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SSPC The Society For Protective Coatings
The Voice of SSPC: The Society for Protective Coatings

Cover photo courtesy of Dr. Yasir Idlibi, Jason Hartt, Dr. Mike O'Donoghue, Vijay Datta, MS, and Bill Johnson, AScT.

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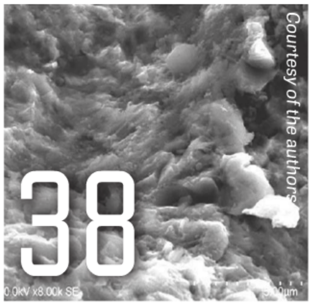
By Dr. Yasir Idlibi, MICHAL Consulting; Jason Hartt, ADANAC Global Testing & Inspection; Dr. Mike O'Donoghue and Vijay Datta, MS, International Paint LLC; and Bill Johnson, AScT, Acuren Group Inc.

Is there such a thing as "blind chance"? Enter the realm of cause and effect and lining performance. Failing to see sulfide contaminants on a so-called ready-to-be-coated steel surface may be like not seeing the bullet in the chamber in a game of Russian roulette — not necessarily good for longevity in either case.



52 SSPC 2017 IN TAMPA: EVENTS AND AWARDS

This section previews the special events and awards scheduled to take place during SSPC 2017 featuring GreenCOAT at the Tampa Convention Center in Tampa, Fla., Jan. 30 to Feb. 2, 2017.

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DEPARTMENTS

FROM THE OFFICES OF SSPC The Society For Protective Coatings

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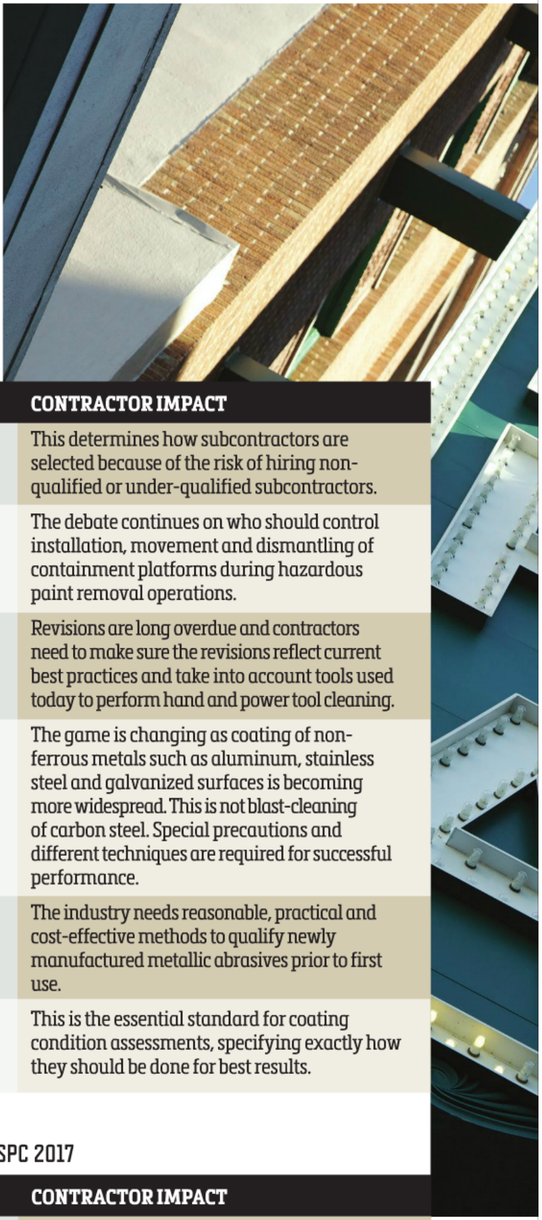

MEETINGS AT SSPC 2017 IN TAMPA WILL IMPACT CONTRACTORS

SSPC 2017 featuring GreenCOAT is about two-and-a-half months away, but that doesn't mean contractors shouldn't start planning to attend. Looking ahead, the reality is that when you account for the holiday season, there are actually fewer than 10 full working weeks before the conference.

Events at the SSPC conference in recent years have demonstrated that being in the room at key meetings is an important part of making sure that your voice is heard and your position is represented on the coatings industry's hot-button technical issues of the day. Again, another reality: the SSPC conference is where those discussions take place. If you're not there, you're simply not part of the process.

Many standards committees will hold meetings at the SSPC show. Standards that are being created, revised and updated will be center stage at these meetings and the opportunity to provide input for some of them will be ending soon. These standards will directly affect the projects that you work on — and in turn, affect your livelihood. You and your company will need to live with these standards when written into future contracts. The best way to register your views is to be present and participate!

The standards revisions that are on tap for SSPC 2017 are listed in Table 1. In addition, standards that will be under

TABLE 1: STANDARD REVISIONS AT SSPC 2017

STANDARD(S)	CONTRACTOR IMPACT
SSPC-QP 1, Standard Procedure for Evaluating the Qualifications of Industrial/Marine Painting Contractors	This determines how subcontractors are selected because of the risk of hiring non-qualified or under-qualified subcontractors.
SSPC-QP 2, Standard Procedure for the Qualification of Painting Contractors	The debate continues on who should control installation, movement and dismantling of containment platforms during hazardous paint removal operations.
SSPC-SP 2, Hand Tool Cleaning SSPC-SP 3, Power Tool Cleaning	Revisions are long overdue and contractors need to make sure the revisions reflect current best practices and take into account tools used today to perform hand and power tool cleaning.
SSPC-SP 16, Brush-Off Blast Cleaning of Coated and Uncoated Galvanized Steel, Stainless Steels, and Non-Ferrous Metal	The game is changing as coating of non-ferrous metals such as aluminum, stainless steel and galvanized surfaces is becoming more widespread. This is not blast-cleaning of carbon steel. Special precautions and different techniques are required for successful performance.
SSPC-AB 3, Ferrous Metallic Abrasives	The industry needs reasonable, practical and cost-effective methods to qualify newly manufactured metallic abrasives prior to first use.
SSPC-PA 5, Guide to Maintenance Coating of Steel Structures in Atmospheric Service	This is the essential standard for coating condition assessments, specifying exactly how they should be done for best results.

TABLE 2: STANDARDS UNDER DEVELOPMENT AT SSPC 2017

STANDARD(S)	CONTRACTOR IMPACT
Surface Area Measurement Preparation of a standard procedure for measurement of surface area for estimating painting, decorating and coating work	This will have a significant impact on how contractor and engineering estimates are performed on industrial coating jobs moving forward.
Surface Preparation of Concrete Development of new standards for cleanliness of concrete substrates following dry abrasive blast cleaning	More concrete than ever is being painted for protection. Learn how it should be done, or tell the committee how to do it if you're already performing surface preparation of concrete successfully.
Commercial Cleaning & Painting Development of standards for evaluating moisture in concrete walls and ceilings, and for classifying frequency of pinholes in coated surfaces	Moisture in concrete has such a huge impact on commercial coating application, that the consequences of failure could be devastating.
Commercial Contractor Qualification Development of a commercial version of the SSPC-ACS 1 standard	This committee is taking CAS to the commercial painting world and setting the standard for the future of worker certification.


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development at SSPC 2017 are listed in Table 2.

As in the past, the Painting Contractor Certification Program (PCCP) Advisory Committee will meet in two sessions: an Open meeting for all interested parties and a Business meeting for committee members. Issues before the committee that are sure to generate long discussions include the SSPC-QP 1 revision, especially as

it relates to subcontractors, and the -QP 2 revision with its related platform issues.

In addition, as outlined in the recent QP Contractor Bulletin, beginning January 1, 2017, QP contractors will be required to have two CAS-certified Level I or II (minimum one Level II – Interim Status) craftworkers to two non-certified craftworkers (50 percent) on each painting crew during blast cleaning and spray application (Atmospheric and Immersion Service). While this issue is well known and QP contractors are already in the position to address it, we expect it to be a popular topic of conversation at SSPC 2017.

Action for contractors isn't just limited to committee meetings. The technical program covers several strong and relevant topics, including the following presentations.

- "Bedevilled Bridges: An Answer to a National Scandal," by Mike O'Donoghue, Ph.D., and Vijay Datta, M.S., International Paint LLC.
- "How to Non-Destructively Measure Dry Film Thickness (DFT) on Concrete Substrates," by Joseph Walker, Elcometer Inc.
- "Up Periscope: Hunting for the Scope of Work," by Troy Fraebel and Chuck Fite, The Sherwin-Williams Company.
- "Maintaining Aged Infrastructure with Difficult to Coat Features," by Allen Skaja, Ph.D., U.S. Bureau of Reclamation.
- "OSHA's New Silica Standard," by Thomas Enger, M.S., CSP, CHMM, Clemco Industries, Corp.
- "Regulatory Update: New and Revised Regulations and Actions Affecting the Coatings Industry," by Alison Kaelin, CQA, ABKaelin, LLC.
- "Ladder Safety: Protecting Workers from a Complex Hazard," by Stanford Liang, Golder Associates, Inc.
- "Avoiding or Resolving Common Problems with Inspectors and Owners Related to Surface Profile on Blasted Steel," by Michael O'Brien, MARK 10 Resource Group, Inc.
- "Blasting Jobsite Project Management Tips," by Brian Kenimer, Blast-One International.

And, of course, there's networking. You can accomplish more face-to-face with people than you can on the phone or via email and text messages. People that you do business with in the coatings industry — the key decision makers who drive industry policy — want to meet you in person. Take a few days out of your busy year to hear the lessons-learned and tricks of the trade that you cannot hear anywhere else.

Finally, a full slate of SSPC training and certification programs are scheduled to be held both before and after the conference, enabling a one-stop-shop for contractors looking to get their employees trained and certified heading into the 2017 painting season. To date, we're planning 28 programs for Tampa. You can see the complete lineup at www.sspc2017.com/training-courses-at-sspc-2016/.

Registration for the conference is now open at www.sspc2017.com. Hotel rooms are still available, but don't wait to reserve yours — they're expected to sell out soon.

OSHA Retaliation Rule Postponed Again

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Implementation of a controversial new rule regarding workplace health and retaliation has again been postponed by the U.S. Department of Labor's Occupational Safety and Health Administration (OSHA). The rescheduling affects portions of the "Improve Tracking of Workplace Injuries and Illnesses Rule." Originally set for enforcement Aug. 10, and later delayed until Nov. 10, the provisions which, in part, prohibit employers from using drug testing or the threat of drug testing as a form of retaliation, have been delayed a second time.

The anti-retaliation measures are now to go into effect Dec. 1, OSHA has announced. However, the reporting provisions of the rule, which require employers to make all injury and illness data public, are still to take effect Jan. 1, 2017.

The delays follow a federal lawsuit, filed by the Associated Builders and Contractors, the National Association of Manufacturers and other groups challenging the provisions and seeking to enjoin the rule's implementation.

OSHA says the second delay was issued at the request of the U.S. District Court for the Northern District of Texas to allow additional time to consider the motion challenging the rule. The previous delay was issued to "allow time for outreach to the regulated community," OSHA said.

"Under the rule, employers are required to inform workers of their right to report work-related injuries and illnesses without fear of retaliation; implement procedures for reporting injuries and illnesses that are reasonable and do not deter workers from reporting; and incorporate the existing statutory prohibition on retaliating against workers for reporting injuries and illnesses," according to OSHA.

One of the main challenges to the rule is that it includes language that restricts some forms of post-accident drug testing. "The final rule does prohibit employers from using drug testing (or the threat of drug testing) as a form of adverse action against employees who report injuries or illnesses," according to OSHA. "To strike the appropriate balance here, drug testing policies should limit post-incident testing to situations in which employee drug use is likely to have contributed to the incident, and for which the drug test can accurately identify impairment caused by drug use."

The language has raised questions as to the types of situations where post-incident drug tests would be unreasonable, as well as how to test for "impairment," as most current testing methods are unable to test for impairment by alcohol, marijuana and other drugs but rather indicate whether levels are present in the employee's system at the time of testing, according to an analysis by The National Law Review.

Further, those groups challenging the rule's anti-retaliation provisions say the measures will likely impact an employer's ability to operate and maintain a safe construction jobsite. The groups also take issue with the agency's "attempt to restrict or eliminate programs that recognize workers for helping to establish a high-performance safety culture," said Greg Sizemore, ABC vice president of Health, Safety, Environment and Workforce Development. While the rule does not prohibit incentive programs, OSHA believes programs, such as bonuses or drawings for prizes offered in an effort to encourage workplace safety, result in the significant underreporting of recordable injuries and could be viewed as an act of retaliation.

"Incentive programs should encourage safe work practices and promote worker participation in safety-related activities," the agency wrote on its FAQ website.

Construction Forecast Predicts Lift for 2017

Public works construction, along with most U.S. building sectors, can expect to see a boost in business in the coming year, according to a major new construction forecast that sees a $713 billion year ahead.

Although electric utilities/gas plant projects are expected to decline and multifamily housing will level off, single-family housing, commercial, institutional and public works sectors are in for a positive year, according to the 2017 Dodge Construction Outlook, from Dodge Data & Analytics (formerly McGraw Hill Construction).

All told, total U.S. construction starts will advance 5 percent in the coming year, following gains of 11 percent in 2015 and an estimated 1 percent in 2016, the forecast says.

"The U.S. construction industry has witnessed signs of deceleration in 2016, following several years of steady growth," Robert Murray, chief economist for Dodge Data & Analytics said in an announcement. "Total construction starts during the first half of this year lagged behind what was reported in 2015, raising some concern that the current construction expansion may have run its course." However, Murray notes that the early 2016 shortfall reflected the comparison to "unusually elevated activity" during the first half of 2015, boosted by 13 very large projects valued each at $1 billion or more, such as a $9 billion liquefied natural gas export terminal in Texas and a $2.5 billion office tower in New York City.

Public works construction is expected to improve 6 percent, regaining momentum after falling 3 percent in 2016, according to the forecast. Highway and bridge construction are expected to derive support from the new federal transportation bill, while environmental works should benefit from the expected passage of the Water Resources Development Act. Natural gas and oil pipeline projects are expected to stay close to 2016 levels.

Following steep declines in 2015 and 2016, manufacturing plant construction will increase 6 percent, according to the forecast. New starts in electric utilities will fall another 29 percent after dropping 26 percent in 2016. The lift that had been present in 2015 from new liquefied natural gas expert terminals continues to dissipate. "Power plant construction, which was supported in 2016 by the extension of investment tax credits, will ease back as new generating capacity comes on line," said Dodge.

"[T]he construction industry has now entered a more mature phase of its expansion, one that is characterized by slower rates of growth than what took place during the 2012-2015 period, but still growth," Murray said. "Since the construction start statistics will lead the pattern of construction spending, this means that construction spending can be expected to see moderate gains through 2017 and beyond."

Williamson Trade School Holds Career Fair; Next Set for Feb. 2017

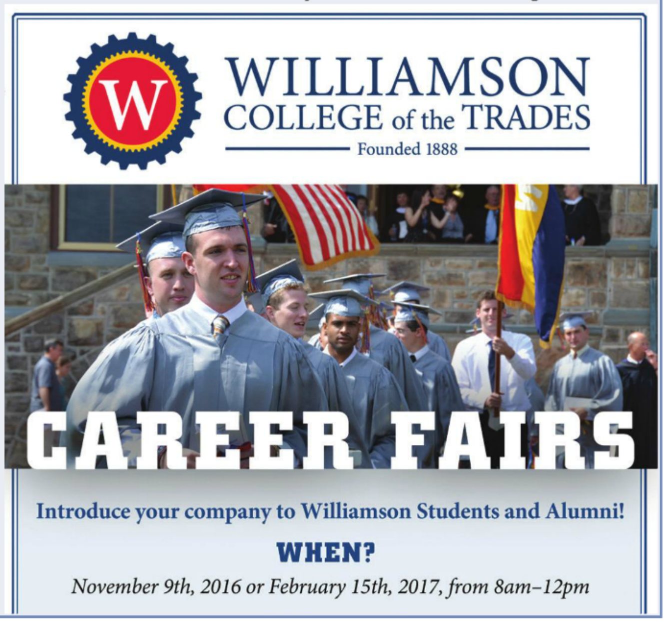
The Williamson College of the Trades held the first of its two annual career fairs at its Media, Pa. campus on Nov. 9. The next career fair will take place at the school's Restall Sports Center on Feb. 15, 2017.

These events provide opportunities for companies to present information to Williamson students, including those from the school's Glenn E. Stevick Paint and Coatings Technology Program. This program is designed to teach students the basic knowledge and proper application of protective coating systems, protection of various surfaces and the prevention of corrosion and other surface deterioration.

Registration for Williamson's second career fair is open now until Feb. 1, 2017. Registration costs between $150 and $1,500, depending upon your company's desired sponsorship level.

Register online at www.williamson.edu/careerfairs. For more information, contact Margaret Kingham, Williamson's placement director, at mkingham@williamson.edu or 610-566-1776, ext. 247.

Photo courtesy of the Williamson College of Trades.



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Bridge of Firsts Celebrates $48M Rehab *(Oct. 24)*

An important structure in the history of bridges has just undergone an extensive four-year, $48 million restoration.

Constructed in 1874, St. Louis, Mo.'s Eads Bridge was not only the world's first steel bridge but also one of the first structures of any kind in the United States to use steel as a primary construction component, according to the City of St. Louis. It was also the first to use tubular cord members, and the first large-scale use of the cantilever technique in bridge construction.

Built by the St. Louis Bridge and Iron Company and named for its designer, James B. Eads, the structure was, at the time, the longest arch bridge in the world, at a length of 6,442 feet, GreatRiverRoad.com noted.

More than 140 years after its completion, the bridge continues to make history. Connecting downtown St. Louis to East St. Louis, the Eads remains the oldest bridge still in operation over the Mississippi River, the *St. Louis Post-Dispatch* reported. And with rehabilitation now complete, Metro Transit – St. Louis expects it has extended the bridge's lifespan by another 75 years.

Photo: St. Louis Bridge Construction Co.

Work on the bridge, which began in September 2012, was reportedly the first major rehabilitation of the structural steel, requiring crews to replace struts, bracing and other support steel that dated back to the 1920s or earlier. This needed 580 tons of steel, according to Metro Transit.

As many as nine layers of paint, rust and corrosion were blasted off the bridge, which required containment measures for environmental purposes. The bare metal was then primed with a rust inhibitor and topped with an anti-corrosion coating. About 7,500 gallons of protective coatings were used in the process, Metro Transit said.

Rebuilding the concrete that supports the road deck and sealing the steel structure with a protective coating, in addition to replacing track supports, track and rail ties, and patching masonry will all help to increase the expected lifespan.

WHAT'S GOT US TALKING

FEMA has proposed new rules that require new construction that uses federal money, including roads and bridges, to build at higher elevations, to mitigate flood-related risks. Is this the best way to address potential flood dangers?

(PaintSquare News *Weekly Poll, Oct. 3-9*)

	Votes
Yes. Flooding is an increasing problem and new construction needs to take into account more volatile weather.	56%
No. Builders will have to incur greater costs in building to code, resulting in overpriced buildings that don't sell. This will ultimately hurt the regions it purports to be helping.	7%
Building higher is good where possible, but these new regulations sound like they'll cause more headaches than they're worth.	37%

PSN TOP 10 *(as of Oct. 31)*

1. Hempel Fires 4 in Bribery Scandal
2. Sherwin-Williams Reports Earnings, New CFO
3. BASF Blast Kills 2, Injures More
4. Ohio Bridge Closed After Beams Buckle
5. Pair of Pipeline Breaches Vex OK, PA
6. Carboline Announces New President
7. Contractor Defaults, Bridge Job Restarts
8. RPM Reports Q1 Growth Amid Challenges
9. Firm Cited Over Permit in PA Bridge Fire
10. Cracks Plague Sydney Metro Project

On Amine Blush in Epoxy Topcoats

WHAT CAUSES AMINE BLUSH IN EPOXY TOPCOATS?

David Zuskin
EXCET Inc. /U.S. Naval Research Lab
Cool, damp and still conditions can cause amine blush of epoxy topcoats.

Eric Piotrowski
SSPC: The Society for Protective Coatings
High humidity and/or cool temperatures during application or curing will cause the blush condition.

Irvin Hosford
Tennant Company
Amine blush usually occurs at high humidity under slow curing conditions (which happens to be at low temperatures in most instances). Condensation of water at the surface could promote it as well. Excess carbon dioxide from fuel combustion sources should be avoided when the epoxy is curing. Blushing can be prevented by using low-blush amines and the proper surface additive package, keeping the stoichiometric ratio of amine slightly lower than the epoxide content, and increasing cure speed without using faster curing amines, but rather catalytic components like benzyl alcohol and/or tertiary amines.

James Prevatt
Asset Preservation Partners
Coating manufacturers typically make epoxy with a percent or two of excess catalyst by weight to assure full curing. Most amines have an affinity for water and take on either a whitish appearance or a tacky feel, which must be removed prior to applying additional coats or the bond will be at risk. Soap and water wash with agitation or solvent wipe can address this issue. There are some cases where no appearance or tacky state can be observed. To be sure, use pH paper and if the result is alkaline, you know amine blush has occurred. Always remove the blush prior to taking the next step.

Warren Graves
Warren Graves Coating Consultant Inc.
It is the reaction of carbon dioxide with the amine component of epoxies that forms amine carbamate. When there is enough moisture in the air, this reaction product reacts further to create amine blush. However, I can tell you from experience that there are times when you will not see the amine carbamate blush. When a tank interior is heated, such as in the winter in northern climates, in order to provide optimal application temperatures, the humidity in the tank can be so low that the blushing will not take place. The carbamate exude remains on the surface as a thin, glossy oily layer. There simply is not enough moisture present to cause the blushing to occur.

John Schultz
O-Gee Paint Co.
We see that under certain conditions amine blush is elicited but I believe there are epoxies that are formulated in such a way to be more or less blush resistant. To that end, I have seen advertisements for marine epoxies that state they will not blush. On the other end I have seen technical data sheets (TDS) that state a particular epoxy should not be applied in conditions with greater than approximately 85-percent humidity. It seems then that the formulation of the coating has a lot to do with whether or not it will blush in a particular environment. If this is the case, then the cause of amine blush is either unexpected environmental conditions after application or the specification and/or use of an epoxy that is inappropriate for high-humidity conditions.

Chuck Pease
MMI Tank
To that end, with all of the possibilities of amine blush, why then wouldn't the engineer specify a moisture-cured urethane in lieu of an epoxy topcoat?

Om Prakash Jat
Tech International
Amine-cured epoxies are sensitive to amine blush. Blushing is caused by absorption of moisture and carbon dioxide from the atmosphere during the curing process. This can happen when the coating is subjected to a drop in temperature shortly after application. Carbon dioxide in the air along with any moisture that is present combines with the amine-curing agent and forms a carbamate on the surface of the coating. This carbamate is an oily-feeling, sticky liquid that cannot be overcoated and must be removed prior to overcoating. Blush is relatively easy to see with the unaided eye. View the surface under a good light, then rub a swab or gloved finger across it to disturb the oily layer enough to refract the light and the blush becomes visible. Sometimes, a greasy feel is evidence enough. There are a number of commercial methods to determine if blush is on the surface.

HOW TO PREPARE GALVANIZING FOR PAINTING

By E. Bud Senkowski, P.E., KTA-Tator, Inc.

Galvanizing presents many challenges to painting operations. While the zinc coating can add substantial life to steel surfaces, its surface chemistry and electrochemical activity can result in conditions leading to adhesion failures of applied organic coatings. The key to successful painting lies in recognizing the many surface conditions presented by new and weathered galvanizing and then employing effective cleaning operations to mitigate their effect. Success is ultimately achieved by selecting coating products that will develop a strong and enduring bond to the galvanized surface.

WHAT IS GALVANIZING?

Galvanizing is a general term for the metallurgical process that applies a layer of zinc metal over a steel surface in order to prevent corrosion of the steel. In the corrosion reaction, the zinc layer will sacrifice itself to protect the underlying steel substrate. In this electrochemical reaction, the zinc performs as the anode and the steel becomes the cathode. As long as there is adequate zinc, the steel will be protected from corrosion.

TYPES OF GALVANIZING

Structural steel, piping and many other steel shapes are coated with zinc using a hot-dip galvanizing (HDG) process. This process involves cleaning the steel using a combination of hot acid baths to remove rust and scale followed by fluxing and immersion into a molten bath of pure zinc heated in a range of 820-to-860 F. The zinc thickness achieved by HDG is in the range of 2-to-8 mils for many steels and is dependent on immersion time in the bath. However, an HDG thickness in the range of 20-to-30 mils can be achieved with some reactive steels.

The HDG process creates a dense coating of zinc that is metallurgically bonded to the steel surface. As the molten zinc diffuses into the steel surface, it creates four distinct layers that vary in their zinc-to-iron ratio. They range from 100-percent zinc at the outermost layer to 75-percent zinc and 25-percent iron at the steel substrate.

Other methods are also used to apply a zinc layer to steel that include electroplating and sherardizing (dry galvanizing named for the British metallurgist Sherard Osborn Cowper-Coles). Electroplating deposits zinc on a steel surface immersed in a chemical solution of zinc salts and exposed to electrical current. Sherardizing is a process that rotates steel parts and fasteners with zinc dust in a heated drum to diffuse the zinc into the steel surface. Both methods apply much thinner layers of zinc than HDG.

HOW LONG WILL ZINC PROTECT STEEL?

Zinc is not immune to corrosion. When zinc is exposed to the atmosphere it enters into chemical reactions with oxygen, moisture, carbon dioxide and soluble airborne salts like chlorides and sulfates. The rate of zinc corrosion will depend on the severity of the environmental exposure. A rural exposure results in far less corrosion than do seaside or industrial exposures. The American Galvanizers Association (AGA) has data showing that a galvanized steel surface with 2 mils of zinc will only develop 5-percent rusting after approximately 35 years of exposure in an industrial environment.

HOW DOES ZINC DETERIORATE?

The corrosion of HDG begins immediately after the molten zinc layer has cooled.

The appearance of HDG can vary. Typically, the zinc surface is smooth with a pattern of random spangles resembling snowflakes in zinc. When the steel contains trace elements of silicon and phosphorus outside of recommended ranges, it is considered a "reactive" steel. The HDG of reactive steel produces a matte finish after cooling. After exposure to atmospheric oxygen and moisture, the zinc surface begins to corrode, developing a thin layer of zinc oxide. Continued atmospheric exposure results in the formation of zinc hydroxide. Eventually, after about two years of exposure, the zinc surface layers have been converted largely to a metallic gray patina composed of insoluble zinc carbonate and zinc oxide. At this point, the zinc surface has essentially stabilized and continued atmospheric corrosion is substantially reduced.

WHY DO WE PAINT GALVANIZING?

To Replace Lost Corrosion Protection

While the corrosion rate of atmospherically stabilized zinc is relatively low, the thickness of the zinc layer will continue to be reduced with time. Both the original zinc thickness and the severity of the atmospheric exposure will affect the life of the galvanizing. As the zinc layer is reduced through corrosion, its ability to protect the underlying steel substrate is diminished and the galvanic protection afforded by the zinc is lost. At this point, the application of a polymer overcoating may be considered to extend the life of the structure.

To Extend Galvanizing Life with a Duplex System

There are situations where new HDG may be immediately overcoated to extend the life of the structure beyond the longevity afforded by the zinc layer alone. When new HDG is overcoated with an organic coating, a synergistic effect is created that extends the life of the galvanizing. The organic overcoating becomes a barrier to penetration by moisture that slows down the corrosion of the zinc layer. A duplex coating system can extend the life of a galvanized coating by a factor of from 1.4-to-2.7 times the sum of the lives predicted for each coating layer alone.

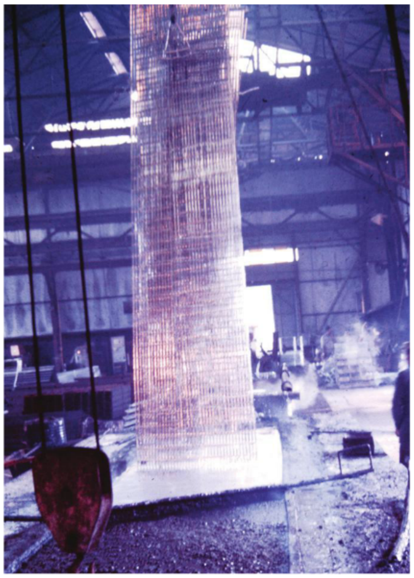

Fig. 1: Hot-dip galvanizing bath.
All photos courtesy of KTA-Tator, Inc.

To Improve Appearance

Because the natural appearance of metallic gray spangling may be objectionable, HDG is often overcoated with an organic coating to improve its appearance or impart a specific color required by an architectural rendering. In these situations, the addition of an overcoat will extend the life of the galvanized layer.

PROBLEMS WITH PAINTING GALVANIZING

Galvanizing can be a difficult surface for the successful retention of an organic paint film. Difficulties arise when surface contamination is not recognized and removed before the galvanizing is coated. There are many possible types of surface contamination on galvanizing that must be removed before painting is attempted.

SURFACE CONTAMINANTS

Oil and Grease

Oil and grease can be removed using an aqueous alkaline cleaning solution followed by a hot water wash; mineral spirit solvent followed by wet steam flushing; or wet steam with the injection of a biodegradable detergent. To avoid damaging the zinc carbonate film, water pressure cleaning should not exceed 1,450 psi.

Zinc Oxide

Zinc oxide is the natural corrosion product that starts to form when the HDG has cooled and is exposed to air. The oxide layer is very thin and forms slowly. It is not considered to be problematic to painting within the first 48 hours of galvanizing.

Wet Storage Stain

Wet storage stain (also known as white rust) primarily consists of zinc hydroxide. The white rust forms as the galvanizing is exposed to moist air without sufficient air circulation between the parts. White rust is hygroscopic and if not removed, will affect paint adhesion. Light deposits of white rust can be removed by scrubbing with an ammonia solution followed by a water flush. Heavy deposits of white rust can be removed by applying such materials as acetic acid (vinegar), citric acid, or a commercial rust remover and scrubbing with a soft bristle brush. Flushing with warm water should follow removal. Avoid using any concentrations of hydrochloric (muriatic) or sulfuric acid as cleaning agents. Both will attack and remove any sound galvanizing.

Chromate Conversion Coatings

Chromate conversion coatings may be applied at the galvanizing facility to protect new galvanizing from excessive growth of zinc oxide and zinc hydroxide (wet storage stain). The chromate is slowly removed by natural weathering, but may persist for up to two years. When in doubt, a standard test (ASTM B201, "Standard Practice for Testing Chromate Coatings on Zinc and Cadmium Surfaces") can be performed

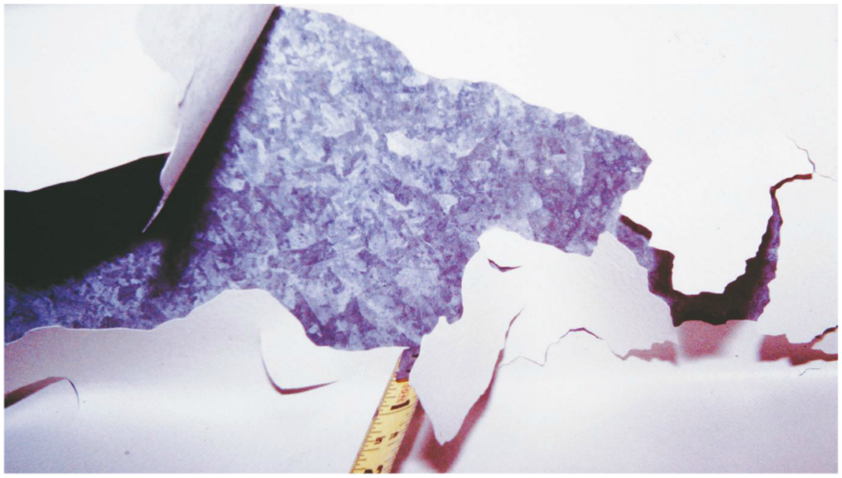

Fig. 2: Coating delamination at a galvanized surface.

to determine the presence of chromate. The test involves placing a drop of lead acetate solution onto the galvanizing. If the zinc surface turns black, there is no chromate present. If there is no color change, chromate is present. The chromate coating must be removed prior to any paint application. Methods to remove the chromate layer include weathering for six months, sanding or sweep blasting. Liquid solutions are not recommended for removing chromate conversion coatings.

If sweep blasting is used, the abrasive media must be chosen with care to provide a cleaning action without removing excess zinc layers or fracturing one of the subsurface zinc/iron diffusion layers that form the total galvanized layer. Nozzle movement should be rapid with rates in excess of 1,200 square feet per hour. Removal of up to 1 mil (25 microns) of the uppermost 100-percent zinc with a profile in the range of 1-to-2 mils is acceptable.

Before using sweep blasting, the contractor should consult SSPC-SP 16, "Brush-Off Blast Cleaning of Coated and Uncoated Galvanized Steel, Stainless Steels, and Non-Ferrous Metals." One of the abrasives that has been used successfully is aluminum/magnesium silicate. Particle size should be in the range of 8-to-20 mils (200-to-500 microns). Other

abrasives that can be used are silica-free soft mineral sands with a mineral hardness of 5 MOHs or less, organic media such as corn cobs or walnut shells, corundum and limestone. The use of mineral slags should be avoided. Blasting nozzle pressures should be in the range of 20-to-40 psi.

Rust

Rusted areas may be present on heavily weathered galvanizing. In order to facilitate painting, the rusted areas must be cleaned to a level compatible with the coating product to be applied. If cleaning to a tight rust condition is acceptable, hand-tool cleaning (SSPC-SP 2), power-tool cleaning (SSPC-SP 3) or brush-off blast-cleaning (SSPC-SP 16) can be used.

NEWLY GALVANIZED STEEL

Newly galvanized steel (exposed to the atmosphere for no more than 48 hours) has few zinc compounds on the surface simplifying the cleaning, but is relatively smooth so profiling is necessary to ensure the adhesion of an overcoating.

Before profiling, the galvanizing must be cleaned to remove any grease or oil contamination. Following cleaning, create a profile in the zinc compatible with the coating product to be applied. Brush-off blast cleaning (SSPC-SP 16) is a viable method of profiling. When blast-cleaning, caution must be taken to avoid removing too much of the galvanizing or damaging the metallurgical bond of the zinc to the steel.

PARTIALLY WEATHERED GALVANIZED STEEL

Partially weathered galvanized steel (exposed to the atmosphere from 48 hours to one year) can contain a wide range of the surface contaminants previously described. The problem lies in identifying each contaminant and applying appropriate remedial action before paint application. The amount of contaminants will be a function of the duration of weathering, the severity of the weathering environment and the metal treatments applied immediately after galvanizing. Surface contaminants present could include the following.

- Oil and grease.
- Chromate conversion coatings.
- Zinc oxide.
- Zinc hydroxide (white rust).
- Rust.

Methods for dealing with each contaminant have been previously described with the exception of rust, as found on galvanized surfaces with atmospheric exposure in excess of several days. This involves cleaning solutions, wash primers and acid-based acrylic solutions. Depending on the condition, mechanical means may also be necessary to

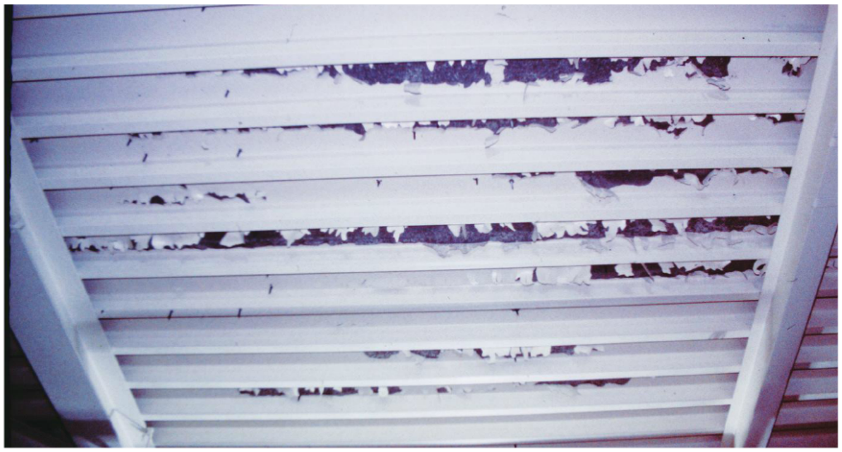

Fig. 3: Coating delamination from galvanized roof panels.

clean and profile weathered galvanized surfaces.

Phosphate Conversion Coatings

Following initial cleaning to remove oil and grease contamination, iron phosphate and zinc phosphate coatings are frequently used to improve paint adhesion. The conversion coatings can be applied by dipping, spraying or with a soft-bristled brush. After a reaction time of 3-to-6 minutes, the surfaces are flushed with clean water and allowed to dry before painting. Product manufacturers should be consulted regarding the specific application time and temperature requirements for their products.

Basic Zinc Chromate-Vinyl Butyral Wash Primer

One treatment for partially weathered galvanizing is a basic zinc chromate-vinyl butyral wash primer (SSPC Paint No. 27). When applied within the recommended DFT range of 0.3-to-0.5 mils, it cures rapidly to a resin finish that neutralizes zinc corrosion products and retards their formation. The bonding ability of the converted zinc surface will accept many paints. Paints that contain ketone or alcohol solvents develop the best bond. Once the wash primer is applied, it dries in about 15 minutes and should be overcoated in about 30 minutes. It is extremely important to apply the wash primer

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within the range of 0.3-to-0.5 mils DFT. Exceeding 0.5 mils will lead to delamination failures after overcoating. The wash primer also etches the zinc surface and eliminates the need for sweep blasting.

Acidic Acrylic Pretreatment

Another surface treatment for partially weathered galvanizing is an acidic acrylic solution. When applied, the solution first reacts with the zinc surface forming a passivating conversion coating, to suppress further corrosion while simultaneously forming an acrylic coating suitable for subsequent painting on top of the passivation layer. The underlying conversion coating provides strong adhesion to the galvanized surface while the thin film acrylic layer provides barrier protection, inhibiting corrosion and providing a highly compatible surface for the application of organic paint films. The coating is approximately 0.04 mil (1 micron) thick. Painting is possible at any time during a period of four months after application, as long as the surface remains free of visible zinc oxides or white rust. The pretreatment also etches the zinc surface and eliminates the need for sweep blasting.

FULLY WEATHERED GALVANIZED STEEL

After approximately one year of outdoor exposure, weathered galvanized steel will develop a stable and finely etched surface of zinc carbonate that can remain on the surface and is favorable to coating adhesion. Zinc carbonate is insoluble, tightly adhered to the surface and should be preserved. However, before painting, any oil or grease must be removed and the zinc surface modified to enhance paint adhesion. Modification can be accomplished by either using one of the previously described chemical wash primers to promote paint bonding or by sweep blasting to create an acceptable profile in the galvanized surface. Because zinc oxide forms rapidly on blasted surfaces, paint application should take place within 30 minutes of cleaning.

COATING CHOICES FOR GALVANIZING

There are some alkyd formulations that are recommended for painting galvanizing. These coatings incorporate a modified alkyd that integrates Portland cement into the binder.

Coating products, such as epoxy or polyaspartic, require higher levels of cleaning such as a minimum of commercial blast cleaning (SSPC-SP 6). In these cases, only the necessary profile should be created in the zinc, taking care not to remove too much of the surrounding sound galvanizing or damage the metallurgical bond between the zinc and the steel.

Avoiding Saponification

The saponification reaction forms water-soluble soaps at the interface between the coating and the galvanizing. The soaps become soft, sticky and dissolve when exposed to moisture. The moisture can be present in the original wet coating or as atmospheric humidity that passes through the cured coating film and reaches the galvanized substrate.

Saponification can be destructive to paint films. Oil-based paints that utilize alkyd esters, epoxy esters or linseed oil derivatives in their composition can saponify when placed on an alkaline surface and galvanizing is such an alkaline surface. Some polyvinyl acetate (PVA), water-based latexes can also be broken down by saponification. Latex acrylic paints resist saponification. Other acceptable coating choices include solvent-based epoxies, urethanes and polyaspartic formulations.

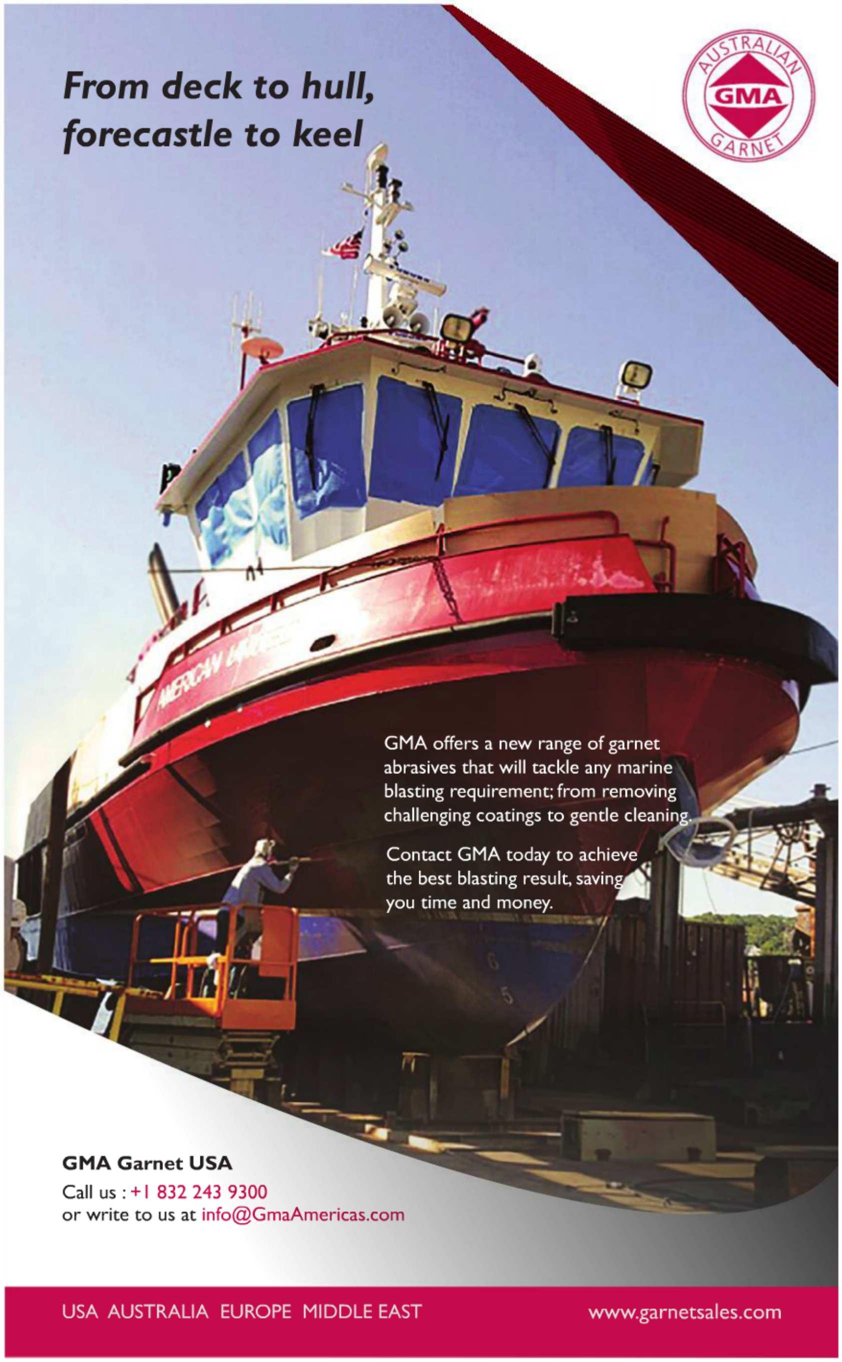
VALUABLE REFERENCES

There are documents available that describe methods of preparing surfaces of new and weathered hot-dip galvanized steel for painting.

In addition to SSPC-SP 16 referenced earlier, ASTM International has published Standard Practice D6386-10, "Standard Practice for Preparation of Zinc (Hot-Dip Galvanized) Coated Iron and Steel Product and Hardware Surfaces for Painting." The document describes methods of preparing surfaces of new and weathered hot-dip galvanized steel for painting. These resources should be consulted before any painting of galvanizing is attempted.

ABOUT THE AUTHOR

E. Bud Senkowski, P.E. is a senior consultant with KTA-Tator, Inc., where he has been employed for over 24 years. He is a registered professional engineer in several states, an ANSI-Certified Nuclear Coatings Inspector, an SSPC-certified Coatings Specifier and a NACE-certified Level 3 Coating Inspector. Senkowski has over 45 years of coating engineering, inspection, training and project management experience. He has an extensive background in the engineering, application and inspection of coatings and linings used in nuclear and fossil-based service, water and chemical storage facilities, and is the primary instructor for KTA's Nuclear Inspection and Pipeline Coating training courses. Senkowski holds an MBA from Drexel University and a Bachelor of Science degree in fuel engineering from Pennsylvania State University.



FAILURE OF A BRIDGE DECK TOPCOAT

BY WARREN BRAND, CHICAGO CORROSION GROUP, LLC.

It's never a good day when large chunks of a newly installed three-layer epoxy coating system begin to come off of any concrete floor — and even more troubling when they come off of a bridge deck.

Concrete is absorbent. It will hold chlorides, moisture, oils, greases, chemicals, gases and anything else that comes into contact with it. Cracks on a roadway, and more specifically on a concrete bridge, can provide a pathway to the rebar for contaminants, and particularly for chlorides from road salt. Rebar is wrapped in a figurative alkaline blanket approaching a pH of 11 when sitting in concrete. The alkalinity creates a thin patina on the rebar which, if maintained at that pH, will prevent corrosion for decades. However, if chlorides do enter the concrete and lower the pH, the corrosion rate of the rebar can skyrocket and therefore, preventing this phenomenon is critical.

Cracks and concrete go hand-in-hand. Concrete tends to crack for a variety of reasons and while almost always inevitable, instances of cracking can be reduced with proper design and engineering and if cracks do occur, they can be properly managed with appropriate coatings and other remedial solutions.

THE BACKGROUND

The original specification called for an epoxy flood coat and two layers of an epoxy overlay with aggregate as well as the following surface preparation procedure.

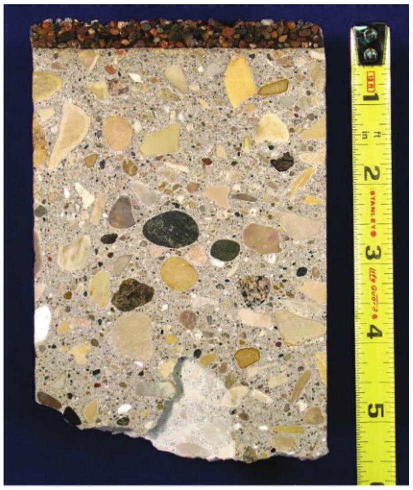


Fig. 1: An overall view of a lapped section of Core Sample No. 4. Photos courtesy of CTL Group.

"Prepare the surface in accordance to the manufacturer's recommendation. At a minimum, ensure that the bridge deck surface is clean and free of any loose materials and unsound concrete or any other surface materials that, in the manufacturer's and engineer's opinion, would prevent proper bonding to and cure of the system. Abrade the entire deck surface by shot blasting to expose the course aggregate."

The coating system applied was representive of industry standard materials and the specification was well-written. The system was designed to repair and protect a bridge deck and the associated sidewalk which was showing typical signs of wear, such as cracking and spalling.

The Flood Coat

Flood coats are self-leveling sealers and typically have very low viscosity — somewhere between corn oil and maple syrup. Their rheology is designed to penetrate deeply to fill cracks, voids and other imperfections, as well as allow for a level surface over which to apply successive overlays and topcoats. Flood coats are typically pure resin and designed to completely saturate the concrete but not necessarily leave a measurable film thickness, or at least a very thin one.

The Overlay

Overlays can be made from a variety of base resins and are typically aggregate-filled. In this case, the specification called for an epoxy mixed with aggregate.

FAILURE ANALYSIS

The failure in this case was disbondment and was clear and widespread, but trying to determine what was disbonded from what was the challenge.

Visual Inspection

The deck showed clear signs of distress in the form of disbonding sheets of what appeared to be the concrete overlay. Hammer testing (listening for changes in sound) was carried out which confirmed that the overlay was compromised.

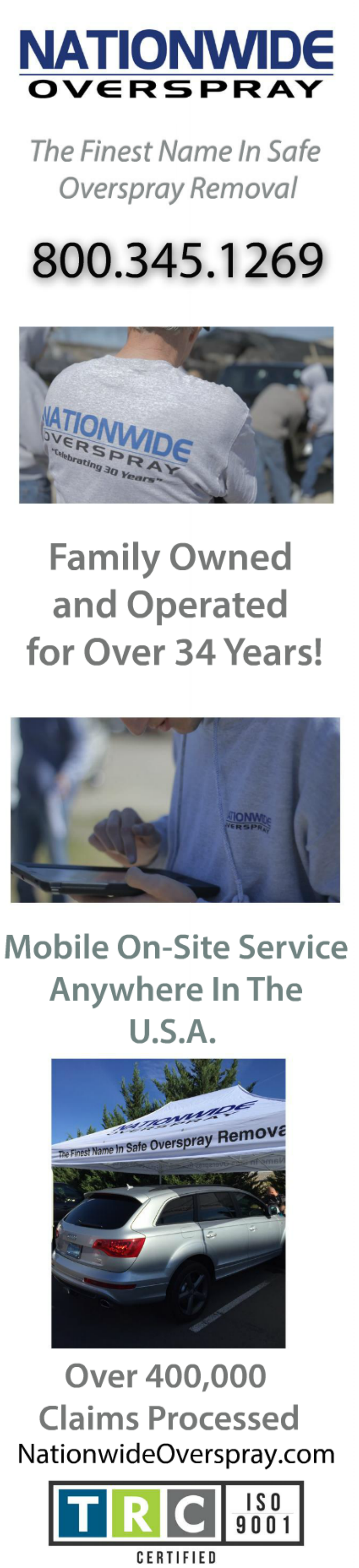
A hammer and chisel were then used to test the overlay for adhesion, which further confirmed the ongoing disbondment. The concrete deck substrate appeared to be sound and exhibited cracking, which was anticipated.

Laboratory Analysis

Unlike coatings on steel, where a Tooke Gauge can be used to obtain a cross-section view of an entire coating system, the only way to examine coating systems and overlays on concrete is to extract a core sample taking care to avoid damaging the rebar.

Figure 1 is a side view of the top of the core sample which was roughly 5.5-inches thick. The view below the dark top band is of the concrete slab and the top dark area is the flood coat with the overlays on top of that.

Figure 2 (p. 24) is a closer look at the top of the same core. The magnification is not yet sufficient to view the flood coat, but the resin in the two layers of the overlay are clear. Visually, the two coats of overlay appear as one and the border, or plane, between them is invisible, which is the desired outcome. Further, the overlay does not exhibit any air entrapment, blistering,



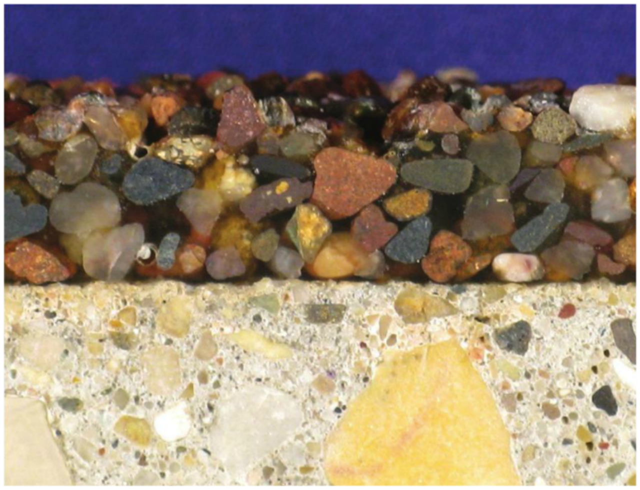


Fig. 2: A close-up of a lapped section of Core Sample No. 4 showing the epoxy overlay/concrete substrate interface.

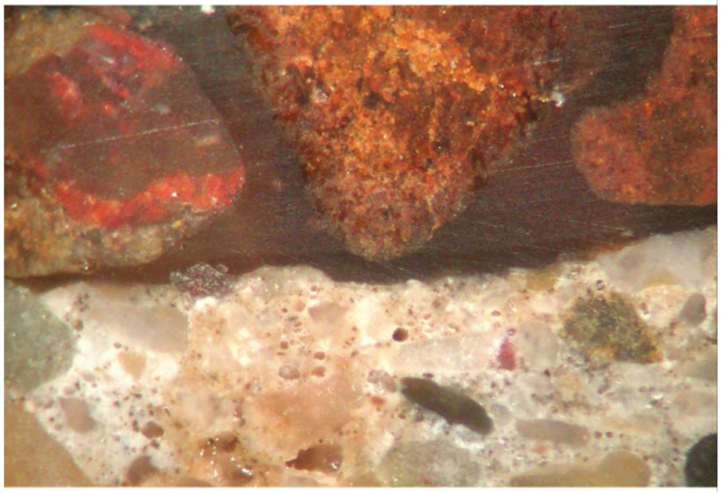


Fig. 3: A close-up view of the separation between the epoxy overlay and the concrete substrate.

discoloration, cloudiness or any other type of visual distress.

Figure 3 shows the magnification necessary to successfully view the flood coat. This photo shows what appears to be good adhesion between the flood coat and the overlay above, as well as good adhesion between the flood coat and the concrete substrate. Of some concern, however, is the apparent lack of penetration of the flood coat into the concrete substrate, as well as the surface appearance of the substrate.

CONCLUSION

Figure 4 reveals the adhesive separation between either the flood coat and overlay or concrete substrate and overlay. The three coats of material appeared to have cured, become well adhered to one another and forming one monolithic system. Because the flood coat is so thin, it could be reasonably asserted that the failure is adhesive in nature between the monolithic coating system and the concrete substrate.

Most coating failures, particularly those on concrete, are due to application error, and the main cause of application error is poor or inappropriate surface preparation.

Referring back to the specification for surface preparation, guidelines revealed

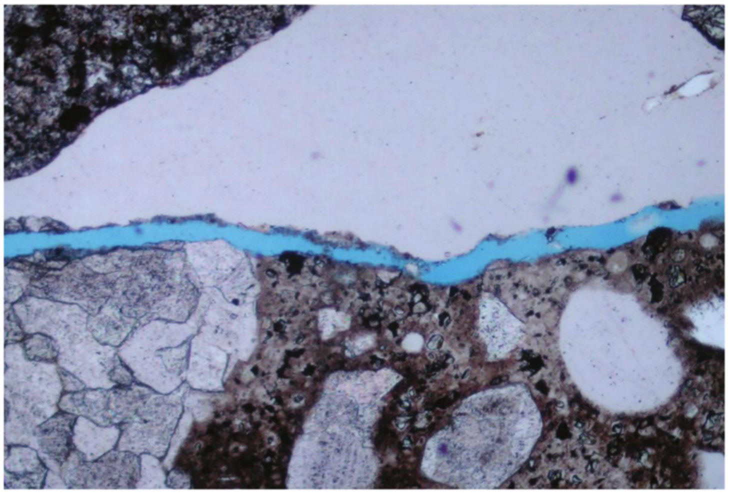


Fig. 4: Close-up view of separation (filled with blue epoxy) between the epoxy overlay and the concrete substrate under cross-polarized light.

a common but questionable practice of referring or deferring to the manufacturer's recommendation for guidance. This is a common practice more often found in public works specifications than private sector specifications due to the requirement of specifying multiple products. The problem with this is that manufacturer application specifications are sometimes overly broad and lack specificity.

This specified surface preparation included abrading "the entire deck surface by shot blasting to expose the course aggregate" and herein lies a strong clue.

The photos fail to show any exposed aggregate of the concrete substrate, which can clearly be seen in Figure 2 where the concrete substrate is uniformly straight and lacks the hills and ruts often associated with abraded concrete. Also, inspection of the concrete underneath the disbondment showed substandard surface preparation.

Further analysis determined also that the surface preparation itself was not sufficiently aggressive to 1) provide sufficient surface area and expose enough course aggregate for adhesion of the flood coat and successive overlays, or B) remove any contamination which might prevent the penetration of the low-viscosity flood coat.

Both the driving deck and the sidewalk were coated, and while the sidewalk received similar surface profiling to the deck (roughly CSP 3-to-4) it was apparently sufficient enough to remove a dense concrete topping of some type, which allowed the flood coat to penetrate into the exposed pores of the concrete on the sidewalk, providing better adhesion and performance than on the bridge deck.

The findings report stated: delamination is occurring between the epoxy overlay and the original bridge deck concrete. The delamination is primarily the result of inadequate concrete surface preparation. The bridge deck concrete estimated surface profile is CSP 3-to-4. For epoxy overlay systems, a fairly rough surface profile is desired (CSP 7 with large aggregate exposed/partially uncovered). The observed surface profile of the existing concrete indicates that surface preparation was not aggressive enough to expose coarse aggregate to provide a proper surface profile for bonding.

ACKNOWLEDGMENT

The author would like to thank the CTL Group of Skokie, Ill for assistance with this article.

SINGLE-COMPONENT POLYSILOXANE TOPCOAT FOR NAVY SURFACE SHIPS

BY ERICK IEZZI AND JAMES TAGERT, U.S. NAVAL RESEARCH LABORATORY

Silicone alkyds have been the predominant exterior topside coating for U.S. Navy surface ships for over 50 years[1]. These single-component (1K) haze gray colored coatings were originally specified under TT-E-490E[2] (enamel, silicone alkyd copolymer, semigloss) when first introduced, but have since been qualified to the performance requirements found in MIL-PRF-24635E[3] (Coatings Systems, Weather-Resistant, Exterior Use). Silicone alkyd topside coatings have proven to be a user-friendly technology because they are an "all-in-one-can" system that does not require the addition of components or a catalyst before application. They have an indefinite pot-life in a closed can, are free of hazardous isocyanates, and will crosslink (i.e., cure) even under the most adverse conditions.

Silicone alkyd coatings are based on alkyd polymers that have been reacted with silicone intermediates[4]. Coatings that contain silicone (i.e., polysiloxane) provide enhanced weatherability due to the presence of silicon-oxygen (Si-O) bonds, which have a greater bond strength than the carbon-carbon (C-C) bonds found in all-organic coatings, such as epoxies. Although haze gray silicone alkyds demonstrate improved exterior performance compared to straight alkyds[5], they nonetheless lose their gloss, chalk and/or color fade to a light gray within 9-to-12 months after application on Navy ships, and silicone alkyds formulated with low-solar-absorbing (LSA) pigments (i.e., titanium dioxide, yellow iron oxide, red iron oxide and copper phthalocyanine blue) have been observed to color-shift towards a pinkish hue after six months of exposure (Fig. 1). Silicone alkyds also provide a three-fold longer recoat window than straight alkyds[5], yet their surface hardness is

Fig. 1: (Left) "Pinking" of an LSA haze gray silicone alkyd on the topside of a Navy surface ship. Figures courtesy of NRL.

reduced due to a lower crosslink density. As a result, running rust, soot and other contaminants will easily stain the surface of these Navy topcoats and produce an unsightly appearance. To address these performance issues, sailors are continually over-coating weathered and/or stained silicone alkyds with fresh silicone alkyd, which perpetuates a cycle of topside painting and increased maintenance costs to the Navy (Fig. 2). For years, silicone alkyds have provided the Navy with adequate performance. However, the need to maintain visual camouflage and aesthetics for longer periods of time, in addition to reducing maintenance costs as ship life cycles are extended, has meant that silicone alkyds can no longer provide the performance that is required for Navy ship topside coatings.

Two-component (2K) polysiloxane topside coatings have been qualified to MIL-PRF-24635E requirements by several manufacturers during the past decade. These topcoats are hybrid cure coatings based on the reaction of organic functional groups (i.e., epoxies with amines or acrylates with amines) and moisture-curable alkoxysilanes that hydrolyze and crosslink to form polysiloxane linkages[6]. Haze gray 2K polysiloxanes have demonstrated a significant enhancement in color and gloss stability compared to silicone alkyds, in addition to providing greater cleanability and hydrocarbon resistance. However, these 2K coatings require the mixing of components before application, which can result in insufficient cure and/or reduced performance if the coatings are not mixed at the proper ratios or for the specified lengths of time. These systems also have a limited pot-life once mixed, which can be troublesome for sailors attempting to paint on hot days.

SINGLE-COMPONENT POLYSILOXANE TOPCOAT

The U.S. Naval Research Laboratory (NRL) has recently developed novel moisture-curable alkoxysilane-terminated N-substituted urea polymers for use in single-component polysiloxane topcoats for military assets[7, 8]. As a haze gray topcoat for Navy ships, the coating provides significantly greater exterior durability and resistance to contaminants compared to qualified silicone alkyds, in addition to demonstrating greater color stability and flexibility compared to qualified two-component polysiloxanes. The 1K polysiloxane offers applicators, especially sailors, a user-friendly system for painting ship topsides, in addition to reducing the generation of hazardous waste by providing for a longer pot-life compared to 2K systems.

EXPERIMENTAL PROCEDURE

NRL's LSA haze gray single-component polysiloxane topcoat was formulated to provide a system that contains less than 250 g/l of volatile organic compounds (VOCs); is free of hazardous air pollutants (HAPs) and isocyanates; possesses a flash point (Fp) of greater than 100 F; can be brushed, rolled or sprayed; and will cure over a wide range of temperatures and humidity to provide a semi-gloss finish. The coating is currently

Fig. 2: Sailors roll-apply fresh silicone alkyd.

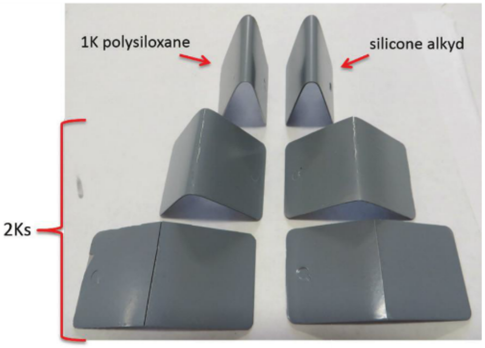


Fig. 3: A comparison of flexibility between NRL's 1K polysiloxane, a qualified silicone alkyd and various 2K polysiloxane topside coatings after being bent over a ¼-inch cylindrical mandrel.

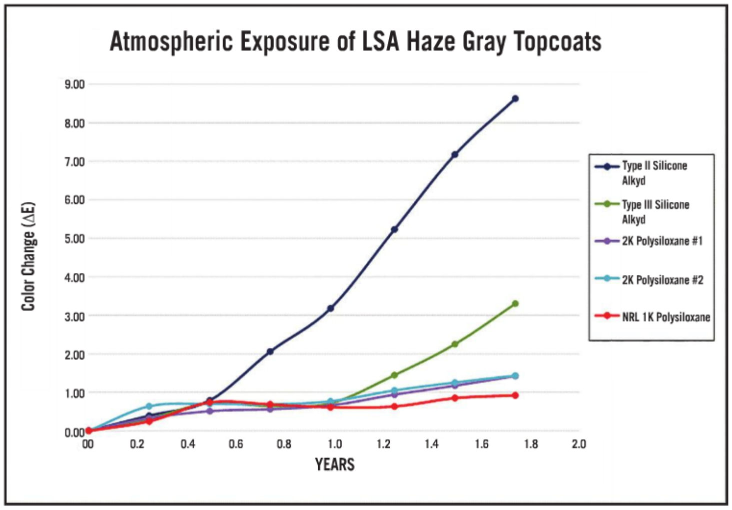


Fig. 4: Color change after atmospheric exposure of low-solar-absorbing haze gray topcoats.

being qualified to MIL-PRF-24635E, Type V (high-durability coating), Class 2 (Semigloss), Grade B (LSA pigments) performance requirements, which include laboratory tests and active ship demonstrations. For all tests, the 1K polysiloxane was applied by roll, spray or drawdown bar to achieve a dry film thickness (DFT) of 2-to-4 mils, then allowed to cure at ambient conditions (72 F, 50-to-60-percent RH) for 14 days before testing occurred. Adhesion tests were performed over MIL-DTL-24441, Type IV epoxy, MIL-PRF-23236, Type VII high-solid epoxy and other primers according to MIL-PRF-24635. Adhesion was also tested over weathered silicone alkyds according to ASTM D3359[9]. Solvent resistance was tested in accordance with ASTM D5402[10], whereas flexibility was tested over sanded 3-by-6-by-0.025-inch 3003-H14 aluminum panels according to ASTM D522[11]. Accelerated weathering was tested in accordance with ASTM G155 and ASTM G154[12,13], and atmospheric exposure (i.e., outdoor) testing was conducted on panel racks in Key West, Fla. Qualified LSA silicone alkyds and 2K LSA polysiloxane topcoats were applied at similar DFTs to the 1K polysiloxane for comparative testing.

RESULTS

The haze gray 1K polysiloxane topcoat demonstrated excellent adhesion to a variety of 24-hour- and seven-day-cured primers, showing an X-Cut rating of 5A in

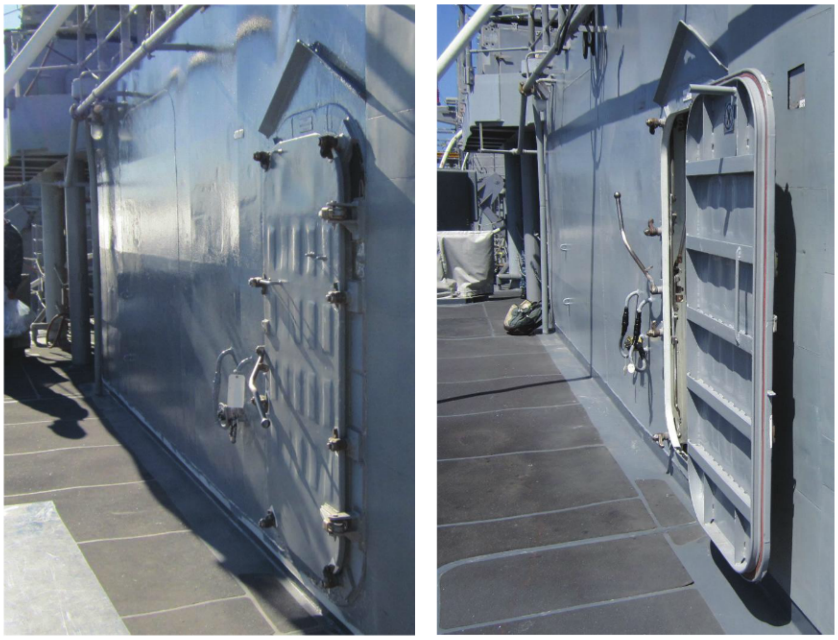


Fig. 5: (Left) NRL's 1K polysiloxane topside coating immediately after the roll application was finished, and (Right) after seven months of service on the USS COWPENS *(CG-63).*

all cases. The 1K also demonstrated a 5A rating over both weathered silicone alkyds and weathered silicone alkyds that were sanded and solvent wiped. In addition, 1K polysiloxane possesses excellent hydrocarbon resistance and passes over 100 double-rubs with a methyl ethyl ketone (MEK)-soaked rag without marring, whereas silicone alkyds cured for the same period will only resist 25-to-50 double rubs before rubbing through the coating. However, even though the 1K polysiloxane possesses greater solvent resistance than silicone alkyds it remains highly flexible, unlike the two-component polysiloxanes. Figure 3 (p. 28) shows a comparison of flexibility between NRL's 1K polysiloxane topside coating, a qualified silicone alkyd, three qualified 2K polysiloxanes and a non-qualified 2K polysiloxane after being bent on a ¼-inch cylindrical mandrel at room temperature. As can be seen in the photo, all 2K polysiloxanes cracked after partial bending on the mandrel, whereas the 1K polysiloxane and silicone alkyd did not. Even after being heated at 140 F for 24 hours the 1K polysiloxane was able to pass a conical mandrel bend test without cracking.

With regard to color stability, the 1K polysiloxane demonstrated a color change (ΔE) of less than 1.0 after 2,000 hours of accelerated weathering in a Xenon Arc Weatherometer (WOM) chamber, in addition to a color change of 0.08 after 300 hours of exposure in a UV-B (313 nm bulb) chamber. Furthermore, exposure of the 1K polysiloxane, a qualified Type II and Type III silicone alkyd, and two qualified 2K polysiloxanes on an atmospheric exposure rack in Key West, Fla. for a period of 1.7 years showed that the 1K polysiloxane retained greater color stability with a color change of only 0.92 (Fig. 4, p. 28).

During the past two years, multi-gallon quantities of the haze gray 1K polysiloxane have been scaled-up by a coating manufacturer for topside demonstrations aboard active Navy ships. These include applications aboard the *USS Winston S. Churchill* (DDG-81), *USS Chosin* (CG-65), *USS Cowpens* (CG-63), and the *USS San Antonio* (LDP-17) from 2014 through 2015, in addition to applications on the *USS Laboon* (DDG-58) and *USS Gunston Hall* (LSD-44) in 2016. In November of 2014, the 1K polysiloxane was roll-applied by Ship's Force on approximately 400 square feet of the 03 Level Starboard bulkhead aboard the *USS Cowpens*. The substrates were an abraded and solvent-wiped silicone alkyd and a 24-hour-cured MIL-PRF-23236, Type VI/VII high-solids epoxy primer. Figure 5 (p. 29) shows the bulkhead immediately after the 1K polysiloxane was roll-applied and began to cure. The 1K coating was inspected in June of 2015, and after seven months of service the color change (ΔE) was approximately 0.6 and the loss of gloss was 8 percent. It should be noted that these topside demonstrations are inspected by NRL every three-to-six months, or when ships are available in port.

CONCLUSIONS

NRL has recently developed a novel moisture-curable, haze gray single-component (1K) polysiloxane topcoat for Navy surface ships. The topcoat contains reduced levels of VOCs, is HAPs-free and provides excellent hydrocarbon resistance, flexibility and weatherability, especially when compared to silicone alkyds. The topcoat has also demonstrated excellent performance when applied on active surface ships. The 1K polysiloxane provides applicators with a "user-friendly" system that eliminates the measuring and mixing of multiple components, eliminates potential curing and performance issues associated with incorrectly mixing components, in addition to providing for a longer pot-life and reducing the amount of hazardous waste generated from unused mixed materials.

ACKNOWLEDGMENTS

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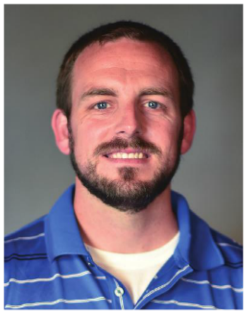
ABOUT THE AUTHORS

Erick Iezzi is a Ph.D. organic chemist with over 10 years of experience developing novel molecules and coating technologies. At NRL, he is the principal investigator of several basic and applied research programs and his primary areas of research are the synthesis of novel small molecules, oligomers and polymers, the formulation of thermosetting coatings, the study of coating surface interactions with liquids and coating degradation due to weathering and corrosion, and mechanical property testing of coatings. Several of Iezzi's technologies are currently being demonstrated on Navy surface ships and submarines.



James Tagert is a materials research engineer working at the Naval Research Laboratory and has over 10 years of experience working in the coatings industry. He graduated from the University of Maryland in 2004 earning a Bachelor of Science degree in mechanical engineering and is a member of both the American Society of Naval Engineers and NACE International. Tagert has worked at NRL since 2008 supporting U.S. Navy research and engineering programs related to materials science with an emphasis on the development and transition of advanced coating systems.

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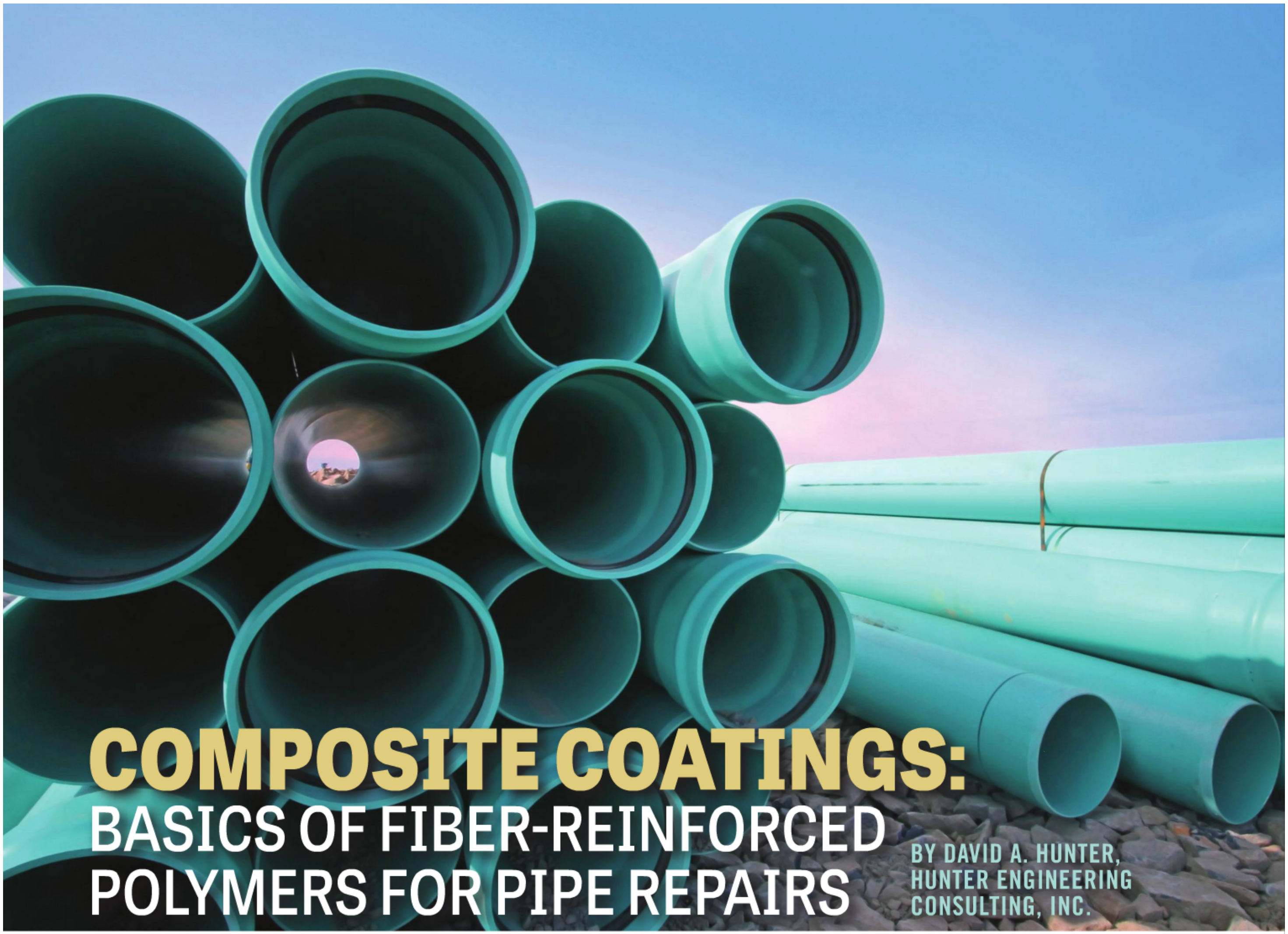

COMPOSITE COATINGS:
BASICS OF FIBER-REINFORCED POLYMERS FOR PIPE REPAIRS

BY DAVID A. HUNTER,
HUNTER ENGINEERING CONSULTING, INC.

Composite coatings are a class of materials that are described as fiber-reinforced polymers (FRP) and consist of extremely strong tensile fibers saturated with a binding resin. From the original development as tank bottom lining materials designed to handle surface movement and corrosion, the applications for composite coatings have broadened and moved into the mainstream, with industry-accepted design codes written around their uses and applications.

THE BACKGROUND

Composites, as the name implies, are combinations of two or more materials, which act as one material. Often the combination will take advantage of each material's individual strengths to provide a functional combination that is greater than each individual material by itself.

In a general sense, composite materials have been around for a very long time. One composite with which most people are familiar is reinforced concrete. Concrete is often rated in terms of its compressive strength in pounds-per-square inch (psi); a typical value might be 4,000 psi. Unreinforced concrete is a very durable material that handles stresses extremely well in compression but has very poor tensile strength. Unreinforced concrete has a tensile strength of only about 10 percent of its compressive strength, so if, for example, samples of concrete have a compressive strength of 4,000 psi, the tensile strength would only be about 400 psi. In order to overcome this limitation of the concrete material, engineers place steel "reinforcing" bars into the concrete in the location of tension in the member. The steel can pick up the tensile stresses to overcome the brittleness, thus addressing the concrete's lack of ability to handle this by itself. When this concept was first introduced, the materials were tested exhaustively to understand how they would behave under different types of loads, weathering conditions, immersion environments, buried environments, salt exposure, chemical exposure, radiation exposure and more, until the behavior was predictable enough that design and construction standards (codes) could be written around the use of these materials for safe and reliable construction. From those standards, text books are written today that are considered the gospel of civil engineering curriculums worldwide. This is a good thing. You might be surprised to know that the first reinforced concrete house was built in France in the 1850s. All those Roman structures you see are simply unreinforced concrete, which is why the Romans used a lot of

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arches and not long-beam expanses for bridges because arches are in compression. Without the reinforcing steel, it simply cannot be done.

The key feature in adopting a construction product as a mainstream building material is the standardization of manufacturing of processes so they can be specified with confidence as design elements. As technology has progressed, new composite materials have been developed which combine properties of several materials in order to achieve a desirable material that solves industry challenges. New is a relative term, in that, in the case of composite coatings or fiber-reinforced polymers (FRP), we are talking about more than 30-year-old technology, based on resin and fiber-reinforcing materials differing in weave density, direction and make up. As with all newly developed materials, it takes time for the manufacturing processes to be honed in order to make materials consistent from batch to batch. Once batch consistency or tolerances are assured, the materials go through extensive testing to determine the dynamics of the matrix.

Let's explore an example near and dear to the author's heart — an aviation example. The author flies about 250,000 miles per year on all sorts of aircraft. The new Boeing 787 is the first plane to be designed with carbon fiber composite materials, in particular in the wings, which is where the stress is very high and cyclic in nature, which could lead to metal fatigue. I promise you, that since I am personally involved in flying on the aforementioned aircraft, I want to be 100 percent sure that the materials are properly tested and manufactured to a standard that eliminates error or as near as is statistically possible.

Which is why I'm happy to say that Boeing has literally conducted millions of hours of simulation and testing to have a thorough understanding of the dynamics of their composite formulas.

This technology, when properly installed, can achieve the following.

- Increase the load capacities of bridges, parking decks and other structures.
- Restore maximum operating pressures of existing pipes and pipelines where wall thickness has been lost due to corrosion.
- Maintain the operating pressures of existing pipes with corrosion wall losses of up to 80 percent (Fig. 1).
- Provide extreme abrasion and impact resistance in horizontal directionally drilled (HDD) lines.
- Provide reinforcement for storage tanks — pitting or general corrosion.
- Allow low-pressure leak repairs on up to 12-inch-diameter pipes and operating up to 4-bar pressure.
- Provide protection of pipes at support areas from abrasion caused by thermal expansion, as well as crevice corrosion and galvanic cells by isolating any dissimilar metals, if present.

Some interesting features include the following.

- Installation that can usually be done while in service and in certain situations, even underwater (Figs. 2 and 3, p. 34).
- Applications that can be installed for ISO 12944 (Paints and varnishes — Corrosion protection of steel structures by protective paint systems) service environments of C1 to C5I and C5M, as well as Im1 through Im3 environments for immersion and below-grade.
- Newer formulations that provide operating service temperatures up to 300 F (150 C).

MANUFACTURING CONSIDERATIONS

Composite coatings use a liquid-cured polymer (the binding resin), typically a two-part epoxy or moisture-cured polyurethane (MCU), with an extremely strong fiber cloth. The fiber can be unidirectional (allowing tensile stress in one direction), bidirectional (allowing tensile stress in two directions), and can be made of fiberglass, carbon fiber or a combination of both. If a pipe repair requires only reinforcement in the hoop direction, then uniaxial fibers are sufficient. If additional strength is needed for bending, torsion or shear loads, however, then a biaxial cloth should be selected. Biaxial fabric has strength fibers oriented at 90-degree angles to each other.

The choice of carbon fiber versus fiberglass fiber is primarily one of strength versus cost. Carbon fiber tends to make a higher strength composite per layer, but costs more. The FRP resin can be either a pre-impregnated (the resins are pre-applied into the fiber in the plant) or a field-wetted system, denoted

Fig. 1: View of a pipe section over pressure testing.
Photos courtesy of the author unless otherwise noted.

Fig. 2: Installation of a composite coating system.

Fig. 3: View of the application of an epoxy/carbon fiber system repair of a T-section.

as wet layup. Pre-impregnated systems consist of a single-component that is cured by environmental exposure, such as moisture, or ultraviolet light, whereas field-wetted systems are typically two-part epoxies.

There are advantages and disadvantages to each. For example, the moisture-cured systems offer good strength and are very user-friendly during application, even including application underwater. Epoxy-based systems have higher strength characteristics, but limited working times due to finite pot lives.

It all seems fairly straightforward, but the devil is in the details. Depending on the specific fiber used and the specific formulation of resin, the tensile strength of the material will vary. Any changes in the resin formulation or any change in the fiber used, such as thickness, weave or type, will change the properties of the materials. Most importantly, simply combining the materials together does not yield the full tensile strength properties of the fiber. On average, the tensile strength of the fiber is reduced by nearly 80 percent. In addition, resin-rich combinations and resin-poor (drier) combinations can also change the performance of the materials.

Fiber-reinforced polymers are an interesting class of materials that call for proper specification of the material properties in order to ensure that the mechanical properties of the material meet the required tolerances. This is a process that may not be fully understood, so clearly specifying the testing and acceptance values of a composite coating material is of the utmost importance.

ASME International Post-Construction Code, PCC-2, has issued guidance on the use of nonmetallic and bonded repairs to piping systems in its publication, ASME PCC-2-2011, "Repair of Pressure Equipment & Piping."[1] It contains a section detailing material test requirements under Part 4, Section 3.2, Table 1, and additional mandatory testing in Appendix II. Many companies have entered the market using systems which may not meet such a standard, or they may not even be aware that such standards exist. Most importantly, under Part 4, Section 3.6, any change in a repair system, such as resin formula or new or different fiber reinforcement requires requalification testing of the system.

Note that these are not the only standards. For instance, ISO/TS 24817:2006 "Petroleum, petrochemical and natural gas industries — Composite repairs for pipework — Qualification and design, installation, testing and inspection"[2] might be applicable for a given facility, and for concrete structures, ACI 440.8-13, "Specification for Carbon and Glass Fiber-Reinforced Polymer (FRP) Materials

Made by Wet Layup for External Strengthening of Concrete and Masonry Structures."[3]

FIBER-REINFORCED POLYMER (NONMETALLIC COMPOSITE) REPAIRS

Fiber-reinforced polymers have been in use in a variety of industries for over 30 years, including aviation, oil and gas development and distribution, concrete structural repairs and upgrades and even water and wastewater transmission and collection.

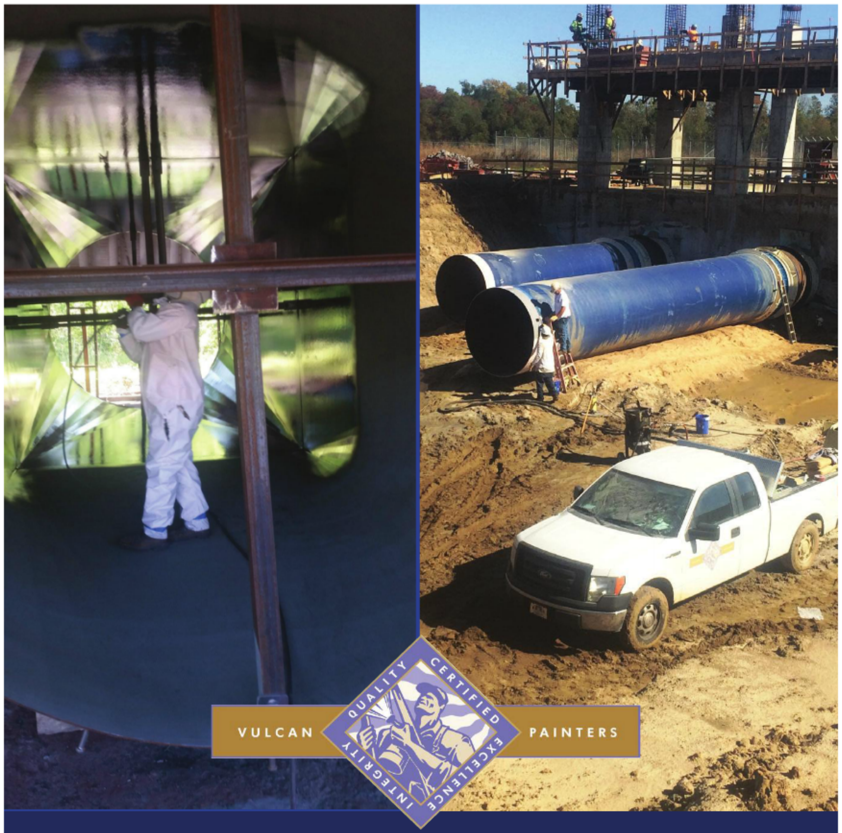
FRPs are a useful option for repairing steel pipes damaged by either internal or external corrosion. One of the most significant advantages of these materials is that a section of pipe can be reinforced without shutting down operations, allowing many large industrial facilities to operate for extended periods of time between scheduled maintenance shutdowns. If a pipe is found to have internal or external corrosion, mechanical damage, or requires a higher factor of safety, there is no need to cease operations to fix the problem. Often the repair or reinforcement can be performed quickly with damaged sections being reinforced in a matter of hours or days and minimal disruption to ongoing operations.

Although the FRP reinforcement can be installed while a pipe is pressurized, the FRP is most effective if applied to a pipe in an unstressed (depressurized) state. All pipes expand, or strain, when pressurized. By relaxing the load on the pipe the strain is reduced so that when the system is repressurized, the FRP and steel both absorb the pressurization load and the composite immediately goes into load-sharing with the existing steel. As the FRP absorbs load, the amount of load carried by the steel at the repair is reduced.

A design engineer, knowing the strength and material properties of the composite, can use the equations from PCC-2-2011 to calculate the number of layers necessary to meet a specified repair requirement. Interestingly, the repair can be designed so as to make the reinforcement stronger than the pipe itself, in pristine condition. In other words, the repair could be applied to a brand new pipe with a defect that simulates a wall loss of up to 80-percent, the pipe pressurized to failure, and the pipe would fail but not the repair, as in Figure 1 (p. 33). In addition, the code provides for a 20-year design life of the repair, and a 50-year design life can be interpolated.

FIBER-REINFORCED POLYMER REPAIR INSTALLATION

A typical repair consists of proper surface preparation of the pipe or substrate.



Surface oils, dirt and grease should be removed using an approved solvent, followed by a high-pressure hydroblast or dry abrasive blasting to prepare the surface to an Sa 2.5[4] or an SSPC-SP 10/ NACE No. 2, "Near White Blast Cleaning"[5] finish, and then an epoxy primer should be applied to the metal. Once the FRP fabric is saturated with resin (either factory-saturated polyurethane [MCU] or field-saturated epoxy), the fabric is then wrapped around the damaged pipe area until the desired number of layers is attained (Fig. 2, p. 34). One of the principal benefits of this application method is that repairs are highly customizable — the fiber can conform to irregular shapes in the pipe, such as bends, tees and elbows (Fig. 3, p. 34). If more damage is discovered, additional layers can be added.

The wet, uncured laminate is then wrapped with a compression film similar to plastic food wrap. This serves to exert a net compressive force on the laminate so an effective bond will form and eliminate voids or any delamination in the repair. After the repair has cured, the compression film can be removed. If the repair will be exposed to the environment, an ultraviolet (UV) protective outer layer is typically applied as well. This is usually a coating selected from a wide range of commercially available UV coating products. Novalac-based epoxies are good choices for environments with extreme temperature and chemical exposure. Novalac epoxies are highly chemical resistant and widely used as a base resin in many FRP products. They generally have outstanding resistance to sulfuric acids (H_2SO_4), hydrochloric acids (HCl), acetone, toluene, naphtha and gasoline, which makes them suitable for repairs on pipes that are transporting these chemicals.

As previously mentioned, MCU-based resins are ideally suited for undersea applications. The preparation and application are basically the same as for dry environments: the surface of the pipe is prepared using hydroblasting or grit blasting, local damages such as pits or dents are filled with a high-compression-strength fill material, and the pipe is wrapped with the desired number of layers until a specified reinforcement is attained (Figs. 4 and 5).


Fig. 4: Underwater application of composites. Note the prepackaged, pre-impregnated resin system.

BUYER BEWARE

Particular attention should be paid to evaluation of the testing criteria carried out by the manufacturer. The majority of manufacturers of these types of materials are small companies and with the testing being expensive, instances do exist where manufacturers have provided questionable testing results. A good coatings consultant can weed through the marketing information and recommend a product for the particular


Fig. 5: View of underwater application of composites.

application. If you plan to use engineered composite repairs, do not do so without a well-written specification and product research.

SUMMARY

Composite FRP materials provide facility and process operators with the ability to reduce risk as well as the flexibility to maintain operability using materials with mechanical capabilities greater than the original materials. By being able to schedule maintenance proactively rather than in a reactionary way, the cost of operation in a variety of industries can be reduced.

ABOUT THE AUTHOR

David Hunter is the president of Hunter Engineering Consulting, Inc. He graduated from Virginia Tech with a Bachelor of Science degree in civil engineering and has more than 20 years of experience in the corrosion and coatings industry. Hunter is certified as an SSPC Protective Coatings Specialist (PCS), an SSPC Level-2 Coatings Inspector, a NACE Level-3 Coating Inspector, a NACE Offshore Corrosion Assessment Technician (OCAT), and is an instructor for each of these associations.

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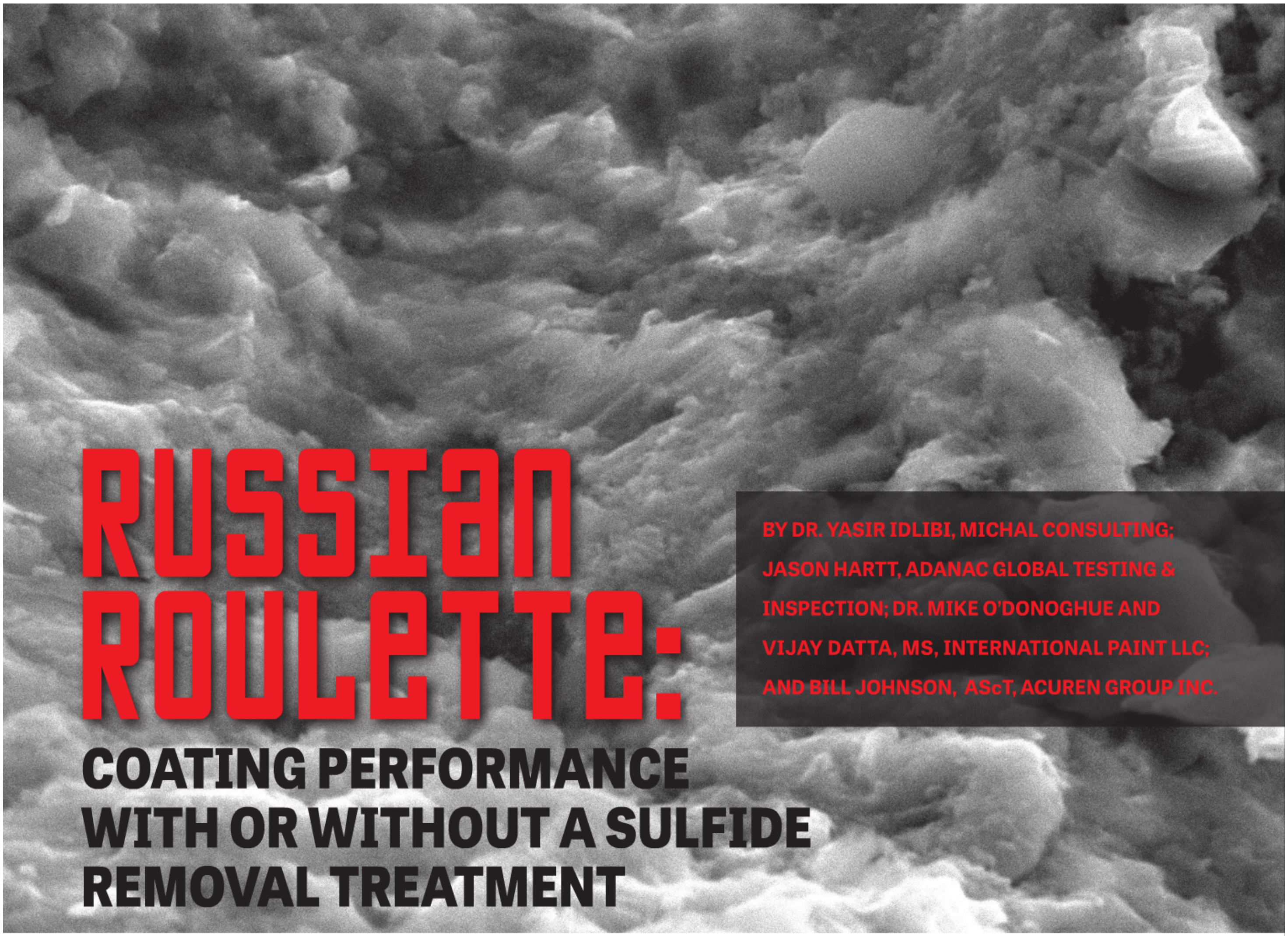


RUSSIAN ROULETTE:

COATING PERFORMANCE WITH OR WITHOUT A SULFIDE REMOVAL TREATMENT

BY DR. YASIR IDLIBI, MICHAL CONSULTING;
JASON HARTT, ADANAC GLOBAL TESTING & INSPECTION; DR. MIKE O'DONOGHUE AND
VIJAY DATTA, MS, INTERNATIONAL PAINT LLC;
AND BILL JOHNSON, AScT, ACUREN GROUP INC.

Is there such a thing as "blind chance"? Enter the realm of cause and effect and lining performance. Failing to *see* sulfide contaminants on a so-called ready-to-be-coated steel surface may be like not *seeing* the bullet in the chamber in a game of Russian roulette — not necessarily good for longevity in either case.

Worldwide, many thin- and thick-film innovative polycyclamine-cured epoxy linings have performed admirably in oil patch, high-temperature service for tank, vessel and pipe spool internals. Notwithstanding, with ever-increasing temperatures and pressure and chemical resistance requirements in oil and gas environments, the demands placed upon linings are becoming more stringent.

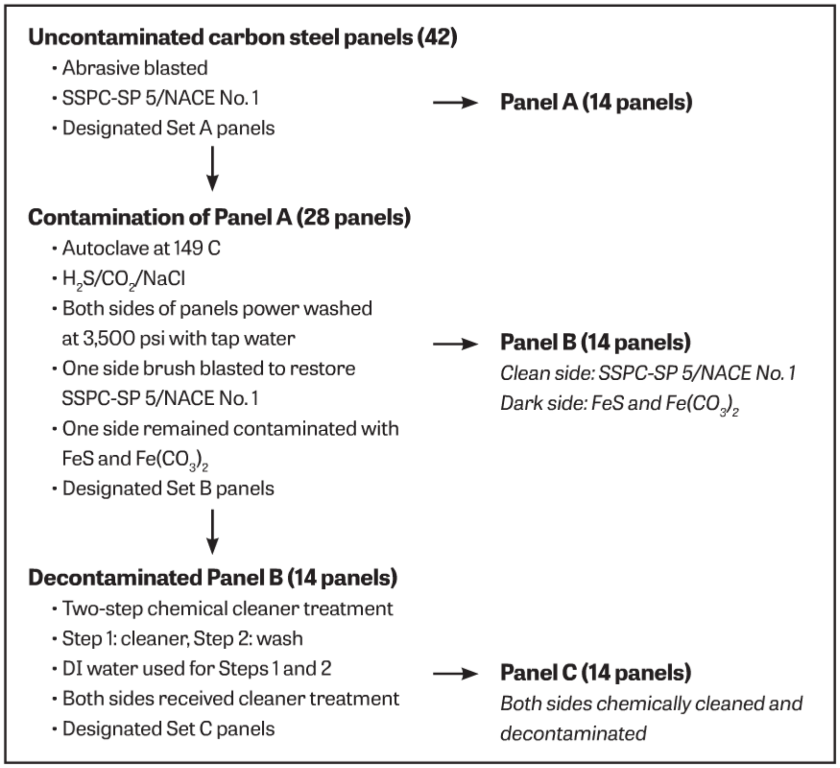
This article investigates whether the performance of these linings could be enhanced by first abrasive blasting the steel substrate and then providing a subsequent application (and removal) of a unique chemical reagent to remove deleterious sulfide contaminants, improve lining performance in aggressive immersion service conditions and potentially extend the life-cycles of the applied linings.

Accelerated laboratory investigations were carried out on a set of reagent-treated, and untreated, carbon steel test panels. Sets of panels were lined with a three-coat, thin-film solvent-borne epoxy novolac coating or a single coat solvent-free, thick-film polycyclamine-cured epoxy.

Characterization of the lining performance, the lining-steel interface and efficacy of the sulfide removal reagent was achieved using autoclave (NACE-TM0185), electrochemical impedance spectroscopy (EIS), scanning electron microscopy (SEM/EDX) and X-Ray diffraction (XRD).

Proper surface preparation for the application of lining systems is fundamentally crucial to long-term coating success. Carbon steel that has been abrasive blasted to an SSPC-SP 5/NACE No. 1, "White Metal Blast Cleaning" standard has rightly undergone scrutiny as the benchmark of lining performance when it is ensured that soluble chlorides and sulfates are kept below threshold levels where they would initiate lining failure. Predictors of successful or failure-prone lining applications in the real world include the influences of surface profile, peak height and peak count density, and cleanliness of the steel substrate. Importantly, from a surface profile and morphology viewpoint, a deeper profile with a greater surface area is required for these linings[1-4]. Furthermore, in earlier investigations the authors contend that with single-coat and solvent-free thick-film lining applications, the peak height of the profile should preferably be 3-to-4 mils and be jagged as opposed to evidencing a peen pattern (peak height, peak density and coating rheology are all important factors)[1]. From a surface cleanliness viewpoint, much has been discussed in the literature about the deleterious effects on lining performance by non-visible contaminants, notably soluble salts[5-8]. With an industry emphasis on an understanding of the effect of anions such as chlorides, sulfates and more recently nitrates (for example flash rusting, osmosis and blistering of linings) the effect of cations and insoluble sulfides has received comparatively scant attention.

Iron sulfide species are an ever-present reality in the oil and gas, mining and wastewater industries. Given that iron sulfide is cathodic to steel, and often the scourge of many industrial processes, this investigation was spurred by the authors' curiosity to evaluate lining performance on carbon steel that had been intentionally contaminated by iron sulfide. Iron sulfide may form a thin adherent protective layer on steel surfaces, or a thick, porous detached layer depending upon the pH, H_2S concentration, temperature, flow rate and pressure[9]. When iron-sulfide-fouled surfaces are intended to be coated, it is imperative that any residual iron sulfide or other contaminants are removed. Any iron-sulfide deposits remaining would act as both a barrier between the coating and substrate that may affect coating adhesion and become a possible corrosion initiation site due to a cathode-anode reaction when sufficient permeation of an aggressive solution through the coating occurs.



Uncontaminated carbon steel panels (42)
- Abrasive blasted
- SSPC-SP 5/NACE No. 1
- Designated Set A panels

→ **Panel A (14 panels)**

Contamination of Panel A (28 panels)
- Autoclave at 149 C
- $H_2S/CO_2/NaCl$
- Both sides of panels power washed at 3,500 psi with tap water
- One side brush blasted to restore SSPC-SP 5/NACE No. 1
- One side remained contaminated with FeS and $Fe(CO_3)_2$
- Designated Set B panels

→ **Panel B (14 panels)**
Clean side: SSPC-SP 5/NACE No. 1
Dark side: FeS and $Fe(CO_3)_2$

Decontaminated Panel B (14 panels)
- Two-step chemical cleaner treatment
- Step 1: cleaner, Step 2: wash
- DI water used for Steps 1 and 2
- Both sides received cleaner treatment
- Designated Set C panels

→ **Panel C (14 panels)**
Both sides chemically cleaned and decontaminated

Fig. 1: Preparation and treatment of 42 panels prior to coating application.
All figures courtesy of the authors unless otherwise noted.

Previous autoclave and EIS studies carried out by the authors on coated panels subjected to 149 C (300 F) in acidic gases (10-percent H_2S, 10-percent CO_2, 80-percent CH_4), 5-percent aqueous sodium chloride solution, and sweet or sour crude oil, had indicated that a proprietary post-abrasive-blast, water-based cleaner and surface decontamination process appeared to show considerable merit[10]. Yet studies reported elsewhere on soluble salt removal from steel and coating performance concluded that the same cleaner and decontamination process (using tap water and not deionized water) had neither a positive nor negative effect on the performance of ten atmospheric coating systems or on four internal lining systems[11, 12].

The primary interest in the present investigations centered on A) the efficacy of the post-blast chemical cleaning treatment to remove insoluble iron sulfide contaminants and the difference in lining performance with or without the chemical treatment, and B) comparing and contrasting

Fig. 2: Examples of deliberately contaminated panels.

Fig. 3: Examples of pre-test panels. (Left to right): Coating 2-Panel A, Coating 1-Panel B, Coating 2-Panel B and Coating 1-Panel C.

Fig. 4: Coating 1 panels, post autoclave test. (Left to right): 2A, 1B, 2B and 1C.

the metal surface after abrasive blasting and post-blast chemical treatment.

The cleaner and decontamination procedure was touted to remove both soluble salts and *insoluble sulfides* (authors' emphasis), carbonates and oxides, and afford a residue-free and so-called passivated iron layer on the steel substrate. Furthermore, it appeared to have improved the performance of a thin-film epoxy novolac tank lining system applied to an SSPC-SP 5/NACE No. 1 white metal standard (jagged profile of 3-to-4 mils) in our previous studies[10]. How? The epoxy novolac lining blistered in the conditions tried on a white metal surface that had not received the chemical treatment. In contrast, the same epoxy novolac lining did not blister under the experimental conditions after having been applied to the white metal surface post treated with the surface cleaner decontamination procedure. Yet lingering questions remained.

1. Were the results repeatable and therefore, other things being equal, able to genuinely demonstrate the efficacy of the post-abrasive-blast-applied, water-based cleaner to enhance the adhesion and performance of the lining system?

2. Did the cleaner and decontamination process serve as an effective, complementary and arguably necessary treatment to abrasive blasting? Did they decontaminate the surface and remove non-visible and insoluble iron sulfide contaminants?

3. Did the cleaner "passivate steel" as reported in the literature?[13]

4. Was the steel surface modified by the cleaner in some unknown way?

5. As for "blind chance," did the cleaner *unload* the gun?

These questions made the present investigations exhilarating from a pioneering perspective. Read on for the answers.

CANDIDATE SURFACE DECONTAMINATION TECHNOLOGY CHEMICAL CLEANING

A two-step decontamination process was intriguing in that it was stated to remove deleterious soluble salts, flash rust and insoluble *metal sulfides* from carbon steel substrates. This process was said to be accomplished first by application of a proprietary acidic cleaner, then followed by the application of an alkaline wash to neutralize the substrate prior to a coating application.

Table 1: Coating 1 Autoclave Analysis

149 C, 250 psig, 10% H_2S, 10% CO_2, 80% CH_4, Sour Crude, 5% NaCl in Distilled Water, 96 hrs.

Coating 1	Avg. DFT	Adhesion Rating (ASTM D6677)				Blistering (ASTM D714)			Impedance (log Z @ 0.01 Hz)			
		Pre-Test	Water	HC	Gas	Water	HC	Gas	Pre-Test	Water	HC	Gas
1A	13.0	8	10	10	8	N	N	N	10.29	7.85	9.99	10.08
2A	14.3		10	10	8	N	N	N		7.74	10.05	10.33
1B	14.0	8	10	8	8	N	N	N	10.10	7.79	10.33	10.09
2B	13.8		8	8	8	F#2	N	N		7.63	10.60	10.75
1C	16.4	10	10	10	8	N	N	N	10.39	7.91	10.78	11.01
2C	15.0		10	10	8	N	N	N		6.61	10.10	10.71

1. DFTs were measured for each coating and each phase. Average DFT reported.
2. HC = hydrocarbon.
3. Panels A – Applied to SSPC-SP 5/NACE No. 1 abrasive blasted steel.
4. Panels B – Applied to panels above which were then deliberately contaminated with gaseous H_2S (10%) and NaCl solution (5%), washed with tap water and brush blasted on one side.
5. Panels C – Applied to Panels B treated with the chemical cleaner.

In Step 1, a non-toxic and eco-friendly acidic cleaning material was spray-applied as a gel to abrasive-blasted steel panels. The cleaner consisted of a powdered mixture added to deionized water. The mixture consisted of citric acid to afford the desired acidic, dispersing and free-rinsing properties, and a poly-sugar thickening agent to achieve vertical cling properties of the gel. Other additives facilitated removal of water-soluble contaminants such as chlorides and sulfates, and insoluble contaminants such as metal sulfides and flash rust. In most instances, the typical application of the cleaner would be 15 mils wet-film thickness (WFT), with a thirty-minute dwell time.

In Step 2, a power wash rinse of the cleaned substrate was undertaken using an alkaline, non-toxic, acid-neutralizing fugitive amine dissolved in deionized water. The latter ensured that an essentially chemical-free surface is achieved once the substrate is dry. The alkalinity of the wash combined with the reactive and acidic gel treatment ensures that a neutral effluent is obtained. Any portion of the rinse that does not neutralize the acidic gel, volatilizes off the metal substrate with the water. Because the chemistry used is free-rinsing, the resulting surface has a very low conductivity and is naturally in a passive state due to blocking of reactive sites that upon drying would otherwise flash-rust upon exposure to air.

CANDIDATE EPOXY LININGS

Based on earlier studies, a thin-film multi-coat solvent-borne epoxy novolac coating and a thick-film single-coat solvent-free polycyclamine-cured hybrid epoxy coating were chosen for the present investigations. Each lining is known to be well-suited to the oil and gas industry for new construction as well as maintenance and repair projects for tanks, vessels and pipe spools.

In earlier work, with a four-day autoclave test at 149 C under a 10-percent H_2S, 10-percent CO_2, 80-percent CH_4 gas mixture, a sour crude hydrocarbon phase, and a 5-percent NaCl water phase, the solvent-borne lining had indicated a pass or fail performance-dependency in the aggressive water phase based on the presence (pass) or absence (fail) of the surface decontamination cleaner treatment[10].

While the solvent-free epoxy lining system had not been investigated in terms of the efficacy of the cleaner, the fact that the solvent-free epoxy lining system ranked number one in three third-party independent laboratory tests (out of nine epoxy candidate systems in each test) warranted its inclusion as the *prima facie* solvent-free lining in the current test program. Of great interest was the need to determine whether the performance of this lining improved or diminished using the surface cleaner as a complementary treatment to panels that had been abrasive blasted to SSPC-SP 5/NACE No. 1 white metal.

Coating 1

Coating 1 was applied in either a two- or three-coat application to achieve approximately 12-to-15 mils total dry-film thickness (DFT). A solvent-borne, thin-film epoxy novolac, Coating 1 possesses a three-dimensional (3-D) molecular network. Spanning decades, Coating 1 has an extensive worldwide track record in the lining of tanks and vessels in the oil and gas industry. It possesses excellent hydrolytic, thermal (up to 121 C [250 F]) and chemical

Fig. 5: Coating 2 panels, post autoclave test. (Left to right): 2A, 1B, 2B and 1C.

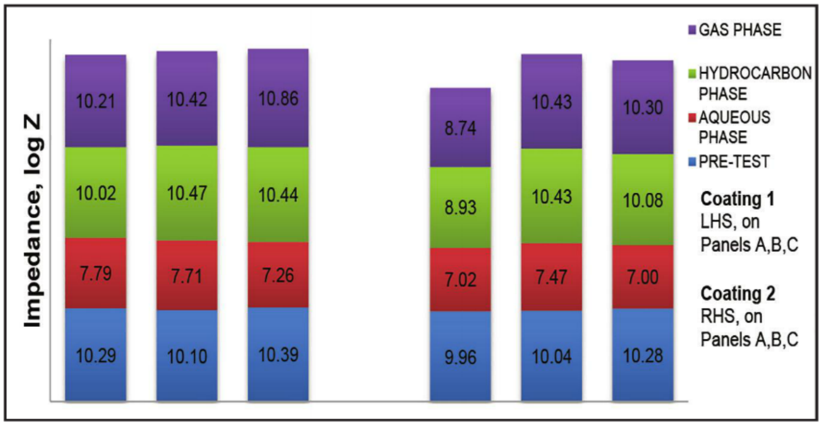


Fig. 6: Impedance, pre- and post-autoclave exposure.

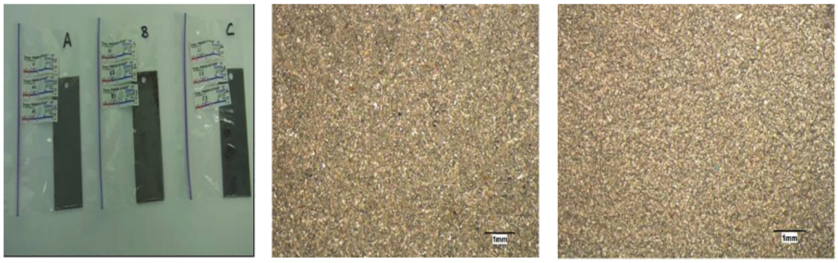


Fig. 7: (Left) Panel A, Panel B (washed, brush blasted one side; contaminated on other side) and Panel C. (Center) Panel A, SSPC-SP 5/NACE No. 1 and (Right) Panel C, SSPC-SP 5/NACE No. 1 and chemically cleaned.

Fig. 8: (Top row, Left) Test panels as received, (Center) unpacking of Test Panel B washed, uniform rusting throughout; Test Panel B unwashed similar and (Right) Test Panel B, boiling extraction method, all others similar. (Bottom row, Left): Test Panel A, surface profile measurements (ASTM D4417) prior to boil extraction, (Center) Test Panel C, surface profile measurements (ASTM D4417) prior to boil extraction and (Right) Liquid reagent sample cooling and test panels repackaged after boil extraction. Photos courtesy of Norske Corrosion and Inspection Services Ltd.

resistance. Coating 1 cures at temperatures as low as 10 C (50 F).

Coating 2

Coating 2 was applied in a one-coat application at 20-to-25 mils by single-leg spray equipment. Coating 2 was a new-generation, rapid-cure, solvent-free epoxy lining with a longer pot life than most rapid-curing, single-coat solvent-free epoxy linings. As with Coating 1, Coating 2 possesses excellent hydrolytic, thermal (up to 149 C) and chemical resistance. Coating 2 cures at temperatures as low as 5 C (41 F).

EXPERIMENTATION

Preparation and Treatment of Steel Panels

Figure 1 (p. 39) is a schematic outline of the preparation of carbon steel panels designated as A, B and C.

Uncontaminated Carbon-Steel Panels

Using staurolite 20/40 abrasive media, 42 ASTM A36 carbon-steel panels at 4.5-by-1.5-by-⅛-inches were abrasive blasted to SSPC-SP 5/NACE No. 1 white metal blast to achieve a sharp angular profile in the range of 2.5-to-4 mils. Abrasive blasting was performed by a reputable coating contractor. Fourteen of these panels were set aside and designated as Set A.

Deliberately Contaminated Carbon-Steel Panels

The remaining 28 bare panels were deliberately contaminated by exposing them to a gaseous phase of 10-percent H_2S, 10-percent CO_2, 80-percent CH_4, and an aqueous phase of 5 percent NaCl, in an autoclave for four days at 149 C and 250 psig. Figure 2 (p. 39) shows the rusted panels after their removal from this exposure. This contamination procedure was undertaken to ensure that a significant amount of black iron sulfide was formed on the steel panels and that the steel was also contaminated with iron carbonate and chlorides.

After taking some conductivity measurements, the 28 deliberately contaminated panels were then pressure washed on both sides at 3,500 psi with regular Alberta tap water. One side of the panels was then abrasive swept to restore the clean and original SSPC-SP 5/NACE No. 1 condition and the other side did not receive further abrasive sweeping and turned dark over time. Fourteen of these panels were set aside and designated as Set B.

Decontaminated Carbon-Steel Panels

Both sides of the remaining 14 panels were designated as Set C and treated with the cleaner and surface decontamination gel almost two weeks later. Nineteen liters (five gallons) of the gel was prepared by adding 2.4 kilograms (5.3 lbs.) of the powdered mixture to the appropriate amount of deionized water and mixed for about ten minutes using a squirrel cage mixer.

The test panels were treated by exposing the entire panel to the acidic gel cleaner in a ziplock bag. This technique was used in order to avoid exposing the clean front (washed and abrasive-blasted) and dark back (residual iron sulfide contaminant) panel sides individually. An aliquot of gel was poured into the bag with three or four test panels inserted. This ensured that the panels did not touch one another. Thereafter, the panels had a 30-minute exposure to the gel, with the bag being flipped-over at the 15-minute interval. The initial panels turned the gel dark grey.

The panels were then placed on a polymer-based sink protector and placed inside a plastic kitchen drying rack. All the panels were then power washed on one side with a 1-percent solution of alkaline rinsing aid in deionized water using a low-pressure, 4,000 psi pressure washer (equipped with a standard 'V' spray tip). Using latex gloves, the panels were then turned over and the reverse side of each panel was power washed as above.

Given that only about 90 percent of the dark side of the panel became clean, in accordance with the technical data sheet (TDS) of the chemical cleaner, the panels were retreated and rinsed a second time. The panels were left exposed under indoor ambient conditions. Prior to the first attempt to ship the panels, it was noticed that a sink protector pattern was evidenced on a few of the panels. Therefore, according to the technical data sheet, the panels were retreated again. It was determined that when the panels were turned over to rinse the opposite sides, that the clean side was found to come into direct contact with acid-gel-contaminated surfaces left behind on the sink protector. This time, very careful attention was paid not to recontaminate

the initial clean sides. Prior to shipment to the laboratory, the panels were vacuum-packed using a food saver. This way, the excellent condition of the cleaned panels was preserved during shipping.

Lining Application

Coating 1 was applied in three coats while Coating 2 was applied in a single coat. Both Coating 1 and Coating 2 were applied in accordance with the lining manufacturer's instructions to the three sets of panels; Set A, Set B and Set C. Figure 3 (p. 40) shows examples of the coated panels. The same applicator who performed the abrasive blasting of the steel panels undertook the coating application.

TEST METHODS FOR COATING EVALUATION

Autoclave

The primary screening test most commonly employed by facility owners in the oil patch for tank and vessel linings is NACE TM0185, "Evaluation of Internal Plastic Coatings for Corrosion Control of Tubular Goods by Autoclave Testing."[14] The test environment consisted of three phases: a gas phase mixture of 10-percent H_2S, 10-percent CO_2, 80-percent CH_4, a hydrocarbon phase of sour crude, and an aqueous phase of a 5-percent NaCl solution. The tests were conducted at 149 C and at a total pressure of 250 psig. The test temperature had an accuracy of plus or minus 3 degrees C.

Electrochemical Impedance Spectroscopy (EIS)

EIS was used as a diagnostic tool to compare barrier properties before and after autoclave exposure. Essentially, the low frequency impedance (AC electrical resistance) is related to the permeability of the coating to water, organic molecules and small gaseous molecules such as H_2S and CO_2. The log Z value, where Z is impedance at 0.01 Hz is typically used as the basis for comparison of a coating's barrier properties[15, 16]. The higher the impedance of a coating, the higher barrier properties it has, thus the more protective the coating is. A basic rule of thumb is that the barrier performance of a coating is excellent, good or marginal when log Z values are on the order of 10, 8 and 6; respectively.

Table 2: Coating 2 Autoclave Analysis

<table>
<tr><th colspan="14">149 C, 250 psig, 10% H_2S, 10% CO_2, 80% CH_4, Sour Crude, 5% NaCl in Distilled Water, 96 hrs.</th></tr>
<tr><th rowspan="2">Coating 1</th><th rowspan="2">Avg. DFT</th><th colspan="4">Adhesion Rating (ASTM D6677)</th><th colspan="3">Blistering (ASTM D714)</th><th colspan="4">Impedance (log Z @ 0.1 Hz)</th></tr>
<tr><th>Pre-Test</th><th>Water</th><th>HC</th><th>Gas</th><th>Water</th><th>HC</th><th>Gas</th><th>Pre-Test</th><th>Water</th><th>HC</th><th>Gas</th></tr>
<tr><td>1A</td><td>21.1</td><td rowspan="2">8</td><td>10</td><td>10</td><td>6</td><td>N</td><td>N</td><td>N</td><td rowspan="2">9.96</td><td>7.07</td><td>10.68</td><td>10.49</td></tr>
<tr><td>2A</td><td>21.0</td><td>10</td><td>10</td><td>6</td><td>N</td><td>N</td><td>N</td><td>6.98</td><td>7.19</td><td>6.98</td></tr>
<tr><td>1B</td><td>24.5</td><td rowspan="2">8</td><td>8</td><td>4</td><td>6</td><td>N</td><td>N</td><td>N</td><td rowspan="2">10.04</td><td>7.44</td><td>10.57</td><td>10.28</td></tr>
<tr><td>2B</td><td>24.5</td><td>6</td><td>4</td><td>4</td><td>N</td><td>N</td><td>N</td><td>7.50</td><td>10.29</td><td>10.58</td></tr>
<tr><td>1C</td><td>16.7</td><td rowspan="2">8</td><td>10</td><td>10</td><td>8</td><td>N</td><td>N</td><td>N</td><td rowspan="2">10.28</td><td>6.54</td><td>10.05</td><td>10.01</td></tr>
<tr><td>2C</td><td>17.4</td><td>10</td><td>10</td><td>10</td><td>N</td><td>N</td><td>N</td><td>7.45</td><td>10.11</td><td>10.60</td></tr>
</table>

1. DFTs were measured for each coating and each phase. Average DFT reported.
2. HC = hydrocarbon.
3. Panels A – Applied to SSPC-SP 5/NACE No. 1 abrasive blasted steel.
4. Panels B – Applied to panels above which were then deliberately contaminated with gaseous H_2S (10%) and NaCl solution (5%), washed with tap water, and brush blasted on one side.
5. Panels C – Applied to Panels B treated with the chemical cleaner.

Table 3: Conductivity and Surface Profile Measurements of Test Panels Pre-Coating Application

Test Panel from Set	General Characteristics and Comments	Total Dissolved Salts (TDS)	Average Surface Profile (mils)
A: No contamination abrasive blast	SSPC-SP 5/NACE No. 1 white metal blast standard	0 µS/cm	2.63 (1st panel) 2.50 (2nd panel)
B: Deliberate contamination, washed*, not re-swept	Black surface: uniform rusting throughout (FeS/iron oxide)	32 µS/cm	N/A
B: Deliberate contamination unwashed, not re-swept	Black surface: uniform rusting throughout (FeS/iron oxide)	14 µS/cm	N/A
C: Chemical treatment to a Panel B that was washed	SSPC-SP 5/NACE No. 1 white metal blast standard	0 µS/cm	3.63 (1st panel) 3.53 (2nd panel)

*The washed Panel B was cleaned with low-pressure water washing at 3,500 psi with Alberta tap water that had a conductivity of 348µS/cm (chloride, sulfate and nitrate concentrations of 4, 65 and 0 ppm)

Adhesion and Visual Rating

After the coating panels were removed from the autoclave they were evaluated visually for any defects such as blistering per ASTM D714[17]or cracking. The coatings' adhesion was also assessed per ASTM D6677[18] and the DFT was measured. The pre- and post-test adhesion of each coating was rated according to ASTM D6677.

Surface Profile Measurements

Surface profile measurements were performed using high-temperature, extra-course replica tape. Three measurements were taken on each sample. No surface profile measurements were carried out on panels that had heavy black iron sulfide deposits.

Conductivity Measurements

The retrieval of total dissolved salts (TDS) and analysis of conductivity were carried out in accordance with SSPC-Guide 15[19]. A 500-milliliter liquid reagent sample was retrieved from each steel panel using the laboratory boiling extraction method. The TDS conductivity analysis was performed using a probe-type conductivity meter. The conductivity and pH measurements were taken with a cooled to room temperature sample (25 C [77 F]) instrument with temperature-compensation capability.

SEM-EDX

The SEM is capable of examination of surfaces with enhanced depth of field up to magnifications of 250,000 times. The EDX analysis system detects elemental composition from very light elements such as carbon, to heavy elements such as lead. The instrument was used to evaluate the surface of the panels to characterize the surface profile and detect the elemental composition present at the surface. The depth of beam penetration was approximately 5 µm. One limitation of this analysis is that it will not determine the compounds present. Various forms of iron oxide exist, for example FeO, Fe_2O_3 and Fe_3O_4, however, these would only be characterized as iron and oxygen.

X-Ray Diffraction

The X-ray diffraction system was utilized to further characterize the crystallographic phase of compounds present on the surface. The depth of beam penetration for this method was approximately 10 µm. X-ray diffraction will differentiate between crystallographic compounds such as the aforementioned FeO, Fe_2O_3 and Fe_3O_4, or Fe $(OH)_2$. Analysis was performed on the surface of test panels in Sets B and C.

RESULTS AND DISCUSSION

The results of the autoclave testing of Coating 1 and Coating 2 at 149 C in sour crude are summarized in Table 1 (p. 40) and Table 2.

In Table 1, 1A refers to the front side of a given panel from the A panel set, whereas 2A refers to the back side of the same panel. The entire panel was coated with Coating 1. The same applies to panels B and C.

In Table 2, 1A refers to the front side of a panel from the A set, and once again, 2A refers to the back side of the same A panel with the entire panel coated with Coating 2, and the same for panels B and C.

Post-autoclave test panels are shown in Figures 4 (p. 40) and 5 (p. 42). Figure 6 (p. 42) provides a comparison of pre- and post-test impedance values.

A coating was deemed to have failed in the autoclave test if it blistered, cracked or flaked in any of the three phases. Adhesion ratings of the coating film were considered of lower importance than the presence, or absence, of film blistering. Coatings may provide sufficient adhesion and sub-film corrosion resistance even when water has been imbibed and reached the coating-metal interface.

The solvent-borne Coating 1 showed no blistering in all phases regardless of panel type, with the exception for panel 2B which showed F#2-sized blisters in the water phase. Coating 1 maintained or in many cases improved its adhesion rating compared to its pre-test condition. The coating showed excellent pre-test impedance and maintained high log Z of greater than 10 values post-test in the gas and hydrocarbon phases. However, these values decreased in the water phase to log Z of 7-to-8 indicative of the more aggressive water phase.

Inspection of the EIS values shows that the performance of Coating 1 slightly improved in the gas phase on chemically treated Set C panel surfaces compared to Set A and Set B panel surfaces.

In earlier studies, the performance of Coating 1 at 149 C was excellent when applied to an SSPC-SP 5/NACE No. 1 white metal blasted surface that had been post treated with the chemical cleaner and subject to a surface decontamination process;

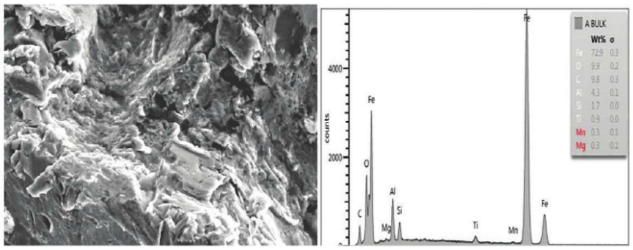


Fig. 9: SEM image of Panel A (2,000 times as taken) showing surface and bulk energy-dispersive X-ray analysis (EDXA) elemental analysis showing iron, oxygen and other elements.

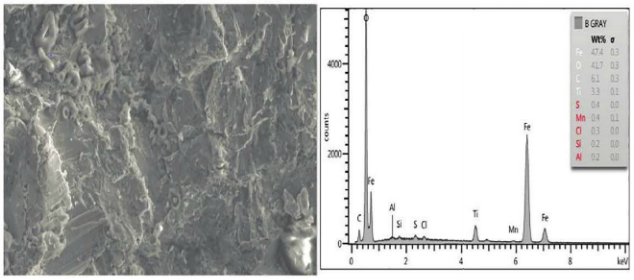


Fig. 10: SEM image of Panel B clean surface (2,000 times as taken) showing surface and bulk EDXA elemental analysis showing iron oxide and other elements.

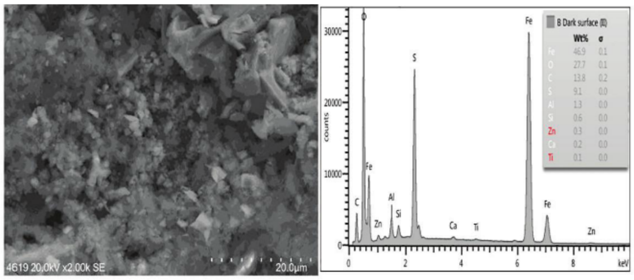


Fig. 11: SEM image of Panel B dark surface (2,000 times as taken) showing surface and bulk EDXA elemental analysis showing iron sulfide and iron carbonate (as per XRD analysis).

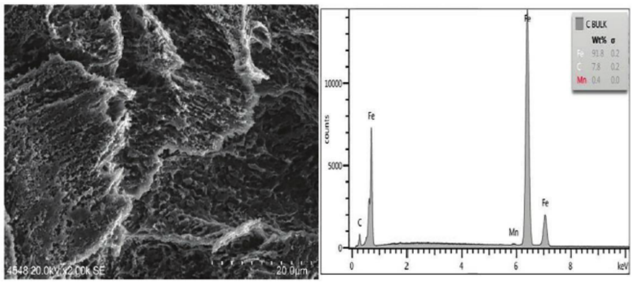


Fig. 12: SEM image of Panel C (2,000 times as taken) showing etched surface from exposure to corrosive environment subsequently treated with cleaner. Surface is clean as shown by the predominantly iron peak shown in the EDX analysis.

the performance of Coating 1 at 149 C was very poor when applied to a surface prepared to an SSPC-SP 5/NACE No. 1 standard but not post-treated with the chemical cleaner[10]. In the present study, however, the performance of Coating 1 under similar conditions was very good on both types of surfaces. This result indicates that a certain inconsistency of coating performance arises on steel that has been prepared to a white metal standard alone. This is not surprising since the appearance of a white metal surface does not signify the absence of residual soluble or insoluble moieties, nor detrital materials.

The solvent-free Coating 2 had as high pre-test impedance values as did Coating 1 and showed similar post-test impedance behavior. With Coating 2 on white metal Set A panel surfaces there was an inconsistency of EIS values not seen on the chemically cleaned Set C panels. Adhesion of Coating 2 on Set B panels decreased significantly in all phases when compared to panels from sets A and C which maintained, or slightly changed, vis-à-vis adhesion rating. Overall, the adhesion ratings of Coating 2 were lower than Coating 1 indicating superior wetting out of the solvent-borne Coating 1. Interestingly, the adhesion ratings for Coating 2 improved significantly in the gas phase on the chemically prepared Set C panel surfaces.

The adhesion of Coating 2 was significantly improved on Set C panel surfaces versus Set B panel surfaces. This showed that the chemical cleaner had performed well in achieving a contaminant-free surface, removing both soluble and insoluble moieties. In the case of Set C panels with the chemical cleaner treatment, as evidenced by the log Z values, the excellent barrier performance was consistent on both panel sides (Table 2). However, in the case of Set A panels with only the SSPC-SP 5/NACE No. 1 abrasive blast, there was good barrier performance on one side of the panel but poor performance on the other side. Hence, as seen in our earlier studies, the efficacy of the chemical treatment appears to lead to an increasing consistency of superior performance when using the cleaner as a complementary (and to re-iterate, arguably necessary) treatment for the abrasive blast-cleaning prior to coating application.

The chemical treatment improved the adhesion of the solvent-free Coating 2 on decontaminated steel, compared to the Coating 2 adhesion on either SSPC-SP 5/NACE No. 1 white metal or contaminated, power washed and white metal surfaces that were subsequently brush-blasted (Table 2).

Surface Profile Measurement and Visual Observations

As shown in Table 3 (p. 44), the surface profile of two panels that were abrasive blasted to an SSPC-SP 5/NACE No. 1 white metal standard averaged 2.63 mils for the first panel, and 2.50 mils for the second panel. In marked contrast, the surface profile of two panels that were abrasive blasted to SSPC-SP 5/NACE No. 1 white metal, contaminated in the autoclave prior to a low-pressure water wash at 3,500 psi, and then given the chemical cleaner treatment, averaged 3.63 mils for the first panel and 3.53 mils for the second panel. This increase in profile depth occurred as a result of the corrosion of the steel in the autoclave since, in separate work, the cleaner itself was shown not to increase the profile depth on bare steel panels abrasive blasted to SSPC-SP 5/NACE No. 1. Application of the cleaner and its subsequent neutralization and removal with low-pressure washing removed all abrasive media embedment on a panel from Set C (whereas the abrasive-blasted white metal panel from Set A was full of embedment). The removal of embedded detrital material was not achieved by pressure washing alone.

The abrasive-blasted surface that was cleaned to SSPC-SP 5/NACE No. 1, and subsequently treated with the chemical cleaner, evidenced a cleaner looking surface and a dull matte pewter color (Fig. 7, p. 42). Interestingly, in the mid-1980s, an abrasive-blasted surface also cleaned to SSPC-SP 5/NACE No. 1 by ultra-high pressure (UHP) water jetting at 140 Mpa evidenced a dull matte bluish-golden color (thought at the time to be a thin film of a coherent metal oxide layer)[20].

Conductivity Measurements

An uncontaminated panel from Set A and a chemically treated panel from Set C had conductivity measurements of 0 μS/cm (Table 3). The unwashed and deliberately contaminated panel had a conductivity of 14 μS/cm. The deliberately contaminated panel that was low-pressure washed at 3,500 psi with Alberta tap water had a conductivity of 32 μS/cm. Hence, the conductivity of the tap water was questioned. This tap water was later determined to have a conductivity of 348 μS/cm, with chloride, sulfate and nitrate concentrations of 4, 65 and 0 ppm, respectively. Figure 8 (p. 42) shows laboratory and test panel conditions prior to conducting conductivity and surface profile measurements.

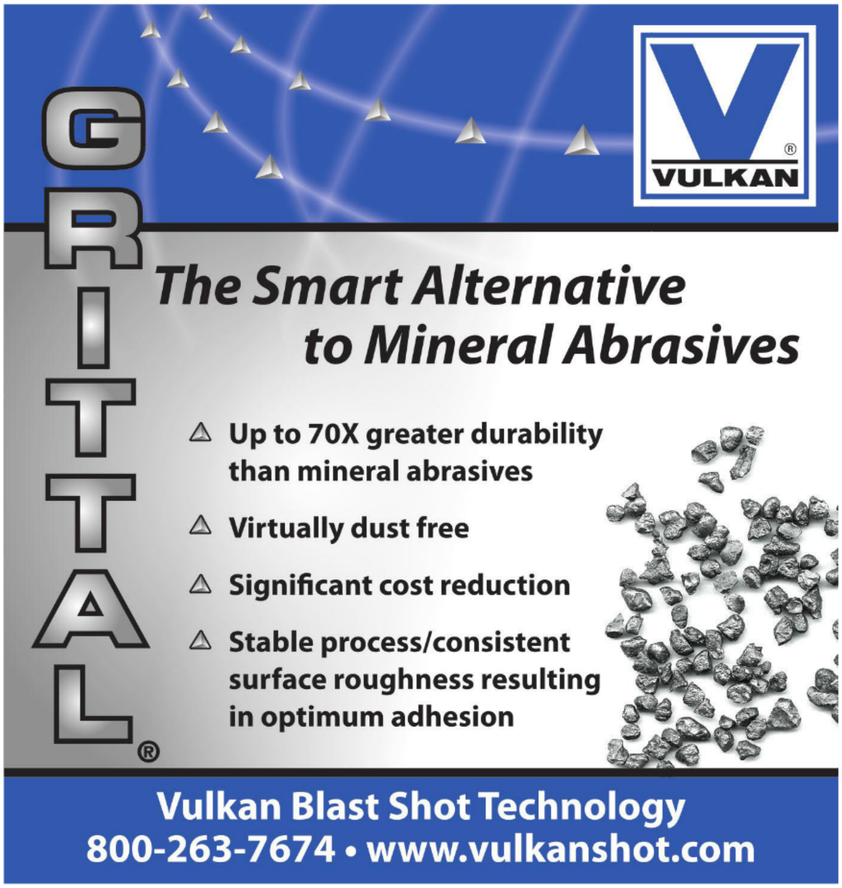
It is important to note that per the manufacturer's stipulation to achieve proper chemical decontamination, in the present study, only deionized water should be used (and indeed was used) to prepare the Step 1 cleaner solution and the Step 2 wash solution. The efficacy of this two-step cleaning process is *not* based on the application of corrosion inhibitors where inhibitor moieties are intentionally left on the steel surface and can affect the performance of the coating. Rather, this system is designed to clean the steel surface *without* leaving any chemicals which can interfere with the coating performance or participate in corrosion.

SEM-EDX

Investigations were carried on the uncoated panels shown in Figure 7. A bulk surface analysis performed with EDX indicated the presence of iron, oxygen and carbon with aluminum, silicon and titanium, suspected oxides from the embedded blasting media. The initial examination revealed surface contamination versus the metal surface more clearly. Secondary electron imaging was then performed at the same magnifications (50, 200 and 400 times magnification) to compare the surfaces of all three panels.

For the panels from Set A blasted to SSPC-SP 5/NACE No. 1 and the post abrasive-blast chemically treated panel from Set C, much higher magnification was employed to evaluate and compare the arresting features found on the latter's surface. Magnifications of 1,000, 2,000, 4,000, 8,000 and 15,000 times magnification were utilized. It was learned after the analysis that a latent carbon peak exists, which places a small carbon peak in all EDX printouts. Notable findings from SEM and EDX analysis were as follows.

Residual oxides, sulfides and embedment of abrasive media were clearly seen on the SSPC-SP 5/NACE No. 1



blast-cleaned surface of Set A panels (Fig. 9, p. 46).

Residual oxides and sulfides were present on a panel from Set B, especially the back surface which also exhibited a dark surface with a visible cross-hatch pattern (panels were placed on a grid). The amount of surface oxide and sulfide constituents was greatest on this sample (Figs. 10 and 11, p. 46).

The post abrasive-blast (SSPC-SP 5/ NACE No. 1), water-washed and chemically treated surface of a panel from Set C was extremely clean and as shown in Figures 12 (p. 36) and 13 evidenced a uniformly etched surface with greater angularity and profile depth compared to the blasted and water-washed surface of panels from Set B. These features accord well with a) the greater profile depth of panels from Set C versus panels from Set B when measured with coarse replica tape, b) a difficulty observed in removing the replica tape on panels from Set C, and c) the snagging of a rubber glove when moved across a panel from Set C but not when moved across panels from Sets A or B. This profile difference is a direct result of the corrosion of the abrasive-blasted steel in autoclave conditions and not due to the cleaner treatment itself.

Embedded alumina and silica were observed in the white metal blasted surface of panels from Set A and to a lesser degree on panels from Set B, and a significant oxygen and carbon peak when the surfaces were analyzed at very low kilovolts (kV). The lower accelerating voltage of 5 kV results in less beam penetration and facilitates enhanced analysis of light elements compared with analyses made at 20 kV. Panels from Set C exhibited virtually no evidence of embedded material, surface oxide or any contamination of sulfur, chloride or oxygen, or indeed any other contamination. When the analysis is run at low kV, one essentially observes the iron L peak, and a small carbon peak, compared with the white-metal-blasted surface which exhibits a much higher carbon, oxygen peak and their ratio to the iron L peak.

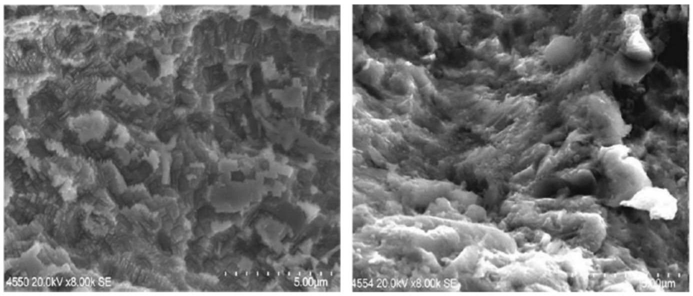


Fig. 13: (Left) At 8,000 times magnification, the surface of Panel A as blasted and (Right) Panel C after chemical treatment. Panel C shows etching effect from exposure to corrosive environment. By removing all the contaminants the chemical cleaner system has revealed the surface topography.

Analysis by X-ray diffraction (XRD) was carried out in order to further evaluate the surface of a panel from Set C and to compare with the pre-chemically cleaned surface of a panel from Set B. It was suspected that the surface of the Set C panel must have some thin surface coating, possibly iron carbonate, or iron oxide present, which are both crystallographic and would be detected and characterized by XRD. Comparison surfaces were also analyzed, the relatively clean front surface of the Set B panel, and the unique dark patterned surface on the back of the panel labeled B2. The results of the XRD analysis are shown in Table 4 and summarized as follows.

Sample B, the clean side of panel B, consisted of 94 percent (by weight) iron with 5.3 percent embedded abrasive blast media in the form of alumina and silica.

Sample C, the chemically treated surface of panel C, consisted of 99.4 percent iron (from the steel substrate), 0.3 percent iron phosphate, 0.1 percent calcium carbonate, 0.1 percent silicon oxide and 0.1 percent manganese based oxide.

Sample B2, the back surface of panel B, consisted of 53.5 percent iron (II) carbonate, 36.4 percent iron (II) sulfide, 4.1 percent zinc sulfide, 1.4 percent silicon oxide, 2.3 percent iron and other trace compounds.

Sample C2, the back surface of panel C, consisted of 96.6 percent iron, 0.3 percent silicon oxide, 0.8 percent iron carbonate, 1.3 percent iron (II) sulfide, 0.4 percent iron phosphide, 0.4 percent calcium carbonate and 0.2 percent magnetite (Fe_3O_4).

The results from XRD confirm the findings of the EDX analysis. The chemically cleaned pewter-colored panel shows significant cleaning with negligible surface film, no sulfide deposits, no carbonate deposits or any apparent oxide formation (Fig. 13). Both EDX and XRD penetrate the surface somewhat, and there is a possibility that a very thin surface film may be present that is

Table 4: Summary of XRD Results (wt%)

Sample ID	Iron	Silicon Oxide	Aluminum Oxide	Iron Carbonate	Iron Sulfide	Zinc Sulfide	Calcium Carbonate	Iron Phosphide	Iron Oxide	Magnesium Hydroxide
Sample B	94.0	1.0	4.3	–	–	–	–	–	–	0.7
Sample B2	2.3	1.4	–	53.5	36.4*	4.1	–	–	1.5	–
Sample C	99.4	0.1					0.1	0.3		0.1
Sample C2	96.6	0.3	–	0.8	1.3	–	0.4	0.4	0.2	–

*FeS consists of Troilite (33.2%), Rudashevskyite (3.2%), and Mackinawite (0.8%)

not detectible using these techniques. It is speculated that the surface is not passivated per se, in terms of a protective oxide layer, but to be in a passive state given that it appears to essentially consist of pure iron (Fig. 12).

Also of significance, is that the back surface of panel B, which exhibited a large amount of surface contamination, was essentially a bare steel substrate after the chemical cleaning process. The surface was approximately 97-percent iron after cleaning, with small concentrations of other crystallographic constituents present.

CONCLUSIONS

High-temperature 149 C autoclave studies were conducted on a multi-coat, solvent-borne, epoxy novolac system (Coating 1) and a thick-film single-coat solvent-free polycyclamine-cured hybrid epoxy coating (Coating 2). The lining performance on steel panels subject to the chemical cleaner decontamination procedure after first abrasive blasting to an SSPC-SP 5/NACE No. 1 white metal standard is equal to (or marginally superior in the case of Coating 2) the performance observed on steel prepared to an SSPC-SP 5/NACE No. 1 white metal standard.

The chemical treatment afforded discernible performance increments in terms of adhesion for the increasingly popular solvent-free coating, Coating 2.

Based on conductivity measurements, abrasive blasting to an SSPC-SP 5/NACE No. 1 white metal standard showed no difference between coated panels tested with or without the chemical decontamination procedure. The efficacy of the proprietary cleaner used as a means to decontaminate abrasive-blasted steel was clearly demonstrated in the SEM-EDX and XRD studies. The cleaner was not deleterious to the carbon-steel substrate even during extended surface contact of the cleaner with steel as tested. It readily removed ample amounts of insoluble iron sulfide species, iron carbonate and iron oxide from the substrate.

Comparing the results of this work and earlier work by the authors, a certain inconsistency of coating performance has been noted on steel that has been prepared to an SSPC-SP 5/NACE No. 1 white metal standard. This reflects the fact that the white metal standard does not signify the absence of residual soluble or insoluble moieties, nor detrital materials.

Now for the answers to questions posed at the outset of this study. First, some of the autoclave, EIS and adhesion trends seen in previous studies were not repeated in this work. The cleaner did demonstrate an advantage using the post-abrasive-blast applied treatment to enhance the adhesion of the Coating 2 solvent-free system, but not the Coating 1 solvent-borne system. Second, the cleaner decontaminated the carbon steel surface and removed both non-visible (and ample amounts of visible) iron sulfide, iron carbonate, iron oxides and soluble salt contaminants. Third, the cleaner afforded a passive state surface (perhaps as opposed to passivation vis-à-vis an oxide layer) of iron alone on the carbon steel. Further studies are underway on characterizing the surface. Fourth, the cleaner did not show any evidence of etching the steel surface.

Is there such a thing as "blind chance"? For those *true* fans of Russian roulette, we are sorry that we cheated and unloaded the gun! Yes, the answer to question 5 was indeed affirmative: the cleaner did unload the gun. The question remains: will industry unload the gun or continue to get shot by anomalies?

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Park Derochie, Edmonton, Alberta, Canada for preparing the steel panels and the coating application.

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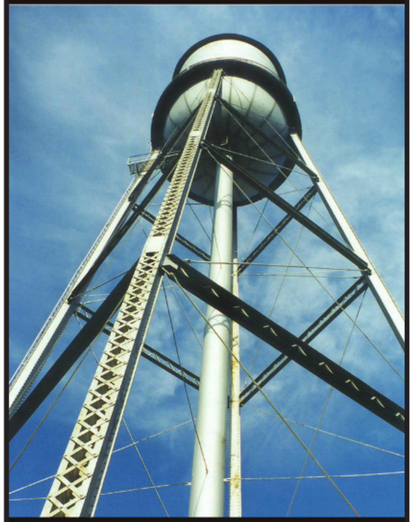

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Bob Tucker, Stone Tucker Instruments Inc. Edmonton, Alberta, Canada for surface profile analyses.

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(Top): SSPC 2016 Business Meeting and Awards Luncheon.
(Bottom): Ribbon cutting to the SSPC 2016 exhibit hall. Photos courtesy of SSPC.
Background: ©iStockphoto.com/AppalachianViews

JAN 30 - FEB 2, 2017 • TAMPA, FL
SSPC 2017 featuring GREENCOAT

SSPC 2017 IN TAMPA: EVENTS AND AWARDS

SSPC's Annual Business Meeting and Awards Luncheon, opening and closing receptions, networking meetings and tours for spouses and guests are among the special events planned for SSPC 2017 featuring GreenCOAT at the Tampa Convention Center in Tampa, Fla., Jan. 30 to Feb. 2, 2017.

Complete information on SSPC 2017 is available at the official conference website, www.sspc2017.com and will be published in the SSPC 2017 Advance Program section of the December 2016 *JPCL*.

ANNUAL BUSINESS MEETING AND AWARDS LUNCHEON

MONDAY, JANUARY 30,
11:30 A.M. TO 1:00 P.M.

SSPC President Gunnar Ackx, SSPC Executive Director Bill Worms, the Board of Governors and your coatings industry peers will gather to listen to the SSPC annual report and honor the 2016 award recipients. The awards to be presented include the following.

SSPC HONORARY LIFE MEMBER AWARD

This honor recognizes extraordinary contribution and long-term activity on behalf of SSPC. To become an Honorary Life Member, an individual must be nominated by a Board of Governors member and approved by two-thirds of the Board. Only one Honorary Life Membership is awarded each year.

JOHN D. KEANE AWARD OF MERIT

Named for SSPC's executive director from 1957 to 1984, this award acknowledges outstanding leadership and significant contribution to the development of the protective coatings industry and to SSPC.

SSPC COATINGS EDUCATION AWARD

This award is presented for significant development and dissemination of educational material and technical information related to protective coatings and their application.

SSPC TECHNICAL ACHIEVEMENT AWARD

This award recognizes outstanding service, leadership and contribution to the SSPC technical committees.

WOMEN IN COATINGS IMPACT AWARD

Established in 2014, this award was established to recognize women in the coatings industry who have contributed to creating a positive impact on the culture of the industry.

PRESIDENT'S LECTURE SERIES AWARD

This award is presented to papers handpicked by the SSPC President and chosen for the reflection of the coatings industry and profession.

SSPC OUTSTANDING PUBLICATION AWARD

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

JPCL EDITORS' AWARDS

The same panel of judges selects the recipients of these awards, which also recognize excellence in technical writing. Winners are selected from a field of more than 100 eligible papers from SSPC 2016 and from *JPCL* articles published between May 2015 and July 2016. Awards are also based on clarity, originality, significance to the industry and effective use of illustrations.

SSPC OUTSTANDING CHAPTER AWARDS

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

SSPC STRUCTURE AWARDS

The 11th annual Structure Awards will recognize teams of contractors, designers, end users and other personnel for excellence and expertise demonstrated on industrial and commercial coatings projects. The following awards will be presented.

- The **William Johnson Award** for outstanding achievement demonstrating aesthetic merit in industrial coatings work.
- The **E. Crone Knoy Award** recognizing outstanding achievement in commercial coatings work.
- The **Charles G. Munger Award** for an outstanding industrial or commercial project demonstrating longevity of the original coating.
- The **George Campbell Award** that recognizes a single outstanding achievement in the completion of a difficult or complex industrial coatings project.
- The **Military Coatings Award of Excellence** for exceptional coatings work performed on U.S. Military ships, structures or facilities.
- The **Eric S. Kline Award** for outstanding achievement in industrial coatings work performed in a fixed shop facility. The project can be repair work or new construction.

JPCL will feature Structure Awards recipients in a photo essay in early 2017.

OPENING CELEBRATIONS

WELCOME RECEPTION

MONDAY, JAN. 30, 5:30 TO 7:30 P.M.

Sponsored by Carboline

Join your friends, colleagues and peers to kick off SSPC 2017 with complimentary food, beverages and entertainment.

EXHIBIT HALL RECEPTION

TUESDAY, JAN. 31, 5:00 TO 8:00 P.M.

Sponsored by The Sherwin-Williams Company

Don't miss the ribbon cutting at 5:00 p.m. and the opportunity to be among the first to visit the exhibit hall.

MEETINGS AND OTHER EVENTS

HAPPY HOUR WITH YOUNG PROFESSIONALS

MONDAY, JAN. 30, 4:30 TO 5:30 P.M.

Join SSPC's Young Professionals group for cocktails and conversation and to interact with some of the young people who are working to shape the future of the coatings industry.

FACILITY OWNERS BREAKFAST AND PEER FORUMS

TUESDAY, JAN. 31, 7:30 TO 10:00 A.M.

Facility owners are invited to join the SSPC QP-certified contractors at a complimentary breakfast to thank them for their commitment to quality coating projects. Technical discussions will follow breakfast. Facility owners only, please. An RSVP is appreciated.

POSTER SESSION

TUESDAY, JAN. 31, 3:00 TO 4:00 P.M.

WEDNESDAY, FEB. 1, 10:00 TO 11:00 A.M.

One of SSPC's goals is to bring more young people into the organization. The Poster Session provides a forum for college students and young professionals to participate in the conference by sharing research presentations. This year prizes will be awarded to the 1st, 2nd and 3rd place posters. For more information, contact Sara Badami at badami@sspc.org.

MEGA RUST MID-YEAR FOLLOW-UP

WEDNESDAY, FEB. 1, 8:00 A.M. TO 12:00 NOON

The mid-year follow-up to the Mega Rust 2016 conference, which was held this past June in San Diego, is scheduled to be part of SSPC 2017. This meeting is designed to continue the discussions on key corrosion issues concerning the U.S. Navy enterprise, generate questions and talking points for potential presenters at Mega Rust 2017, discuss the meeting theme and draft the conference agenda. If interested in participating, please email ASNE at megarust@navalengineers.org.

LUNCH WITH EXHIBITORS

WEDNESDAY, FEB. 1, 11:30 A.M. TO 1:00 P.M.

THURSDAY, FEB. 2, 11:30 A.M. TO 1:00 P.M.

***Sponsored by* CoatingsPro**

SSPC and sponsors will provide complimentary lunches in the exhibit hall on these days. Tickets will be provided in your registration packet.

REVITALIZE AND REFRESH BREAKFAST

THURSDAY, FEB. 2, 8:30 TO 9:30 A.M.

SSPC will provide a complimentary breakfast buffet for attendees to begin the final day of the conference.

** RSVP for any of these events by contacting Jim Kunkle, SSPC, at kunkle@sspc.org or 412-281-2331, ext. 2210.*

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SPOUSE AND GUEST TOURS

TAMPA HISTORY TOUR BY BOAT WITH LUNCH

TUESDAY, JAN. 31, 10:30 A.M. TO 1:30 P.M.

Learn about how the city of Tampa grew from a Spanish outpost to the fastest-growing city in Florida. The tour will take you step-by-step through the evolution and offer little-known facts about the city that even locals might not know.

$115 per person. Lunch is included.

CHIHULY COLLECTION

WEDNESDAY, FEB. 1, 9:30 A.M. TO 1:30 P.M.

The Chihuly Collection is a permanent collection of world-renowned artist Dale Chihuly's unique artwork in a magnificent 10,000-square-foot setting. This is the first installation of Chihuly art in a building designed especially for it, so that the art and architecture work together to create a visitor experience unlike any other.

$95 per person.

CLOSING CELEBRATIONS

EXHIBIT HALL CLOSING BLAST

THURSDAY, FEB. 2, 1:30 TO 3:00 P.M.

One final opportunity for interaction with the exhibitors before the hall closes at 3:00 p.m. Grab a beverage and dessert and get that last bit of vendor information to complete your conference.

EXHIBITORS AT SSPC 2017

This list of companies planning to exhibit at SSPC 2017 is current as of press time. For information about exhibiting, contact Kate Jurik, SSPC event manager and sales specialist, at jurik@sspc.org or 877-281-7772, ext. 2211.

Abrasives, Inc.
Abrasives Manufacturing LLC
Air Systems International
AirTech Spray Systems
ARID-DRY
ARMEX
ARS Recycling Systems LLC
Atlantic Design Inc.
Axxiom Mfg./Schmidt Engineered Abrasive Systems
Barton
Bellemare Group
Binks
Blast-One International
Carboline Company
Chlor Rid International, Inc.
Clemco Industries Corp.
Cold Jet
Cortec Corporation
CSI Services, Inc.
Dampney Co. Inc.
DeFelsko Corp.
Dehumidification Technologies, LP
Denso NA
DESCO Manufacturing Co.
Detroit Tarp
Doosan Portable Power
DRYCO
Dupont Protection Solutions
Eagle Industries
Elcometer
Entech
Ervin
ESCA Blast
Fischer Technology
Forrester Environmental Services
FS Solutions
GMA Garnet
Graco
Green Diamond Sand
Greener Blast Technologies
Greenman-Pedersen Inc.
Harsco
Hempel
HippWrap Containment
HoldTight Solutions
HRV
Industrial Vacuum
International Paint
IUPAT/FTI
JAD Equipment
Jotun
Kennametal Inc.
KTA-Tator, Inc.
Luoyang HongFeng Abrasives
Marco Group
MES Rentals
Minerals Research Inc.
MONTI Tools
Montipower
National Equipment CO. (NECO)
New Age Blast Media
NexTec, Inc. / PreTox
Novatek
Olimag
Oxifree
Pacific Dust Collectors
Paul N. Gardner Co., Inc.
Pinnacle Central Co., Inc.
Polygon
PPG Protective & Marine Coatings
Rapid-Prep, LLC
Raven Lining Systems
RBW Enterprises Inc.
Ring Power
Rust-Oleum
SAFE Systems Inc.
Safety Lamp of Houston
Safway Services LLC
Sand Express
Saueréisen
The Sherwin-Williams Company
Specialty Products, Inc.
Spider
Sponge-Jet, Inc.
Sulzer Mixpac
Tarps Manufacturing Inc.
Technofink
Technology Publishing Co.
Tesla NanoCoatings
Tioga Air Heaters
Tital Tool
Tnemec Company, Inc.
Tractel Inc.
TruQC LLC
US Minerals
Van Air Systems
Vector Technologies Ltd.
Versaflex Inc.
VitaFlex Soft-stretch Protective Hoods
VRSim
The Warehouse Rentals & Supplies
Wasser Corp.
Western Technology
WIWA LP
Zibo TAA Metal Technology