save a considerable amount of time and be a more efficient use of the limited resources available for physical inspection, limiting inspections to only high-risk vessels. The threshold of high risk can be tailored to a specific port or could be set for all ports in a country's territorial waters. A web-based system that can automatically assess the risk of a vessel being fouled is under development[1]. In this case, the risk is assessed in real time using the fouling challenge based on a vessel's operational profile of the vessel and its specific fouling-control measures. A ship's operational profile is a combination of speed, activity and position, and is derived from ship movement data. Automatic identification systems (AIS) are designed to automatically provide information about a ship to other ships, and to coastal authorities. Regulation 19 of SOLAS Chapter V, "Carriage requirements for shipborne navigational systems and equipment" sets out navigational equipment to be carried on board ships according to ship type, and in 2000, IMO adopted a new requirement for all ships to carry automatic identification systems[2].

Thus, such a web-based system requires multiple large data sets to allow a risk assessment to be carried out. Examples of the types of data sets include the following.

- Operational profile.
  - Location and local environment factors.
  - Vessel speed.
  - Vessel activity.
  - Number of port calls.
- Fouling control.
  - Type of hull coating.
  - Application date.
  - In-service hull cleaning.
  - Any extended static periods.

Using this data would allow the cumulative assessment of the risk of fouling due to the particular vessel's operation and biofouling management control.

At the end of the day, despite which fouling-risk-assessment method a port authority uses to control the potential threat of IAS, it comes down to basically which type of hull coating has been used and when it was applied. The premium generic coating systems mentioned previously have claimed performance lifetimes varying from 36-to-60 months, and now even 90 months of protecting a hull from major fouling, but how effective these coatings are at preventing the transport of fouling over time has yet to be fully understood.

In addition to preventing IAS transport, hull coatings should not adversely affect the local ecosystem, and as such, increasing research is being carried out into non-biocide-containing systems. These include surfaces that mimic nature, for example, sharkskin, and a bio-repellent additive to prevent hard fouling. More recently, a novel fouling solution based on UV-LED technology has been proposed. This innovation will integrate UV-light-emitting diodes into a hull coating that will allow UV light to be emitted from the surface to prevent biofouling accumulation on the surface of the protected area.

CONCLUSION

Currently, no matter which hull coating technology is used, ships could have some degree of biofouling, even those recently cleaned or those that have had a new application of an antifouling coating system, as the biofouling process can begin within the first few hours of a ship's immersion into water. Implementing good practices to control and manage this biofouling can greatly reduce the risk of the transfer of invasive aquatic species.

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POWER TO THE TOWER

BY MARK B. DROMGOOL, KTA-TATOR AUSTRALIA PTY LTD

Fig. 1: Often, elevated lattice structures require a series of orange and white bands to provide aviation obstruction marking. Rather than just applying the requisite colors, using protective coatings can extend the life of the HDG and thus the lifespan of the structure. Photos courtesy of the author.

In a world where electronic communications and power transmission is expected to always be available, the reliability of the infrastructure underpinning these networks is often taken for granted by the millions of users. Outages due to failure or loss of service of elevated towers, masts and poles from corrosion in the western world is considered intolerable. Many of these elevated structures are made from bolted, lattice-type carbon steel — usually hot-dip galvanized (HDG) — and because in many countries, especially Australia, a large portion of the population lives and works close to the coastal fringe of the continent, a good number of these assets are located and serve in quite corrosive environments. How can facility owners of elevated lattice structures lengthen the life of these structures, lower the risk of section loss or diminished structural functionality and concurrently lower the cost per year of service? This article outlines some of the measures that have been employed by several leading Australian asset owners who are responsible for a portfolio of vulnerable structures in severe marine environments.

The continent of Australia encompasses a very broad range of service and exposure environments ranging from extremely hot and dry desert in the Outback, to sub-Antarctic rocky islands in the Roaring 40s latitudes, to full tropical and severe marine north of the Tropic of Capricorn.

The tropical coastal country and offshore islands around the Queensland, Northern Territory and Western Australia shorelines and islands around Tasmania are examples of some of the more aggressive and corrosive marine-influenced environments that have to be dealt with, and there are literally many thousands of elevated towers, masts and poles supporting power, telecommunications and broadcasting to service the scattered populations in these locations.

History has shown that simple galvanized steel lattice structures in severely corrosive environments can have a very short lifespan. Because these assets are mostly in remote and rugged locations, maintenance and inspections are expensive and sporadic, and with monsoonal cyclones being frequent through the wet season in northern latitudes, the risk of damage or collapse, even with a small amount of steel section loss due to corrosion, is ever-present.

This means that there is a strong incentive to build a population of longer-lasting and more durable structures whenever a new tower or mast is required or when an old structure has moved past an acceptable level of structural risk or functionality and thus needs replacement. The argument the author has made to these facility owners is that they can only reduce the pending maintenance workload and costs for future years by progressively transitioning to assets with longer durability and less frequent maintenance demands by changing what they have been doing over decades past, thereby taking them off (or at least significantly postponing) the future typical maintenance and degradation curve.

A number of new broadcasting structures have been designed, fabricated and erected on several offshore islands and along the coast of Far North Queensland over the past four or five years. In most cases, these were replacement towers or masts for existing aged and badly corroded items that were deemed as unsuitable for refurbishment or were required to support different or additional antennae or services not hitherto provided that would be beyond the structural limits of the existing and degraded structure to carry. In all cases, the service exposure was deemed to be at least Corrosion Category C5-M (Very High Marine) or CX (Extreme) as defined in AS/NZS 2312:2014[1]. This degree of exposure is estimated to have corrosion rates for steel of between 80 and 200 microns per year (for C5-M) or 200 to 700 microns per year (for CX). In the aforesaid standard, Corrosion Category CX is intended to be representative of sites on or close to the shoreline with breaking surf or similar. The incumbent structures had survived for about 12-to-15 years before reaching a stage where they were assessed as being too risky to retain and/or too expensive to maintain.

The underlying philosophy adopted was that if an extension of life of, say, five years was potentially achievable, this would equate to around a 35-to-40-percent increase in service life. If a further 10 years of life could be realized, this would double these figures, meaning that there was a very strong motivation and a high potential reward for the test program.

ELEMENTS THAT MAKE A DIFFERENCE

The following list of actions were selected as being theoretically contributory to an extended lifespan for these structures.

- Attention paid in the design of the elevated structure so that ponding zones and contaminant collection areas are avoided, crevices are minimized and paintability is maximized.
- Consideration paid in both the design and field installation of concrete footings and guy-wire anchor points to minimize corrosion and aid longevity.
- Use of a dedicated high-performance wire rope protective compound on galvanized strand-type guy wires.
- Care with selection of steel grades, especially those aspects relating to metallurgy, due to its influence on galvanizing.
- A very high quality of structural steel fabrication.
- Careful and diligent attention to metal finishing, i.e., removing sharp edges and weld spatter, countersinking drilled or punched holes.
- Performing a full abrasive blast of the fabricated steelwork before hot-dip galvanizing.
- Performing the HDG in a manner that optimizes the film build and integrity of the galvanizing.
- Proper and appropriate sweep abrasive blasting of the HDG to provide a suitable substrate for coating application.
- The use of masking stickers over all structural holes prior to painting so as to ensure full electrical conductivity across the bolted structure after erection.
- Application in controlled conditions by an experienced coating application contractor of the specified high-performance protective coating system (either tower paint vinyl or epoxy and polyurethane) over the HDG.
- Careful packing of coated members to ensure damage during transport and erection is minimized.
- Diligent touch-up of any coating damage after erection.
- Use of an elastomeric sealant film patch over unused bolt holes in the structure and on antenna or feeder mounting bars.

It would be immediately clear that there is an additional cost to undertaking some or all of these measures on a new elevated tower or mast, as opposed to supplying and erecting a standard galvanized structure in the manner that was done in the past. Estimates prepared by the network operator have shown that the price premium is of the order of 50-to-60 percent. However, the potential payback by a much-reduced maintenance intensity through the asset's service life — especially for structures in very remote locations — and a longer durability and lower risk of loss or damage were also brought into consideration and were accepted as representing value for money.

DESIGNING FOR DURABILITY

All aspects of the design of the structures were reconsidered. The traditional way of making elevated lattice structures is to use predominantly angle steel sections. For the most part, these are more than satisfactory. However, if the design loads are more than can be tolerated by a single angle of an appropriate size, it used to be common to use two angle members, often back-to-back. For main tower legs under high-compression loads, using two angles in a toe-to-toe or star configuration was also common. This might make construction and erection quicker, but these arrangements can be problematic for durability and maintenance.

Some of the initiatives explored or adopted included using stronger members, and specifically, those that have balanced structural properties and thus have a greater ability to be protected and maintained. Angle steel is particularly vulnerable in this regard because it has a different moment of inertia in different axes. If employed in simple tension mode, this matters little; but many tower angle members are in compression. Think of the main legs of masts and towers and the lower plane truss sections of power tower conductor support cross arms. A bias in the moment of inertia can mean a propensity to flex or distort about a predictable neutral axis, which in a compression member can be decidedly problematic.

The following is a good example. A 75-mm-by-75-mm-by-6-mm (3-inch-by-3-inch-by-¼-inch) angle has the same effective mass of steel per unit of length as a

Fig. 2: The structural complexity of an erected lattice mast makes through-life recoating or maintenance very difficult and expensive. It is preferred to engineer in the desired durability by the use of sound galvanizing and compatible high-performance coatings applied prior to assembly and erection.

75-mm-by-75-mm-by-3-mm wall-thickness rolled hollow section (RHS), yet the latter has exactly the same moment of inertia about both principal axes that the angle member doesn't have. This makes the RHS a much superior compression member because it has no preference for the plane of distortion. There are other differences, too. Each angle has three sharp corners, which is where the paint film will inevitably draw thin. Structural RHS sections have a comfortable radius to their corners. On angles, the corners are also the locus of the first signs of breakdown due to corrosion. This makes the application of the initial preconstruction coating film and any through-life maintenance coating much easier to apply on the RHS member than on the angle. A similar argument can be made for the structural and maintenance properties of circular tubular or solid round bar members, on which there are effectively no corners. This logic can be applied to many other sections right across the structure to lower the surface area, avoid or minimize sharp section corners and improve the structural properties of the entire structure.

Another less obvious difference relates to sheltered faces. In many orientations, angle members will have one or more of their four faces in a sheltered or veranda orientation. These are the zones where rainwater doesn't have ready access, meaning that corrosives such as airborne salt or industrial ionic materials do not get reduced or removed during rainfall events. These areas are almost always where corrosion starts and advances fastest.

On some of the new towers and masts constructed and erected in recent years, careful attention to the design and constructability has resulted in cleaner and less complex sections, members and assemblies. These have proven not only easier to initially protect with long-term coating systems but will also be much easier to maintain in the decades ahead.

Another design element that has been explored but not yet implemented on a major structure (although some smaller masts have been manufactured) is to make a series of fully welded mast sections, either square or triangular in plan section, using solid round bar for the main leg and all bracing members. Solid round bar might be somewhat heavier than tubular hollow members of the same outside diameter (OD) but it is almost always much cheaper per metric ton. The concept is to eliminate the bolted joints and crevices except where successive sections bolt together, say every three or four meters. Round members and welded joints are cleaner and easier to paint or repaint; they avoid crevices and pockets; the surfaces self-clean better during rainfall events (avoiding veranda corrosion); and the extra section thickness of solid bar members means a huge increase in corrosion allowance. The design means that bolts are only used on mating flange joints between adjacent sections, reducing the bolt count by close to 90 percent. Further considerations with this design allow for potential attachment points on each welded mast section that could support a jury rig in the event that an individual section of the mast ever needed to be changed out in decades ahead if it was damaged or corroded.

FOOTINGS AND GUY ANCHOR POINTS

It is easy to concentrate only on the steel and metalwork of an elevated structure, but corrosion and the longevity of the tower or mast footings is equally important. A number of initiatives have been explored, adopted or trialed by some asset owners. In corrosive situations, properly coating the steel reinforcing by the use of HDG coatings or FBE (fusion-bonded epoxy) is strongly recommended, as is making sure that the amount of concrete cover is not compromised during placement of the reinforcing into the formwork and the pouring of the concrete. No embedded reinforcing should be closer to the formwork than about 75 mm and the compaction and subsequent finishing of the concrete should be very carefully undertaken to minimize porosity or other compromises.

It is often required to have emerging steel as well as totally embedded reinforcing. This includes guy-wire attachments and guy-tensioning anchor points. It is preferred to have these items coated with at least 250-to-300 microns (10-to-12 mils) of a suitable high-build epoxy which runs at least from about 50 mm (2 inches) above the concrete to around 200 mm (8 inches) below. Small details such as making sure there is a positive fall on the concrete upper surface away from emerging steel and perhaps coating across the transition between steel and concrete will also improve the free drainage of moisture and thus the longevity of these footings.

On a number of sites where high groundwater levels are expected, measures have been taken to step the height of the footings to well above ground level, thus minimizing the chance that soil or sand buildup over time will swamp the footing; and additionally, to apply a penetrating silane treatment so that oxygen, moisture and ionic materials such as chloride or sodium don't penetrate. Parallel measures on a few sites have had proprietary tape wrappings, such as petrolatum grease and cotton fiber cloth, to encapsulate the emerging steel, the tension turnbuckles and the swaged ends on the guy wires.

Guyed broadcasting and telecommunication constructions such as masts allow for a much physically smaller structure with much less steel than a free-standing tower of the same height. These are often preferred in areas where cyclonic or monsoonal winds are possible. The smaller cross section of a mast results in a commensurately lower collective wind load than a self-supporting tower, and because guys can only act in tension, their engineering performance is optimized. However, stranded galvanized wire guys are very susceptible to corrosion because of the relatively light weight of the zinc coating on each wire strand (typically around 400 gm/m^2), plus the proliferation of crevices in spiral multi-strand guys are a trap for corrosives. One of the author's major telecommunications clients has been very active in using a dedicated high-performance wire lubricant and corrosion protection compounds on their guys, applied before erection of the structure. These compounds are mixtures of low-slump, low-tack greases, lanolin and waxes with a viscosity that minimizes creep or flow down an inclined guy through countless temperature cycles and also doesn't act as a capture mechanism for dirt, dust and other detritus, some of which can increase the time-of-wetness and thus advance the corrosion. Doing a midterm guy changeover on a remote elevated structure is a very large, complex and expensive task indeed — in some instances the extent of corrosion and section loss on guys has been the time-determining step for the rest of the structure's life. This has meant that a mast with some considerable residual structural life has had its service term truncated before it was due, simply because the guys had to be replaced — the easiest and best economic outcome being to build and erect a totally new structure. This demonstrates the benefit of trying to get matched durabilities out of the critical components of a complex structure.

STEEL GRADES FOR GALVANIZING

The metallurgy of the steel can have a huge difference on how it galvanizes. Carbon steel — unlike many grades of stainless steel and aluminum where the compositional aspects such as alloying materials, additives and heat treatments are very strictly specified — can vary quite extensively around the world. Carbon steel (often called mild steel) consists of mostly iron with a small amount of carbon.

Fig. 3: Galvanized steel has a finite life and in severe environments, rapid depletion of the zinc layers can occur. Methods to increase the film build of the initial HDG can have substantial rewards, especially if augmented with soundly engineered organic coatings.

However, there are usually a few other elements or compounds present in very small quantities, some by design, others by them being introduced or retained as contaminants, which can cause over thickness of the HDG.

The increased thickness of the HDG caused by these more reactive steels can be problematic. Flaking or disbondment of the entire galvanized layer can occur, either due to physical handling or more commonly during the sweep blasting prior to overcoating. The increased brittleness comes mainly from the significantly higher thickness and hardness of the *zeta* layer. A light sweep blast that would normally just slightly roughen the outer surface of the *eta* layer, will in some situations cause disbondment of spots or stripes of the entire galvanized layers.

The author has often observed that very high zinc thickness is found on lighter members such as 50-by-50-mm and 60-by-60-mm angles. A likely cause is a mixture of lighter and heavier tower members galvanized at the same time by wiring these items to the same dipping jig. The galvanizing time (the immersion time under the molten zinc in the kettle) is determined by the time it takes to "cook" the heavier sections. It is thus too easy for the lighter members to "overcook" and if the rate of zinc/iron alloy layers doesn't plateau, excessive zinc build can occur and the HDG coatings can become fragile.

FABRICATION AND METAL FINISHING

Some very simple steps taken at the time of fabrication can make quite a difference in durability. This includes the careful radiusing of cut or guillotined edges and the light countersinking of drilled or punched holes. This is not intended to imply that the standard edges of rolled structural members need grinding, but anything that has power-cut, flame-cut, guillotined or other corners or edges should be addressed. Anything that minimizes the tendency for the protective coating to draw thin on edges, which is usually the locus for the start of breakdown and corrosion, has to be advantageous to durability. Metal finishing also includes careful attention to welding. Weld spatter, porosity and undercut all cause stress to the coating and will in some measure compromise the long-term durability.

There is another potential issue with galvanizing welded items, particularly if they have been fabricated using manual inert gas (MIG) welding processes. MIG weld metal is metallurgically different from the adjacent parent metal and under the influence of HDG it can cause quite different growth rates of the zinc/iron alloy layers and even exhibit porosity and some apparent undercut because of the disproportionate rate of growth of the zinc/iron alloy layers as compared to the adjacent parent metal.

PREPARATION FOR HDG

With most commercial galvanizing of carbon steel, the usual preparation involves acid pickling to remove the mill scale and other oxides, and to chemically clean the fabricated item so the molten zinc in combination with the flux can properly react with the steel. With this pickling treatment on the usual steel grades, a build of zinc of around 80-to-110 microns (around 3.1-to-4.3 mils) typically results during the HDG process. In AS/NZS 2312.2:2014[2] the zinc-thickness requirement for Grade HDG600 is a minimum of 85 microns (3.3 mils) for steel greater than 6 mm in section thickness. This equates to a zinc loading of 600 gm/m^2 (about 2 oz/ft^2). One of the durability-enhancing measures on structures for severe environments is to increase the film build of the zinc/iron and pure zinc layers and one method to reliably achieve this is by abrasive blasting the steel before galvanizing. A sharp, angular surface profile slightly increases the reactive area of the steel which has been shown to increase the zinc film build. AS/NZS 2312.2 also has a Grade HDG900, which nominates a minimum zinc thickness of 125 microns (5 mils), equating to a zinc loading of 900 gm/m^2 (3 oz/ft^2) and this is usually specified as the treatment requirement for these structures.

There can be some resistance by some galvanizers to abrasive blast prior to the HDG process and on a recent tower project fabricated and galvanized in Asia, no blasting facilities were said to be available, so the galvanizer proposed he would achieve the 125 microns by other means, most likely by using a longer kettle immersion time. The specified minimum zinc thickness was achieved, however, a greater range of thicknesses resulted that proved to be problematic. Lighter-weight angle members proved to have very high zinc thicknesses (over 200 microns [8 mils]) as compared to heavier items such as the main leg angles. In this case it was predicted that the kettle immersion (dipping) time was excessive and when sweep blasting the light angle members, some quite extensive damage to the HDG was observed even though the blasting was done using a very fine mineral abrasive and a greater standoff distance. This proved that the more reactive steel and the longer dipping time combined to produce a fragile HDG product that didn't have the fortitude or ductility to remain a functional base for the subsequent organic coating system. The lesson learned from this was that the steel metallurgy is very important and the step of abrasive blasting prior to the HDG process must be insisted on, as it can help to partly normalize the steel to minimize the consequences of the adverse metallurgy.

APPLICATION OF THE COATING SYSTEM

A duplex coating system is, by definition, a coating or protective system applied over HDG. If properly designed and carefully applied, the organic coating system has the ability to provide a synergistic and complimentary level of durability and protection to the steel substrate. However, it can definitely work the other way if care in system design and application isn't maintained.

The coating system that has been most commonly applied to these trial structures over the past four or five years has been a two- or three-coat solution vinyl system. Vinyls might be considered in some circles to be an older technology and obsolete material but they most certainly are not. Some may say that Australia is still lucky that it doesn't have formal VOC regulations that have been the main driver to retire solid workhorse coatings like chlorinated rubber and vinyl in some overseas markets.

Like chlorinated rubber, solution vinyls are non-convertible coatings, in this case made from vinyl resin dissolved into an aromatic solvent. One feature of these products is that they are very limited in their volume solids percentage — they were typically 35 to 40 percent but more recent formulations are up to around 50 percent — thus they contain quite a large amount of solvent while in their liquid form. Vinyls dry by simple loss of solvent, meaning a great deal of film-build shrinkage from wet to dry. Where these products excel is their amazingly low moisture vapor transmission (MVT) rate. As a guide, around 120 microns (4.7 mils) of vinyl has about the same MVT rate as 400 microns (16 mils) of epoxy.

Elevated towers used for telecommunications and broadcasting in particular — and the same most likely applies to power transmission structures — usually need to have full electrical continuity across the structure, i.e., zero electrical resistance across all bolted joints. With a galvanized-only tower, this comes as a matter of course. By painting the tower members prior to erection, there is a risk that the double thickness of paint in between any bolted joint could act as an insulator. For some structures including masts used for amplitude modulated (AM) radio, the entire mast acts as an antenna. To do this it sits on an insulated pin base and each guy wire has series-mounted insulators. To address this electrical continuity problem, circular self-adhesive stickers were developed to mask every structural bolt hole on both sides of each member right across the tower, applied after sweep blasting and prior to painting. The stickers are sized so as to be slightly larger than a structural washer used under each tower bolt. Applying and later removing these stickers is a tedious job but is vitally necessary to ensure full electrical continuity, which occurs through each and every bolt.

Being solvent evaporative films, vinyls are somewhat slower drying than convertible coatings such as epoxies, which can mean logistic implications in the coating shops (for instance, they can't usually be turned over to coat the other side of members too soon or the drying film can be damaged). Nonetheless, once dry and after commissioned into service, their durability and long-term performance is legendary, so the time through the coating shop must just be accepted. For elevated towers, the coating product employed is a specific formulation of vinyl using some micaceous iron oxide (MIO) pigmentation called tower paint vinyl supplied as a primer and then a colored finish. The MIO doesn't predominate in the color; it is employed to aid in the non-slip performance for climbing painters field-applying coating to aged galvanized towers — its original purpose. In locations where the tower needs obstruction marking to comply with Civil Aviation Safety Authority (CASA), the topcoats are applied in alternating horizontal bands of orange and white. Other towers not requiring obstruction marking are typically coated in light gray or a light green so as to blend with the adjacent foliage or background.

The towers in a recent trial were coated over the past three or four years. Care was taken with handling, packing and transport so as to minimize damage. After erection of the structures, any damage was spot painted and the zones where the masking stickers were applied, and any associated bolts were similarly cleaned and painted. One beneficial but not foreseen consequence of the vinyl system has been the tendency for the coating to squeeze slightly from between bolted joints under the compression load of the torqued bolts. Being a thermoplastic coating means that this occurrence is perhaps not startling, but its real benefit was that the potential for a crevice joint around every contact or faying surface is very deftly protected with the creep out of the paint film.

Normally, the author doesn't advocate field-painting bolts, certainly not once they have been exposed or if they are showing signs of corrosion. However, as the masked zones from around the bolt-hole stickers needed to have their protection reinstated, it made sense to concurrently patch paint the bolts.

With many towers it is common that they have some excess bolt holes. This might not be right across the structure but items such as cable feeder runways and antenna mounting bars often have to allow for future hardware settings, such as alignment of antennae or cable additions later in life. To prevent corrosion developing in these unused holes, a simple system adopted was to fill them with a high-viscosity, anticorrosive compound usually employed inside plastic cap plugs over bolts on offshore oil and gas platforms and then patch over these holes with a self-adhesive flexible polymeric patch.

Early Life Feedback

The towers involved in this trial have been inspected several times since they were commissioned. Even though it is early in their expected service lives, the initial site findings are outstanding. The tower paint vinyl coating is proving to be an excellent performer. It is not baked hard as one would expect from a catalyzed epoxy coating of the same age, which means it is not on a pathway where it is likely to become brittle as it ages in the decades ahead. On lattice structures with lots of bolts and relatively sharp edges to the myriad steel sections, brittleness that develops with lengthening exposure of the coating would be where other generic materials would be vulnerable. In the alternate, it is not glossy and slippery where risk could arise for tower climbers. On several structures that the author climbed when the weather was decidedly suboptimal, specifically drizzling with rain, it was comforting to climb on wet steel, confident that slipping was unlikely.

The author's confidence in vinyl coating systems for these types of structures stems from the excellent performance witnessed over many decades.

SUMMARY

This real-world trial shows the prospect of achieving a significant increase in durability, a dramatic decrease in through-life maintenance efforts, and a lower cost per year of service by adopting a series of coordinated and interrelated initiatives. It is not just about the performance potential of the tower paint vinyl coating system; it's how all of the other measures can work synergistically to increase service life and lower risk. All parts of the world have or are installing power, telecommunications and broadcasting networks. The default configuration is lattice, piece-small, galvanized, bolted towers and masts, all of which will have a finite life. A quantum leap in durability and its fellow travelers of risk and maintenance intensity is achievable.

ABOUT THE AUTHOR

Mark Dromgool is the managing director of KTA-Tator Australia Pty Ltd, based in Melbourne, Australia. He has been active in the protective coatings industry for over 40 years. Dromgool's experience includes 10 years as a coating application contractor and about seven working for two of the largest protective coating suppliers in Australia and New Zealand. In 1994, he formed KTA-Tator Australia as a protective coating engineering, inspection and consulting company.

A long-standing member of SSPC and NACE, Dromgool is former president of the Blast Cleaning and Coating Association (BCCA) of NSW. He has written and published many papers on coatings and linings and has lectured widely at local and international conferences. In 1996 and again in 2007, he was the recipient of the *JPCL* Editor's Award for papers entitled "Maximizing the Life of Tank Linings," and "Epoxy Linings — Solvent-Free But Not Problem-Free," respectively. In 2006, Dromgool was awarded the John Hartley Award for Excellence by the BCCA of NSW.

Dromgool has qualifications as a mechanical engineer; is an ACA-certified Coatings Inspector; a NACE-accredited Protective Coating Specialist; an SSPC-accredited Protective Coatings Specialist and a NACE-certified Coating Inspector – Level 3.

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STATISTICAL AND TECHNICAL EVALUATION OF RAPID DFT MEASUREMENT TECHNOLOGIES

BY JEFF O'DELL, WAYNE MCGAULLEY AND EVAN PARSON, VISION POINT SYSTEMS, INC.; AND JOHN WEGAND, PAUL SLEBODNICK AND JIMMY TAGERT, U.S. NAVAL RESEARCH LABORATORY

Dry film thickness (DFT) is an important parameter of coating application and both low and high DFTs can contribute to premature coating failures. Typically, DFTs are measured in accordance with SSPC-PA 2, "Procedure for Determining Conformance to Dry Coating Thickness Requirements" or other similar standards as dictated by the specification[1]. Based on the requirements established in these standards, a minimum number of DFT measurements are made due to time constraints placed on the inspectors as well as limitations of the devices used to conduct the inspections. The ability of an inspector to capture larger DFT data sets within the defined parameters may result in lower statistical variation of the data and higher confidence in the results. This should lead to fewer coating failures resulting from improper DFTs, thereby reducing maintenance costs.

Recent advancements in technology have produced DFT probes capable of achieving a higher rate of DFT data collection than previous devices. However, current standards do not cover the implementation of these new probes. The National Shipbuilding Research Program's Surface Preparation and Coatings Panel (NSRP SP-3) recently conducted a study to demonstrate this new technology[2]. The project's final report detailed a comparison between a conventional Type II DFT gauge, a fixed-calibration Type II gauge and a conventional Type II DFT gauge with scanning probe capabilities. According to the NSRP report, calculating DFT using the scanning instrument was more than three times faster than the current method used by Naval Sea Systems Command (NAVSEA) as outlined in the SSPC-PA 2 procedure noted within NAVSEA Standard Item (NSI) 009-32. The report also claimed that scanning technology would reduce the labor cost of a DFT inspection by almost 70 percent and that scanning technology has a lower standard deviation than current DFT readings taken using the procedures outlined in SSPC-PA 2.

This article reports on a study conducted to investigate a proposed alternative to the SSPC-PA 2 method, that of rapid scanning procedures to measure DFT using handheld electronic devices, and to verify whether any losses in precision, and thus fidelity, of the data resulted from the use of the new scanning method. Findings from the Naval Research Laboratory were used to develop recommendations for the use of DFT scanning probe technology in the field.

OBJECTIVE

Large surface area samples were coated with U.S. Navy coatings in a laboratory setting and characterized using traditional spot-measurement DFT gauges and new gauges equipped with scanning probe technology. Sampling was based on established standards, such as SSPC-PA 2, as well as more robust plans that included larger data sets to improve statistical significance. Laboratory findings were used to develop recommendations for the use of DFT scanning probe technology in the field. The technology was also demonstrated in various spaces onboard U.S. Navy surface ships to ensure the viability of the new DFT scanning technique protocol. Laboratory testing was conducted at the Naval Research Laboratory.

EXPERIMENTAL PROCEDURE

Eight 4-foot-square-by-3/16-inch steel panels were prepared using a NAVSEA-approved epoxy, applied manually. Coating thicknesses of 5, 10, 20 and 40 mils were used for the test program. A coating thickness of 5 mils was applied to each test specimen prior to the start of DFT measurements. Upon completion of testing with the appropriate test method on coatings at 5 mils, an additional coating thickness of 5 mils was added to each test specimen, and the DFT measurements were repeated. This process was repeated with the addition of 10 and then 20 mils until a coating thickness of 40 mils was achieved. In addition, three 6-by-12-by-¼-inch drawdown test sample panels coated with various coatings in accordance with ASTM D823, "Standard Practices for Producing Films of Uniform Thickness of Paint, Coatings and Related Products on Test Panels" were used for a DFT probe wear analysis[3].

Conventional Probe DFT Measurements

DFT measurements taken using a conventional Type II gauge were done in accordance with SSPC-PA 2. Prior to DFT measurements, gauge calibration was verified through a two-point adjustment in accordance with Appendix 8 of SSPC-PA 2. For the 4-foot-by-4-foot-by-3/16-inch flat surface test panels, five DFT spot measurements were taken from random spaces throughout the test specimen. In accordance with SSPC-PA 2, spot DFT measurements were composed of the average of three gauge readings within a 1.5-inch-diameter circle. DFT measurements were no less than ½-inch from any surface edge and 1 inch from any other spot measurements (Fig. 1).

Scanning Probe DFT Measurements

Scanning probe DFT measurements are taken by running a specialized probe tip across

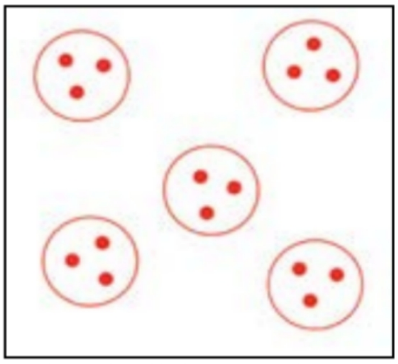


Fig. 1: Conventional DFT measurement pattern. Figures courtesy of the authors.

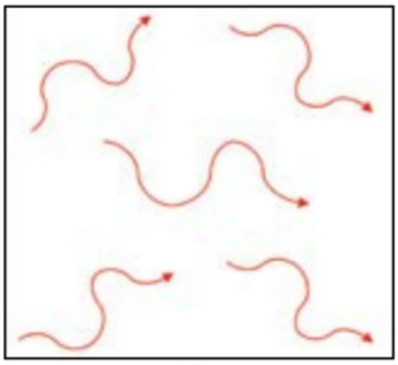


Fig. 2: Scanning probe DFT measurement pattern on a large steel panel.

the surface of the coated panel and measuring numerous DFT readings without breaking contact with the coated surface. DFT measurements were done in a manner similar to SSPC-PA 2. As before, gauge calibration was verified in accordance with Appendix 8 of SSPC-PA 2. Five randomly spaced DFT scan measurements were taken and measurements were collected in batch sizes of 12, 24, 36 and 48. Again, no measurements were taken less than 1/2 inch from any surface edge and 1 inch from any other scan measurements (Fig. 2).

STATISTICAL MEASUREMENT METHODOLOGY

DFT data collected using the traditional SSPC-PA 2 method and the rapid scanning method were statistically analyzed by examining each test specimen's sample mean DFT, 95.0 percent and 99.9 percent individual confidence intervals for each mean, and margins of error for each method from the 99.9 percent individual confidence intervals.

SSPC-PA 2 Method

The SSPC-PA 2 method uses five spot measurements that are themselves the averages of three measurements taken at that specific spot.

It is important to note that the SSPC-PA 2 method indicates that the three measurements that comprise any of the five spot measurements are fundamentally measurements of the same quantity (location); that is to say, they are not independent measurements. This is acknowledged implicitly in the technique due to the overall average being calculated as the average of the five spot measurements, as opposed to the average of the 15 total readings. While these quantities are mathematically equivalent, the sample size is different. The SSPC-PA 2 technique implicitly uses a sample size of independent observations (the five spots).

Scanning Method

The scanning method operates by moving a probe across the panel surface, taking measurements at fixed batch intervals as the probe is moved. The batch size is set by the operator and is the total number of measurements taken.

DATA ANALYSIS

Laboratory Steel Panel Results

DFT data collected from the coated steel panels was analyzed at a statistical level to provide fundamental comparisons of the SSPC-PA 2 method to the rapid DFT gauges at varying batch sizes. An analysis of variance indicated significant interaction effects between the method of data collection (random batches of size 12, 24, 36 and 48; the full panel scans and the SSPC-PA 2 method) and the experimental panel at all approximate thickness levels except for the approximately 40-mil thickness panels. Since a significant interaction effect was present, the data was separated into per-panel subsets rather than combining all data together, and each panel's sample mean DFT was calculated for each of the different analysis methods.

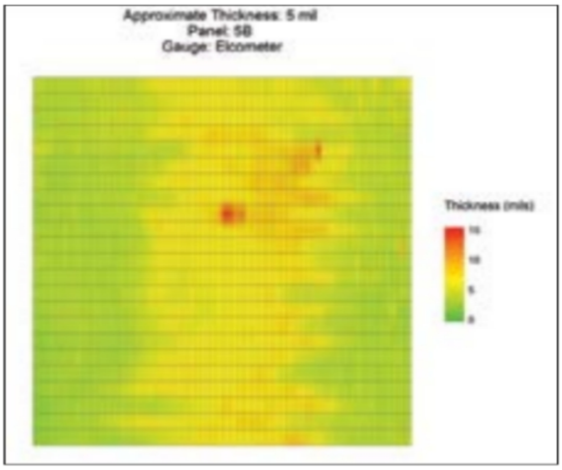
Panel DFT Confidence Intervals

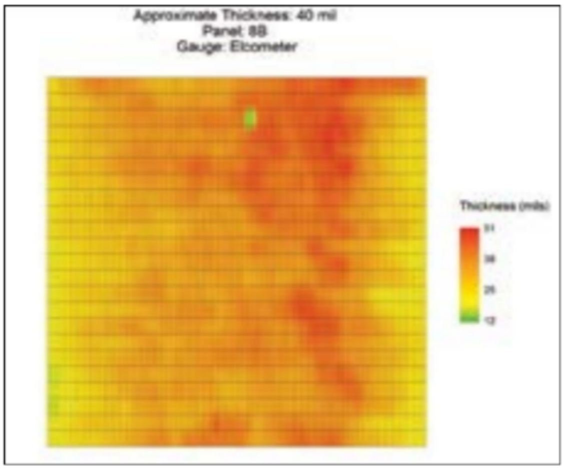
To supplement the sample-mean calculation and provide an estimate of the precision of the techniques, confidence intervals were calculated for each of the means. The confidence interval can be considered a range of plausible values within which the true underlying population mean might lie. Since a comparison of various gauge manufacturers was not the intent of the analysis, the number of simultaneous hypotheses being tested per approximate thickness level was 48 (six methods per panel, with eight panels total).

The intervals for the full panel scans are the most precise, given that they are composed of 2,300 observations per panel (Figs. 3 and 4, p. 34). As can be seen in Figure 5 (p. 34), the intervals for each analysis method tend to overlap. It should be noted that the rapid scans, even with the small batch size of 12, provide a greatly increased amount of precision to the mean estimation over the SSPC-PA 2 method due to the rapid scans much larger sample size of 60 (five batches of 12 each) compared to the SSPC-PA 2 method's sample size of five. This can be seen visually by the large width of the SSPC-PA 2 method's confidence interval compared to the width of the batch size of 12. As an additional note, while the batch sizes of 24, 36 and 48 all offer increased precision over the batch size of 12, there is an element of diminishing return where the decreases in the width of the confidence interval are of a smaller magnitude than the difference between the SSPC-PA 2 method and the rapid scanning method.

PANEL DFT MARGINS OF ERROR

To provide a quick comparison of the uncertainty around a result, margins of error were also calculated for each of the methods from the 99.9-percent-confidence intervals. These margins of error give an indication as to the uncertainty around each calculated sample mean. For example, if the sample mean was 10 mils and the margin of error was ±4 mils with a 99.9-percent-confidence for the individual interval, the





Figs. 3 and 4: (Left) 5-mil full panel scan consisting of 2,300 DFT measurements and (right) 40-mil full panel scan consisting of 2,300 DFT measurements.

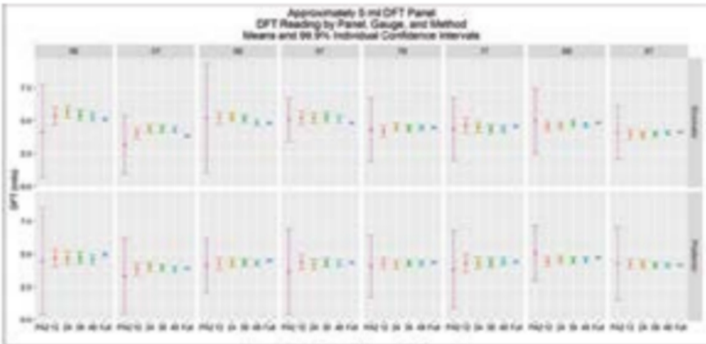


Fig. 5: Panel 5-mil 99.9 percent confidence intervals.

panel's true mean DFT would be estimated as somewhere between 6 mils and 14 mils.

As can be seen in Figure 6 (p. 35), the data once again indicate the difference between the SSPC-PA 2 method and the rapid DFT gauges in terms of margin of error. The margins of error for the SSPC-PA 2 method are substantially larger than those from the rapid DFT gauges, demonstrating that there is a large amount of uncertainty in the SSPC-PA 2 measurements, particularly when compared to those measurements taken from the rapid-scanning DFT gauges.

BOOTSTRAP SIMULATION

Assigning a Measure of Accuracy to the Sample Measurement

DFT data was collected on two sample panels: a 4-by-6-inch panel with an approximate DFT of 20 mils and a 6-by-12-inch panel with an approximate DFT of 3 mils. Measurements were collected on both panels using the SSPC-PA 2 method (taking three readings at five different spots, repeated for five batches per panel;) as well as the rapid scanning technology (taking 10 measurements per batch, repeated for five batches per panel). Across all batches, these results were used to compute estimates of the population mean DFT, μ, and the standard deviations, δ, for both the SSPC-PA 2 and scanning methods. After these quantities were estimated, bootstrap simulations of the techniques were performed under the assumption of normality to estimate the variation around the computed sample means (the standard errors).

RESULTS

Visually, the precision of the simulation results can be seen by examining a plot of 100 bootstrap trials with estimates, and 95 percent confidence intervals, for the mean using the calculations for the SSPC-PA 2 method, the scanning method with a batch size of 10 and the scanning method with a batch size of 25, as seen in Figure 7 (p. 36). The intervals become narrower as the batch size increases, indicating more precise estimations of the sample mean from the scanning technology in comparison to the SSPC-PA 2 method. The dispersion around the sample mean, and thus the precision, can also be seen visually in histograms and density plots of the distribution generated from a bootstrap sample of size 10,000 (Figs. 8 and 9, p. 36).

Finally, from the bootstrap estimates, the average size of the interval around the estimate of the mean was computed for the three different scenarios. The findings are summarized in Table 1 (p. 36). Bootstrap simulation estimates indicate that on average, the 95 percent confidence intervals around the estimated sample means were ±14.43 percent using the SSPC-PA 2 method, ±10.51 percent using the scanning method with a batch size of 10, and ±6.18 percent using the scanning method with a batch size of 25. In other words, for the bootstrap sample, the scanning method represents a 27-percent decrease in interval size from the SSPC-PA 2 method with a batch size of 10 and a 57-percent decrease in interval size from the SSPC-PA 2 method with a batch size of 25. Consequently, the scanning method represents an estimated average increase in precision of 37 percent over the SSPC-PA 2 method with a batch size

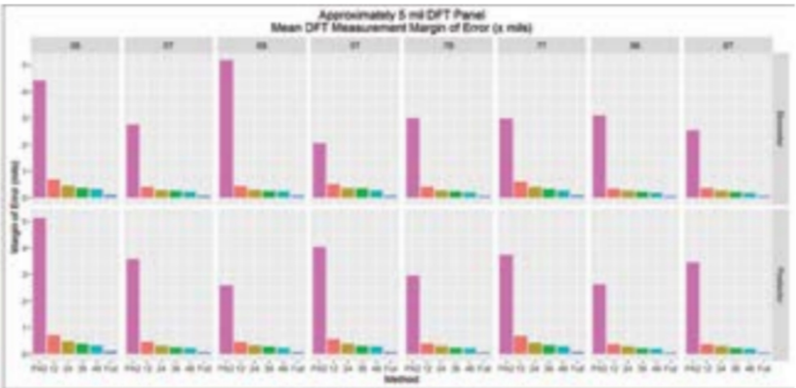


Fig. 6: Panel 5-mil mean DFT margins of error.

of 10 and an average increase in precision of 133 percent with a batch size of 25. These simulations were repeated with the data from the approximately 20-mil panel and indicated even larger increases in precision (48- and 70-percent reductions in interval size from the SSPC-PA 2 method and 93- and 229-percent increases in precision with batch sizes of 10 and 25, respectively).

It should be noted that these simulations were designed to provide preliminary estimates of the precision of each method. A check of the bootstrap simulations using collected data from large panels was then performed using fully-coated 4-square-foot steel panels with varying coating thicknesses.

DFT SCANNING TECHNIQUE VERIFICATION OF ACCURACY

The scanning probe wear test was conducted in order to understand the effects of probe wear on gauge accuracy and precision during the DFT scanning process. A scanning DFT gauge with a disposable probe cap was mounted above a coated 6-by-12-by-3/16-inch steel test specimen and a motor was used to move the scanning probe over the various coated specimens in a pattern that mimics the DFT scanning technique. Three coatings of various roughness were chosen: an epoxy polyamide coating to represent a smooth coating surface and an epoxy polyamide zinc-rich primer to represent a coating with intermediate surface roughness. In order to create an extremely rough coating surface, an alumina aggregate was added to an epoxy polyamide coating designed to mimic a worst-case field scenario for the DFT scanning technique. Prior to DFT data collection and before each test specimen assessment, the scanning DFT gauge calibration was verified through a two-point adjustment in accordance with Appendix 8 of SSPC-PA 2.

Twenty simulations of the probe wear test were run for each disposable DFT scanning probe cap. Each simulation of the probe wear test collected 10 batches of DFT measurements and each DFT scanning batch consisted of 255 DFT measurements. The same verification of calibration conducted at the beginning of each probe wear test was used for all 20 simulations in order to see a progression of probe wear. For each simulation, a total of 2,550 DFT measurements were taken continuously over a coated surface equating to 50.98 ft.^{2} (4.74 m^2). A total of 51,000 DFT measurements were taken with each disposable DFT scanning probe, equating to a total linear distance of 1,019.6 feet (310.8 meters). The disposable scanning probe caps were analyzed with microscopic and vertical scanning interferometer imagery before and after wear testing. DFT data collected during probe wear testing was also analyzed for statistical trends in order to understand the effects of the DFT scanning process on gauge accuracy and precision.

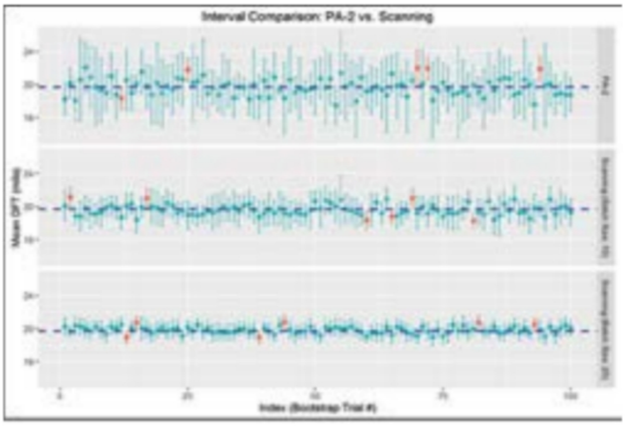
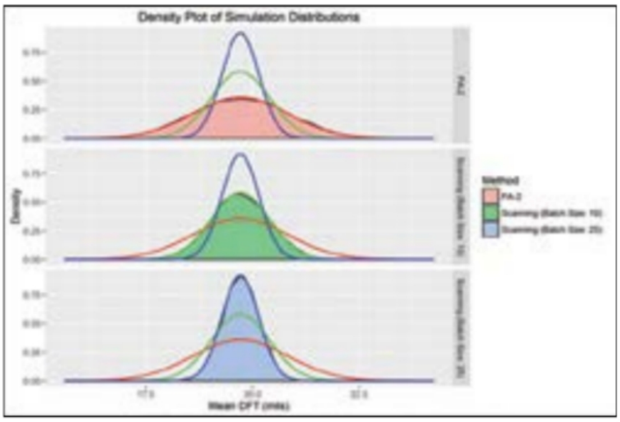
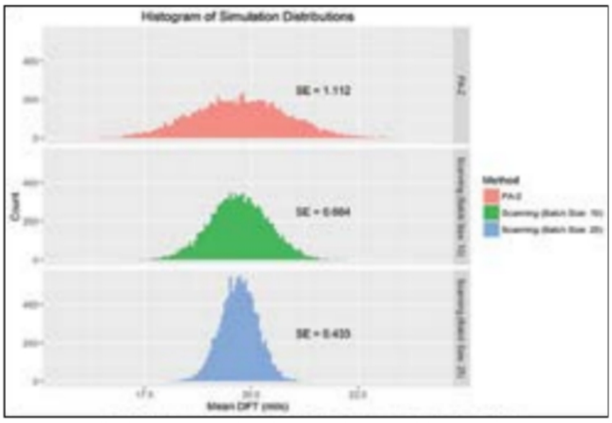


Fig. 7: Conventional versus scanning interval comparison (bootstrap estimates of size 100).





Figs. 8 and 9: (Left) Histogram of simulation distributions and (right) density plots of simulation distributions (both bootstrap estimates of size 10,000).

Table 1: Average Interval Size Around the Estimated Mean.

Method	Interval Size Around Mean
SSPC-PA 2	±14.43%
Scanning (Batch Size 10)	±10.51%
Scanning (Batch Size 25)	±6.18%

**Bootstrap estimates of size 10,000.*

DATA ANALYSIS

Statistical data suggests that greater precision of DFT measurements can be obtained using the scanning method over the traditional SSPC-PA 2 method. Increases in DFT precision were noted during statistical simulations, indicating a greater level of DFT measurement precision during rapid DFT scanning methods. Increases in confidence intervals and decreases in margins of error were also noted during laboratory testing, indicating greater increases in precision during rapid scanning operations. However, due to mechanical friction, great care must be taken during the scanning process to diminish the effects of probe wear on reading precision and accuracy. During the scanning process, frequent calibration verification of the DFT instrument is paramount to DFT measurement accuracy and precision.

PROBE WEAR ANALYSIS

In all cases, 51,000 scanning DFT readers were taken on each coated surface.

Smooth Panel Probe Wear Test

After 51,000 scanning DFT readings were taken on a steel panel coated with an epoxy polyamide primer, the disposable scanning DFT probe cap experienced minimal mechanical wear, with mean DFT values decreasing from 13.195 mils to 12.677 mils. For all 20 simulations of wear testing on the smooth panel, the standard deviation and coefficient of variation both remained fairly consistent at 0.7 mils and 5.4 percent, respectively.

A surface characterization by vertical scanning interferometer imagery of the coating revealed a relatively smooth coating surface. As can be seen in Figure 10, surface features are relatively smooth and sparsely distributed throughout a 25 mm^2 section of the test panel. An average surface feature height of 19.6 µm was observed on the 25 mm^2 section of test panel used during probe wear testing.

Further evidence of minimal mechanical wear on the disposable scanning DFT probe cap used can be seen in Figure 11 (p. 38) where the concentric rings placed on the disposable scanning DFT probe cap during manufacturing were for the most part still intact

INTERMEDIATE ROUGHNESS PANEL PROBE WEAR TEST

With the epoxy polyamide zinc-rich primer, the disposable scanning DFT probe cap experienced moderate mechanical wear with mean DFT values decreasing from 11.686 mils to 9.683 mils. For all 20 batches of wear testing, the standard deviation and coefficient of variation both remained fairly consistent at 0.5 mils and 4.7 percent, respectively.

A surface characterization, as before, revealed a relatively jagged coating of intermediate surface roughness. As can be seen in Figure 12 (p. 38), surface features are relatively jagged and abundantly distributed throughout a 25 mm² section of the test panel. An average surface feature height of 18.3 µm was also observed on the 25 mm² section of the test panel used during probe wear testing. The evidence of this moderate mechanical wear on the disposable scanning DFT probe tip used can again be seen from the concentric rings placed on the disposable probe tip during manufacturing, which had been completely worn off of a 2 mm diameter circle located at the center of the disposable probe cap (Fig. 13, p. 38). The 2-mm-diameter circle located at the center of the disposable probe cap is where the actual probe makes contact with the disposable probe cap during the collection of scanning DFT measurements. Linear gouges in the concentric rings were also seen sparsely distributed on the disposable probe cap at the completion of wear testing.

ROUGH PANEL PROBE WEAR TEST

In the case of the steel panel coated with an alumina aggregated epoxy, the disposable scanning DFT probe cap experienced severe mechanical wear with mean DFT values decreasing from 25.265 mils to 16.831 mils. The standard deviation increased from 3.029 mils to 3.514 mils and the coefficient of variation increased from 12.0 percent to 20.9 percent.

The surface features were relatively jagged and moderately distributed throughout a 25 mm² section of the test panel. An average surface feature height of 55.6 µm was also observed on the 25 mm² section of test panel used during probe wear testing.

As before, the evidence of severe mechanical wear on the disposable scanning DFT probe cap used was seen in the concentric rings placed during manufacturing that were completely worn off and a 1-mm-diameter hole developed at the center of the disposable probe cap.

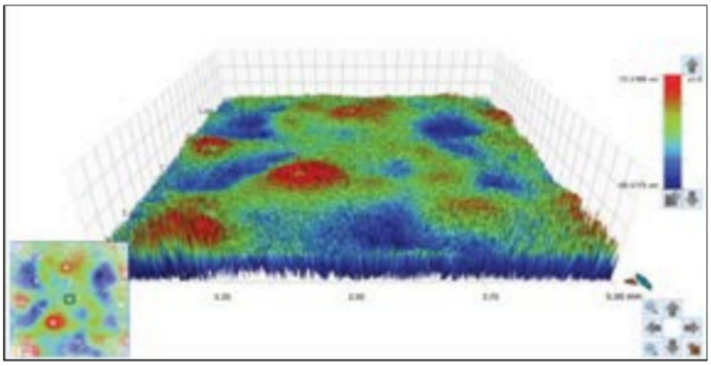


Fig. 10: Smooth panel surface profile.

CONCLUSIONS

Statistical data suggests that greater precision of DFT measurements can be obtained using the scanning method over the traditional SSPC-PA 2 method. Increases in DFT precision were noted during statistical simulations, indicating a greater level of DFT measurement precision during rapid DFT scanning methods. Also, rapid DFT scanning technology enables an operator to collect a larger number of measurements in a shorter time frame than does the SSPC-PA 2 method, validating results obtained in the NSRP SP-3 report. As a result of the increased number of observations collected, better estimates of the sample mean were obtained through increased precision. Statistical data suggests the increase in precision of rapid

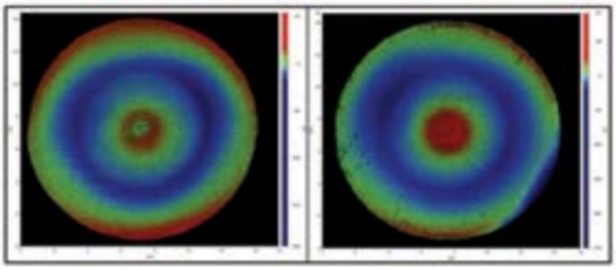


Fig. 11: Smooth probe VSI imagery before probe wear (left) and after probe wear (right).

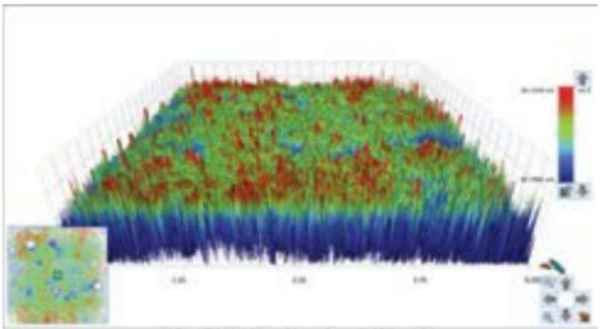


Fig. 12: Intermediate roughness panel surface profile.

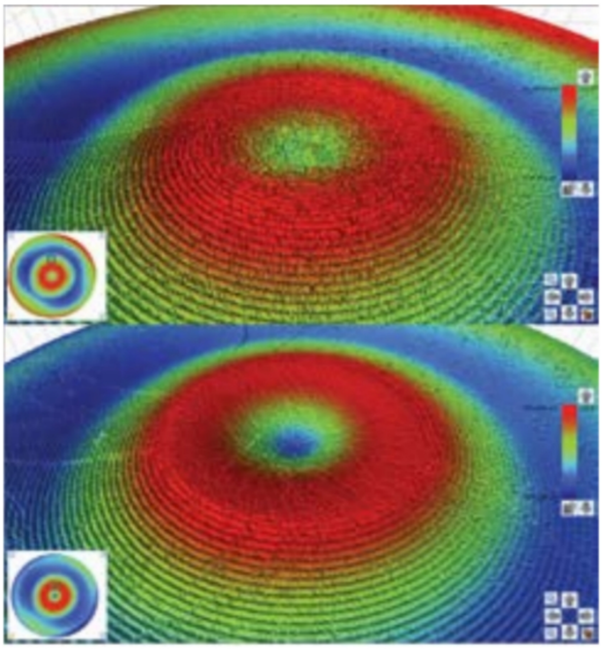


Fig. 13: Intermediate probe tip VSI imagery before probe wear (top) and after probe wear (bottom).

scanning DFT measurements over traditional SSPC-PA 2 methods can be substantial.

For bootstrap simulations, the results indicated a substantial increase in estimated precision utilizing the rapid scanning method. Bootstrap simulations estimated average increases in DFT precision ranging from 37-to-133 percent with scanning batch sizes of 10 and 25, respectively. Increases in DFT precision were also validated by data collected in the laboratory.

The increase in precision can be attributed to the rapid scan's much larger sample size of 60 (five batches of size, 12 each) in comparison to the SSPC-PA 2 method's sample size of five. This can be seen by visually comparing the width of the SSPC-PA 2 method's confidence interval to that of the batch size of 12 intervals. While batch sizes of 24, 36 and 48 all offered increased precision over a batch size of 12, there is an element of diminishing return.

The SSPC-PA 2 method's margin of error is substantially larger than those of the rapid DFT scanning method, indicating there is a large amount of uncertainty in the SSPC-PA 2 measurement method in comparison to the rapid DFT scanning method. Although scanning DFT measurements provide more precise readings than traditional SSPC-PA 2 methods, special attention must be taken to ensure the accuracy and precision of scanning DFT measurements due to the effects of probe wear created by mechanical friction.

Probe wear test results indicated that degradation of probe tips during DFT scanning operations can have significant effects on the accuracy and precision of scanning DFT measurements. Depending upon the type of coating measured, the severity of drift in accuracy and precision of scanning DFT measurements ranged from minimal on smooth surfaces to severe on rough surfaces. The mean DFT scanning values taken with the same instrument calibration verification over a rough coating surface decreased approximately 10 mils during probe wear testing. The large standard deviations of the rough coating DFT measurements can be attributed to the differential surface feature heights created by the alumina aggregate in the epoxy polyamide coating. For the smooth and intermediate roughness surfaces, the mean DFT scanning values decreased approximately 0.5 mils and 2 mils, respectively, during probe wear testing. Due to probe wear created by mechanical friction during the scanning process, DFT gauge calibration verification is a key component of the DFT scanning process.

RECOMMENDATIONS

The authors recommend implementing scanning DFT measurements into SSPC-PA 2 and NSI 009-32. Increases in precision of DFT measurements can be achieved with the implementation of rapid scanning techniques. Statistical data suggests that increases in confidence intervals and decreases in margins of error can be achieved with rapid scanning DFT techniques.

Develop and implement scanning DFT verification of a calibration schedule for greater DFT data precision. A DFT probe verification of calibration schedule will vary significantly depending upon the type of coating being measured. Rougher coating surfaces will require more frequent DFT probe verification of calibration and smoother coating surfaces will require less frequent DFT probe verification of calibration. A DFT scanning probe verification of calibration schedule should be established to limit drift in probe precision and assist DFT gauge operators in the field.

Use larger batch sizes, within reason. The larger the scanning batch size, the greater the precision of DFT measurements. A minimum batch size should be established depending upon the level of precision desired, time constraints and the risks associated with coating failure.

ABOUT THE AUTHORS

Jeff O'Dell has over 15 years of military experience as an Army forward observer and fire support officer and four years of mechanical and materials engineering experience including gas transmission and distribution systems, pipeline design, subsurface engineering and maritime engineering. O'Dell has a Bachelor of Science degree in mechanical and materials engineering from the University of Virginia. He is a NACE CP2 Cathodic Protection Technician and a NACE CP3 Cathodic Protection Technologist.

Wayne McGaulley is the director of engineering for Vision Point Systems and has over 18 years of experience in corrosion and coatings research. He began his career supporting projects for the Federal Highway Administration and the U.S. Navy performing coating inspections. Upon joining Vision Point Systems in 2005, McGaulley has supported various U.S. Navy and USMC programs investigating corrosion prevention and maintenance. He holds a Bachelor of Science degree in geo-environmental engineering and an MBA. McGaulley's efforts are focused on developing a targeted approach to corrosion and coatings research based on statistically significant design of experiments and total quality management. He is a NACE-certified SCAT Technician and certified NAVSEA Basic Paint Inspector.

Evan W. J. Parson is a data scientist and statistician at Vision Point Systems in Fairfax, Virginia. He holds a Bachelor's degree in economics and a Master's degree in data analytics engineering/statistical analytics from George Mason University. Parson has presented at MegaRust and coauthored multiple publications working in tandem with the U.S. Naval Research Laboratory.

John Wegand is a senior engineer at the U.S. Naval Research Laboratory within the Center of Corrosion Science and Engineering. Wegand has a Bachelor of Science degree in mechanical engineering from the University of Maryland and has over 30 years of experience working with the U.S. Navy executing and managing various research, development, test and evaluation technical programs. His experience ranges from development in the laboratory to implementation in the fleet, including policy and requirements development for the Naval Sea Systems Command.

Paul Slebodnick is employed by the NRL 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.

Jimmy Tagert is a materials research engineer at the Naval Research Laboratory and has over 12 years of experience working in the coatings industry. He graduated from the University of Maryland in 2004 with a Bachelor of Science degree in mechanical engineering and is a member of both the American Society of Naval Engineers and NACE International. 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.

REFERENCES

1. SSPC-PA 2, "Procedure for Determining Conformance to Dry Coating Thickness Requirements," Society for Protective Coatings, 2015.
2. Walker, Joseph. National Shipbuilding Research Program (NSRP) Surface Prep and Coatings (SP&C) Panel Project, Elcometer, Rochester Hills, 2015.
3. ASTM D823-95, "Standard Practices for Producing Films of Uniform Thickness of Paint, Varnish, and Related Products on Test Panels," American Society for Testing of Materials International, West Conshohocken, Pa., 1995. ***JPCL***

SeanPavonePhoto / Getty Images

SSPC COATINGS+ 2019: Events And Awards

The agenda for Coatings+ 2019, SSPC's rebranded annual conference and exhibition scheduled for Feb. 11 to 14, 2019 in Orlando, includes the annual SSPC awards luncheon and a number of other planned special events and activities.

All events will be held at Disney's Coronado Springs Resort unless otherwise noted. Complete information on the Coatings+ 2019 conference and exhibition is available at www.sspc2019.com.

PHIL CALVO MEMORIAL GOLF TOURNAMENT
Sunday, Feb. 10
Disney's Magnolia Golf Course

All proceeds for the second annual event in memory of the late Eagle Industries founder and former SSPC Board of Governors member Phil Calvo will go towards the SSPC Scholarship Fund. Registration is open and will be limited — sign up for a foursome today!

**Sponsorship opportunities are still available, including a Beverage Cart Sponsor for $2,500 and multiple Hole Sponsors at $500 each. For more information, please contact Nathan Wyman at wyman@sspc.org or 412-281-2331, ext. 2234.*

ANNUAL AWARDS LUNCHEON
Monday, Feb. 11, 11:30 a.m.–1:00pm

SSPC President Garry Manous, Executive Director Bill Worms and the Board of Governors will recognize the coatings industry's finest with the following honors.

The **SSPC Honorary Life Member Award** is given for extraordinary contribution and long-term activity on behalf of SSPC. To become an Honorary Life Member, an individual must be nominated by an SSPC Board member and approved by two-thirds of the Board. Only one Honorary Life Membership is awarded each year.

The **John D. Keane Award of Merit**, named after SSPC's executive director from 1957 to 1984, recognizes outstanding leadership and significant contribution to the development of the protective coatings industry and to SSPC.

The **SSPC Coatings Education Award** is given for significant development and dissemination of educational material and technical information related to protective coatings and their application.

The **SSPC Technical Achievement Award** is awarded for outstanding service, leadership and contribution to the SSPC technical committees.

The **Women in Coatings Impact Award**, established in 2014, recognizes women in the coatings industry who have helped create a positive impact on the culture of the industry.

The **President's Lecture Series Award** is presented to papers handpicked by the SSPC President and chosen for the reflection of the coatings industry and profession.

The **SSPC Outstanding Publication Award** is presented annually to the author(s) of the best technical paper or presentation from the SSPC conference or from *JPCL* that scores the highest in the following categories: clarity of expression and organization; originality of content or presentation; importance to the protective coatings industry; and effectiveness of figures or tables. SSPC selects a panel of judges from SSPC and *JPCL* to vote on the award.

The ***JPCL* Editors' Awards**, selected from a field of more than 100 eligible papers from *JPCL* articles published between May 2017 and July 2018, are voted on by *JPCL* readers and judged on significance to the industry among other criteria.

The **SSPC Outstanding Chapter Awards** are presented to an Outstanding North America Chapter and an Outstanding International Chapter each year. Chapters are evaluated on their overall operation and the creativity and quality of the events held each year.

The 13th annual **SSPC Structure Awards**, recognizing teams of contractors, designers, end users and other personnel for excellence and expertise demonstrated on industrial and commercial coatings projects, will also be presented at the luncheon. The Structure Awards categories include the William Johnson Award for a project demonstrating aesthetic merit in industrial coatings work; the E. Crone Knoy Award for commercial coatings work; the Charles G. Munger Award for a project demonstrating longevity of the original coating; the George Campbell Award for the completion of a difficult or complex industrial coatings project; the Military Coatings Award of Excellence for exceptional coatings work performed on U.S. Military ships, structures or facilities; the Eric S. Kline Award for industrial coatings work performed in a fixed shop facility; and the SSPC Coatings Industry Spirit Award for a coatings project that demonstrates extraordinary service benefitting a community or the industry at large. *JPCL* will feature award winners in a photo essay in 2019.

**At the luncheon, SSPC will also present a donation to the Adult Literacy League, which strives to build a literate community through tutoring and classes. For more information, visit www.adultliteracyleague.org.*

COATINGS+ 2019 EXHIBITORS

This list is current as of press time. For information on exhibiting, contact Nicole Lourette at lourette@sspc.org or 412-288-6023.

Abrasives Inc.
Abrasive Blasting Manufacturing Alliance (ABMA)
Air Systems International
Airtech
Alchemy Mineral
APE Companies
APPI - Technology
Arid-Dry
ARMEX
ARS Recycling Systems, LLC
Atlantic Design Inc.
Atlas Copco Power Technique
Axxiom Mfg./ Schmidt Engineered Abrasive Systems
Barton International
Bellemare Abrasives & Minerals
BlastOne International
Borchers Americas, Inc.
BrandSafway
Bullard
BYK-Gardner USA
Carboline Company
CESCO
Chemours
Clemco Industries Corp.
CoatingsPro Magazine
Cold Jet
Cortec Corporation
CSI Services
Dampney Co., Inc.
Daubner Advanced Coating Solutions
DeFelsko Corporation
Dehumidification Technologies, LP
DoD Corrosion Policy & Oversight
DESCO Manufacturing Inc.
Detroit Tarpaulin, Inc.
D.H. Charles Engineering, Inc.
DocoPro Ltd.
Doosan Portable Power
Dupont Protection Solutions
Dustnet by EMI
Eagle Industries
Easy Kleen Pressure Systems Ltd.
Elcometer
Element Materials Technology
EnTech Ind.
Ervin Industries
Fischer Technology, Inc.
Forensic Analystical Consulting Services (FACS)
Global Safety Management
GMA Garnet USA
GMA Industries
GNP Ceramics, LLC
Graco Inc.
Green Diamond Performance Materials
Greener Blast
Greenman-Pedersen Inc. (GPI)
Harsco Minerals
Hempel
Herc Rentals
Hippo Coatings Company
Hippwrap Containment
HoldTight Solutions, Inc.
HRV Conformance Verification Associates Inc.
Indian Valley Industries
InduMar
Induron Protective Coatings
Industrial Vaccuum Equipment Corp.
International Paint
IUPAT/ Finishing Trades Institute
Jetstream of Houston/FS Solutions
Jiangsu LM Mining Co., Ltd
JPCL
Kennametal
Kordata
KTA-Tator
Langtry Blast Technologies
LiUNA
MES – Rentals & Supplies
Minerals Research, Inc.
MONTI Tools
Montipower
NACE Institute
NACE International
National Equipment Corp. (NECO)
NCERCAMP @ The University of Akron
Nextec, Inc. / PreTox
Novatek Corporation
Nu Way Industrial Waste Mgmt, LLC
Olimag Sand
P & L Metalcrafts
Paul N. Gardner Co. Inc.
Pinnacle Central Co. Inc.
Polygon
Polyset
PPG Protective & Marine
Rapid Prep
Raven Lining Systems
RBW Enterprises, Inc.
Ring Power
SAFE Systems, Inc.
San-Blast-Ture
Sand Express
SciTeex Sp. z.o.o. / Mettalisation
Shanghai Xiang Rong Industrial Equipment Co. Ltd.
The Sherwin-Williams Company
Sky Climber Access Solutions
Somay Q Technologies (CBC America)
Spider by BrandSafway
Sponge-Jet
SSPC Hampton Roads Chapter
SSPC Brazil Chapter
SSPC Malaysia Chapter
SSPC Panama Chapter
SSPC Ecuador Chapter
SSPC Saudi Arabia Chapter
SSPC Peru Chapter
Sulzer Mixpac USA
Surface Prep Supply
Tank Industry Consultants
Tarps Manufacturing
Technofink, LLC
Technology Publishing Co.
Texan Stone LLC
Tinker & Rasor
Titan Tool
Tnemec
TruAbrasives by Strategic Materials
TruQC
Ultimate Linings
U.S. Minerals
Valentus Specialty Chemicals
Van Air Systems
Vector Technologies Ltd.
The Warehouse Rental & Supply
Watson Coatings Inc.
Western Technology
WIWA
ZIBO TAA Metal Technology Co., Ltd.

SSPC ON THE FRONT LINE

SSPC ANNUAL BUSINESS MEETING

Monday, Feb. 11, 2:30–3:00 p.m.

Following the Awards Luncheon, Garry Manous, Bill Worms and the Board will update SSPC members on the past year's performance and the Society's goals for the future.

WELCOME RECEPTION

Monday, Feb. 11, 5:30–7:30 p.m.
Sponsored by Carboline Company

Get your Coatings+ conference off to a good start by enjoying complimentary food and beverages — as well as life-sized "pong" games — at the Biergarten-themed opening party.

BREAKFAST KEYNOTE ADDRESS (NEW!)

"Demographics Is Human Analytics: Planning for What's Next," by Kenneth W. Gronbach
Tuesday, Feb. 12, 8:30–10:00 a.m.
Sponsored by Elcometer Inc.

Explore the fascinating realm of demography, which can seem to be both common sense and very counter-intuitive. How will the workforces change? What is the future of communications? Will big data change marketing and branding forever? What is the fate of mass media? What countries and continents are demographically positioned to excel?

FACILITY OWNERS' LUNCH AND PEER TECHNICAL DISCUSSION

Tuesday, Feb. 12, 11:30 a.m.–1:00 p.m.
Sponsored by IUPAT/FTI

As a thank-you for their commitment to SSPC standards and quality programs, facility owners are invited to a complimentary lunch followed by an open technical discussion on best practices and solutions related to industrial coatings. RSVP for this event is appreciated.

SSPC ON THE FRONT LINE

OPEN QP COMMITTEE MEETINGS

Tuesday, Feb. 12, 10:30 a.m.–12:00 p.m. (QP 5); 1:00–2:00 p.m. (QP 1); 2:00–3:00 p.m. (QP 2)

SSPC technical committees with work in progress will meet to discuss the further development of standards, guidelines and best practices. All SSPC members are encouraged to join technical committees and contribute to the consensus process.

INTERNATIONAL CHAPTER MEETINGS: LATIN AMERICA AND ASIA PACIFIC

Tuesday, Feb. 12, 2:00–3:00 p.m.

SSPC's industry influence continues to grow internationally with the establishment of a number of new chapters around the world. Stop in and listen to what SSPC chapters abroad are up to.

STUDENT POSTER SESSION

Tuesday, Feb. 12, 3:00–4:00 p.m.
Wednesday, Feb. 13, 10:00–11:00 a.m.

Aligning with SSPC's efforts to bring more young people into the organization, the Poster Session provides a forum for college students and young professionals to participate in the conference and show off some of their recent research. Prizes will be awarded to the first-, second- and third-place posters.

EXHIBIT HALL GRAND OPENING

Tuesday, Feb. 12, 5:00–8:00 p.m.
Sponsored by The Sherwin-Williams Company

Watch Garry Manous cut the ribbon to the exhibit hall and be among the first to peruse the floor and enjoy complimentary food and drinks. Be sure to take a trip around the world and visit some of SSPC's international chapters — including the Brazil, China, Hampton Roads, Ecuador, Malaysia, Panama, Peru and Saudi Arabia chapters — in aisle 1200.

**The Coatings+ 2019 Exhibit Hall is nearly sold out! At press time, only five booths remain available for purchase. Please contact Nicole Lourette at lourette@sspc.org or 412-288-6023 for information on exhibiting.*

MEGARUST MID-YEAR FOLLOW-UP

Wednesday, Feb. 13, 8:00 a.m.–12:00 p.m.

This annual follow-up meeting to the MegaRust Naval corrosion conference is designed to continue the discussions on key corrosion issues concerning the Navy, generate questions and talking points for potential presenters at the 2018 conference, and draft the conference theme and agenda. If interested in participating, please email megarust@navalengineers.org.

LUNCH WITH EXHIBITORS

Wednesday, Feb. 13, 11:30–1:00 p.m.
Sponsored by CoatingsPro Magazine

SSPC and industry sponsors will provide complimentary lunch tickets with your conference registration packet. The outdoor exhibit demonstrations area will also be open during regular exhibit hours.

PCS AND YOUNG PROFESSIONALS HAPPY HOUR

Wednesday, Feb. 13, 5:00–6:00 p.m.
Sponsored by PPG Protective & Marine Coatings

Join SSPC's Young Professionals group, as well as SSPC-certified Protective Coatings Specialists, for cocktails and conversation and to interact with both newcomers and industry veterans who are working to shape the future of the coatings industry.

CLOSING BLAST

Thursday, Feb. 14, 7:00–9:00 p.m.
Sponsored by LiUNA

Join your friends both new and old one last time before returning home. This year's reception features a Harley Davidson raffle giveaway! All attendees will receive a raffle ticket in their registration packets and must drop their tickets off at LiUNA's exhibit hall booth to enter. The winner will be chosen at random at the closing party and must be present to collect the prize.

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Coating types evaluated for wet and dry adhesion to investigate the significance of adhesion testing in modern lining systems.
See page 11.

C5-M

The corrosion category designation for very high marine as defined in AS/NZS 2312:2014, estimated to have corrosion rates for steel of between 80 and 200 microns per year.
See page 24.

2008

The year that the International Maritime Organization's International Convention on the Control of Harmful Antifouling Systems on Ships (AFS Convention) came into force.
See page 20.

2-Point Adjustment

The system used to verify gauge calibration for conventional probe DFT testing — comparing SSPC-PA 2 and scanning probe methods.
See page 32.

1.7 miles

The length of the newly constructed and coated Queensferry Crossing in eastern Scotland, the longest three-tower, cable-stayed bridge in the world.
See page 18.

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SSPC chapters from around the world — including the U.S., Brazil, Malaysia, Panama, Ecuador, Saudi Arabia and Peru — that will exhibit at SSPC Coatings+ 2019 in Orlando, Feb. 11-14.
See page 40.