PAINTSQUARE.COM

# JPCL

VOLUME 35, NUMBER 8 THE VOICE OF SSPC AUGUST 2018

The Society for Protective Coatings

Cover: © iStockphoto.com/JamesBrey

## FEATURES





PAINTSQUARE.COM
# JPCL
THE VOICE OF SSPC

## DEPARTMENTS



## ALSO THIS ISSUE



## STAFF

**Editorial:**
Editor in Chief: Pamela Simmons / *psimmons@paintsquare.com*
Managing Editor: Charles Lange / *clange@paintsquare.com*
Technical Editor: Brian Goldie / *bgoldie@jpcleurope.com*

**Contributing Editors:**
J. Peter Ault, Peter Bock, Warren Brand, Robert Ikenberry,
Alison Kaelin, Alan Kehr, Robert Kogler, E. Bud Senkowski

**Production / Circulation:**
Art Director: Peter F. Salvati / *psalvati@paintsquare.com*
Associate Art Director: Daniel Yauger / *dyauger@paintsquare.com*
Circulation Manager: JoAnn Binz / *joann@qcs1989.com*
Business Administration Manager: Nichole Altieri / *naltieri@technologypub.com*

**Ad Sales Account Representatives:**
Vice President, Group Publisher: Marian Welsh / *mwelsh@paintsquare.com*
Business Development Manager: John Lauletta / *jlauletta@paintsquare.com*
Classified and Service Directory Manager: Lauren Skrainy / *lskrainy@paintsquare.com*

**PaintSquare:**
Vice President, Operations: Andy Folmer / *afolmer@technologypub.com*
Vice President, Content: Pamela Simmons / *psimmons@technologypub.com*
Editor, PaintSquare News: Andy Mulkerin / *amulkerin@paintsquare.com*

**SSPC:**
SSPC Individual Membership: Marina Pahountis / *pahountis@sspc.org*
SSPC Corporate Membership: Nathan Wyman / *wyman@sspc.org*
Telephone: 1-877-281-7772 (toll free); 412-281-2331 (direct)

**Finance:**
Vice President, Finance: Michele Lackey / *mlackey@technologypub.com*
Accounting Manager: Andrew Thomas / *athomas@technologypub.com*
CEO: Brion D. Palmer / *bpalmer@technologypub.com*

Periodical class postage at Pittsburgh, PA and additional mailing offices. The Journal of Protective Coatings & Linings (ISSN 8755-1985) is published monthly by Technology Publishing Company in cooperation with the SSPC (877-281-7772). ©2018 by Technology Publishing. The content of JPCL represents the opinions of its authors and advertisers, and does not necessarily reflect the opinions of the publisher or the SSPC. Reproduction of the contents, either as a whole or in part, is forbidden unless permission has been obtained from the publisher. Copies of articles are available from the UMI Article Clearinghouse, University Microfilms International, 300 North Zeeb Road, box 91, Ann Arbor, MI 48106. FOR SUBSCRIPTIONS CONTACT US AT: Journal of Protective Coatings and Linings, 1501 Reedsdale St., Ste. 2008, Pittsburgh PA 15233-2341; Tel: 1-800-837-8303 (toll free); 412-431-8300 (direct); Fax: 412-431-5428; email: subscriptions@paintsquare.com. Subscription Rates: North America $90 per year; Rest of World $120 per year. Single issue $10.00. POSTMASTER: send address changes to Journal of Protective Coatings and Linings, 1501 Reedsdale St., Ste. 2008, Pittsburgh PA 15233-2341.

PAINT SQUARE

Printed in the USA / www.paintsquare.com

# SSPC Train the Trainer Update

The SSPC Train the Trainer (TTT) program is a two-day class designed to prepare a company's selected trainer(s) to effectively deliver the SSPC Trainthepainter curriculum. In this class, the trainers immerse themselves in ideas relating to conveying knowledge and adult learning, while looking into their own qualities as a trainer, practicing their skills and ultimately feeling comfortable instructing their craft workers.

Trainthepainter (TTP) itself is a very useful tool that is growing in popularity among contractors. When a company continuously strives for top-notch quality in this industry, health and safety programs, trained craft workers and real results that show at the bottom line are critical factors.

SSPC's TTP program is broken down into three modules: applicator, blaster and sprayer. Those modules include 39 hands-on workshops, in total equating to approximately 80 hours of flexible training material that contractors can mold to fit their company's needs. Additionally, these modules prepare craft workers for some of SSPC's certification level exams, specifically the C-6, C-7, C-12 and CAS exams. The training curriculum is housed entirely online, but is set up to be delivered by a trainer.

For more information on both the TTT and TTP programs and how to get started, please contact course instructor Jennifer Buzzatto at buzzatto@sspc.org.

SSPC instructor Jennifer Buzzatto (center) taught four TTT students at General Dynamics NASSCO in San Diego, Calif., from April to May 1. (L-R): Ricardo Mendoza, Daniel Robles, Buzzatto, Michael Osuna and Juan Arvallo.

From May 7 to 8, Seifert Construction in Bremen, Ohio hosted TTT for three of its employees. (L-R): Tracy Cook, Mike Vess and Chad Hutchison.

Seven individuals completed the TTT course at Puget Sound Naval Shipyard in Bremerton, Wash., from April 10 to 11. (L-R): Andrew Shelton, Charles Fletcher, Chad Young, Jared Kern, Allen Amilton, David Votroubek and Travis McGreger. Photos courtesy of SSPC.

(Above): Three companies from Sudbury, Ontario, Canada — Lopes Limited, Morin Industrial and ETC Industrial Cleaning — came together May 15 to 16 to host TTT for seven employees. (L-R): Austin McMurdy, Joe Morin, Adam Eusepi, Bob McMurdy of SSPC, Buzzatto, Ryan Smith, Andrew Freelandt, Paul Yaw and Douglas Paterson.


(Left): Three more trainers were TTT-certified at Knight Industrial in Baytown, Texas from June 21 to 22. (L-R): Bert Ocon, Adrian Sanchez, Buzzatto and Charlie Ozuna.

# Sherwin-Williams Reports Record Sales in Q2

Sales were up in the second quarter of 2018 for The Sherwin-Williams Company, which reported consolidated net sales of $4.77 billion in its quarterly report issued July 24, attributing the 27.8 percent increase to sales of the Valspar brand and a strong showing in the Performance Coatings Group.

The company also noted that consolidated net sales increased 34.5 percent to $8.47 billion in the last six months, which, in addition to Valspar sales, it attributes to higher paints sales volumes in the Americas Group, as well as selling price increases.

© iStockphoto.com / enot-poloskun

Sherwin reported a net sales increase of 7.7 percent to $2.63 billion on the quarter for the Americas (which includes the company's own paint stores), attributed to higher architectural paint sales volume and selling price increases. Segment profits also increased by $37.2 million to $569.9 million in the quarter, however, segment profit as a percent to net sales decreased in the quarter from 21.9 percent to 21.7 percent, as the margins were not enough to offset unfavorable foreign currency transaction losses and a postretirement benefit settlement, according to the company.

The Consumer Brands Group, including paint sales in other retailers, saw a net sales increase of 45 percent, to $777.7 million in the quarter, which was also attributed to Valspar sales and selling price increases, but also partially offset by lower volume sales to some retail customers, the company noted. Higher raw-material costs did take their toll on segment profit, which decreased in the quarter from 14.2 percent to 11.7 percent.

Net sales for the Performance Coatings Group, which includes protective and marine as well as industrial coatings, had the highest increase in the quarter, with a 79.9 percent increase to $1.37 billion, also attributed to both Valspar sales and selling price increases. The profit increased in the quarter to $144.2 million from $62.3 million, and the segment was the only one to see an increase of profit as a percentage of net external sales in the quarter, to 10.5 percent from 8.2 percent last year.

"All three operating segments delivered year-over-year improvement in net sales and profit," said John G. Morikis, Sherwin-Williams' chairman, president and chief executive officer.

Morikis said that the company anticipates further growth in Q3 and the rest of the year, also noting that it purchased 850,000 shares of its common stock in the six months that ended June 30.

# PPG Announces Leadership Changes

Global PPG announced two leadership changes mid-July: Diane Kappas, currently vice president, protective and marine coatings, Americas, was appointed as the vice president, Americas, automotive original equipment manufacturer coatings; and Juanjo Ardid, currently general manager of global adhesives and sealants, will become vice president, PMC, U.S. and Canada. Kappas' appointment begins September 1, while Ardid's tenure began on August 1.

Kappas joined PPG in 1986 as a res-in process engineer for the company's industrial and packaging coatings businesses, eventually moving on to work with architectural coatings, including purchasing, operations management, technical and quality control management. Throughout her 30-year tenure with PPG, she has also served as plant manager for PPG's specialty chemicals manufacturing facility at Barberton, Ohio; supply chain director for automotive replacement glass; and vice president of environment, health and safety, among other roles.

Kappas will be replacing Matt Marek, who joined PPG in 1994 in the company's acquisition of Nalco. Marek's tenure included working with automotive specialty products, industrial pretreatment and mill-applied products. Marek will be retiring.

Ardid, who joined PPG in 1992 as a finance analyst, has served through sales and marketing positions in industrial coatings and automotive OEM coatings. "In 2008, Ardid was appointed market director automotive parts and accessories decorative and in 2013 added responsibility for all Central Europe automotive OEM accounts," PPG said in a press release. Currently, Ardid serves as general manager, global adhesives and sealants, a position to which he was appointed in 2015.

## PAINTSQUARE COMMENTS


© iStockphoto.com.com / narvikk

# In Response to "NYDOT Awards Contract for $1.2M Bridge Rehab"

(PaintSquare News, July 26)

A recently rewarded rehabilitation contract from the New York Department of Transportation on a bridge in Cayuga County had PaintSquare users discussing the evolving scope of work in bridge painting specifications and how this affects project planning.

***Michael Beitzel:***

"I have noticed a trend that bridge repainting projects are now routinely including structural repairs. The subject of sequencing of the work on these projects warrants some discussion. When should structural repairs be conducted: before, during or after the cleaning and repainting operations?"

***David Kennicutt:***

"[There are] pros and cons for before or after; not sure during is feasible. Contractor scheduling usually drives the decision, but I prefer performing structural repairs in the spring before cleaning and repainting in the summer, before inclement weather sets in. Blasting may expose some additional (usually minor) repairs that can be done after repainting."

***Tom Schwerdt:***

"Michael, to me there should be two structural inspections. The first is before contract letting to include obvious items into the bid process. This should also identify areas of concern for the second inspection. The second inspection is immediately after blast/prime to review section loss, corrosion depth or other issues uncovered when the corrosion product has been removed. In my experience with bridges, it is quite uncommon to have zero additional structural repair items uncovered during the project."

***David Zuskin:***

"The U.S. Navy deals with the need to perform structural repairs in tanks, voids, chain lockers and such in conjunction with abrasive blasting a coating. Often the Navy will specify an initial blast to SSPC-SP 6/NACE No. 3, 'Commercial Blast Cleaning,' with the surface left 'broom clean.' Structural steel inspection is performed and repairs are accomplished. The surface is then blasted to an SSPC-SP-10/NACE No. 2, 'Near White Blast Cleaning' finish and coated. For the Navy, this is also beneficial in dealing with chloride contamination of steel. The chloride contaminated steel turns black (sometimes looking like mill scale) and can normally be removed with the SP 10 blast. Sometimes pressure washing is specified prior to the SP 10 blast."

## Problem Solving Forum

*paintsquare.com/psf*

### What percentage of deterioration is acceptable at a one-year warranty inspection of water tank linings before a contractor must repair the coating job?

***Larry Muzia, Exceletech Coating & Applications, LLC:***

"It is my position that no failure should be evident at one year. If the proper coating selection has been made in conjunction with proper application of the product to include surface prep and environmental controls, any evidence of failure should be many years away. Recently, I was involved in recoating a municipal potable water tank in which the existing coating had solvent entrapment from improper circulation during the application and cure of the coating. I can see this as an issue when applying coatings in a confined space."

***Trevor Neale, TF Warren Group:***

"I agree with Larry — when expertly applied [and] properly selected coatings are specified, there should not be any defects visible after 12 months unless the coating has been mechanically damaged by others."

***Erik Andreassen, CPS:***

"I agree with previous letters; however, the phrase 'What percentage is acceptable?' is wide open. The warranty would have been signed for a length of time at the contract award. Any repairs within one year would be covered, no matter what the percentage of deterioration. As Larry states, if the correct selection of lining has been both specified and applied correctly, there should be little or no damage to the system."

Photo: Pamela Simmons

# WATCHING PAINT DRY: NOT AS SIMPLE AS IT SOUNDS

BY TROY FRAEBEL, ABKAELIN, LLC

Over the last 30 years, I have been asked by numerous people, including my children, what I do for a living. After trying to explain corrosion, site condition assessments, coating system selection, specification writing, inspection and training, I default to a standard answer that I'm sure many readers have used: "I watch paint dry." While it may truly seem simple to someone outside of the protective coatings business, I have spent years helping engineers, architects and owners understand the complexities of coating systems and the need for proper planning, specifications and inspection. Let's explore some of the aspects that have changed over the last 30 years adding to the complexity of painting.

## REGULATIONS

Lead regulations are the first that come to mind and lead is still a hot topic, especially since the water pipes in Flint, Michigan hit the news. The U.S. Consumer Product Safety Commission (CPSC) banned lead in consumer products in 1978 before I entered the coatings industry[1]; however, the Occupational Safety and Health Administration (OSHA) did not finalize the lead in construction rule (29 CFR 1926.62) until 1993[2]. There was much confusion early on trying to apply OSHA 29 CFR 1910 general industry standards[3] to construction projects (field painting is considered construction) and there is still confusion about OSHA and Environmental Protection Agency (EPA) regulations — how they apply and the definition of lead-based paint. Additives can be incorporated into abrasives or applied to surfaces to chemically render the lead less leachable and thus allow for less costly hazardous disposal. Especially early on, passing a Toxicity Characteristic Leaching Procedure (TCLP) on the waste was misinterpreted to mean that the OSHA worker safety regulations did not apply, but OSHA has no de minimis (lower limit) when considering lead. Some have tried to use the Housing and Urban Development (HUD) housing limit of 5,000 ppm[4] or the CPSC's 90 ppm (originally 600 ppm)[5], but none of these apply when considering worker safety.

To complicate matters, it is not just lead that concerns OSHA and the EPA. Other heavy metals such as cadmium, chromium (especially hexavalent chromium), arsenic and beryllium can be present in old paint and new abrasives. The industry learned the hard way about polychlorinated biphenyl (PCB) plasticizers in some older paint formulations after a high-profile project had started, and asbestos was used to improve the cohesive strength of some inorganic zinc-rich primer technologies, especially in the nuclear industry. The Nuclear Regulatory Commission (NRC) also has very stringent rules about protective coatings that are beyond the scope of this article.

OSHA has also made notable changes to fall protection, banning body belts in 1998[6], and confined space regulations that affect the painting industry. In addition, the EPA, typically through the states, regulates volatile organic compounds (VOC) and hazardous air pollutants (HAPS). The Federal Architectural and Industrial Maintenance (AIM) Coatings Limits were issued in 1998 and limit the VOC content of various paints[7]; however, many states, especially California and the New England states, have varied and much lower limits.

While this discussion of regulations is by far not exhaustive, it should be clear that anyone involved in the protective coatings industry must be mindful of worker and environmental safety and the consequences of not complying, both moral and financial.

SSPC committees have generated several guides to help contractors and specifiers navigate the worker safety and environmental challenges, including the following[8].

- Guide 6: Containing Surface Preparation Debris Generated During Paint Removal Operations.
- Guide 7: Disposal of Lead-Contaminated Surface Preparation Debris.
- Guide 12: Illumination of Industrial Painting Projects.
- Guide 16: Specifying and Selecting Dust Collectors.
- Guide 17: Developing a Corporate Safety Program for Industrial Painting and Coating Contractors.
- Guide 18: Specifier's Guide for Determining Containment Class and Environmental Monitoring Strategies for Lead-Paint Removal Projects.
- Technical Update 7: Conducting Ambient Air, Soil and Water Sampling.

### SURFACE PREPARATION METHODS AND STANDARDS

The biggest change I've experienced regarding surface preparation is not saying or writing the word "sandblasting." While abrasive blast-cleaning with sand is still permitted in the United States, OSHA published — and since late 2017 is now enforcing — its final rule for silica (29 CFR 1926.1153) due to silicosis.

SSPC-SP 2, "Hand Tool Cleaning," SSPC-SP 3, "Power Tool Cleaning" and traditional abrasive blast-cleaning standards, SSPC-SP 5/NACE No. 1, "White Metal Blast Cleaning," SSPC-SP 10/NACE No. 2, "Near-White Blast Cleaning," SSPC-SP 6/NACE No. 3, "Commercial Blast Cleaning" and SSPC-SP 7/NACE No. 4, "Brush-Off Blast Cleaning" have not changed much; however, there have been some significant additions and an association name change. SSPC itself began in 1950 as the Steel Structures Painting Council, but in 1997, the name was changed to SSPC: The Society for Protective Coatings to better include protective coatings used on other substrates, especially concrete. Coincidentally, in 1997, SSPC-SP 13/NACE No. 6, "Surface Preparation of Concrete" was introduced. I have learned over the years, as I'm sure have many of you, that preparing and painting concrete is much more complicated than painting steel.

In 1995, SSPC-SP 12/NACE No. 5, "Surface Preparation and Cleaning of Steel and Other Hard Materials by High- and Ultra-High-Pressure Waterjetting Prior to Recoating" was added. It was amazing to me back then that ultra-high-pressure water (typically over 30,000 psi) could be used to remove paint from steel, but it works and continues to be used today for repainting, especially large, flat structures.

Improvements in pump technology and reliability have aided in the acceptance of this cleaning method. Water does not impart a surface profile, remove mill scale or ricochet like abrasives do, so the method has some limitations. Also, rust inhibitors are often used to hold a blast until painting, but this practice is well-accepted by most manufacturers. Coatings tolerant of flash rusting can also be used. To better align with the traditional blast-cleaning standards, SP 12 was replaced in 2012 by the following four standards.

- SSPC-SP WJ-1/NACE WJ-1, "Waterjetting to Bare Substrate."
- SSPC-SP WJ-2/NACE WJ-2, "Very Thorough Waterjetting."
- SSPC-SP WJ-3/NACE WJ-3, "Thorough Waterjetting."
- SSPC-SP WJ-4/NACE WJ-4, "Light Waterjetting."

Wet abrasive blast-cleaning was introduced to overcome the limitations of ultra-high-pressure waterjetting mentioned earlier, while still maintaining the advantages of low dust, less debris and potential chloride removal. Water collars, slurries and now vapor blast-cleaning have become very popular on repainting projects. After much discussion and committee work, the standards that follow were published in 2016, similar in ranking to the waterjetting and traditional abrasive cleaning standards. These standards were much appreciated by this specification writer.

- SSPC-SP 5 (WAB)/NACE WAB-1, "White Metal Wet Blast Cleaning."
- SSPC-SP 6 (WAB)/NACE WAB-6, "Commercial Wet Blast Cleaning."
- SSPC-SP 10 (WAB)/NACE WAB-2, "Near White Wet Blast."
- SSPC-SP 7 (WAB)/NACE WAB-4, "Brush-Off Wet Blast Cleaning."
- SSPC-SP 14 (WAB)/NACE WAB-8, "Industrial Wet Blast."

New power tools and standards have also come into play in the last 30 years. SSPC-SP 11, "Power Tool Cleaning to Bare Metal" was introduced in 1987. Per SP 11, "[a] bare metal power tool cleaned surface, when viewed without magnification, shall be free of all visible oil, grease, dust, dirt, mill scale, rust, coating, corrosion products and other foreign matter, with the exception of trace amounts of coating and corrosion products in the lower portion of pits on pitted substrates." Apart from the pit exception, SP 11 requires a cleanliness similar to that specified in SP 5 or 10, and it was the first cleanliness standard to require a minimum profile (1.0 mil).

Like SP 5, it was soon learned that SP 11 was a little too strenuous and costly for some applications, but it was not until 2002, that SSPC-SP 15, "Commercial Grade Power-Tool Cleaning" was introduced. Like SP 11, SP 15 requires a profile and allows trace amounts in the pits, but similar to SP 6, it also allows "Random staining … limited to no more than 33 percent …" New standards lead to new tools and now we have a power wire brush wheel that when used properly will actually produce a profile.

One of this specifier's most valued newer surface preparation standards was released in 2010. SSPC-SP 16, "Brush-Off Blast Cleaning of Coated and Uncoated Galvanized Steel, Stainless Steels and Non-Ferrous Metals" requires surfaces to "be free of all visible oil, grease, dirt, dust, metal oxides (corrosion products) and other foreign matter" and "have a minimum profile of 19 micrometers (0.75 mil)." SP 16 and its appendices are very useful when preparing galvanized surfaces for painting.

One change that has diminished the complexity of painting projects was the addition of the SSPC visual (VIS) guides. While the pictures in these guides cannot be enforced on a project unless specified, they are a valuable tool, especially for an untrained engineer or architect. The wet abrasive guide actually came out before the written standard.

- SSPC-VIS 1: Guide and Reference Photographs for Steel Surfaces Prepared by Dry Abrasive Blast Cleaning.
- SSPC-VIS 3: Guide and Reference Photographs for Steel Surfaces Prepared by Hand and Power Tool Cleaning.
- SSPC-VIS 4: Guide and Reference Photographs for Steel Surfaces Prepared by Waterjetting.
- SSPC-VIS 5: Guide and Reference Photographs for Steel Surfaces Prepared by Wet Abrasive Blast Cleaning.

One factor that hasn't changed: surface preparation remains the most important element in a coating system's performance.

**COATING TECHNOLOGY AND APPLICATION METHODS**

Paint materials themselves have changed, especially due to the VOC limitations mentioned previously. Low in solids and high in solvent, alkyd paints that would stick to anything have been replaced by low-VOC alkyds and waterborne paints and primers. Putting a waterborne acrylic primer direct-to-metal was almost unheard of when I started, but is now common, and waterborne epoxy and alkyd primers are now used. Key to the success of waterborne primers on any substrate is, of course, surface preparation. Water is not a good wetter, so the specifications and manufacturers' data sheets must be followed and enforced. Waterborne acrylic topcoats are actually better performers than unmodified alkyd topcoats, and waterborne polyurethane topcoats are now common.

Solution vinyl linings and coatings are no longer used except on "impacted immersion" surfaces typically found on Corps of Engineers' lock and dam structures. Old high-solids epoxy linings have been replaced with ultra-high and 100-percent solids epoxy, polyurethane and polyurea materials. As with waterborne materials, surface preparation is also critical with high-solids materials because the lack of solvent and fast set times (with some polyureas it is only seconds) limit the ability of the material to bond to an improperly prepared surface.

Many multi-component, ultra-high and 100-percent-solids materials have a limited pot life (per SSPC: "The length of time after combining two or more components of a multiple-component coating system that the mixed coating can be successfully applied") so plural-component spray equipment must be used. Plural component equipment "automatically proportions and mixes two or more components of a paint material in the process of delivering them to the spray gun … components may be mixed just before or just after the nozzle[9]." In addition to precise proportions and pressures, most materials require pre-heating for successful application. With plural-component spraying, the person working with and monitoring the pumps and heaters is often more important to the success of the application than the person who is actually spraying. Computer technology has allowed for equipment to be used at different proportions without reconfiguration and sophisticated monitoring, alarms, automatic shutdowns and record keeping capabilities are available. Some still prefer dial gauges and fixed-pump configurations, but all can benefit from SSPC's Plural Component Application for Polyureas and High-Solid Coatings and other training programs.

SSPC is also changing from formula-based paint standards to performance-based standards and a systems approach. While there are now numerous performance standards, SSPC Paint 36, "Two-Component Weatherable Aliphatic Polyurethane Topcoat, Performance-Based" led the way in 2000. Newer technologies may have first appeared in SSPC technology updates, before they became standards, for example, SSPC-TU 12, "Ambient-Curing Fluoropolymer Finish Coats Applied to Metal Substrates," which was published in 2015. While fluoropolymer technology has been around since the 1930s, there have been major advancements in recent decades including waterborne technology. Industrial field application became popular with the introduction of fluoro-urethanes in the water tank market. Fluoro-urethanes have far superior color and gloss retention when compared to standard polyurethane finishes.

I expect to see updates and standards for polysiloxanes and polyaspartics in the near future. These technologies allow for one thick topcoat that provides both sufficient barrier and ultraviolet (UV) protection. While more expensive, these technologies deliver cost savings by reducing the number of coats (less labor) and quicker throughput. The performance of traditional three-coat zinc/epoxy/polyurethane systems can now be achieved in two coats and epoxy/urethane system performance can be achieved in one. By combining epoxy and siloxane polymers, polysiloxanes can provide UV protection without an isocyanate. Polyaspartics merge the UV protection of polyurethanes and the thick-build and quick-cure properties of polyureas. Care must be taken to achieve the surface preparation required by the manufacturer when applying polyaspartics direct-to-metal.

**INSPECTION**

All of the advancements in surface preparation and coating technology will not yield the desired results and life-cycle improvement without proper inspection and documentation. Inspection itself has changed much in the last 30 years. When I began my career in this industry, third-party inspectors, hired by the owner, did everything. Now, contractor quality control (QC) and owner quality assurance (QA) are much more clearly defined. SSPC's Painting Contractor Certification Programs (PCCP) make it clear that the painting contractor is responsible for first-line inspections.

Inspection equipment has also evolved. Now almost all equipment is digital. Sling psychrometers and psychrometric tables are only seen in the hands of older inspectors. A single digital gauge now measures air and surface temperature along with relative humidity and warns the user when the surface temperature is getting too close to the calculated dew point (the temperature at which moisture will condensate on the surface). Digital gauges are used to analyze blast profile characteristics, not just depth. "Banana" gauges with simple springs and magnets are rare, and digital gauges for measuring dry-film thickness (DFT) have evolved from old-fashioned slot-machine number wheels to sophisticated readouts that can calculate and average gauge readings into spot readings, warn the user when the DFT is out of specification, and record and download readings. The one good thing about the old number wheel DFT gauges was that you knew when they were going bad — the numbers would just keep spinning. There are now DFT probes that will take continuous readings while moving the probe along the surface. We can now inspect for holidays (non-visible pinholes in a lining) with

UV light when fluorescent coatings and primers are used (see SSPC-TU II, "Inspection of Fluorescent Coating Systems").

Digital gauges with removable heads can now do many of the tasks listed previously with the same gauge body and then directly download measurements to a computer or cellphone via Bluetooth. Bluetooth technology has made sharing inspection data instantaneous and paperless QA/QC is being embraced by many.

As gauges have evolved, so have standards. SSPC-PA 2, "Procedure for Determining Conformance to Dry Coating Thickness" had a major revision in 2015 to coordinate the document with ASTM D7091, "Standard Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals." Now PA 2 addresses conformance on both ferrous and non-ferrous substrates while D7091 addresses the operation of the DFT gauges. SSPC-PA 2 is now much clearer on addressing non-conformances and allows for various levels of conformance. SSPC-PA 9, "Measurement of Dry Coating Thickness Using Ultrasonic Gages" and ASTM D6132, "Standard Test Method for Nondestructive Measurement of Dry Film Thickness of Applied Organic Coatings Using an Ultrasonic Coating Thickness Gauge" are used similarly on concrete and other non-metallic surfaces.

Similarly, surface profile is now addressed by SSPC-PA 17, "Procedure for Determining Conformance to Steel Profile/Surface Roughness/Peak Count Requirements" and ASTM D4417, "Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel." While D4417 Method C (replica tape) is still prevalent, Method B (depth micrometer) has become more practical with digital advancements. Profilometers that measure peak density in addition to depth are not yet feasible for field work but may be in the future.

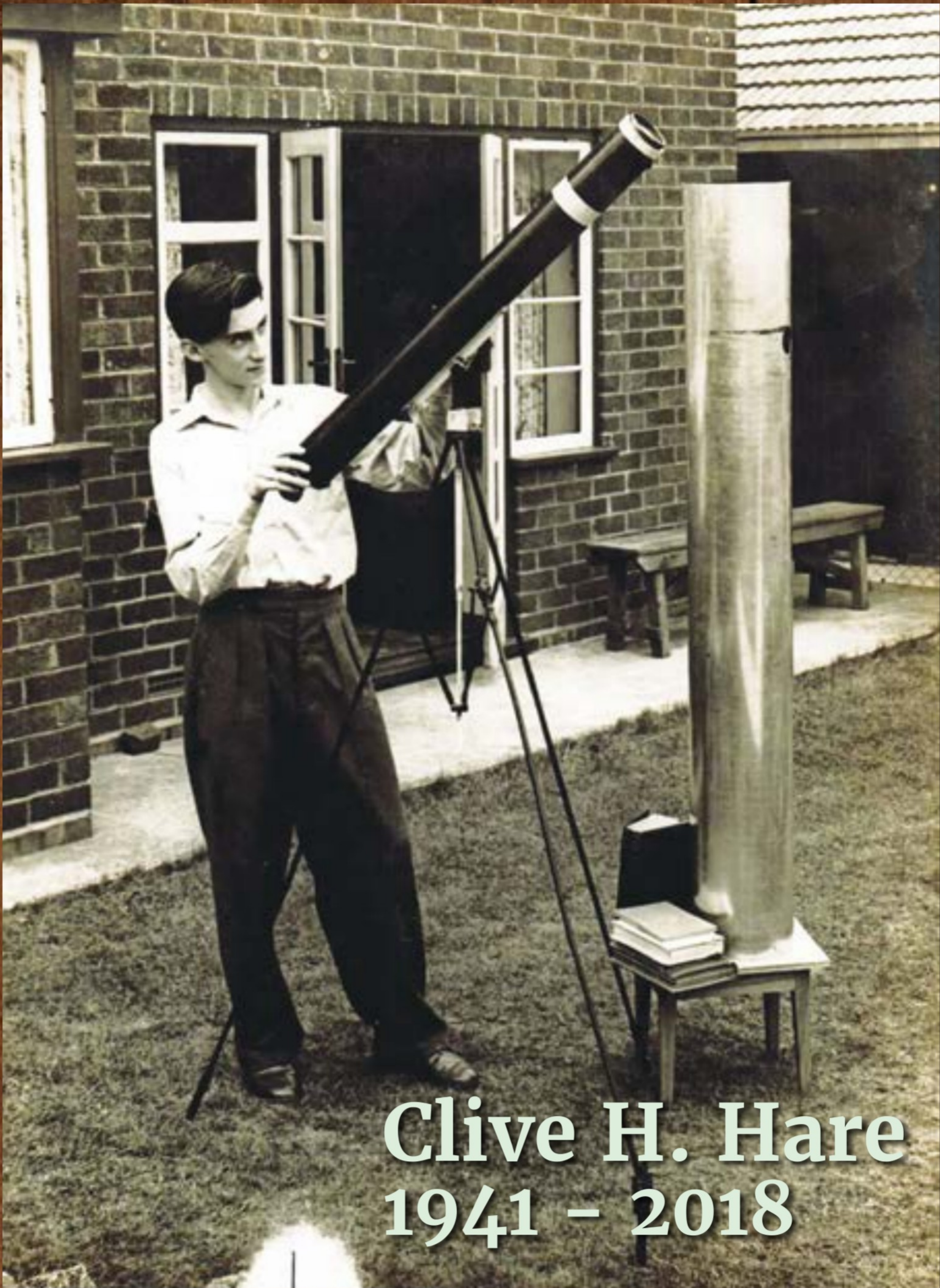


## CONCLUSION

There are many things to consider when watching paint dry and the changes mentioned along with future changes will keep coating consultants busy for a long time. Of course, some things have not changed in the last 30 years, like the nature of corrosion. The most important step on any painting and coating project also has not changed.

## REFERENCES

1. "CPSC Announces Final Ban on Lead-Containing Paint," U.S. Consumer Product Safety Commission (CPSC) Release # 77-096, September 2, 1977.
2. "Regulatory Review of 29 CFR 1926.62 Lead in Construction" Occupational Safety and Health Administration (29 CFR), U.S. Department of Labor.
3. "Occupational Safety and Health Administration (29 CFR)," Occupational Safety and Health Standards (1910 Z), Toxic and Hazardous Substances (1025) Lead, U.S. Department of Labor.
4. "Residential Lead-Based Paint Hazard Reduction Act of 1992," Public Law 102-550, references "limits established under section 302(c) of the Lead-Based Paint Poisoning Prevention Act," 42 U.S. Code, Chapter 63.
5. "Lead in Paint," U.S. Consumer Product Safety Commission (CPSC).
6. "Safety Standards for Fall Protection in the Construction Industry," Occupational Safety and Health Administration (29 CFR 1910 / 1926), Final Rule FR 59:40672-40753, U.S. Department of Labor.
7. "Detailed Fact Sheet - Architectural Coating Rule for Volatile Organic Compounds."
8. Systems and Specifications, Volume 2, SSPC: The Society for Protective Coatings.
9. SSPC Protective Coatings Glossary, SSPC: The Society for Protective Coatings.



# Clive H. Hare
# 1941 - 2018

Clive Hare and his homemade telescope from *The Daily Telegraph*, 1956. Photo courtesy of Jean Hare.

On July 14 of this year, the coatings industry lost an icon. Clive Hare passed away at the age of 76. In addition to authoring the bible of protective coatings, *Protective Coatings: Fundamentals of Chemistry and Composition*, Hare was a valued colleague and friend to many in this industry. Some who knew him and worked closely with him share their thoughts.

**KAREN KAPSANIS, FORMER EDITOR IN CHIEF, *JPCL***

In his novel, *East of Eden*, John Steinbeck observed that no matter how great our "talents and influence and genius," we want to be both good and loved.

Clive had abundant talents, influence and genius, which he used wisely and generously — because above all else, Clive was good and much loved.

For 20-odd years in the editorial trenches, I worked with Clive on most of the articles he published in *JPCL*. In the back-and-forth of phone calls and emails to get each manuscript to press, I came to know and treasure Clive for his inexhaustible energy, accomplishments and knowledge; his devotion to his family; his generosity; his sense of humor; his wisdom; his modesty and his compassion. Two anecdotes about Clive have a particular hold on me as I grieve his passing.

In the mid-1960s, while Clive was traveling between the States and England to establish himself in his career and to court Jean, his soon-to-be wife, he still found time to volunteer as a counselor for a suicide hotline in Boston. In fact, he became the Boston police's go-to guy for helping people in crisis. Clive never told me this story — Jean did. He was modest about all of his accomplishments, personal and professional. As Jean said, he was always "reluctant to be in the spotlight."

In 1973, he prepared a coating for part of the equipment that the Apollo 17 astronauts would leave on the moon. That coating, likely still adhering, is an apt metaphor for the elevated aspirations and the enduring impact of Clive's life and work. He was a dear, dear man who made us all want to reach a little higher, be a little better.

Jean told me that more than 100 people attended the simple service she had for Clive and that hundreds more sent their condolences, including people she and Clive hadn't seen in years. That's no surprise because Clive was good and because he will always be much loved.

Godspeed, Clive.

**HAROLD HOWER, FOUNDER OF TECHNOLOGY PUBLISHING COMPANY, PUBLISHER OF *JPCL***

"Where do all the great ones go when they're gone" is a haunting refrain in an elegaic country song. It brings to mind the recent passing of Clive Hare, one of the great ones of coating chemistry and technology, who is gone. But he didn't go altogether, for he remains in the minds of many colleagues and friends, in the thinking they do and in the work they produce. Here are a few thoughts about why he persists and why he should.

He believed in and practiced his craft, not merely the craft of coating formulation and coating-system design but also the craft of writing and communicating verbally with his peers and those who studied him. Consider his first *JPCL* article, "Specific Utility in the Design of Coatings for Bridges." Here he begins with several paragraphs describing how battleships were eventually engineered with a compromise between armor and speed, in which very thick armor was placed on the most vulnerable ship areas and less-thick armor on less-vulnerable areas. Both speed and protection were thereby achieved in the engineering design.

Several things are of note in this opening to the article. First, it shows that Clive had detailed knowledge of specific battleships and their designs, as well as the successes and failures they achieved in battle. He was extremely well read, not merely in coating science and technology, but in numerous subjects, such as naval warfare. Second, being a true thinker, he applied the principle of engineering compromise as shown with battleships to a central problem of bridge painting, the need to maximize corrosion protection while minimizing cost. And finally, he used a colorful analogy having to do with battleship armor and speed to engage the reader's mind and to crystallize the idea of "specific utility" in bridge coating design — using high-performance and costly coating systems on areas of bridges that are most vulnerable, such as where the steel is exposed to road salt, and using less-costly systems on areas where exposure conditions are more benign.

Consider the masterful conclusion to this article and note the great writing skill: "Like so many disciplines, the employment of specific utility in coating system design is a multi-faceted discipline that borrows from quite different technologies — basic corrosion science, bridge maintenance engineering and coatings technology. To make full use of the concept, the bridge engineer must learn from the coatings chemist, and the coatings chemist must become more familiar with the details of bridge design and the patterns of deterioration that occur with age. If this can be done, then by a process in which we emulate those naval architects of years ago, we may learn to use those means of protection that we already have more carefully and judiciously, without compromise, but equally without waste. In this way we may provide our bridges with a measured degree of sure protection that is sufficient for the job at hand, but neither so ill-balanced that key features go underprotected, nor so overengineered that hard-found dollars are unnecessarily squandered."

The thinking and writing exemplified by this article, as well as by the nearly 150 additional articles he penned for *JPCL* in the monthly columns "Anatomy of Paint" and "Trouble with Paint," make it obvious why *JPCL* created the Clive Hare Honors, celebrating the Top Thinkers in protective and marine coatings. In these thinkers Clive lives on.

### DR. MIKE O'DONOGHUE, DIRECTOR OF ENGINEERING AND SERVICES, INTERNATIONAL PAINT LLC

The sheer volume of written works by Clive is quite astonishing. He was no mere dabbler with an encyclopedic knowledge of topics. Rather, transcending his prolific writing output was a real depth which explains why, to this very day, his work is routinely referenced by authors around the world.

If one word was to characterize Clive it would be "passionate." It is rare to encounter someone with such a heightened passion in their field, but make no bones about it — throughout his career, his zeal for all things chemistry in the coatings and linings industry was formidable.

With a sense of wonder this self-effacing English gentleman articulated with clarity what occurred at a fundamental level, and then with an uncanny ability, brought this knowledge into sharp focus and real-world relevance for both layman and scholar alike. An example of this is what he called his "pathology of paint" book published by SSPC in 2001 entitled *Paint Film Degradation: Mechanisms and Control*. If you are curious as to why paint and coatings fail in service, there is arguably no better source of concise, technical and practical information to be found anywhere.

The mark of any great scientist is to take his or her accomplishments from the confines of the laboratory and make them eminently useful and understandable to the world at large. Here, too, Clive was a great success. And while we wax lyrical about his writing skills, Clive also enjoyed a worldwide reputation as a researcher, coatings formulator, public speaker and consultant. In each of these areas, his clients included NASA, the military, highways and numerous chemical companies.

According to Jean, Clive's grandmother noted that when Clive was just four years old, he was an avid reader, fascinated by science — the stars in particular — and even built his own telescope at the age of 14. A year later, and having joined the British Astronomical Association, Clive made history: British newspaper, *The Daily Telegraph* declared, "Boy, 15, First in Britain to Report Comet." Yes, Clive Hare had discovered a comet with his homemade telescope!

Unbeknownst to many, since retiring, Clive authored a number of novels centered around the First World War, a subject he was very well conversant with. His novel, *Residuals*, marked his first foray into the world of fiction. Here, on an entirely different level from his chemistry works, he showed his consummate writing skills weaving stories involving complex personalities, dramatic and heart-stirring scenarios, amusing sidelines and episodes of deep pathos — all the while interspersed with his perfect clarity and deep empathy with his characters.

Clive Hare. Photo courtesy of Robert Hare.

The legacy of this innovative thinker and writer will be far-reaching. While we particularly mourn his loss to the coatings industry, we will encounter Clive again and again through his monumental written works. And thus, a new generation will come to know, admire and respect this true giant in the world of chemistry and coatings.

As much as I admired and esteemed the works of this highly accomplished man, Clive was above all my friend and I was privileged to have him call me that. I shall miss him very much.

### STEVE COLLINS, VICE PRESIDENT, NORFOLK CORPORATION/ ZRC WORLDWIDE

How do you say goodbye to a legend?

When it comes to Clive Hare, you can't! We are truly his legacy — you, me and all those who have had an opportunity to work with and to know him. He lives on through us and through his prolific writing.

When I started in this business around 35 years ago, one of the very first things I did was meet with Clive. Little did I know at the time, this relationship would grow into a lifetime of mentoring and friendship. Clive was like a father, imparting more and more of his wisdom with every meeting. What a joy it was to have him to bounce ideas off of and to share successes and failures. He especially liked the failures, from which as he would often remind me, we must take the opportunity to learn.

A few of the most exciting times of my career have been when Clive actually referenced me in one of his many articles for *JPCL* (talk about acceptance!) and later, when he, Matthew Steele and I cowrote a paper, "Zinc Loadings, Cathodic Protection and Post Cathodic Protective Mechanisms in Organic Zinc-Rich Metal Primers," which won the Outstanding Publication Award from the Society for Protective Coatings (SSPC) in 2002. What a pleasure it was to work with Clive!

Clive was a man of many talents. He was a great family man, friend, avid world traveler, adventurist, amazing photographer, chemist, technical writer, novelist (*Residuals, The Shepherd On The Rock*) and so much more.

As I sit here writing, I am looking at a photograph that Clive gave me many years ago taken at his lake home in Maine. I am captivated by the sheer beauty of the scene and by the beauty of the man who captured it. In the preface to his book, *Paint Film Degradation: Mechanisms and Control*, this most modest gem of a man wrote, "It is my hope that something I have said herein will light a light in somebody I do not know, and that he or she will do a little more to preserve and decorate all that we make for longer and longer. And that may be the sum of a life's endeavor, nothing more." Well, Clive, old friend, mission accomplished.

FEATURE

# FIREOSAURUS REX:

## KING OF EPOXY PFP IN HOT AND COLD CLIMATES

BY DR. MIKE O'DONOGHUE; VIJAY DATTA, MS; RAVI NAGARAJAN; BILL DEMPSTER; ROBIN WADE, MA; AND SHERMAN SPEAR, INTERNATIONAL PAINT LLC

If Tyrannosaurus Rex and the Ice Age have the power to fire the imagination, then the tongue-in-cheek Fireosaurus Rex, and extreme cold environments, will do likewise for coating practitioners in matters both hot and cold.

This article explores the footprint and characteristics of the newly discovered Fireosaurus Rex, a novel and solvent-free, low-temperature-cure, epoxy-polysulfide intumescent passive-fire-protection (PFP) coating. The power of this fiery king lizard is compared and contrasted with the other behemoths in the passive-fire-protection jungle.

Turning from hot to cold climates, factors that probably lie behind a recent spate of intumescent coating failures are also examined in this article, a tale of woe where cracking of some traditional epoxy-amine-PFP coatings occurred in subzero temperature conditions or even prior to exposure to the cold environment.

Deep questions abound: will this cracking be systemic in extreme cold service? Can the cracking phenomenon be narrowed down to result from intrinsic properties common to, or absent in, a particular group of epoxy-PFP coatings? Or is the cracking the exception rather than the rule as evidenced by the absence of cracking in well-formulated, and time-proven, epoxy-PFP coatings. Not so fast. In the heat of the moment perhaps it is tempting to say, "it is even evidence of climate change!"

Over the past decade, there has been a progressive evolution within the North American construction industry for the betterment of downstream petrochemical projects. "We've always done it that way" practices are now "I can't believe we used to do it that way!" Increase in modular construction with a large majority of passive fire protection being delivered pre-applied from the shop is now the norm. Much tighter and condensed project schedules are bringing assets online faster for owners to capture their investment profits in a time of market volatility.

The suppliers of passive-fire-protection materials have reacted brilliantly with revolutionary innovations to assist in the construction changes and at the same time bridge the elusive gap between engineering, construction and procurement. The lowest cost option may not be the best overall solution for a specific project requirement. The principal also applies during field work on shop-applied structures, where climatic field conditions present a dynamic set of parameters.

To fully assess the passive-fire-protection requirements, a singular focused approach does not come close to providing the entire picture for in-place performance over the lifetime of the asset. As global mega projects move into arctic cold climate conditions, a multiple practical parameter approach, taking into account the total steel package, is an absolute must.

It is no secret that cold climates and short construction schedules can make or break a coatings installation in new construction, facility expansions, or maintenance and repair. So productivity enhancements derived from an epoxy PFP with low-temperature cure and rapid cure at normal shop temperatures would be most helpful. Better still, if the coating was easy to spray and hand-apply in the field, mesh-free (or mesh-only on flange tips), and subject to only minimal transportation and erection damage.

Where is such a PFP beast, one may ask? And what would it mean to the applicator if he or she could extend their coating season by 30 days, or start their project 30 days sooner?

Predictability of coating performance in the real world of epoxy PFP can prove elusive,

© iStockphoto.com / IPGGutenbergUKLtd

uncertain or downright non-existent when the importance of accelerated laboratory tests on coatings is overemphasized, or the tests prove inappropriate, inadequate or invalid[1,2]. Why so? With coating evaluations in real life, the variables experienced are much larger than controlled variables imposed in accelerated laboratory tests. Notwithstanding, epoxy-PFP evaluations in Norsok, ISO 20340 or recent ASTM D5894 test protocols have shown corrosion prevention relevancy to field-observed epoxy-PFP behavior after 10 years of service[3,4].

Consider the case of a properly applied intumescent epoxy fireproofing system that uncharacteristically cracks when exposed to extremely cold temperatures of ca -50 C (-58 F). To fully comprehend both the onset and subtlety of the cracking process, it is instructive to not just obsess with aspects of laboratory determined data for coating flexibility and adhesion as though they were the sole causal factors for cracking. Instead, it is essential to recognize and assess multiple relevant real-world (or a veritable ecosystem of) stress and strain factors involving both the coating and the steel to which it was applied.

> "THE IMPORTANT THING IN SCIENCE IS NOT SO MUCH TO OBTAIN NEW FACTS AS TO DISCOVER NEW WAYS OF THINKING ABOUT THINGS."
> – SIR WILLIAM BRAGG

A Rubik's cube helps to visualize the stress and strain phenomena in an epoxy-PFP coating. Each face of the cube represents different stress and strain factors relevant as to why crack initiation and propagation may occur in the coating. Factors not to be overlooked include the following.

- Internal stress of the epoxy-PFP coating system.
- Overall mechanical capacity of the epoxy-PFP coating system.
- External stress on the coating — numerous temperature scenarios.
- Design and geometry of the steel structure.
- Points of intense stress in the structure.
- Aging and fatigue effects and the impact this has on the virgin material properties reported.

This is cold comfort indeed, if the focus is only on a few of these factors with regard to cracking in epoxy PFP.

Problems and possible solutions for intumescent epoxy-PFP technology in cold climates will now be outlined for both the Fireosaurus Rex epoxy-polysulfide PFP and traditional epoxy-amine-PFP technology after a brief introduction to their respective chemistries.

## COLD CLIMATES: INTUMESCENT EPOXY-AMINE PFP

Since the early 1970s, intumescent epoxy coatings that are characterized by their ability to swell, char and insulate as they react in a fire have been at the forefront of fire protection in the oil and gas market. In the main, these engineered materials have an exemplary track record of fireproofing prowess, corrosion mitigation in corrosive and cold conditions, resiliency to weathering and the ability to withstand large temperature variations without loss of future fireproofing performance.

Figure 1 (p. 22) shows a schematic cure process for a two-component reaction. Figure 2 (p. 22) shows the principal epoxy-amine reaction[5]. The initial reaction of small epoxy and amine molecules is fast and produces larger and linear molecules. In the second but slower reaction, the growing molecules start to cross-link and branch out. This cross-linking involves a reactive hydrogen atom or proton attached to a nitrogen atom (NH) to open the epoxy ring. In the third reaction, the molecules cross-link on a large scale and form a three dimensional network.

Properties such as flexibility and water resistance of the epoxy coating can be engineered by the formulator by manipulating carefully chosen molecules for the cross-linking. Even in the case of well-formulated epoxy-amine-PFP coatings, they only cure down to ca 7-to-10 C (45-to-50 F) unlike thin-film epoxy-amine coatings based on Mannich-base and phenalkamine curing agents that apply and cure down to -18 C (0 F) without the use of deleterious accelerators[6].

## COLD CLIMATES: NOVEL INTUMESCENT EPOXY-POLYSULFIDE PFP

Today, in the absence of a low-temperature-cure intumescent epoxy-amine-PFP coating, there has been a significant development with the recent introduction of a novel, intumescent polysiloxane-modified epoxy-polysulfide-PFP coating that cures at ambient temperature down to -10 C (14 F). This is a formulation approach where the cross-linking involves a reactive hydrogen atom or proton attached to a sulfur atom (SH) to open the epoxy ring.

Figure 3 (p. 22) shows the reaction of the thiol SH sulfurhydril end groups of polysulfides with terminal epoxy groups. A small amount of a tertiary amine catalyst such as tris (dimethylaminomethyl) phenol speeds up the reaction and facilitates the development of a more highly cross-linked 3-D network[7].

The novel epoxy-polysulfide reaction is much faster than the traditional epoxy-amine reaction and the speed of curing can be dialed-in, so to speak, depending on the functionality of the polysulfide polymer and the type and level of the basic catalyst employed. The cure speed stems from the mildly acidic SH group of the polysulfide polymer rapidly releasing its proton to any strongly basic material present in the coating, and forming the thiolate ($S^-$) anion. The powerfully nucleophilic thiolate undergoes a fast reaction with the strained epoxy ring, opening it to form a cross-link and an alkoxide moiety. This newly formed alkoxide may either abstract a proton from any residual thiol, reforming a new thiolate anion (which undergoes nucleophilic attack on further epoxy), or it may react directly with epoxide in an anionic chain growth cross-linking process.

These competitive processes continue until cure is achieved. This is in contrast to amine curatives where the nucleophilic attack of a traditional amino (NH) group on an epoxy ring is much more sluggish, particularly at low temperatures. The number and spacing of SH groups confers excellent reactivity and the coating formulator can attenuate internal stresses and control the curing reaction latently by turning the reaction on like a switch.

Without the intermediacy of anionic chain

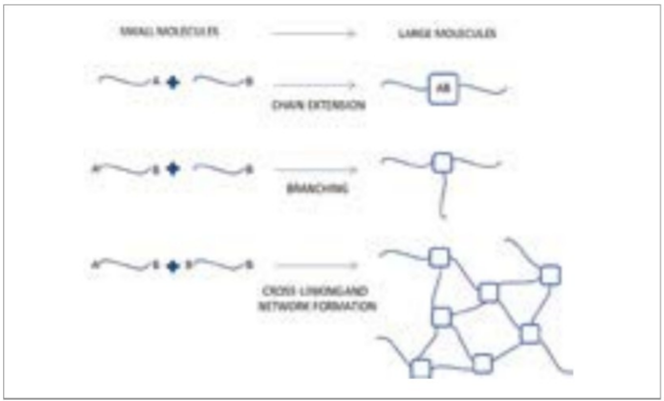



Fig. 1: Schematic cure process for two-component epoxy coatings. Figures courtesy of the authors unless otherwise noted.

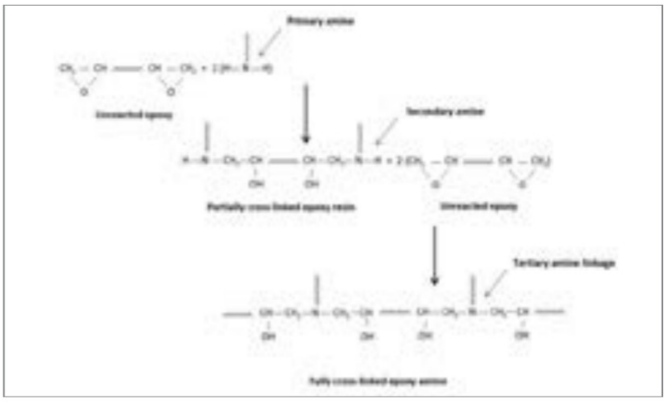


Fig. 2: The epoxy-amine reaction. Photo courtesy of Clive H. Hare.

growth epoxy cure processes, the novel epoxy polysulfide cross-linking reaction would form a rather loose structure with linear and extended chains of flexible, or soft, molecular segments. With the additional anionic curing process, harder molecular segments may also be formed, ultimately yielding the novel epoxy-polysulfide PFP, possessing a 3-D network that is resistant to impact damage but still with excellent flexibility and water resistance.

For optimum anticorrosive performance and fire protection of the epoxy-polysulfide PFP, a carefully designed stoichiometric ratio of epoxy groups over thiol groups is used. The resulting film can be readily formed at subzero temperatures, and has high tensile strength.

The novel epoxy-polysulfide PFP outperformed the amine-epoxy PFP in the hydrocarbon pool fire testing according to BS476 part 20, "Method for determination of the fire resistance of elements of construction." While the general class of epoxy-polysulfides is well known, the molecular architecture and several attributes of the subject epoxy-polysulfide PFP are unique.

Table 1 outlines some of the differences between the novel epoxy-polysulfide PFP and traditional types of epoxy-polysulfide PFP. The structural integrity of the epoxy-polysulfide PFP is reinforced with a mesh on the structural steel flange tips. In common with epoxy-amine PFP, the novel epoxy-polysulfide PFP is suited to applications on carbon steel, aluminum, galvanizing and concrete substrates when typically applied over a holding primer. It meets the fire performance requirements of Norsok M501 (Revision 5) without the addition of a separate topcoat. Two-part polyurethane finish coats can be used for aesthetic purposes given that, as expected, the epoxy PFP will chalk, fade and discolor over time.

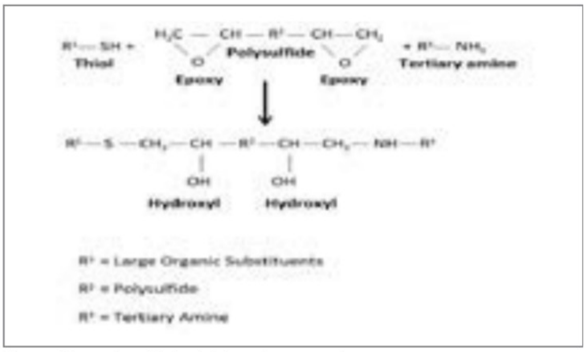



Fig. 3: The polysulfide-thiol-amine reaction.

For continuous immersion conditions, where the topcoat may be absent, the novel epoxy-polysulfide PFP sustained less than a 1-percent weight increase over a 17-week period when immersed in a 5-percent sodium-chloride solution at 10 C (50 F) and a less than 8-percent weight increase when immersed in de-ionised water at 25 C (77 F) after the same immersion period. Furthermore, the impact on the insulation performance of the epoxy-polysulfide PFP in a fire is minimal after the immersion period. The authors agree that poorly formulated epoxy technology (specifically not covered by this novel technology route) and other so-called "flexible epoxy PFPs" may not exhibit this behavior.

The epoxy-polysulfide PFP is an ideal replacement and upgrade for cohesively weak lightweight cementitious PFP. The latter is prone to corrosion under fireproofing (if it does not contain a corrosion-inhibitor package or a suitable heavy-duty primer) and concerns may exist regarding its durability and potentially expensive field repair.

## SHOP APPLICATION AND PRODUCTIVITY

One of the most important aspects of a successful coating application is for the applicator to be able to completely transfer and apply the product with ease whether using

**Table 1: Comparison of Epoxy-Polysulfide PFPs.**

| Test | Novel Polysiloxane-Modified Epoxy–Polysulfide PFP | Standard Epoxy-Polysulfide PFP |
|---|---|---|
| ASTM D570-98 (2005)<br>12 weeks immersion | Very little water uptake<br>(Maintenance of fire performance) | 100 percent water uptake<br>(Loss of fire performance) |
| ISO 20340 in Norsok MCR501 Revision 5 (System A) | No blisters<br>Scribe creep minimal | Blisters<br>Scribe creep extensive |
| Mesh reinforcement | Flange tips only | Complete system |
| Odor | Very low | Intense |

plural-component or airless equipment. The novel epoxy-polysulfide PFP is mixed 1:1 and applied by plural-spray equipment. As with most coating types, it is best applied when the steel substrate temperature is at least 3 C (37 F) above the dew point.

Fabricators can run steel through shops with the epoxy-polysulfide PFP and have the ability to turn the shop floor as much as three-to-five times more than if lightweight cementitious fireproofing is used. Moreover, using the epoxy-polysulfide PFP has been shown to be two-to-three times faster compared to using several other epoxy-amine-PFP coatings. Ordinarily, the novel epoxy-polysulfide PFP can be exposed to the elements in less than eight hours.

Prior to erection, novel epoxy-polysulfide-PFP-coated steel shipped to a laydown yard suffered no damage. Hence, there were considerable savings for steel delivery to the site and elimination of PFP site applications. No matter how good a coating system is, however, if the project does not have the predictability for success from a quality specification, quality application and quality inspection, then things can go very wrong. The key differentiators of the novel epoxy-polysulfide PFP are shown in Table 2.



### CHALLENGES AND CONTROVERSY WITH COLD CLIMATES

Simply stated, if the usable strain of any intumescent epoxy-PFP coating is exceeded, then that epoxy PFP will crack.

Structures fabricated by a stick-built method and protected by epoxy PFP at large have an excellent performance history and many manufacturers can show extensive track records for assets situated in the most extreme cold climates of the world. Indeed, simple pipe racks pose no issue when built via a module-build methodology.

It is becoming an increasing market trend that structural steelwork destined for cold climates is fabricated via a modular-build process. These modules can range in size from small pre-assembled units to large mega-modules 50 meters in height. Modular construction has facilitated fabrication and construction in all parts of the world with many originating in warm or even tropical climates. Large mega-modules applied at high temperatures pose a unique challenge where the final destination of the facility may be in the coldest areas of the planet, where temperatures reach as low as -50 C (-58 F).

Design of these modules can be simple in nature (as in the case of pipe racks fabricated from I sections) or extremely complex, in order to accommodate densely packed process equipment and deal with the handling and transport of large modules from one continent to another. As the design becomes more complex involving extensive grillage decks, heavy bracing and support of the primary structure, temperature cycling to low temperatures in a heavily restrained steel structure can lead to extreme localized stresses and strains in the steelwork. These designs have similar characteristics to offshore modules

**Table 2: The Basics of a Novel-Epoxy-Polysulfide PFP.**

| |
|---|
| • Low water uptake in immersion or condensing environments |
| • Single-coat, high-level protection |
| • Rapid-cure and rapid application |
| • Low-temperature cure and application to -10 C (14 F) |
| • Apply at 15 C, cure at -10 C (14 F), ship steel in 24 hours at -10 C |
| • Apply and cure at 27 C, ship steel in 8 hours |
| • Reduced heating requirements |
| • Turns shop floor 3-to-5 times faster than lightweight cementitious PFP |
| • Applicator friendliness |
| • Pre-installed mesh in shops for flanges |
| • Mesh free block-outs and repairs; mesh flange edges only in shop |
| • Mesh flange edges only in shop |
| • Flexible epoxy-polysulfide-intumescent PFP |
| • Up to 4 hours ANSI/UL 1709 certification |
| • ISO 22899 Jet-fire tested up to 2 hours rating in a 1-coat application (8.68 mm) |
| • UL XR 645 – 8.68 mm for a 2-hour rating |
| • UL XR 646 – 8.89 mm (galvanized) for a 2-hour rating |
| • ASTM D5894 – rigorous cyclic test standard for industrial environments |
| • ANSI/UL 1709 – certified to meet standard |
| • No reduction in fire performance after 25 cycles in ISO 20340 (Norsok pre-qualification requirements for insulation robustness) |
| • Boron Free |
| • No corrosion under fireproofing |

for floating production storage and offloading (FPSO) and floating liquified natural gas (FLNG) structures, but the degree of out-of-plane and rotational movement for beams may be greater. While these stresses do not necessarily pose a specific issue to the structural integrity, the differential strain built up between an epoxy PFP and steel due to their individual rates of response to thermal loads can become excessive.

Furthermore, the fabrication of modules occurs via pre-assembled units, or so-called pancake decks. The handling of these structures and tools used to align pancake decks when fabricated in the final module may result in strains generated in the epoxy PFPs becoming close to their maximum capacity. This ultimately reduces the strain capacity when in service, or locks in strain into the coating thereby reducing the overall usable strain.

Interestingly, the design codes are not always helpful in how to deal with the interaction between epoxy PFP and steelwork when large Delta Ts are experienced and design of the structural steelwork is complex. However, the best guidance appears to be given in the Eurocodes. It is advised here that thermal loadings are treated as a live load and recommendation is given to apply a factor of safety to ensure that a sufficient margin is available for assessing the strength resistance of the structure when subjected to significant thermal variations. This principle, in turn, can then be used as a guide to ensure there is a sufficient safety margin when epoxy PFP is applied to the structure. Strain development for a Delta T of 80 C is therefore treated as a Delta T of 120 C (factored case). While this may appear excessive, it has been shown for recent cases that this marries with recent observations, particularly where restraint in the steelwork is also taken into account.

Strain between the steel and coating can be calculated by consideration of the coefficients of thermal expansion of the materials at the appropriate temperatures concerned. The overall capacity of the coating is generally taken from tensile properties. Tensile

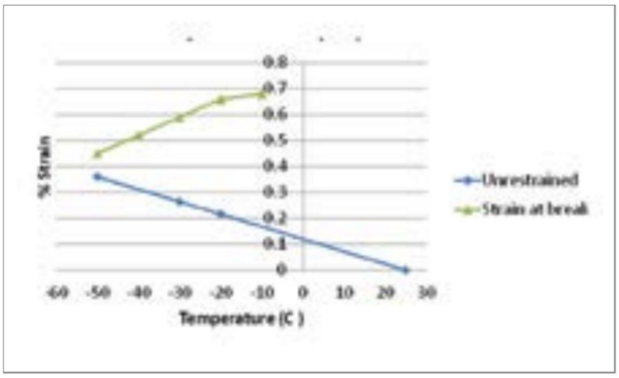



Fig. 4: Example of strain development as a function of temperature for epoxy-amine PFP.

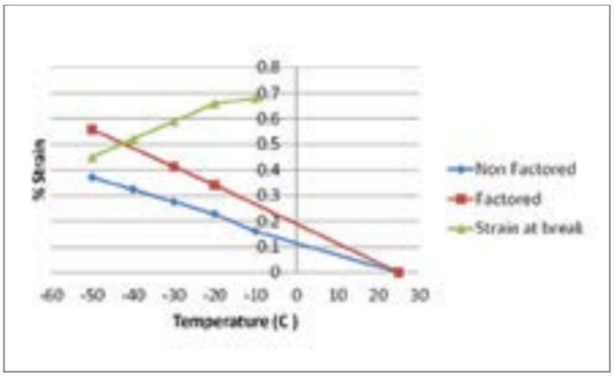



Fig. 5: Example of strain development as a function of temperature for epoxy-amine PFP.

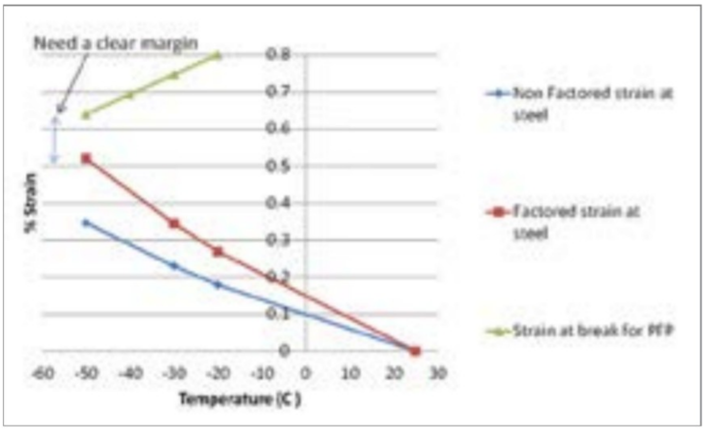



Fig. 6: Strain development compared to material strain capacity for epoxy-polysulfide PFP.

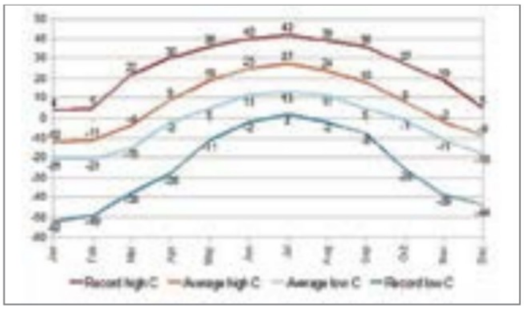


Fig. 7: Annual temperature profile Kazakh Steppe in 2017.

deformation is expected to be limiting in epoxy PFP as the temperature reduces and the PFP material tries to contract at a greater rate than the steel substrate response to the same temperature fall. This relationship means that the epoxy PFP is being restrained from contracting to its natural dimensions as a free film in the absence of its bond to the steel substrate. Mechanical properties are required to be representative of the as-built structure and considerable care is required in the measurement of these properties as well as the expected variances which may result in real-world applications. Thermal-cycling testing on steel specimens must also represent the curvature between web and flange on the actual structures as well as being of similar stiffness to the as-built structure.

Figure 4 shows an example of an epoxy-amine-PFP system where performance in the real world, with temperatures as low as -50 C, has been successful for simple modular and stick-built structures. Strain develops at the steel/coating interface as the temperature drops. The overall capacity (tensile strain to break) of the epoxy PFP also reduces as the temperature falls. For all temperatures down to -50 C, there is a margin between the tensile strain and strain built up between the steel and epoxy PFP. Consequently, this has resulted in an excellent track record for this epoxy PFP of a range of primer types, where the ambient temperature has ranged between 40 C and -40 C, over a 10-year period. In another example, good performance of epoxy PFP was observed in the Antarctic where structures fabricated in South Africa at an ambient temperature of 25 C (77 F) have operated for many years down to -50 C.

Fig. 8: Clip-on mesh on flange tips.

Fig. 9: Epoxy-polysulfide PFP applied to structural steel.

Notwithstanding, where fabrication of structures may lead to a reduction in usable strain, factored strains showed that there would be concerns with this type of epoxy PFP where the temperature falls lower than -40 C (Fig. 5).

There is a requirement within the industry for an epoxy PFP that can provide confidence in the integrity and insulation performance in the event of fire after exposure to wet-dry cycling and periodic immersion in all climates of the world (including cold climates where extended periods of melt water may compromise performance) and have excellent tolerance to the strains expected from structures resembling offshore modular construction that may be highly restrained. An overview of stresses expected include the following.

Thermal stresses

- Cycling due to changes in the environment.
- Cycling due to process conditions.

Mechanical stresses

- Fabrication and construction.
- Transport and in-service fatigue.
- Loading (from thermal, dead loads, blast loading).

Wet/dry cycling stresses

- Cycling due to changes in the environment (humidity, snow, rain, immersion, ponding).
- Cycling due to process conditions (condensation).

Interestingly, mechanical properties of epoxy-amine PFP are often based upon “virgin properties” of the coating with no mention of the ramifications of moisture absorption of flexible and more rigid thermoset systems. Without a topcoat, these systems may not hold up in harsh service environments. In fact, some epoxy PFP in the absence of a topcoat have been visibly observed to expand due to moisture uptake in high-humidity and high-temperature environments. Topcoat maintenance is also a low priority for operators who will have little confidence in such an epoxy PFP providing the necessary long-term fire protection. In addition, topcoats introduce an extra cost burden if they are used. Novel, low-temperature-cure, intumescent epoxy-polysulfide-PFP coatings are capable of providing confidence after weathering with minimal reduction in properties observed.

Figure 6 shows the expected strain build-up of this type of novel epoxy-polysulfide PFP when applied to simple stick-built and modular structures (such as some pipe rack structures) and more complex structures where the factored strain has been accounted. Against this, the overall capacity of the novel epoxy polysulfide PFP is shown, again the overall capacity reducing as the temperature is reduced. For this epoxy polysulfide PFP, even in the factored, restrained case there is margin between overall capacity and the expected strain development at the steel/coating interface.

It is therefore expected that this thermally efficient, water-resistant, epoxy-polysulfide PFP coating will withstand the strains of the harshest Delta T (greater than 80 C) where the environmental temperatures may fall to -50 C for all structure types.

Lap shear adhesion testing was carried out on the epoxy-amine PFP that had a successful 10-year track record at -50 C. Adhesion measurements were obtained for films cured at 25 C and 60 C (140 F) and tested at -50 C. The average shear strengths were between 10 and 15 MPa.

A multi-year test program was carried out in the field on the same epoxy PFP applied in the laboratory. Systems were evaluated on 3-meter beams and T pieces exposed to a temperature range as high as 25 C and as low as -50 C. After two years, no cracking has been observed on any of the coated surfaces.

Irrespective of whether it is an epoxy-polysulfide PFP or epoxy-amine PFP, its performance in extreme cold climates or near its end of life, the issues involved are all about balance. Our knowledge of challenges for epoxy PFP in cold climates shows that striking the right balance in developing appropriate physical properties in the coating is necessary for coating longevity.

> "MONTAIGNE'S LAW: NOTHING IS SO FIRMLY BELIEVED AS WHAT IS LEAST KNOWN."

So, what is a good approach to the judicious selection of an epoxy PFP for extreme cold climates at -50 C? Although not all-encompassing, the answer boils down to the following.

- A proven track record of the epoxy-PFP system, for example, more than two-to-20 years in the Arctic circle.
- Laboratory testing that provides relevant data for resistance to cracking and maintenance of fireproofing properties.
- Passive fire protection that has sufficient usable strain even when considering strains in the steel over a temperature drop 1.5 times greater than expected in the real world.

### COLD CLIMATE
### Case History #1 - Epoxy-Amine PFP

The ancient Kazakh Steppe, covering approximately 311,000 square miles and home to some of the harshest climates known to man, is a hostile environment for an epoxy-intumescent-PFP coating. As shown in Figure 7 (p. 26), extreme heat in the summer and matching extreme cold in the winter can bring about an average Delta T of between 50 and 80 C (122 and 176 F) with temperatures as low as -50 C[8].

On a 600,000-barrel-per-day (bpd) oil refinery located on the northeastern shore of the Caspian Sea, an epoxy-amine-intumescent-PFP system has been applied since 2008 to pipe racks, structural steel, vessel supports and divisions on new expansion projects. The steel was abrasive blasted to an SSPC-SP 6/NACE No.3, "Commercial Blast Cleaning" standard to achieve a 2-to-4 mil angular profile and primed with an epoxy primer to 3 mils DFT. The epoxy-amine PFP was then applied at 8-to-14 mm to meet the required hourly ratings for the project. After 10 years of exposure to this formidable environment, reports from the site indicate remarkable performance with no cracking or damage.

In addition, beginning in 2013, the epoxy-intumescent material replaced existing cementitious material on the LNG vessel farm. Five years later, after reports from the site were outstanding with no damage, cracking or material failing, the epoxy-amine PFP was selected for a 37.5 million square foot facility expansion for pipe racks, structural steel and modules that will be constructed and coated in a South Korean shipyard.

### COLD CLIMATE
### Case History #2 - Novel Epoxy-Polysulfide PFP

During a fall pre-project trial at a modular yard in Edmonton, Alberta, Canada, three fire-protection systems were compared for ease of application, speed of steel delivery and susceptibility to transportation and erection damage to ascertain the overall cost-in-place of the PFP versus an estimator's normal straight-cost comparison of PFP materials.

The UL 1709, "Standard for Rapid Rise Fire Tests of Protection Materials for Structural Steel" design category for a three-hour fire-protection rating determined the DFT of the candidate fireproofing materials. A novel and low-temperature-cure epoxy-polysulfide PFP, standard-cure epoxy-amine PFP and lightweight cementitious PFP were evaluated. Preliminary PFP evaluations were based on UL-rated loadings and the epoxy-polysulfide PFP offered the lowest loadings per UL XR 645 fire-resistant ratings.

After application, the epoxy PFPs hardened for just half a day under warm shop conditions before the W10 X 45 steel beams were moved to the modular yard. There they continued to cure at temperatures as low as -10 C (14 F) and as high as 4 C (39 F). After application, the epoxy PFPs hardened for just half a day under warm shop conditions before the coated W10 X 45 steel beams (3 m and 5 m) were lifted for belt-rigging assessment and shipped in a pickup truck to the modular yard. There they continued to cure at temperatures as low as -10 C (14 F) and as high as 4 C (39 F). Five months later, after experiencing temperature variations from 30 C to -20 C, the coated beams with the novel epoxy-polysulfide PFP evidenced no rigging, transport or handling damage and did not require repair.

The pre-installation of preformed galvanized mesh for flange tips afforded considerable time savings in the case of the novel epoxy-polysulfide PFP (Fig. 8, p. 26). There was no need to wait for mesh installation by pins welded to steel or having to build additional epoxy-PFP thickness to compensate for the absence of mesh.

The final evaluation was based on field repairs and coating rework. This is a litmus test for any fire-protection system transported under all sorts of weather conditions and subject to rigging and rough-handling damage. Field tests were carried out on the system including flexibility, impact damage from transport, belt rigging or the forceful removal of the PFP when site modifications are necessary. The coating performed well.

### WARM CLIMATE

### Case History #3 - Novel Epoxy-Polysulfide PFP

One theory of the dinosaur demise was sudden and dramatic climatic changes caused by a meteor impact. Fireosaurus Rex thrives in the resulting desert environment where others wither into extinction. The Middle East, specifically the Arabian Peninsula region, is just such a desert environment that is also rich in oil deposits. This region is an arid, extremely hot climate with daily temperatures remaining at or exceeding 34 C (93 F) for seven-plus months and with average annual precipitation of less than 4 inches.

In 1982 a 105,000-bpd oil refinery was commissioned next to the coastline with terminal capabilities for shipping product via tanker. During a shutdown in 2017, approximately 9,000 square feet (837 square meters) of structural steel was installed as part of a plant expansion and protected with the novel epoxy-polysulfide-PFP material. The steel was abrasive-cleaned to an SSPC- SP 6/NACE No. 3 standard and primed with a fast-cure epoxy-based primer to 3 mils maximum DFT. The epoxy-polysulfide PFP was applied at 6.85 mm to meet the 90-minute UL 1709 rating (Fig. 9, p. 26). Stick steel was erected on-site and blockouts were completed as required. The PFP scope of the project was completed two weeks ahead of schedule with zero defects of damage during transportation and erection.

### CONCLUSIONS

Even though flexible and rigid intumescent-epoxy-PFP systems may yield considerably different flexibility data, the overall formulation technology and multiple intrinsic and extrinsic stress-strain factors determine whether or not epoxy PFPs crack in cold environments.

It is important to choose a fireproofing system that fulfills the requirements for application to steel in shop and field environments during fabrication and construction phases — a fireproofing system that can be practically and economically maintained during the life of the asset.

Fireosaurus Rex is by no means extinct!

## ABOUT THE AUTHORS

Mike O'Donoghue is the director of engineering and services at International Paint. He has 35 years of experience in the marine and protective coatings industry.

Vijay Datta is the company's director of industrial maintenance. He has 47 years of experience in the marine and protective coatings industry.

Ravi Nagarajan is the company's key account manager – specifications. He has 23 years of experience in the marine and protective coatings industry and nine years in fire protection.

Bill Dempster is the company's North America fire protection market manager. He has 34 years of experience in the protective coatings industry with 20 years in fire protection.

Robin Wade is the segment manager in fire protection/technical with International Paint. He has 25 years of experience in the protective coatings industry with 15 years in fire protection.

Sherm Spear is the company's technical sales support fire protection manager. He has 38 years of experience in fire protection with a focus on epoxy passive fire protection.

## AUTHORS' NOTE

This article is dedicated to Clive H. Hare.

## REFERENCES


1. O'Donoghue M., Datta V.J., Winter M., and Reed C., "Hubble, Bubble, Tests and Trouble: The Dark Side of Misreading the Relevance of Coating Testing," *JPCL*, May, 2010.
2. Reed C., O'Donoghue M., and Datta, V.J., "Hubble, Bubble, Rising: A New Beginning, The Better Way," *JPCL*, December, 2017.
3. Wade R., "A Review of the Robustness of Epoxy Passive Fire Protection (PFP) to Offshore Environments," Corrosion 2011, NACE International, Paper No. 11037.
4. Norsok M501 edition 6 (2012); Surface preparation and protective methods; Norwegian Standard ISO 20340 (2009); Paints and varnishes — Performance requirements for protective paint systems for offshore and related structures.
5. Hare C.H., 'Protective Coatings Fundamentals of Chemistry and Composition," SSPC 94–17, chapter 15, p.232, 233, 1994.
6. O'Donoghue M., Garrett R., Datta V.J., Meli P., and Meilus L., "Optimizing Performanceof Fast-Cure Epoxies for Pipe and Tank Linings: Chemistry, Selection, and Application," *JPCL*, March 1998. December, 2017.
7. Abdouss M., Farajpour T., and Derakhshani M., "The Effect of Epoxy-Polysulfide Copolymer Curing Methods on Mechanical-Dynamical and Morphological Properties". Iran J. Chem. Eng, Vol. 30, No.4, 2011.
8. www.kazakhstandiscovery.com.


***JPCL***

# DATA-DRIVEN CORROSION PREVENTION AND CONTROL DECISIONS FOR THE USAF

BY ERIC HERZBERG, LMI; CHARLES A. BABISH, JEFFREY K. NUSSER AND DARRYL J. STIMSON, USAF



Aging aircraft, rising operations and support (O&S) costs, and tight defense budgets pose significant challenges for U.S. Air Force (AF) leaders responsible for sustaining AF weapon systems and equipment. Informative performance metrics, when accompanied by an effective decision-making process, enable leaders to make decisions based on facts rather than gut feel or anecdotal information. In the AF, the current constrained fiscal environment with dwindling resources necessitates effective performance metrics to maximize readiness and combat capability at the lowest overall maintenance cost. This article describes a method to take a rigorous look at subsystems and maintenance activities that have the greatest impact on availability and cost due to corrosion maintenance.

Failure to maximize system availability drives the need for the services to maintain a larger inventory and associated logistics support to perform mission requirements. More aircraft drives the need for more infrastructure such as parking pads, aircraft maintenance hangars, parts warehouses and maintenance equipment. More maintenance infrastructure drives the need for more personnel to maintain the aircraft and maintain the infrastructure. Finally, more maintenance personnel drive the demand for more base support functions such as morale facilities, medical, housing and other base support functions and facilities.

Ensuring the mission availability of military systems is vital to U.S. national security. The primary contribution of system maintainers is to maximize that mission capability. Consequently, AF systems mission planners can characterize time as mission capable (MC) or not mission capable (NMC). Mission-capable time can be divided into actual mission time and standby time. Mission time includes flight, flight preparations, fueling and weapons loading. Standby time accounts for time spent waiting on an aircrew and waiting for a mission (Fig. 1, p. 34).

NMC time is the realm of the maintainers. NMC time can be broken into planned or unplanned activities and is reported in non-available hours (NAH). Planned non-available time includes activities such as scheduled maintenance, modifications, repairs, washing and inspections. Examples of unplanned maintenance include checking a warning light, repairing an unexpected structural problem, mitigating corrosion, waiting on engineering direction, waiting on parts, lack of the proper maintenance expertise, or holiday or other non-work days.

Planned non-availability due to maintenance activities can be managed by mission schedulers, but unplanned non-availability can seriously degrade scheduling and the mission performance expected of weapon systems. It is imperative that AF decision makers have the tools necessary to make decisions that can decrease the impact of planned and unplanned non-availability. The impact of corrosion is defined as the combined effect of losses to system safety, availability and maintenance cost for Air Force weapon systems, equipment, facilities, and infrastructure.

Budget pressures have forced AF leaders to extend the operational life of numerous weapon systems including the A-10, B-1, B-52, C-5, C-130, F-15, F-16, KC-135 and T-38. As the life cycles increase, O&S costs increase at alarming rates due to parts obsolescence, as well as corrosion and fatigue problems that were not anticipated. Maintaining old systems contributes greatly to system availability and cost due to corrosion.

Most estimates allocate over half of the life-cycle cost of an AF aircraft system to the O&S phase after the system is fielded[1]. O&S costs begin with the system's initial deployment and include the cost of operating, maintaining and supporting the system including the cost of fuel, spare parts, systems upgrades, contract support and labor. Factors that contribute to O&S costs include how long the system is used, how it is used and where it is used. Some of these costs are beyond the maintenance leader's ability to control, such as fuel and personnel compensation costs, but many opportunities remain to control weapon system sustainment (WSS) costs.

The AF must add consistency to its maintenance decisions by incorporating data into the decision-making process. Frequently, maintenance decisions are based on short-term budget factors instead of data-driven mission readiness and life-cycle cost factors. Similarly, decisions to introduce new technologies, materials and processes are often based on products marketed by vendors, environmental regulations and unscientific observations and not on historic maintenance trends. The need for improved corrosion and other maintenance metrics is well documented. A 2011 report from the USAF Scientific Advisory Board recommended that Air Logistics Complexes (ALCs) adopt an efficiency metric based on the cost of aircraft availability [AA/$] as a function of programmed depot maintenance (PDM) flow rate to select initiatives that drive toward more efficient use of labor and facilities[2]. The authors propose that AF maintenance leaders adopt a decision-making model that is built upon metrics developed by LMI[3] to prioritize opportunities for data-driven corrosion maintenance decisions.

## MISSION IMPACT: THIS IS WAR

As aircraft age, maintenance activities and associated costs increase. Some maintenance is planned at specified time intervals, such as PDM; some maintenance work is performed to increase an operational parameter (e.g., modifications) and other maintenance activities result from the aircraft's usage and aging in its operational environment. Aircraft corrosion is a good example of maintenance resulting from aging in an environment. It is not surprising that an aircraft parked on an aircraft ramp and rarely used for years will still consume increasing maintenance costs over time simply due to corrosion caused by the environment. For example, in 2015, severe corrosion found on HC-130P aircraft at the 920th Rescue Wing at Patrick Air Force Base, Florida, caused the grounding and subsequent retirement of the Wing's entire fleet of six HC-130P aircraft (Fig. 2, p. 34). The corrosion degradation rate depends on several factors such as the proper use of corrosion-resistance materials, treatments and coatings, the application of sealants and primers, the amount of damage to corrosion-protection systems, maintenance practices and the severity of the environment where the aircraft are stationed.

The AF has quantified the impact of corrosion on both aircraft availability and maintenance cost. In military operations, system availability is critical to combat operations, troop safety and the transportation of personnel, parts and supplies. Those factors can directly impact national security. A 2016 DoD-funded "Impact of Corrosion" study showed that the AF loses nearly three million hours of aircraft availability per year to corrosion maintenance (Fig. 3, p. 34). Similarly, the 2016 "Impact of Corrosion" study estimated that aircraft and missile corrosion maintenance cost the AF about $5.5 billion each fiscal year (Fig. 4, p. 36)[4]. This annual amount consumes about one quarter of the annual AF maintenance budget and exceeds what the Pentagon expends each year on the campaign against the Islamic State[5]. The high AF-wide cost of corrosion maintenance is a potentially good target of opportunity for reduction because every dollar saved by reducing the cost of corrosion maintenance could be redirected to other efforts to organize, train and equip the AF warfighter.

## CORROSION MAINTENANCE METRICS: MEET IN THE MIDDLE

Before proposing a data-driven decision process, some background on the methodology of the proposed metrics that will feed the decision-making process is necessary. In fiscal year 2006, LMI began reporting on the impact of corrosion for the Office of the Secretary of Defense Corrosion Policy and Oversite (OSD-CPO). The LMI report provides detailed maintenance and corrosion availability and cost information for each military service to the weapon system, subsystem, maintenance object and even part number level of detail. The purpose of the reports includes quantifying the corrosion problem, assessing the effectiveness and level of resources applied to corrosion, and identifying the highest contributors to cost and availability impacts.

LMI developed a five-digit work breakdown structure (WBS) to associate system availability and maintenance costs to systems and subsystems to help identify improvement opportunities. This WBS allows the AF to compare corrosion impact between weapon systems and by subsystem within a weapon-system family to identify the drivers of corrosion impact. Maintenance actions are divided into preventive and corrective maintenance categories to help decision makers find the optimal preventive-to-corrective maintenance ratio to reduce the overall corrosion impact. Figure 5 (p. 36) illustrates an inverse relationship between preventive and corrective maintenance[6]. High investment in preventive maintenance produces low corrective maintenance actions. Conversely, no preventive maintenance produces unscheduled, expensive corrective maintenance. A common everyday example of this balance between preventive and corrective maintenance is changing the oil in an automobile. Never changing the oil will eventually cause expensive engine repairs and downtime and put the car owner on the right side of the curve in Figure 5. Conversely, changing the oil too often will avoid engine damage but will drive up preventive maintenance costs and downtime and put the car owner on the left side of the chart. Automobile manufactures have found that changing the oil every three- to five-thousand miles is optimum and will place the maintenance strategy near the minimum part of the curve in Figure 5. The challenge for system maintainers is balancing the preventive maintenance investment with corrective maintenance actions that together result in the lowest possible overall maintenance cost.

## TOP-DOWN: DISTILLATION APPROACH TO CORROSION COSTS

LMI uses both "top-down" and "bottom-up" approaches to converge on an accurate estimate for maintenance and corrosion-related cost and availability loss. The top-down method utilizes existing DoD and AF reports and databases to determine the annual maintenance impacts for systems and equipment. The top-down impact of corrosion starts with the sum of all maintenance costs from DoD and AF databases and becomes the upper limit. The upper limit is then iteratively lowered by removing costs that are not related to corrosion to approach the actual corrosion cost by subtracting out non-corrosion maintenance.

The top-down process can be compared to fractional distillation of crude oil as shown in Figure 6 (p. 36). For crude oil distillation, the raw crude is heated, then each fraction distilled off, leaving liquid gas as the final product. Similarly, to estimate the cost of corrosion, the raw material to be "distilled" is the annual DoD budget. In this process, each fraction that is not related to corrosion maintenance is taken off leaving only organic depot-level maintenance (DLM), organic field-level maintenance (FLM), and both depot and field-level contractor maintenance fractions. In Figure 6, these fractions are represented by various colored wrenches. The formula that determines what maintenance tasks are corrosion-related and what percentage of the cost or availability loss should be allocated to corrosion was the result of a joint effort between LMI and AF corrosion subject matter experts.


Fig.1: Breakout of mission-available time and non-available time.
All figures courtesy of the authors unless otherwise noted.

## BOTTOM-UP: STACKING LABOR AND COST DATA FROM INDIVIDUAL MAINTENANCE RECORDS

The bottom-up cost-estimating method aggregates the corrosion-related labor and material data from individual records of maintenance activities. The bottom-up approach provides data that is essential to analyze subsystems and maintenance actions for potential maintenance opportunities. These maintenance activities are documented by a unique task identifier. For instance, AF depots use a work control document (WCD) to generate data from the maintenance activities. Examples of maintenance activities documented on the WCD are applying and removing coatings, applying corrosion prevention compounds in high-risk areas and inspecting for problems in corrosion-prone areas.

## SCALING

Ideally, the top-down fractioning and the bottom-up stacking approaches result in the same maintenance cost or reported availability loss. When the two approaches converge on the same or nearly the same result, this confirms the data collection and analysis assumptions. However, in the real world, these two approaches rarely meet. AF maintenance documentation, especially depot maintenance data, is notoriously inaccurate and missing data and incorrectly coded labor and material entries contribute to gaps between the top-down and bottom-up approaches. Additionally, the top-down labor estimates encompass the entire salary of each maintenance technician including benefits, vacation time and sick time. The bottom-up records contain only the hands-on labor hours expended while performing maintenance tasks. As such, the bottom-up aggregated labor costs will not equal the top-down fully loaded salary amount because no technician spends 100 percent of his or her time in hands-on maintenance labor.

When a gap occurs, LMI first confirms that the gap did not stem from a missing database or missing data from an aircraft model. Next, LMI bridges the gap between the distilled top-down total and the bottom-up material and labor totals by applying a scaling factor to the bottom-up data by assuming the distribution

Fig. 2: HC-130 corrosion at Patrick Air Force Base.

of labor and material costs in collected maintenance records equals distribution from the missing records. This method of bridging the gap is statistically valid because the sample size of data records is very large (in the tens of millions) and is usually between 25 and 100 percent of the top-down total[7]. Consequently, despite the well-known inaccuracy of AF maintenance data[8], this method of estimating costs provides a very accurate and reliable estimate of the actual corrosion costs and availability.

This method of generating corrosion maintenance data and evaluating the impact on system availability and maintenance cost has been used, with minor improvements, since fiscal year 2006. As shown in Figure 7 (p. 37), the

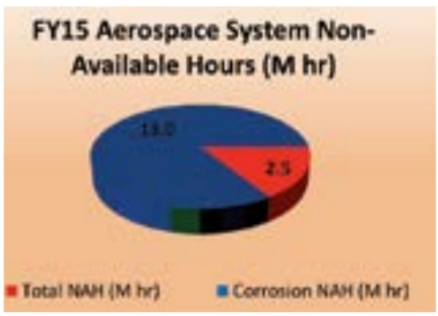



Fig. 3: FY15 aircraft non-available hours (NAH) from corrosion maintenance. Corrosion maintenance consumes nearly 3 million hours —18 percent of all NAH that systems are unavailable to perform their missions.

study found corrosion responsible for 16 percent of non-available hours (NAH) for aircraft and missiles and the NAH rates have remained around 15-to-20 percent since fiscal year 2008. These NAHs account for time when AF weapon systems were not available to perform their national defense missions[9]. Meanwhile, the cost of corrosion maintenance held steady and even modestly decreased after 2010. Similarly, the corrosion portion of maintenance costs, expressed as a percentage, has decreased slightly over this period.

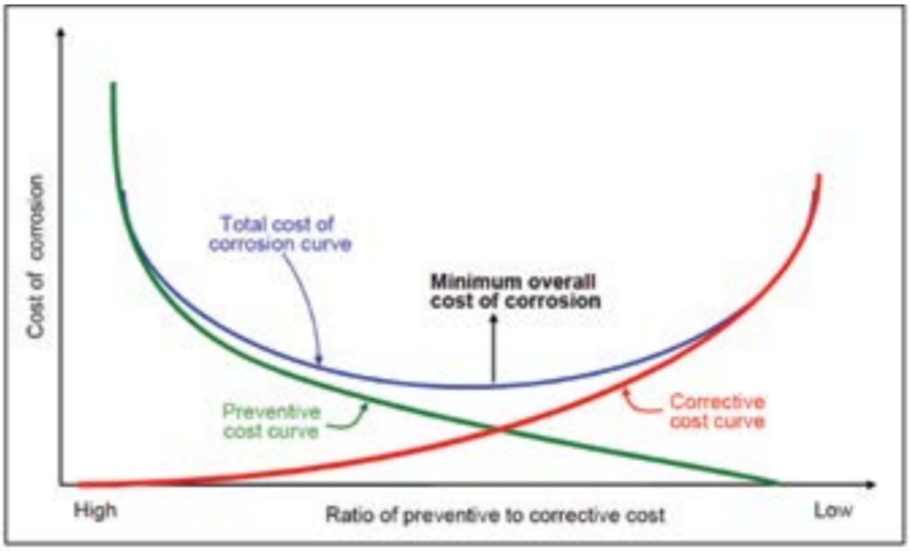



Fig. 5: The inverse relationship between preventive and corrective maintenance. This notional chart illustrates the maintainer's challenge of balancing preventive and corrective maintenance to yield the minimum corrosion maintenance cost.

## NEXT-GENERATION CORROSION ANALYTICS: DATA-DRIVEN MAINTENANCE DECISIONS

In the past, depot maintenance organizations have undertaken many initiatives to improve efficiency. These initiatives include LEAN efforts to improve workflow and eliminate waste, value-stream mapping to remove unnecessary steps, six sigma to optimize repeatability, prime vendor general services administration contracts to streamline parts and materials delivery, public/private partnering[10], vending machines for consumable materials and high-velocity maintenance (HVM) to anticipate the condition of assets before they come to the depot for maintenance. While these efforts have certainly improved efficiency, maintenance decisions are not always focused on the opportunities with the greatest potential impact on availability and cost, nor is data available to objectively estimate downtime and cost benefits.

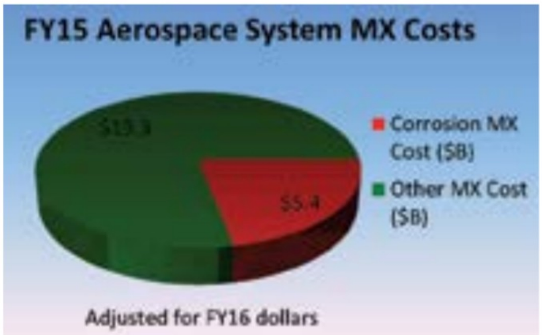



Fig. 4: Corrosion costs the Air Force over $5 billion per year, nearly one quarter of all aerospace maintenance.

The current metrics developed by LMI (Figs. 7 and 8) are useful for tracking AF-wide corrosion maintenance trends. However, the next generation of metrics need more granularity to monitor system and subsystem level trends and facilitate data-driven maintenance decisions. To do this, the AF needs to know what systems, subsystems and parts have corrosion issues that degrade aircraft availability and whether the AF can cost effectively improve the corrosion performance of these subsystems and parts.

## PROPOSED METHODOLOGY

Traditionally, AF maintenance activities use aircraft availability metrics, often measured by the mission capability rate (MCR)[11] to assess maintenance performance. For example, depots report their impact on aircraft availability by tracking the number of flow days and the number of aircraft located at the depot. Maintenance leaders manage maintenance, repair and overhaul processes by monitoring the number of days spent in each process 'gate' such as depaint, incoming, depot repair, fuel shop and functional flight check (FFC), and paint. Maintainers intuitively know many constraints to improving flow days, but there is no systemic method to prioritize improvement initiatives. In addition to striving to optimize aircraft availability

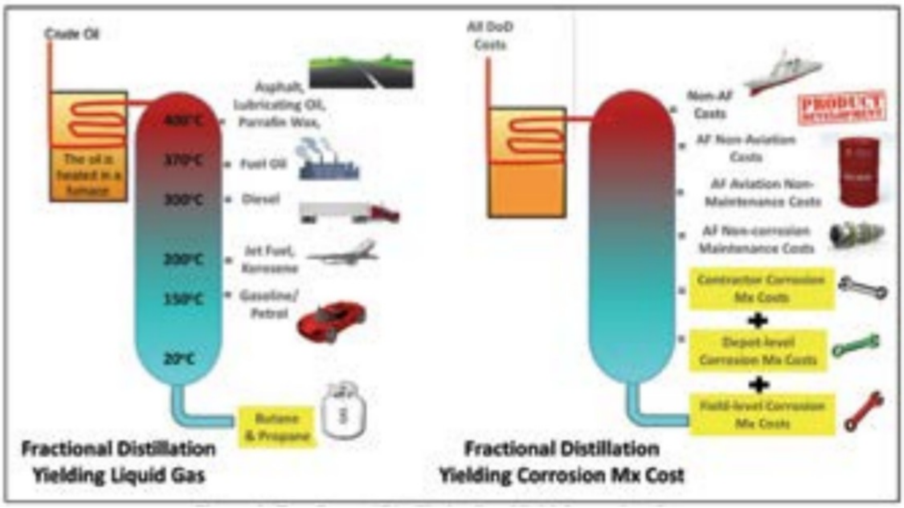



Fig. 6: Top-down distillation to yield corrosion costs. To identify corrosion costs, the total DoD budget is "distilled" by sequentially removing non-AF, non-aviation and non-maintenance costs until only corrosion-related maintenance costs remain. In reality, the crude oil distillation process removes the useful elements from the top. This example shows the most useful elements remaining at the bottom.

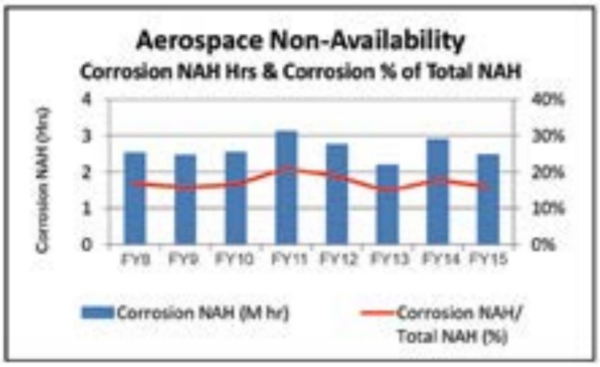



Fig. 7: Aircraft NAH due to corrosion maintenance and corrosion portion of total NAH. These metrics have varied over time.

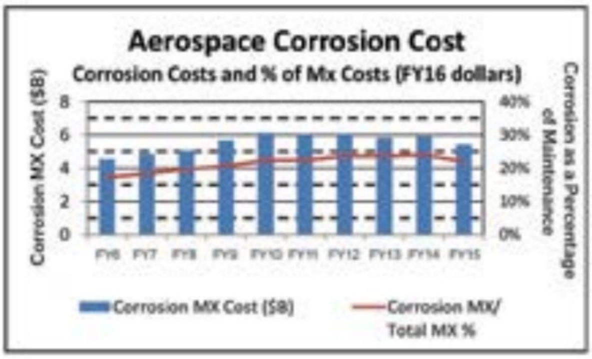



Fig. 8: Corrosion maintenance cost and corrosion percent of total maintenance cost. Both have modestly decreased since 2012.

by tracking workflow, depot leaders serve in a budget-driven environment that compares projected budget versus actual dollars spent with the goal of having a zero net operating result (NOR) by the end of the fiscal year. AF depot maintainers track expended labor and material costs against budgeted amounts in striving to achieve this. Depot leaders can manipulate financial outcomes by granting or denying overtime or delaying or buying parts and materials in advance, all in an effort to achieve a zero NOR. Factors such as asset condition, scope creep and maintainer experience can degrade depot performance, but a wily depot leader can mask production problems with financial decisions that achieve a zero NOR and still be significantly behind or ahead of planned depot production schedules.

Recalling the breakdown of mission availability and non-availability, maintainers can support the mission by minimizing the time that aircraft spend in maintenance. By adopting the LMI data warehouse and resultant metrics, we can prioritize maintenance actions based on their impact on availability and cost. Maintenance leaders can look at the cost of buying aircraft availability (AA/$) to determine what mixture of preventive versus corrective maintenance to pursue, what repairs to perform, and what material and process changes will most benefit the AF mission (Fig. 9, p. 38).

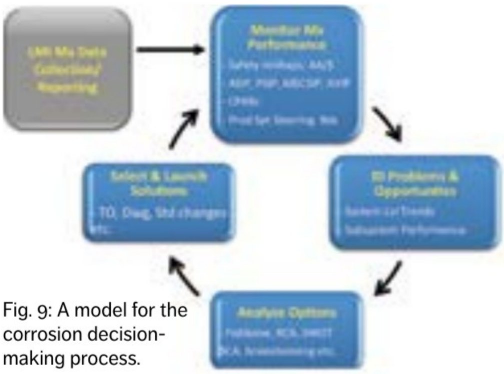


Fig. 9: A model for the corrosion decision-making process.

## MONITOR MAINTENANCE DATA

The model represented in Figure 9 proposes that systems analyze the impact of corrosion on safety, availability and cost at integrity reviews such as the Aircraft Structural Integrity Program (ASIP), Mechanical Equipment and Subsystems Integrity Program (MECSIP) and Propulsion Structural Integrity Program (PSIP). Similarly, the impact of corrosion should be integrated into weapon system corrosion-prevention advisory boards (CPABs), product support steering boards, the annual AF Corrosion Prevention and Control (CPC) Report and similar venues.

This approach is consistent with the 2016 Rand Corporation study that called for sharing O&S cost metrics and supporting data with AF maintainers and leadership, and holding product support managers and sustainment organizations accountable for explaining changes in both cost and performance metrics[12]. In addition, these recommendations are consistent with the November 2012 Secretary of the Air Force memo calling for reduced costs and improved-decision making for WSS activities[13] and the "should cost" principles for sustainment activities championed by the Under Secretary of Defense for Acquisition, Technology and Logistics[14].

## IDENTIFY PROBLEMS AND OPPORTUNITIES

In the past, solutions to corrosion problems have risen from environmental regulations, new technologies presented by vendors and problems identified by the acquisition and sustainment communities. To make objective decisions, the proposed approach focuses on the major NAH drivers and business case analysis efforts and not empirical ideas or contractor sales pitches. Maintenance leaders should use tools such as a Pareto chart (a type of chart that contains both bars and a line graph, where individual values are represented in descending order by bars, and the cumulative total is represented by the line) to methodically identify which systems, subsystems and component parts are having the greatest impact on availability and investigate options to improve aircraft availability per maintenance dollar (AA/$) performance. Examples of proposed metrics to generate data-driven maintenance decisions are shown in Figures 10 through 13. In Figure 10, inspection is clearly the prominent driver for NAH. The next level of data needed is an understanding of the drivers in sufficient detail to identify opportunities. For example, can external NDI methods be developed and validated to preclude the hours associated with getting access to perform visual inspections? Because treatment is the number one cost driver in Figure 11 despite being approximately half the hours as inspection, can lower-cost materials or processes be developed and qualified to reduce the time to apply the treatments? These examples identify possible opportunities that require additional data and metrics to support the data-driven decision-making process.

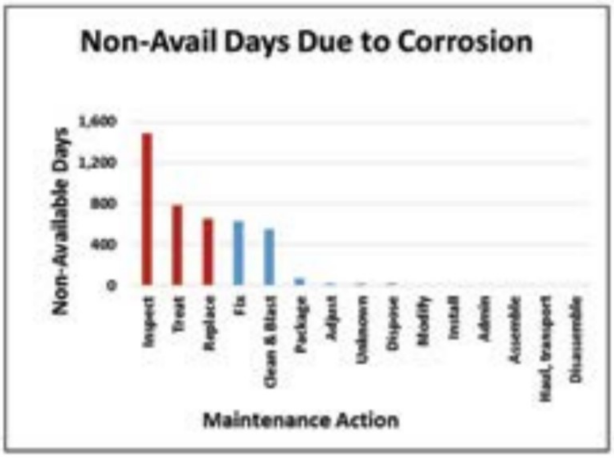



Fig. 10: An example of a metric showing maintenance actions that consume the most mission availability.

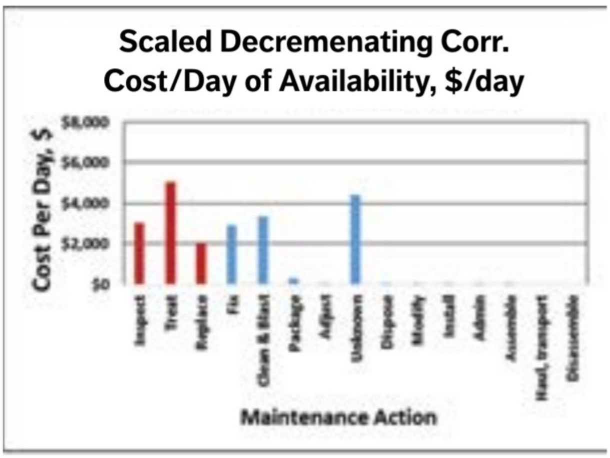



Fig. 11: An example of a metric showing cost per day on maintenance actions that consume the most mission availability.

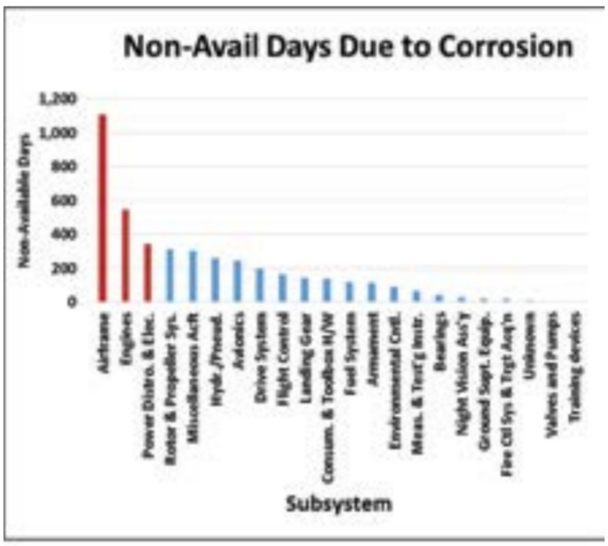



Fig. 12: An example of a notional metric showing aircraft subsystems that consume the most mission availability.

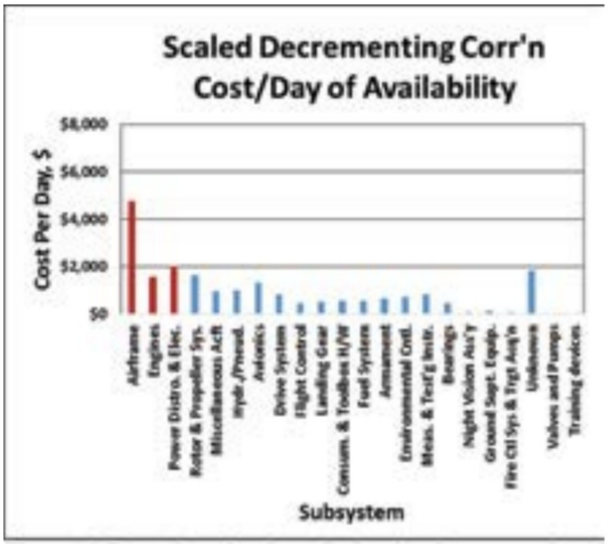



Fig. 13: An example notional metric showing the cost per day of availability on aircraft subsystems that consume the most mission availability.

## ANALYZE OPTIONS

Analyzing metrics data can help engineers identify opportunities to reduce the impact of corrosion on safety, availability and cost. The challenge is performing a cost/benefit analysis of alternatives to adequately inform the decision-making process. The proposed model and associated metrics will provide reliable data to support the cost/benefit analyses and justify financial and scheduling decisions.

The process of analyzing corrosion-maintenance decisions should consider reviewing a prioritized list of corrosion maintenance opportunities with the greatest impact to safety, availability and cost. Maintenance options should consider the full range of options including repair, modification and replacement with an associated cost/benefit analysis. Program offices should use the CPAB as a venue to ensure all possible corrective actions have been considered and that lessons learned from other programs are applied. After implementing data-driven decisions, program offices should forecast improvements to safety, availability and cost over time to support the field- or depot-level maintenance decisions and track the results to enable improved accuracy and confidence over time.

When corrosion damage is discovered in safety-critical locations, the cost of performing inspections, applying treatments and performing repairs should be compared to the cost of replacing the component with one manufactured from corrosion-resistant materials or that employs adequate corrosion protection systems. The cost for corrosion-related maintenance should be based on the metrics already captured and various methods to project future cost. The cost for component replacement and associated future maintenance should also be determined. A simple break-even analysis can be calculated to determine the number of years where a planned component replacement has lower total cost than managing the corrosion damage through inspections, treatments and repairs. If component replacement is not justified by the cost/benefit analysis, options to reduce the cost and schedule for each primary contributor to the cost of managing corrosion damage should be analyzed. This should include combining resources from other programs that share technologies, needs and capabilities such as NDI, paint stripping and application of CPC.

For corrosion damage routinely found in non-safety-critical locations, additional options should be considered such as varying inspection intervals to either find corrosion damage when it is less severe and therefore more economical to repair or allowing it to progress to the point where component replacements are planned.

For potential corrosion damage concerns, the Analytical Condition Inspection (ACI) program should include tasks for inspections of corrosion-susceptible locations. The results of the ACI program should be used to determine when fleet-wide corrosion maintenance is required at both the field and depot locations.

## SELECT AND LAUNCH SOLUTIONS

The actual implementation of corrosion management decisions will be accomplished by the program office with engineering authority to manage technical data and make engineering changes and modifications. After implementation of solutions, the process cycle continues with the tracking of results from corrosion decisions at the integrity programs reviews, CPABs, steering boards and similar venues to consider follow-on activities and additional corrective actions.

## CONCLUSION

AF weapon systems accumulate about 50-to-65 percent of their total life-cycle costs during the O&S phase. Corrosion accounts for about 25 percent of this cost and could rise in the future due to the increased emphasis on the complex coating systems required by an increased emphasis on stealth aircraft. The AF has expanded its focus on corrosion prevention and control and the annual corrosion maintenance costs have leveled out at around $5.4 billion per year. However, to make significant and lasting improvements, the AF needs reliable maintenance data and analytical tools to effectively manage corrosion maintenance. This article proposes a suite of metrics and a decision-making process to make data-driven corrosion maintenance decisions for aircraft and other systems to increase the mission availability in the most cost-effective way possible.

The proposed process will enable stakeholders in the acquisition, sustainment, integrity programs and AF leadership communities to more accurately assess previous corrosion maintenance practices and prioritize future maintenance strategies. In sum, this approach will enable data-driven corrosion maintenance decisions.

Corrosion maintenance is simply a significant subset, albeit a large contributor, to aircraft maintenance cost and availability impacts. Consequently, the metrics and proposed decision-making process suggested here can be migrated to many other aircraft maintenance decisions and should be considered for adaption to a broader range of maintenance decisions from strategic levels at the AF headquarters, through MAJCOMs, and to the field, depot and contract maintainers.

## ABOUT THE AUTHORS

Eric Herzberg has experience in a variety of maintenance and logistics fields, including continuous process improvement, cost measurement, operations strategy and automatic identification technology. He is an expert on the costs and readiness impacts of maintenance and corrosion on Department of Defense (DoD) weapon systems and infrastructure and has created and developed an innovative method for measuring those costs and impacts. Herzberg has a Master of Business Administration degree from Clemson University and a Bachelor of Science degree in mathematics from the U.S. Military Academy.

Charles A. Babish IV is the technical advisor for Aircraft Structural Integrity at the Air

Force Life-Cycle Management Center (AFLCMC) at Wright-Patterson Air Force Base in Ohio. He serves as the recognized Air Force authority in aircraft structural integrity and determination of aircraft remaining service life. Babish entered federal service in 1986 as an aerospace engineer and has held various ASIP-related positions in the F-16, C-17 and F-22 programs and various technical leadership positions within Aeronautical Systems Center and AFLCMC.

## REFERENCES


1. Jones, White, Ryan, and Ritschel, 2014.
2. USAF Scientific Advisory Board, 2011, pp. 57-58.
3. The Logistics Management Institute (LMI) is a not for profit organization started in 1961 by then Secretary of Defense Robert McNamara.
4. Herzberg, Eric F.; Morris, Alexander; Kelly, Amelia R.; Stroh, Rebecca F.; Rutledge, Lauren; O'Meara, Norman T., 2016.
5. U.S. Department of Defense, 2016.
6. Forman, et al., 2009.
7. Forman, et al., 2009.
8. USAF Scientific Advisory Board, 2011, pp. 43, 91-93.
9. Herzberg, Eric F.; Morris, Alexander; Kelly, Amelia R.; Stroh, Rebecca F.; Rutledge, Lauren; O'Meara, Norman T., 2016.
10. Public-private partnerships for depot maintenance are cooperative agreements between AF depots and one or more private-sector entities to perform AF maintenance work, use AF depot facilities and equipment or both.
11. Mission Capable Rate (MCR) = [(FMC + PMCM + PMCBS+ PMCB)/Possessed Hours] X 100.
12. Boito, Light, Mills, and Baldwin, pp. 5-6, 2016.
13. Donley, 2012.
14. Carter, 2011. ***JPCL***

FEATURE

# IN-SERVICE CLEANING & INSPECTION OF STORAGE TANKS

BY IAN DANIEL AND MARK STONE, SONOMATIC LTD

© iStockphoto.com / gong hangxu

This industry is well-versed with the techniques of corrosion mapping of vessels and pipework. However, storage tanks are also susceptible to a range of internal and external corrosion processes. Historically, corrosion mapping and inspection of a tank floor has relied on emptying the tank and personnel entry for cleaning and inspection. Internal inspection for any other problems also takes place at the same time, meaning tanks can be out of service for significant periods of time.

As steps have been taken to minimize work in confined spaces by exploring zero-man entry over the lifetime of storage and process vessels, a novel robotic system has been developed that includes a range of methods for the inspection of storage tanks while in service. A key element of this system is robotic cleaning and inspection of the tank floor with the tank shell also inspected non-intrusively using ultrasonic corrosion mapping supported by statistical analysis. This article gives an overview of the technologies involved and describes how these technologies link into more efficient integrity management of storage tanks.

In-service inspection is a cost-effective alternative to out-of-service inspection for situations where the likelihood of degradation requiring repair has been assessed as low. It can provide significant benefits to tank operators such as eliminating the need for shutdowns, not compromising critical storage capacity, minimizing site personnel requirements during plant shutdowns, eliminating hazards associated with personnel entry to tank internals and improving the knowledge of the tank floor condition, compared to existing out-of-service techniques

## IN-SERVICE STORAGE TANK FLOOR INSPECTION

The floors of storage tanks can be susceptible to internal and/or external corrosion that may lead to failure with severe consequences. Safe management of tanks, therefore, relies on inspection of the floor at appropriate intervals. Historically this inspection has been carried out by tools and techniques that require internal entry following emptying and cleaning and obviously necessitating that a tank be taken out of service.

The robotic tank-floor capability is part of a comprehensive inspection service and is aligned to the requirements of the American Petroleum Institute's API Standard 653, "Tank Inspection, Repair, Alteration and Reconstruction," which covers the inspection, repair, alteration and reconstruction of steel aboveground storage tanks used in the petroleum and chemical industries and the Engineering Equipment and Materials Users Association's EEMUA 159, "Aboveground flat-bottomed storage tanks - a guide to inspection" with the tank remaining in operation throughout. The key features of this robotic system follow.

- Advanced ultrasonic immersion transducers system.
- Integration with proprietary inspection project management and analysis software.
- Optional suction and discharge pumps.
- Umbilical cord and carrier with 106-m-to-115-m cable lengths.
- Advanced navigation system.
- Purge system for products with flashpoints below 37.5 C (99.5 F).
- Optional camera and light system.
- Temperature range from 20 to 50 C (68 to 122 F).

This approach gives a high degree of assurance of tank-floor integrity while avoiding the need for costly shutdowns and minimizing the hazards associated with confined space entry.

Figure 1 shows the steps taken to inspect and evaluate the integrity of the tank floor.

## ASSESSMENT AND PLANNING

By working with the client to plan the inspection of the tank floor, both operational and integrity requirements can be considered. Summaries of the key points for the operational and integrity aspects follow.

### Operational

Successful in-service inspection of tanks relies on comprehensive planning of all operational aspects. This means working closely with the tank owner/operator to establish critical design, operational and safety data relevant to carrying out the inspection. With this information, a detailed project plan can be developed covering logistics, equipment and man-power requirements as well as site requirements to facilitate the inspection.

### Integrity

An approach similar to planning and assessment for the non-instrusive inspection (NII) of pressure vessels is adopted, which is based on the Det Norske Veritas recommended practice, DNV-RPG-103, "Non-Intrusive Inspection." This entails developing a detailed understanding of the degradation threats and associated risks to define the most appropriate inspection strategy, for example, Type A or Type B NII.

Type A inspection applies in situations where there is a low probability of degradation based on previous inspection history. Type B inspection applies when there is some degradation but it is not expected to be severe enough to threaten integrity in the medium term. Detailed inspection requirements such as determining the probability of detection, accuracy and coverage are then defined for each zone of the tank. Finally, inspection plans, defining the inspection technique(s), coverage and locations for inspection are developed.

Fig. 1: Steps for in-service tank-floor inspection.
Figures courtesy of the authors unless otherwise noted.

## Screening

Prior to the robotic inspection, short-range ultrasonic testing (SRUT) is used to screen the annular ring for any degradation. As part of the screening step, acoustic emission (AE) is also deployed with the view of capturing the high-activity region and help to evaluate which type of inspection should be applied, Type A or Type B.

While the AE technology is still under evaluation, the idea is to use AE to confirm that corrosion is not active, in which case, a Type A inspection would be applied. For tanks where a Type B strategy applies, the AE is used to identify areas of corrosion activity for prioritization of coverage for the ultrasonic inspection. This ensures that the sample inspection includes representative areas of corrosion.

## Quantitative Robotic Inspection

By following the previous steps, an inspection strategy and plan can be developed, and with this information, the robotic inspection is then deployed accordingly.

An acoustic navigation system is used to track and reliably locate the position of the robot inside the tank. The robot is also equipped with an array of ultrasonic transducers to capture ultrasonic data from the tank-floor bottom. In a typical tank-floor inspection, millions of ultrasonic signals are captured. A bespoke module has been developed as part of the proprietary integrity management software (SIMS) to reliably and effectively extract wall thickness values from the large number of ultrasonic datasets. SIMS uses advanced signal processing techniques to reliably manage the analysis of the dataset in a short period of time. Once the wall-thickness values have been extracted, they are then used for the statistical evaluation of the tank floor.

## Evaluation

Corrosion has been found to show statistically regular behavior in a wide range of situations including on tank floors. This means that a sampling approach is applicable where the results from a limited coverage inspection can be used to estimate the condition in the areas not inspected.

"Recommended Practice for Statistical Analysis of Inspection Data" was developed by a joint industry project that has been running for more than 30 years and involves more than 40 project partners comprising oil and gas

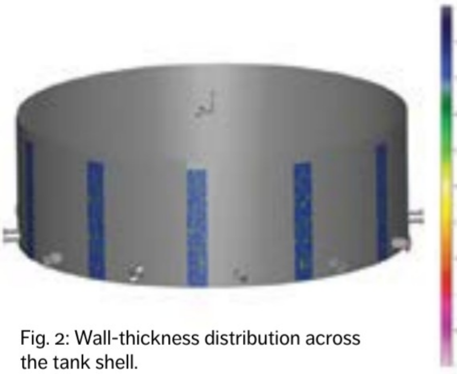


Fig. 2: Wall-thickness distribution across the tank shell.

producers (operators), non-destructive testing (NDT) service companies, NDT equipment vendors and a regulatory authority (UK HSE). The methods in this document are used as a basis for statistical analysis of tank-floor inspection data. This process covers the following.

1. Automated analysis of the data using advanced signal processing algorithms to obtain wall-thickness values.
2. Derivation of wall-thickness distributions.
3. Identification of applicable statistical fit type and parameters.
4. Estimation of minimum wall thickness and probabilities for limiting conditions.

The use of sample inspections supported by statistical analysis conforms to the requirements of API 653 for the internal inspection of tank floors.

The actual evaluation of the wall-thickness values depends on the type of inspection applied. For a Type A inspection, the idea is to confirm the absence of degradation and this is typically done by examining the wall-thickness values extracted from the ultrasonic signals. A Type B inspection uses the wall-thickness values to identify the underlying statistical distribution and then makes minimum remaining wall-thickness estimates of the uninspected area. It is important to note that depending on the inspection performance, extreme value analysis (EVA) can be used for evaluation. Using the estimates of the minimum wall thickness, the remaining life assessment is derived.

**Fitness For Service (FFS) and Remaining Life Assessment (RLA)**

A key aim of the novel inspection service is to provide information that allows effective integrity management decisions to be made and supports clients' integrity requirements by providing FFS and RLA based on inspection data collected in the field. In the case of tanks, this covers complete assessments in accordance with API 653 or EEMUA 159 and includes all levels of assessment from simple hand-calculation checks on remaining wall thickness through to advanced non-linear, finite element analysis in accordance with the Level 3 requirements of API 579, "Fitness-For-Service" (Fig. 2). A key part of the approach to FFS assessment is the application of statistical methods where the inspection has been performed on a sampling basis, as detailed in the previous section. The FFS and RLA are used to make recommendations on any repair and maintenance requirements, as well as defining future inspection intervals.

The FFS capability applies to tanks as well as other equipment found on tank farms such as pressure vessels, pipework and pipelines.

## CLEANING OF STORAGE TANKS

Sludge can be treated in a number of ways. It can be locally disturbed to clear a space for the ultrasonic inspection or be marshalled into a particular location in the tank. The sludge can also be mixed in with the product higher up in the tank, pumped from the floor to the roof manway and then into temporary tankage for treatment or into a neighboring tank.

## SUMMARY

Difficult-to-reach locations and challenging conditions require innovative solutions that are guaranteed to work. By combining screening techniques with immediate inspection of areas of concern, inspection times can be intelligently reduced to focus on getting detailed information from the areas of the plant that need attention. Accurate data enables informed decisions on continued service or replacement.

A major advantage of this novel testing procedure is that it was an iterative process whereby a tank-farm operator could screen all of the tanks and identify which were detected as the worst. On opening the tank and carrying out full base-plate inspection, it would be possible to check the model to see how accurate it was and by the time the third tank had completed its full inspection, the model would be fairly accurate and could be used in the future with more certainly.

## ABOUT THE AUTHORS

Ian Daniel is a business development manager with Sonomatic Ltd. He has over 30 years of experience in inspection management, materials testing, inspection and NDT in both technical and application roles.

Mark Stone is the integrity support services manager with Sonomatic Ltd. responsible for developing the company's integrity capability and leading a team delivering innovative integrity-related services to clients worldwide. He has an honors degree and a Ph.D. in mechanical engineering and over 25 years of experience in integrity engineering and NDT. Stone has authored two joint-industry publications, *Recommended Practices on Non-Intrusive Inspection* and *Statistical Analysis of Inspection Data*. ***JPCL***

# SSPC Organizational Members as of July 25, 2018

**Council of Facility Owners**
***Patron Members***
Air Force Civil Engineer Center
Aker Philadelphia Shipyard
BAE Systems Hawaii Shipyards
BAE Systems Jacksonville Ship Repair, LLC
BAE Systems Norfolk Ship Repair
Bath Iron Works
Bay Ship & Yacht Co.
BC Hydro
Bollinger Shipyards
CB&I, LLC
Central AZ Water Conservation Dist.
Chesapeake Shipbuilding Corporation
Chevron Energy and Technology
City of Virginia Beach
Colonna's Shipyard, Inc.
Continental Maritime Of San Diego
Corrosion Control Inc.
Defence Science & Technology Group
Energy Northwest
GE Power Conversion
Grant County Public Utility District
Gunderson, LLC
Hirschfeld Industries Bridge
Huntington Ingalls (Pascagoula)
Illinois Dept. Of Transportation
Indiana Department of Transportation
Kentucky Transportation Cabinet
Louisiana Department of Transportation & Development
Lyon Shipyard, Inc.
Maine Department of Transportation
Marine Engineers Corporation (MEC Shipyards)
Marinette Marine Corporation
Marisco Ltd.
Maryland State Highway Administration
Minnesota Department of Transportation
MODOT Maintenance Operations
Monroe County Water Authority
National Steel & Shipbuilding Co.
NAVFAC EXWC
Norfolk Naval Shipyard Code 200
Norfolk Naval Shipyard Production Department
North Carolina DOT
NYC School Construction Authority
Ohio Department of Transportation Central Office
Oklahoma Dept. of Transportation
Pacific Ship Repair & Fabrication, Inc.
Pacific Shipyards International
Pearl Harbor Naval Shipyard & IMF
Pennsylvania Department of Transportation Materials & Testing
Port of Seattle - Marine Maintenance
Portsmouth Naval Shipyard Code 250
Puget Sound Naval Shipyard II
Puglia Engineering Incorporated DBA Fairhaven Shipyard
Southern Company
Steel Service Corporation
Sumitomo Heavy Industries Marine Engineering
TARDEC MECC TEAM
Texas Department of Transportation
Vigor Industrial LLC
Washington Suburban Sanitary Comm.
West Virginia DOT Division of Highways

**Council of Facility Owners**
***Sustaining Members***
CALTRANS
Golden Gate Bridge Highway & Transportation District
HII Newport News Shipbuilding
HII Newport News Shipbuilding 2
HII Newport News Shipbuilding 3
Marine Hydraulics International Inc.
Pacific Gas & Electric Company
The Port Authority of NY & NJ
Puget Sound Naval Shipyard Shop 71
Sasebo Heavy Industries Company Ltd.
Seaspan ULC
Tennessee Valley Authority
Trinity Industries, Inc.
U.S. Bureau of Reclamation
U.S. Coast Guard

**Industrial Affiliate Members**
AkzoNobel
Bechtel Corporation
Benjamin Moore & Company
CAL Inc.
Carboline Company
Carlisle Fluid Technologies
Corrpro Companies, Inc.
Covestro LLC
Finishing Trades Institute (FTI)
Greenman-Pedersen, Inc.
KTA-Tator, Inc.
PPG Protective and Marine Coatings
Sherwin-Williams Company
Smartcoat- Engenharia em Revestimentis Ltda.
Tnemec Company, Inc.

**Patron Members**
360 Construction Company Inc.
3X Engineering
446 Painting LLC
A & S Industrial Coatings
ABC Applicators, Inc.
Aberfoyle Metal Treaters Ltd.
Abrasive Blasting & Coating, Inc.
Abrasive Blasting Service & Supplies Pty Ltd
Abu Dhabi Construction Company LLC
Access and Coating Group
Access Coating
Acero Tecnologia S.A. de C.V.
ADF Group Inc.
Advance Coating Solutions Inc.
Advanced Industrial Services LLC
Advanced Industrial Services, Inc.
Advanced Polymer Coatings, Ltd.
Advanced Recycling Systems, LLC
Advanced Surface Finishing Inc.
Advantage Steel & Construction LLC
AEIS, LLC
Afendi Manufacturing Corp.
Ahern Painting Contractors, Inc.
Air Systems International
AirTech Spray Systems
AIS Group
Akzo Nobel International Paint (Suzhou) Co., Ltd.
AkzoNobel - UK
Akzonobel UAE Paints LLC
Alabama Painting, Inc.
Alfa Egypt Academy
Algoma Contractors Inc.
All Set Services LLC
All-Safe Industrial Services, Inc.
All-States Painting, Inc.
Allied Painting Inc.
Allied Research Technology, Inc.
Allnex USA Inc.
Alpaccess
Alpha Painting and Construction Company, Inc.
ALS Industrial Services
Amari Painting & Lining LLC
American Coatings Association
American Suncraft Construction
American Tank & Vessel, Inc.
American Venture Construction LLC
AMP UNITED, LLC
Amstar Of Western New York
Anchor Paint Mfg. Co.
Anka Painting Company, Inc.
Apave See
APBN Inc.
APE Companies
API Distribution
Applewood Painting Co.
Applied Coatings & Linings, Inc.
Applied Corrosion Technology Co. LLC
Applus RTD
Ar-Tech Coating Ltd.
Arena Maintenance Solutions, LLC
Arena Painting Contractors, Inc. (APC)
Arid-Dry By CDIMS
Arizona Coating Applicators, Inc.
Astron General Contracting Co., Inc.
Atlantic Design Inc.
Atlantic Painting Co., Inc.
Atlas Painting & Sheeting Corp.
Atmosheric Plasma Solutions, Inc.
The Aulson Company, Inc.
The Aulson Company, LLC
Austin Hayes Ltd
Automatic Coating Ltd.
Axxiom Manufacturing Inc.
AZZ Metal Coatings
Babcock & Wilcox Universal, Inc.
Barton International
Bay Metals & Fabrication, Inc.
Baytown Painting & Marine Repair, Inc.
Bazan Painting Company
Bellemare Group
Belzona Polymerics Limited
Bender CCP, Inc.
Best Transformer
Bilton Welding & Manufacturing Ltd.
Black Bear Coatings & Concrete
Blake's Painting
Blastco Inc.
Blastech Enterprises, Inc.
Blasting Experts Ltd.
The Blastman Coatings Ltd.
BlastOne International
Blendex Industrial Corporation
Brace Integrated Systems
Bradleys Metal Finishers
Bridges R Us Painting Co., Inc.
Brother's Specialized Coating Systems Ltd.
Bullard Co.
Burleigh Industries
BYK Additives & Instruments
C.E. Adkins & Son Inc.
C.S.I. SA.
C.W. Beal, Inc.
C3 Industrial Blasting & Coatings Inc.
Cabrillo Enterprises, Inc. dba-R.W. Little Company
Cactus Coatings Ltd.
Cahill Heating
Caid Industries Inc.
Cake Commercial Services Ltd.
Caldwell Tanks, Inc.
California Engineering Contractors, Inc.
Caligari Gerloff Painting, Inc.
Cambridge International Systems, Inc.
Campbell Consulting Services, Inc.
CanAm Minerals/Kleen Blast Abrasives
Cape Environmental Management Inc.
Capital Industrial Coatings, LLC
Capitol Finishes, Inc.
Cardolite Corporation
Carneys Point Metal Processing, Inc.
Carolina Growler, Inc. (DBA Growler Manufacturing and Engineering BHG)
Carolina Painting Company, Inc.
Cassidy Painting Inc.
CB Tech Services, Inc.
CDE Construction, Inc.
Cdph, Child Lead Poisoning Prevention Branch
CDV Industrial EIRL
Cekra Inc
Central Sandblasting Company, Inc.
Century Industrial Coatings
CESCO/Aqua Miser
The Chemours Company
The Chemquest Group
Chicago Area Painting Apprenticeship School
Chlomil, Inc. Dba Phoenix Maintenance Coatings
CHLOR RID International, Inc.
Church & Dwight Company, Inc.
Cianbro Corporation
Cimolai Spa
Cives Steel Company, Midwest Division
Civil Coatings and Construction Inc.

# SSPC ORGANIZATIONAL MEMBERS

Clara Industrial Services Limited
Clark & Pattison (BC) Ltd.
Classic Protective Coatings, Inc.
Cleanblast, LLC
Clemtex, Inc.
CMP Coatings, Inc.
Coast To Coast Coatings, Inc.
Coastal Cleaning LLC
Coatek Engineering
Coating Services, Inc.
Coating Solutions, LLC
Coating Systems, Inc.
Coatings & Painting, LLC
Coatings Unlimited Inc. (Wa)
Coatings Unlimited, Inc.
Coblaco Services, Inc.
Cold Jet LLC
College of the North Atlantic
Colonial Surface Solutions, Inc.
Color Works Painting, Inc.
Colorado Lining International
Commercial Sand Blasting & Painting
Commercial Sandblast Company
Commodore Construction Corp.
Commodore Maintenance Corp.
Consulex
Copia Specialty Contractor, Inc.
Corcon, Inc.
Core Industrial LLC
Corporacion Mara S.A.
Corporacion Peruana de Productos Quimicos SA
Cortec Corporation
Cosmos Comprehensive Construction, Inc.
Crescent Coatings & Services, Inc.
Crown Painting, Inc.
CRP Industrial
Crystal Coast Industrial Coatings
CSI Services, Inc.
CTL Group
CTS Substrate and Flooring
Custom Abrasives, LLC
CV Associates NY
Cypress Bayou Industrial Painting, Inc.
D & M Painting Corp
D F Coatings Ltd.
D.H. Charles Engineering, Inc.
DACA Specialty Services
Dampney Company, Inc.
Danos
Darran Green Sandblasting & Painting
Daubert Chemical Company
Davis Boat Works, Inc.
Dawson-Macdonald Company, Inc.
De Koning Groep
DECO Coatings, Inc.
Defelsko Corporation
Dehumidification Technologies, LP
Delta Coatings, Inc.
Demaco Corporation
Demos Painting & Decorating, Inc.
Denso North America Inc.
Derochie Painting Ltd.
Derrick Company Inc.
Desco Manufacturing Company, Inc.
Detroit Tarpaulin, Inc.
Devco Sandblasting & Industrial Coating, Inc.
Diamond Vogel Paint Company
Distribuidora Kroma S.A. De C.V.
Diversified Project Services International Inc. (DPSI)
Dixon Engineering, Inc.
DLG Coatings Inc.
DMB Production Dooel Prilep
DocoPro Ltd
Dogus Vana ve Dokum San. Tic. A.S.
Doosan Portable Power
Drytec Trans Canada
DSL Caspian LLP
Dubai Coating Limited
Dudick Inc.
Dun-Right Services
Duncan Galvanizing Corporation
Dupont Protection Solutions
Dur-A-Flex, Inc.
Dura-Bond Pipe, LLC
E. Caligari & Son, Inc.
Eagle Industrial Painting LLC.
Eagle Painting & Maintenance Co.
Eagle Specialty Coatings
Ease Painting and Construction, Inc.
East Coast Repair & Fabrication
Eastern Shipbuilding Group
Easy Kleen Pressure Systems
ECOBOND LBP LLC
Edeco Peru S.A.C.
Elcometer
Elite Contractors, Inc.
Elite Industrial Painting, Inc.
EMI International LLC
Endisys
Ensafe: Institute for Health, Safety and Counseling Training, LTD
Entech Industries, LLC
Environmental Planning & Management, Inc.
Envirosafe Stripping Inc.
EPAcoat, Inc.
Epsilon Systems Solutions
Era Valdivia Contractors, Inc.
Erie Painting and Maintenance, Inc.
Ervin Industries, Inc.
ESC Al Sharafi Group (Middle East)
ESCA Blast
ESMETAL SAC
Estrutural - Servicos Industriais Ltda.
Euro Paint LLC
Euro Style Management, Inc.
Excel Engineering & Contracting Co.
Exceletech Coating and Applications, LLC
Extreme Coatings, Inc.
Extreme Sandblasting and Painting
F.T.I. District Council 57 J.A.T.F.
Farr Construction Corporation
Farwest Corrosion Control Company
FCS Group LLC
Fedco Paints and Contracts
FeO
FI Coatings Ltd
Fine Painting and Allied Services, LLC.
Finishing Systems of Florida, Inc.
Finishing Trades Institute of New England
Finishing Trades Institute of Western & Central New York
Fischer Technology, Inc.
Fixxus Industrial Holdings Company, LLC
Forecast Sales
Forensic Analytical Consulting Services
Forjak Industrial
Forrest Services LLC.
Fought & Company, Inc.
Frontier Welded Products Inc.
FS Solutions
FTI Of DC 77
Fuels Infrastructure, Inc.
Future DB International Inc.
Future Labs, LLC.
G & S Manufacturing LLC
Gaditana de Chorro Y Limpieza, S.L.
Gapvax Inc.
Garden State Council, Inc.
Gateco, Inc. DBA Gateway Industrial Services
The Gateway Company
Gemstone, LLC
General Dynamics NASSCO - Mayport
General Dynamics/Information Tech.
Genesis Environmental Solutions, Inc.
George G. Sharp, Inc.
Global Coatings, LLC
Global Contracting LLC
Global Inspection Group LLC
GMA Garnet (USA) Corp.
GMA Industries
GMAG Services
Goldenwest Painting Inc.
Goodwest Linings and Coatings
GOS Pte. Ltd.
Gracie Painting LLC
Green Diamond Sand Products
Greener Blast Technologies
Greer Steel
Griffiths Inspection & Training Services Ltd
Groome Industrial Service Group
Gulf Coast Contracting, LLC
H & H Protective Coatings
H D Water Jetting
H-I-S Coatings
H.I.S. Painting, Inc.
Hames Contracting, Inc.
Hancock Sandblast & Paint LLC
Hardesty & Hanover Construction Services LLC
Harrison Muir, Inc.
Hartman-Walsh Painting Company
HCI Chemtec Inc.
HCI Industrial & Marine Coatings Inc.
HDM Spiral Kaynakli Celik Boru A.S. / HDM Steel Pipe
HDR
Henkel
Henkels & McCoy
Herc Rentals
Hercules Painting Company
Hi-Tech Surface Treatment Ltd.
Highland International, Inc.
HIPPO Multipower
Hippwrap Containment
HiTech Painting Inc.
Hitech Projects Trading & Contracting W.L.L.
HJC Protective Coatings Ltd.
Holdtight Solutions Inc.
Honest Horse China Holding Limited / Jinan Junda Industrial Technology Co., Ltd.
Honolulu Painting Company, Ltd.
Howell & Howell Contractors, Inc.
HRV Conformance Verification Associates, Inc.
Hulsey Contracting Inc.
Hunnicutt's, Inc.
Huntsman Polyurethanes
HVEA Engineers
IBIX North America
IDS Blast Finishing
Impresa Donelli, S.R.L.
In-Spec Corporation Pte Ltd
Independent Specialized Inspection LLC
Indian Valley Industries, Inc.
InduMar Products, Inc.
Induron Coatings, Inc.
Industrial Access, Inc.
Industrial Corrosion Control, Inc.
Industrial de Acabados
Industrial Marine, Inc.
Industrial Painting Limited, Inc.
Industrial Painting Specialists
Industrial Technical Coatings, Inc.
Industrial Vacuum Equipment Corp.
Infrastructure Coatings (Ontario Corporation)
Ingress Partners
Innovative Asset Solutions PTY LTD (IAS Group)
Insulating Coatings Corporation
Intech Contracting LLC
Integrity Defense Services Inc.
Inter-City Contracting, Inc.
International Flooring & Protective Coatings, Inc.
International Rigging Group, LLC.
Interpaints SAC
Interstate Painting Company
Intertek Industry Services
Ionion Painting
IPAC Services Corporation
Iron Bridge Constructors, Inc.
ISTI Plant Services
IUPAT
IUPAT, District Council #5
J. Goodison Company, Inc.
J. Mori Painting Inc.
J.S. Held LLC
Jack Tighe Ltd.
Jade Painting
Jag'd Construction, Inc.
Jal Engineers Pvt. Ltd.
Jamac Painting & Sandblasting Ltd.
The JD Russell Company
Jeffco Painting & Coating, Inc.
Jerry Thompson & Sons, Inc.
Jet De Sable Houle Sandblasting Ltd.
JK Industries, Inc.
John B. Conomos, Inc.

John W. Egan Company, Inc.
Johnson, Mirmiran & Thompson, Inc.
Jollyflex
Jos. Ward Painting Co.
JSC Sewon Vertex Heavy Industry
Jupiter Painting Contracting Co Inc.
K + N Finishers (Southern) Ltd.
Kaloutas + Co., Inc.
Kane, Inc.
KBI Painting Inc.
Keene Coatings Corp.
Keensafe Training Limited
Kelson & Kelson Ltd
Kennametal Inc.
Kern Steel Fabrication, Inc.
Kimery Painting, Inc.
Kiska Construction, Inc. (KCI)
Klicos Painting Company, Inc.
KMX Painting, Inc.
Knowles Industrial Service Corporation
Kolona Painting & General Construction, Inc.
Kordata
Koster American Corp.
KS Fabrication & Machine
KVK Contracting Inc.
L & L Painting Company Inc.
L Z Painting Co.
L. Calvin Jones
L. F. Clavin & Company, Inc.
L&M Fabrication & Machine, Inc.
Lambton Metal Service
Langtry Blast Technologies Inc.
Lanza Paint Works, Inc.
Ledcor Fabrication Inc.
Ledwood Protective Coatings Ltd
Legend Painting, Inc.
Lesoon Equipment Pte Ltd.
Level 3 Coating Inspection, LLC
Liberty Maintenance, Inc.
LifeLast
Limnes Corp.
Lindner Painting, Inc.
Liuna Canadian Tri-Fund
Llamas Coatings
Loonglobal Engineering Pte Ltd
Lopes Ltd.
Luoyang Hongfeng Abrasives Co., Ltd.
M & D Coatings Inc.
M & J Construction Company
M. Painting Company, Inc.
M. Pallonji & Company Pvt. Ltd.
MacDonald Applicators Ltd.
Magnum Drywall Inc.
Manda Corporation
Manolis Painting Company, Inc.
Manta Industrial, Inc.
Manta Industrial, Inc.: Mansfield Industrial
Manus Abrasive Systems, Inc.
Manz Contracting Services Inc.
Marathon Industrial Finishing LLC
Marcom Services, LLC
Marine Equipment Supply (MES), LLC
Marine Group Boat Works
Marine Metal Coatings, Inc.
Marine Publications International (MPI Group)
Marine Specialty Painting
Marinis Bros., Inc.
Marunda Utama Engineering Pte Ltd
Mass Coating Corp
Massy Energy Fabric Maintenance Limited
Matheson Painting
Maxon Technologies LLC
Maxworth Minerals India Pvt Ltd
MB Environmental Consulting
McCormick Industrial Abatement Services, Inc.
McCormick Painting Company
McKay Lodge Conservation Laboratory
Mcloughlin Industrial Flooring Limited
Merrill Steel, Inc.
Metallisation Ltd.
Michigan Specialty Coatings, Inc.
MIK Industrial LLC
Mineral Tech, LLC
Minerals Research, Inc.
MMLJ, Inc.
Mobile Pipe Lining and Coating Inc.
Modern Protective Coatings, Inc.
Monoko, LLC
MONTI - Werkzeuge GmbH
Monti Tools Inc.
Montipower Inc.
Morimatsu (Jiangsu) Heavy Industry Co. Ltd. (JMH)
Morin Industrial Coatings Ltd.
MSB Marine Surveyors Bureau S.A.
MST Inc (Modern Safety Techniques)
Muehlhan Cyprus Ltd
Municipal Tank Coatings
Murphy Industrial Coatings
N A Logan, Inc.
N. I. Spanos Painting, Inc.
Nantong Fuchen Tank Co., Ltd
Napier Sandblasting (NSB Insfrastructure)
National Coating and Linings Co.
National Coatings, Inc.
National Equipment Corporation
Natrium Products, Inc.
Naval and Industrial Solutions S.A.
Negocios Metalurgicos SAC
Nelson Industrial Services, Inc.
New England Sandblasting and Painting
New Kent Coatings Inc.
NexTec Inc./PreTox
Niagara Coatings Services, Inc.
Nielson, Wojtowicz, Neu & Associates
Nisku Industrial Coatings Ltd.
NOR-LAG Coatings Ltd.
Nordstrong Equipment Limited
Norfolk Coating Services, LLC
Northwest Sandblast & Paint LLC
Norton Sandblasting Equipment
Novatek Corporation
Nu Way Industrial Waste Management LLC
NUCO Painting Corporation
Nusteel Fabricators, Inc.
Nut Communication & Marketing Strategies
Nyhus Enterprises, LLC
O.T. Neighoff & Sons, Inc.
Odle, Inc.
Offshore Painting Services LTD
Oil Patch Sandblast & Paint Ltd.
Old Colony Construction, LLC.
Olimag Sand, Inc.
Olympus and Associates, Inc.
Olympus Painting Contractors, Inc.
Olympus Painting, LLC
Omega Coatings & Construction, LLC
Ontario Painting Contractors Association
Opti-Blast Inc.
Optimiza Protective & Consulting, Sl.
Orfanos Contractors, Inc.
P & L Metalcrafts LLC
P & W Painting Contractors Inc.
P S Bruckel Inc
P.C.I. International, Inc.
Pacific High Technology Engineering Services
Pacific Painting Co. Inc.
Pacific Titan, Inc.
Paige Decking
Paige Floor Covering Specialists
Paint and Coatings Manufacturers Nigeria PLC
Paint Platoon USA & Coatings Inspectors
Paint Supply Company
Painters & Allied Trades - LMCI
Painters USA, Inc.
Panco Resources and Engineering Consultancy Services
Panther Industrial Painting, LLC
Park Derochie (Seaside) Coatings Inc.
Park Derochie Coatings (Saskatchewan) Inc.
Park Derochie, Inc.
Partner Industrial, LP
Paul N. Gardner Company, Inc.
PCI - Performance Contracting Inc.
PCIROADS, LLC.
Peabody & Associates, Inc.
Peak Industrial Coatings & Linings, Inc.
Pelco Structural, LLC
Penington Painting Company
Performance Blasting & Coating
Performance Industrial
Perupaint SAC
Phillips Industrial Services Corp.
Phoenix Australasia
Phoenix Fabricators & Erectors LLC
Piasecki Steel Construction Corp
Pinnacle Central Company
Planet Inc
Platypus Marine, Inc.
Pond & Company
Pop's Painting, Inc.
Poseidon Construction
PRA Coatings Technology Centre
Precision Welding & Fabrication
Preferred, Inc.-Fort Wayne
Prezioso Nigeria (Insulation Painting & Engineering Services Ltd)
Prime Coatings, Inc.
Prime Time Coatings, Inc.
Principle Industrial Services, LLC
Pro-Tect Plastic & Supply, Inc.
Prospectrum Coatings Bvba
Pt Berger Batam
Public Utilities Maintenance, Inc.
Puget Sound Coatings Inc.
Purcell P & C, LLC
Pyeroy
PYR Preservation Services, Inc. dba PYR
QED Systems, Inc.
Qualicoat Inc.
Quality Linings & Painting, Inc.
Quantum Technical Services
Quincy Industrial Painting Co
Quinn Consulting Services, Inc.
R & B Protective Coatings, Inc.
R & S Steel, LLC
R. J. Forbes Painting Contractor Inc.
R.B. Hilton Limited
Rader Coating Technology (Shanghai) Co., Ltd.
Rainbow, Inc.
RAK Paints LLC
Randell Industrial Services Ltd
Rapid-Prep, LLC
Raven Lining Systems
Ravi Engineering & Land Surveying, P.C.
Rawhide Construction Service
Raydar, Inc.
RBG Trinidad and Tobago Limited
RBW Enterprises
Recal Recubrimientos, SA De CV
Redi-Strip Metal Cleaning Canada Ltd
Regal Industrial Corporation
Reglas Painting Company, Inc.
Reichle Incorporated
Revolution Industrial Coatings
Rhino Linings Corporation
Rhinoceros Ltd.
Righter Group, Inc.
Ring Power Corporation
Rizzo Brothers Painting Contractors Inc.
Robroy Industries
Rogers Industries, LLC
Ross Rex Industrial Painters Ltd
Rotha Contracting Company, Inc.
Rover Contracting Inc.
Royal Bridge Inc.
Rpn Recubrimientos Polymericos Del Noroeste Sa De Cv
S & D Industrial Painting Inc
S & S Bridge Painting, Inc.
S & S Coatings, Inc.
S. David & Company, LLC.
Sabelhaus West, Inc.
SAFE Systems, Inc.
Safespan Platform Systems, Inc.
Safety Lamp of Houston
Saffo Contractors, Inc.
Safway Services LLC
Sahara Sandblasting and Painting Ltd
Samac Painting
San-Blast-Ture
Sand Express
SARL EPI-CA
Sasyma Coatings SL
Sauereisen
Saxon Enterprises
SBAS Training Services
Scicon Worldwide BVBA

## SSPC ORGANIZATIONAL MEMBERS

SDB Engineers & Constructors Inc.
Seal For Life Industries LLC.
Seaway Painting LLC
Secondary Services, Inc.
See Hup Seng Cp Pte. Ltd.
Seifert Construction Inc.
Seminole Equipment, Inc.
SES Infrastructure Services LLC
Shanghai Genesis Chemmical Industry Co. Ltd.
Shanghai Sezhe Trading Co., Ltd
Shanghai Zenhua Heavy Industries Co. Ltd
Shenzhen Asianway Corrosion Protection Engineering Co., Ltd.
Sherwin-Williams Industrial & Marine Coating China
Shimmick Construction
Sil Industrial Minerals, Inc.
Silverline Finishing, Inc.
Simpson Sandblasting and Special Coatings, Inc.
Sky Climber Access Solutions
Skyline Painting, Inc.
Skyline Steel LLC
SME Steel Contractors
Soil & Materials Engineers, Inc.
Solent Protective Coatings Ltd
Southeast Bridge FL Corp.
Southern Paint & Waterproofing Co.
Southern Painting & Blasting, LLC
Southern Road & Bridge, LLC
Southland Painting Corporation
Spartan Contracting, LLC
Special Equipment Safety Supervision Inspection Institute of Jiangsu Province
Specialist Painting Group
Specialty Application Services, Inc.
Specialty Finishes, LLC
Specialty Groups, Inc.
Specialty Polymer Coatings, Inc.
Specialty Products, Inc.
Spectrum Painting Ltd
Spider
Spiegel Industrial
Sponge-Jet, Inc.
SRI Construction LLC
SRT Sales and Service, LLC
Stantec
Steel Fabricators of Monroe, LLC
Steel Management Systems, LLC
Sto Corp
Stork Technical Services
Structural Coatings, Inc.
Sullivan-Palatek, Inc.
Sulzer Mixpac USA, Inc.
Superior Industrial Maintenance Co.
Superior Painting Company, Inc.
SuperVac Truck & More, Inc.
Surface Preparation & Coatings, LLC
Swanson & Youngdale, Inc.
Symmetric Painting, LLC
T & W Industrial Services LLC.
T BAILEY, Inc.
T-Tex Equipment L.P.
Tank Services Inc.
Tarps Manufacturing, Inc.
Taylor's Industrial Coatings, Inc.
TCI Powder Coatings
TDJ Group, Inc.
Team Industries, Inc.
TECHNIJA II
Techno Coatings, Inc.
Technofink
Tecnicas Metalicas Ingenieros S.A.C.
Tecnico Corporation
Temp-Coat Brand Products, LLC
Termobarranquilla S.A. E.S.P.
Terry Mcgill Inc.
Tesla Nanocoatings, Inc.
Testex, Inc.
Textured Coatings of America, Inc.
Thomarios
Thompson Pipe Group - Pressure
TIB Chemicals AG
Tidal Corrosion Services LLC
Tidewater Staffing, Inc.
Tinker & Rasor
Tioga Air Heaters, LLC.
Titan Industrial Services
Titan Tool
TJC Painting Contractors, Inc.
TMI Coatings, Inc.
TMS Metalizing Systems, Ltd.
Tower Inspection Inc.
Tower Maintenance Corp.
Tower Power Group Painting Co. Ltd.
TQC B.V.
Tractel Inc. Griphoist Division
Travis Industries, LLC
TRB Industrial Coatings Inc.
TRC Engineers, Inc.
Tri-State Painting, LLC
Trinity Industries de Mexico S. de R. L. de C.V.
Triple H Construction, Inc.
True Inspection Services
TruQC LLC
Turman Commercial Painters
Turner Coatings LLC
Turner Industries Group, LLC
Twilight S.A. De C.V.
U.S. Tank Painting, Inc.
UHP Projects, Inc.
Ultimate Linings (formerly Ameraguard Protective Coatings)
Uni-Ram Corporation
Uniteam Training
University of Akron / NCERCAMP
US Coatings, Inc.
US Minerals/Stan Blast
Utility Service Company, Inc.
Valentus Specialty Chemicals
Van Air Systems
Vanwin Coatings of VA, LLC
Vector Technologies Ltd.
Veritas Steel LLC.
VersaFlex Incorporated
Ville Platte Iron Works, Inc.
Vima Construction Corp.
Vimas Painting Co., Inc.
Vision Point Systems
Vulcan Painters, Inc.
W Abrasives
W G Beaumont & Son Ltd
W Q Watters Company
W S Bunch Company
W W Enroughty & Son, Inc.
The Warehouse Rentals and Supplies
Wartsila Defense, Inc.
Wasser High-Tech Coatings, Inc.
Waterblasting Technologies
Weir Valves and Controls UK ltd
Wenrich Painting, Inc.
West Coast Industrial Coatings
Western Industrial Services, Ltd
Western Partitions, Inc. DBA, WPI
Wheelblast, Inc.
WIWA LP
Worldwide Industries, Inc.
Worth Contracting, Inc.
Woyt Industries, LLC
Xi'An Jing-Jian Paint & Coatings Group
Yankee Fiber Control, Inc.
Yellow Creek Coating Services
YYK Enterprises, Inc.
Zachry Industrial, Inc.
Zack Painting Company, Inc.
Zebron Corporation
Zibo TAA Metal Technology Co., Ltd
Ziegler Industries Inc.
Zingametall BVBA
Zirtec Industria & Comercio LTDA
ZRC Worldwide

**Sustaining Members**

I625820 Alberta Ltd. O/A Propaint
Abhe & Svoboda, Inc.
Allen Blasting & Coating, Inc.
Alpine Painting & Sandblasting Contractors
American Institute of Steel Construction (AISC)
Argus Contracting, LP
Arkansas Painting & Specialties, Inc.
ASCO - American Stripping Company
Atsalis Brothers Painting Co.
Avalotis Corporation
Brand Industrial Services
Brock Services, LLC
C.A. Hull
Cannon Sline Industrial
Certified Coatings Company
Champion Painting Specialty Services Corp.
Clemco Industries Corp.
Cloverdale Paint, Inc.
Consolidated Pipe and Supply, Inc.
Cor-Ray Painting Co.
Corrosion Resistance
DBM Services, Inc.
Delta Sandblasting Co, Inc.
Deltak Environmental Coating Services, Inc.
Demilec USA
Dex-O-Tex Division Crossfield Products Corp.
Dow Chemical Company
DSI - A Safway Company
Dunkin & Bush, Inc.
Dunn-Edwards Corporation
Eagle Industries
Endura Manufacturing Company Ltd.
Ergonarmor
Evonik Corporation (ECA)
F.D. Thomas, Inc.
FCA International
Fletch'S Sandblasting & Painting, Inc.
G.C. Zarnas & Company, Inc.
General Dynamics NASSCO- Norfolk
Harsco Metals & Minerals
Hempel USA, Inc.
High Steel Structures, Inc.
Industrial Coatings Contractors, Inc.
International Marine and Industrial Applicators LLC
Jotun Paints, Inc.
King Industries, Inc.
Landmark Structures
Line-X Corp.
Long Painting Company
Los Angeles Painting and Finishing Contractors Association (LAPFCA)
Main Industries Inc.
Mandros Painting, Inc.
Manufacturas Metalicas AJAX, SA de C.V.
Marco
MC Painting
Mid-Atlantic Coatings, Inc.
Mistras Group Inc.
MOBLEYSAFWAY Solutions, LLC
Mohawk Northeast, Inc.
National Bridge LLC
Naval Coating, Inc.
North American Coatings CI Coatings Division
North Star Painting Co., Inc.
Northwest Sandblasting & Painting, Inc.
Odyssey Contracting Corporation
OEngenharia LTDA.
Olympic Enterprises Inc.
Olympos Painting Inc.
Ostrom Painting & Sandblasting, Inc.
Polygon
Pro Blast Technology Inc.
Pro Tank - Professional Tank Cleaning & Sandblasting
Profile Finishing Systems, Inc.
Quality Coatings of Virginia, Inc.
Quillopo Painting Inc.
Redwood Painting Company, Inc.
Regional Coating Solutions Inc
Rust-Oleum Corporation
San Diego Protective Coatings Inc.
Scott Derr Painting Co. LLC
Shinko Company Ltd.
Shopwerks Inc.
South Bay Sand Blasting & Tank Cleaning
Sprayroq Inc.
Stebbins Engineering & Mfg. Co.
StonCor Group/Carboline Canada
Surface Technologies Corporation
T. F. Warren Group
Tank Industry Consultants, Inc.
Termarust Technologies
TruAbrasives by Strategic Materials
TSC Training Academy
Unified Field Services Corporation
Williams Specialty Services, LLC

## API 653

The American Petroleum Institute standard requirements that in-service tank interior inspections conform to.
See page 42.

## $5.5 billion

The monetary estimate that aircraft and missile corrosion maintenance costs the U.S. Air Force each fiscal year, as per a 2016 "Impact of Corrosion" study.
See page 32.

## 1964

The year that Clive Hare, longtime *JPCL* columnist and coating-chemistry expert, moved from England to the U.S. to begin his career in coatings. Hare passed away on July 14th of this year.
See page 15.

## -50 C (-58 F)

The low temperature at which a novel epoxy amine PFP system has performed well on simple modular and stick-built structures.
See page 20.

## 29 CFR 1926.1153

The final silica rule now being enforced by OSHA due to the hazard of silicosis.
See page 10.