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

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## FEATURES












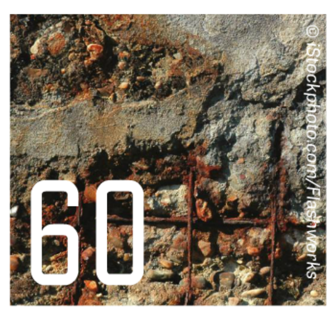

# jpcl

## DEPARTMENTS



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The Society For Protective Coatings



## ALSO THIS ISSUE



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# SSPC Hires New Executive Director

SSPC: The Society For Protective Coatings is pleased to announce the hiring of William (Bill) M. Worms as Executive Director, effective September 1, 2015. Worms will succeed William (Bill) Shoup, who is retiring with over 20 years of distinguished service.

Worms, a Pittsburgh native, joins SSPC following a successful 25-plus-year career with Bayer MaterialScience. In his most recent role as Vice President of Commercial Operations, Worms led the sales, operational marketing and strategy development efforts of Bayer's $1.5 billion raw materials, polyurethanes business. While at Bayer, Worms served as a Board member of the BayOne Joint Venture and as past chair of the Bayer United Way Campaign. His personal commitment to philanthropy led him to becoming the President of the Board of Directors for the Pittsburgh Botanic Garden, an organization with which he will continue to serve.

"The Board of Governors is thrilled that our search led us to Bill Worms, and we enthusiastically welcome him as our new Executive Director. As SSPC continues into the future, it is important that the organization continues to have a strong leader to meet the growing needs of our membership. Bill Worms is such a leader," said Jim King, President of the SSPC Board of Governors.

"I'm excited and honored to be chosen to lead such a prestigious organization. SSPC is poised for continued growth in both North America and internationally. I look forward to building on the foundation established by Bill Shoup and the SSPC staff to meet the needs of our growing membership," said Worms.

SSPC: The Society For Protective Coatings was founded in 1950 and is the only non-profit association that is focused on the protection and preservation of concrete, steel and other industrial and marine structures and surfaces through the use of high-performance protective, marine and industrial coatings. SSPC is the leading source of information on surface preparation, coating selection, coating application, environmental regulations and health and safety issues that affect the protective coatings industry. For more information, visit sspc.org.

# Thank You

You, as readers of the *JPCL*, are well aware that I am retiring at the end of this month. It was a tough decision but it is the right decision for my family and me. Many have asked me why I decided to leave and I have honestly said, "The time is right." I am a numbers guy. People ask me how long I served in the U.S. Army and I say, "22 years, eight months and eight days." It usually brings a chuckle. When I leave SSPC I will have been here 20 years, eight months and 26 days. It is time.

My last 20 years here at SSPC are so memorable. Because of my time in the Army I was able to see much of Europe. Because of my time at SSPC, during conferences I attended, the chapters I visited, and the contacts that were important to make, I have been able to see parts of Asia, Australia, India, the Middle East and a lot of the United States. My 87-year-old mother always makes comments about how much of the world and the U.S. I have seen, and I remind her that there is so much I have not seen. In retirement, my wife and I would like to continue to travel and, we hope, touch base with many of the friends we have made through my association with SSPC.

I would like to thank everyone I could, by name, but it would be page after page. To all the members that I have interacted with over the years, your support of SSPC and me has been invaluable. I say "thank you." To all the SSPC Presidents and Board of Governors members over the years that I have worked for and received your guidance and direction, I say "thank you." I consider you all friends and I have grown as a person because of you. I especially want to thank the Board members who in 1999 gave me the opportunity to become Executive Director of the organization.

I will have a tear in my eye as I write these last two "thank yous." To the SSPC staff, my work family, I have a special "thank you." This organization could not be where it is today if it were not for your dedication, caring and support. From the bottom of my heart, I cannot thank you enough. I wish you all the best and I know that you are the best and the members should be grateful for how much devotion you all have to SSPC. I want to say a special "thank you" to Michael Damiano, Barbara Fisher, Michael Kline and Terry Sowers, the Directors at SSPC. We have been together a long time and I have learned so much from all of you. I will fondly remember all the things we have done as a team in making SSPC what it is today. To those four and the entire staff, again, I wish you nothing but the best, Godspeed and good health.

My last "thank you" goes to my wife Diane. You were a great soldier's wife and a great Executive Director's wife. You were a great help to me throughout my military career and you have been a great help to me during my SSPC career. I could not have done it without you.

I will finish by saying the three things I always told my soldiers when I arrived at a unit: no one will work harder; no one will care more; and when I leave, I hope you will say, "The organization is better than it was when he got here. It is not perfect, but he made it better."

I hope you, as members, can say, "He made it better." I wish you all the best of health and good fortune and ask that you continue to support SSPC and Bill Worms, my successor, as you have done me. Thank you.

Bill Shoup
Executive Director (Outgoing), SSPC

# A Message from the Outgoing SSPC President

It has been an honor and privilege to serve as President of the SSPC Board of Governors this past year. I truly believe we are the premier society serving the needs of the coatings industry. SSPC continues to be financially sound and the outstanding SSPC staff remains totally committed to serving the needs of our members.

Training and certification continue to drive the organization financially, accounting for more than 50 percent of the Society's revenue in 2014. I believe this trend will continue as the demand from owners for certified contractors and more skilled, certified craftsmen performing their work will only increase.

This past February, we held our annual conference in Las Vegas and it was one of the best-attended conferences in some time. During the annual meeting, it was my pleasure to award six deserving young recipients with SSPC scholarships of $2,500 each. Even more exciting, we have agreed to increase the scholarship award to 10 recipients for 2015. It was also exciting to see more young people attending the conference. Over the past several years, we have made a commitment to get the younger members of our industry more involved with SSPC, and I believe we are making great strides.

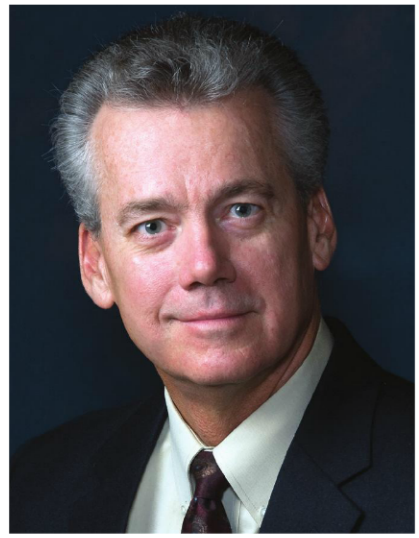
Also, as you've read, Bill Shoup announced that he is retiring as Executive Director of SSPC effective August 31, 2015. During the annual conference, I had the privilege of presenting Bill with the first-ever Board of Governors' Award for his dedicated service to the organization for over 20 years, the last 15-plus as Executive Director. We truly owe a debt of gratitude to Bill for the excellent leadership during his tenure, and he has certainly left his imprint on our organization.

I am also honored to welcome our new Executive Director, Bill Worms, as he takes over on September 1. Hopefully all of you will have the opportunity to meet and speak with Bill over the next several months. I am confident that he is the right person to lead SSPC as we move into the future.

I want to thank the members of the Board of Governors for all of their support and hard work this past year. It was a busy year, and there are more exciting times on the horizon. I also want to thank the SSPC staff for their continued dedication to serving the needs of our membership. I had the opportunity to spend time with the staff on several occasions this past year, and they truly are professional in every way. And finally, I want to thank the membership for their continued support of SSPC. It's truly all of you that make SSPC the organization that it is.

*James R. King*

Jim King
Immediate Past-President, SSPC



# A Message from the Incoming SSPC President

I am honored to become the President of the SSPC Board of Governors. With guidance from the Board, the enthusiasm of a new Executive Director and the talent of the staff, I am confident that the organization will continue to provide outstanding service to its members and meet the goals the Board has set for 2016 and beyond.

The Board and staff are made up of very talented people with the common goal of serving the membership and thereby making the coatings industry even better. The organization has advanced significantly in all areas under the leadership of Bill Shoup, increasing the value to the members in the areas of standards, training and certification.

I would like to welcome Bill Worms to SSPC as its fifth Executive Director in its 65-year history. After talking with Bill and hearing his ideas, I am confident that he is the person for the job and that the search committee and Board have made an excellent selection. I look forward to working with him during my year as President of the Board.

On behalf of the entire Board, I want to give a special "thank you" to Jim King for all the work he did ensuring the smooth transition between Bill Shoup and Bill Worms. No one worked harder for the organization than Jim did this past year.

Again, I look forward to my year as President, working with the Board and staff to make a great and well-respected organization even better. I, like the rest of the Board, am here to serve the members and, with your input, determine the strategic direction of SSPC. The success of SSPC is highly dependent upon the contributions and participation of its members. I urge you to participate in SSPC and to please contact me with any ideas on how SSPC can better serve the membership. With the members' continued support and the staff's hard work, we can continue to increase the value of SSPC.

Skip Vernon
President, SSPC

# In Memoriam

## ERIC S. KLINE, 1943–2015

*By Amy Woodall,* PaintSquare News, *and Charlie Lange,* JPCL

When Eric S. Kline was awarded the American Institute of Steel Construction's (AISC) Lifetime Achievement Award in March 2014, AISC recognized him as "one of the leading experts on coatings." But in a May 2015 profile in *JPCL*, Kline humbly looked back on his years in the industry and shared what guided him in all he did, saying, "I set out to try to make things better for the industry, be of service, and of course, top priority, raise my family."

Kline passed away Friday, July 31, at the age of 71. Those who worked with Kline painted a picture of a man who had a driving passion for the industry he served, believed in the value of volunteering his time, was blessed with wit and a way with words, and was a master of his craft.

### A Life in Coatings

Despite casting himself as "a young person born on the wrong side of the tracks," Kline pursued a Bachelor of Science in chemistry from Ursinus College (Collegeville, Pa.) and his Master of Business Administration from the University of Pittsburgh.

Kline began his career at the Fort Pitt Bridge Works in Canonsburg, Pa., as plant manager for its steel fabricating division. His first step into the industry happened to come at a fortuitous time, as it would influence the path his career would take in the years to come.

"In 1970, the industry decided to switch new bridges away from being coated with red lead paint, to being coated with zinc-rich primer," said Kline. "Nobody there knew anything about zinc-rich paint, so it was my job to become the paint expert."

That expertise led him to SSPC, blast-cleaning standards and Ken Tator, who became a consultant for the Bridge Works. After the Bridge Works closed, Tator eventually reached out to Kline, asking him to join the team at KTA-Tator, Inc., as senior consultant. He and Tator worked together for more than 30 years.

Kline retired as executive vice president of KTA-Tator. During his tenure, he worked on failure analyses for a variety of industries, expanded the company's training programs and served as instructor, consulted on major bridge maintenance projects, and facilitated KTA's entry into working with government programs in addition to private, corporate clients. He also played a key role in starting KTA's steel inspection group.

Kline was also an active member of SSPC, through which he was a certified Protective Coatings Specialist. In its earliest days, Kline helped with fundraising for the association. He played a role in the writing and revision of SSPC standards on surface preparation and coatings for steel structures. He also helped establish the Painting Contractor Certification Program and the SSPC-QP 3 standard for certifying contractors while serving in SSPC committee chair roles.

Other associations benefitted from his participation as well, including NACE International and AISC. At AISC he was involved in the development and implementation of the original paint endorsement for the AISC Certification Program. He also worked on coating issues for the National Steel Bridge Alliance (NSBA) and helped complete AISC's edge grinding study, AISC reported in 2014. He continued to work at that time with the AASHTO/NSBA Steel Bridge Collaboration as well.

In addition to his Lifetime Achievement Award from AISC, Kline earned two of SSPC's highest honors: the Honorary Life Member Award and the John D. Keane Award of Merit. *JPCL*, for which he was a prolific writer, recognized him as a Top Thinker in 2009. Technology Publishing Company founder Harold Hower indicated that Eric had written "some of the most influential articles ever published in *JPCL*."

### A Man Who Gave Back

Following his retirement, Kline continued to share his time and expertise with both KTA and SSPC. He devoted himself to community involvement as well; he served on the local school board, coached the local Little League team, was a member of the Canonsburg Redevelopment Authority and served on the Canonsburg Hospital board, to name just a few of the commitments that were important to him.

Looking back on his career in May 2015, Kline admitted, "It's been a wonderful ride, it really has." For Kline, coatings "became an avocation and eventually a vocation, and became my life's interest."

Kline is survived by his wife of 49 years, Suzie; five children; six siblings; nine grandchildren; and 18 nieces and nephews. The family asks that memorial donations be made to Leukemia and Lymphoma Society, 333 East Carson St., Pittsburgh, Pa. 15219, or American Diabetes Association, 100 West Station Square Dr., #1900, Pittsburgh, Pa. 15219.

Condolences and tributes can be made and viewed at Beinhauer Funeral Home (www.beinhauer.com) or at Legacy.com.

# Thickness Measuring, Waterjetting Webinars on Slate for September

September will bring two new, free webinars — the latest in the 2015 SSPC/*JPCL* Webinar Education Series — to Paintsquare.com, the online home of *JPCL*.

"Update to SSPC-PA 9 Paint Application Specification," will be presented by David Beamish of DeFelsko Corporation on Wednesday, Sept. 16, from 11:00 a.m. to noon, EST. During this webinar, Beamish will discuss the revision of SSPC-PA 9, "Measurement of Dry Coating Thickness Using Ultrasonic Gages." This standard describes procedures to measure the thickness of dry, homogeneous coatings applied to concrete, wood, wallboard, plastic, fiber and composite material using commercially available ultrasonic coating thickness gages.

Beamish is the president of DeFelsko Corporation, a U.S. manufacturer of test instruments sold worldwide. He is a registered Professional Engineer with more than 25 years' experience in the design, manufacture and marketing of these instruments in a variety of international industries including industrial painting, quality inspection and manufacturing. Beamish conducts training seminars and is an active member of various organizations including SSPC, NACE International, ASTM and ISO.

"Waterjetting: A 30-Year Perspective," will be presented by Dr. Lydia Frenzel of the Advisory Council on Wednesday, Sept. 30, from 11:00 a.m. to noon, EST. Since 1985, SSPC has issued three versions of its Waterjetting Surface Preparation Standards and two Visual Guides. Frenzel will explain the steps involved in moving from abrasive blast-cleaning to waterjet-cleaning and how our understanding of the basics — profile, degrees of visible cleanliness and non-visible contaminants — has progressed to focus on what makes a coating adhere and perform as expected. She will also cover changes over the years in personal protective equipment.

David Beamish

Dr. Lydia Frenzel

This webinar is sponsored by NLB Corporation.

Dr. Frenzel, a recognized authority on surface preparation who has co-chaired the SSPC/NACE committees on waterjetting since 1985, founded the Advisory Council, a network that deals with emerging technologies and their social economic effects. She earned her doctorate from the University of Texas and accepted a faculty position with the University of New Orleans. She served on Louisiana's Task Force on Small Business Innovation, as a research director for two international companies, as executive VP and director of CCI Training Services and as chief spokesperson for the Advisory Council. She is a member of the SSPC Surface Preparation Steering Committee and a member of 12 other SSPC technical committees related to surface preparation, coating application and inspection, as well as a member of the Technical Advisory group at NACE for ISO Surface Preparation Committees TC-35, SC 12 and 14. Frenzel is a two-time winner of the SSPC Technical Achievement Award (in 1996 and 2012).

Participants in each webinar will be eligible to receive credit from SSPC.

**Registration, CEU Credits**

These programs are part of the SSPC/*JPCL* Webinar Education Series, which provides continuing education for SSPC re-certifications and technology updates on important topics.

SSPC is an accredited training provider for the Florida Board of Professional Engineers (FBPE), and Professional Engineers in Florida may submit SSPC Webinar Continuing Education Units to the board. To do so, applicants must download the FBPE CEU form and pass the webinar exam, which costs $25.

Register for these online presentations at paintsquare.com/webinars.

# SSPC Releases Mobile App Version 2.0

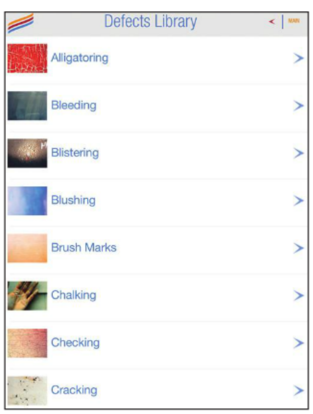
Tools to identify coating defects and select coatings, as well as calculators and other new features are now available in SSPC's newly upgraded mobile app.

The SSPC Mobile App for iOS and Android Version 2.0 builds on the original features of Version 1.0 while adding several new key features, according to SSPC's website.

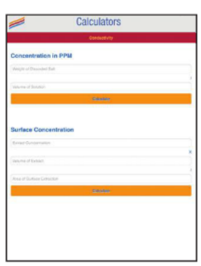
Designed for SSPC members, Version 2.0 includes new job-site tools for coatings professionals. In addition to three new calculators (Conductivity, PA 17 and PA 2), it has "Coating Defects" and "Coating Selection" interactive guides for professionals working in the field, which were developed in conjunction with the Department of Defense Corrosion Policy Office. The app also has videos, a directory of coatings professionals, a library into which users can add their own information, and a training schedule, among other features.

Although some features are available to anyone who uses the app, most features are available only to SSPC members. The app includes a log-in screen for members with a username and password.

SSPC Mobile App Version 2.0 is available on iTunes or Google Play. For more information, visit sspc.org.








*The SSPC Mobile App Version 2.0 includes new features such as the Coating Defects Library (above) and calculators for coating thickness and conductivity (right), among others. Screenshots via SSPC Mobile App.*

# OSHA Delays Confined Space Enforcement

Federal authorities have announced a temporary enforcement period to ease employers into full compliance with the upcoming new rules on confined space work in construction.

The Occupational Safety and Health Administration's final rule on Confined Spaces in Construction was announced May 4 and took effect August 3, 2015. On July 9, however, the agency issued a memorandum announcing a 60-day temporary enforcement policy "in response to requests for additional time to train and acquire the equipment necessary to comply with the new standard." Full enforcement of the new regulation will begin October 2.

The new rule, which has been in the works since March 1980, when OSHA issued the first advanced notice of proposed rulemaking, will protect nearly 800 construction workers a year from death or serious injury, according to OSHA. The regulation matches protections implemented long ago in manufacturing, general industry and shipyards, while adding some new provisions tailored to the construction industry.

The temporary enforcement policy does not change the effective date. However, during the period, OSHA says it will not cite employers who are making good-faith efforts to comply with the new standard. Indications of good-faith efforts would include:

- Evidence of scheduling training for employees as required by the new standard;
- Evidence of ordering the equipment necessary to comply with the standard; and
- Taking alternative measures to educate and protect employees from confined-space hazards.

Moreover, employers must be in full compliance immediately with the training requirements of either the new standard or the previous standard. Citations will be issued to employers who are not in compliance with either regulation. Don't let the enforcement delay lull you into non-compliance. The regulation is now in effect and will be fully enforceable on October 2, 2015 (less than 60 days from now).

More information on the standard and enforcement policy is available at osha.gov.

**Correction**

In the article, "Protecting Offshore Wind Farm Towers" (*JPCL* June 2015), euros-per-square-meter to dollars-per-square-foot conversions were inaccurately stated. The correct conversions read, "€15 and €25 per square meter between ($1.50 and $2.50 per square foot)" and "€1,000 per square meter ($100 per square foot)." *JPCL* apologizes for this error.

# On Protecting Rebar in Concrete

## WHAT IS THE BEST WAY TO PREVENT CORROSION OF REINFORCING BAR IN CONCRETE?

***Luiz de Miranda***
***ECOPROTEC***
Cathodic protection by means of sacrificial flexible anodes is welcome, since hydrogen embrittlement can be avoided. Electrode potential must be greater than -700 mV by report of a copper sulphate reference electrode.

***Joe Miller***
***NextGen (Midwest Traffic Safety Store)***
Without a context for consideration, this question is almost unanswerable. Corrosion of steel requires an anode, a cathode, an electrolyte and oxygen to occur. Removing oxygen is almost impossible, so the only remaining choice is to eliminate the electrolyte. Given the fact that most concrete elements have water in their pore structures, it comes down to reducing or eliminating soluble salts within the liquid or severely restricting their entry into the pore structures. So — waterproofing. One proven way to do that is to apply a liquid, crystalline-penetrating sealer that effectively blocks water and moisture vapor from gaining access to the pore structures.

***Carl Havemann***
***www.corrosioneducation.co.za***
Because concrete is alkaline, the rebar should not corrode, but corrosion will take place when water penetrates the concrete cover to the rebar. Therefore, make sure there is sufficient cover over the rebar and seal the concrete to fill any micro-cracks.

***Joe Miller***
***NextGen (Midwest Traffic Safety Store)***
Yes, Carl, alkalinity of fresh concrete is well known. Less well known is that, as concrete ages, it gets permeated by carbon dioxide gas. As $CO_2$ passes through concrete, it changes the composition of the cement paste into another substance that occupies less volume, is harder, and worst of all, reduces the alkalinity down to a near neutral pH of 7. The protective alkalinity is then gone. Actually, the protective alkalinity values are probably lost at a pH of around 8 or 9. The loss of alkalinity, of course, begins at the surfaces where the $CO_2$ permeates into the concrete. For concrete elements exposed to $CO_2$ such as balconies, bridge decks and columns, and elevated walkways, the loss is occurring on all exposed surfaces. The rate of loss and depth of permeation, of course, is greater with micro-cracks so that permeation can go all the way down to rebar if the micro-cracks form even earlier in the concrete elements. So effective blocking of micro-cracks becomes even more critical for these elements. Soluble salts must not get to the bars since they initiate and accelerate corrosion cell formations. Protecting steel rebar in concrete is complex more so as point loads on these elements induce flexing, as well.

***Mario Colica***
***Colimet srl***
One possible solution is to spray zinc on the concrete surface. The zinc particles

will penetrate the pores of the concrete, acting first as a barrier and then as anodic protection when rain or other contaminants try to penetrate. Zinc can be applied on both new and existing concrete.

***Mark Puckett***
***Orfanos Contractors, Inc.***
Use epoxy-coated rebar. You can also use siloxane sealers to greatly minimize chloride ion passage.

***Andrew Sedor***
***AECOM***
This question just begs for more information. Best way for you, me or my client? Where is this concrete being used? How is this concrete being used? In the manner of your use of the concrete, are there any limitations to using any of the methods mentioned here? If you dismiss these limitations, as well as cost, practicality and opinion, maybe take every suggestion here and all other methods not mentioned. And use them all. Wouldn't a combination of sealer and CP be better than sealer alone?

***Dana Stiles***
***Concrete Plus***
The relationship between steel and concrete is a "perfect marriage" as long as the pH levels maintain passivation. Cover, density, hydrophobicity and elastomeric coatings all help to slow down the loss of pH that occurs with carbonation and chloride ion ingress. I think every respondent is "right" in one way or another. The EN 1504 standard (Products and systems for the protection and repair of concrete structures) addresses many of these issues for repairs, and the addition of anodic protection certainly helps to maintain the electron potential and avoid the so-called "halo effect."

Problem Solving Forum questions and answers are posted on *JPCL's* sister publication, *PaintSquare News*, a daily electronic newsletter. To subscribe, go to paintsquare.com.

# Concrete Floor Coatings Forensics Case History – Part 1, Field Investigation Phase

By James D. Machen, KTA-Tator, Inc.
Richard A. Burgess, PCS, KTA-Tator, Inc., Series Editor

This edition of the F-Files presents the field investigation undertaken to determine the cause of a concrete floor coating failure (Fig. 1). The laboratory forensic work associated with the project, and the conclusions regarding the cause of the problem, will be addressed in a subsequent installment.

The field phase included five steps: project familiarization and interview; moisture detection; coating thickness measurements; adhesion testing; and microscopic examination, sample collection and photographic documentation.

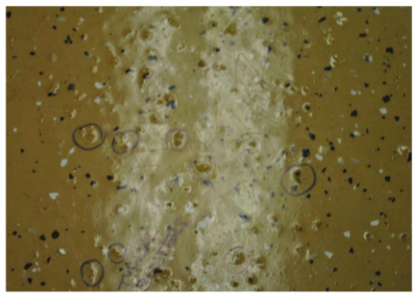


*Fig. 1: Typical appearance of the floor coating problem. Figures courtesy of KTA-Tator, Inc.*

*Fig. 2: Moisture tests being conducted with a moisture meter based on electrical resistivity.*

## Step 1: Project Familiarization and Site Interview

Familiarization with the project began with an initial telephone call and an interview with the maintenance supervisor of the building in order to obtain background information on the failure. The following was revealed.

- The existing coating on the floor of a laboratory was cleaned and overcoated. The laboratory contained a variety of equipment, but with exception of cleaning materials, it was essentially a dry operation. The laboratory itself had two interior doors and one double door, but no windows.
- The failure involved blistering of the overcoat system, believed to be within the clear urethane finish coat. The blisters were present along the back corner of the laboratory and near the exterior door.
- The cleaning and painting work was performed by the building maintenance staff. The laboratory was taken out of service during the work.
- There was no specification, just the manufacturer's product data sheets.
- The work was done in August. Outside doors were opened and floor fans were used for ventilation during application (blowing out) and drying (blowing in). Some days during application were rainy.
- The type of existing floor coating was unknown, but the overcoat system consisted of four coats (two coats of epoxy and two coats of clear moisture-cured urethane).
- The existing floor was cleaned by sanding and detergent washing/rinsing.
- The first epoxy coat was thinned.
- Decorative color chips were broadcast onto the wet surface of the second epoxy coat followed by application of the clear coats.
- All coatings were applied by roller.
- No inspections were performed (i.e., no moisture testing, monitoring of ambient conditions or wet film thickness testing).
- Wet samples of the overcoat products (unopened containers) were available.
- Destructive testing/sampling was permitted.
- The coating manufacturer had been consulted by phone, and based on the information presented by the maintenance supervisor, suggested that blister formation resulted from applying the first clear urethane over the epoxy before adequate curing had been achieved. No reports were prepared.

All of the background information collected must be kept in mind when performing field tests and inspections. Before doing a detailed analysis, do a quick walk-through of the project to understand the "big picture" first, and to identify any obvious failure patterns or trends. This helps to identify specific areas for an in-depth, hands-on assessment.

## Step 2: Field Moisture Detection

When examining floor coating problems, it is helpful to determine if there is a correlation between the moisture content within the concrete and the location or locations of the problems. This is especially important for on-grade concrete slabs.

Several test instruments and test methods were available to determine moisture content. For quick comparative assessments, hand-held moisture meters were preferred because they provide instantaneous results. During the field investigation, moisture meters that operate using electrical impedance (as per ASTM F2659), electrical resistance and radio frequency principles were used (Fig. 2).

Other moisture test methods include the plastic sheet test (ASTM D4263), calcium chloride vapor emission testing (ASTM F1869) and relative humidity (RH) probes that are inserted into the concrete (ASTM F2170). The plastic sheet requires at least 16 hours, and calcium chloride and RH probes require up to 72 hours to complete so they were not used in this case. It should be noted, however, that some manufacturers of the RH probes indicate that results within 3 percent of the RH obtained after waiting 72 hours can be obtained within one hour.

All tests with the moisture meters indicated that the floor was dry in both failing and non-failing areas.

## Step 3: Field Coating Thickness Measurements

When examining coating problems on concrete floors, coating thickness measurements are performed to determine if there is a correlation between thickness and coating failure.

Total coating system thickness on concrete floors can be measured nondestructively using an ultrasound coating thickness gage in accordance with ASTM D6132. This can be useful for the measurement of total coating thickness, but for field forensic work, determining the thickness and consistency of the individual layers (including the presence of pinholes and voids) can provide valuable information. Individual coating thickness is typically performed using a Tooke Gage as per ASTM D4138 and/or from cross-sections of field samples that are measured microscopically in the laboratory. Both methods are destructive and field coating repairs are necessary. Sample removal techniques are discussed in the upcoming section on microscopic examination, sample collection and photographic documentation.

For this failure, the Tooke Gage was used to measure floor coating thickness in both failing and non-failing areas to determine if there was a correlation between thickness and performance (Fig. 3).

The results showed that the thicknesses generally complied with the coating manufacturer's requirements, and more importantly, that there was no difference in thickness between failing and non-failing areas.

*Fig. 3: Tooke Gage being used on the floor to determine coating thickness.*



## Step 4: Field Adhesion Testing

Visual observations alone are often not adequate to determine the extent of potential problems. A coating can appear to be intact and free of blisters, but possess a level of adhesion that will not withstand the abuse and wear that is expected. Adhesion test results are used by professionals when rendering an opinion as to whether a coating should be repaired or replaced. If a coating is repaired, adhesion tests are also used to confirm that the repair material exhibits an adequate bond to the existing coating.

There are three primary ways to test the adhesion of a coating system. All three methods are described in ASTM standards.

ASTM D3359 involves cutting an "X" or cross-hatch pattern into the coating down to the substrate, applying a pressure-sensitive tape to the test area and removing it. The amount of coating removed is rated according to an ASTM rating scale from 0 to 5, with 5 representing no coating removal.

ASTM D6677 involves cutting an "X" through the coating and probing at the cross-section. The ease of removal is rated subjectively on a 0-to-10 scale with 10 representing no coating removal.

ASTM D7234 involves attaching (using a liquid adhesive) a 2-square-inch surface area loading fixture to the coating surface and removing the fixture with a pneumatic or hydraulic adhesion tester after the adhesive has cured. The tester measures the pull-off force (in psi or kilopascals) needed to detach the test fixture from the coating or substrate.

These tests are based on two different testing mechanisms and evaluate two different adhesion properties. The tape and knife adhesion tests are used to evaluate the "shear" or "peel" strength of a coating, while the pull-off test is used to evaluate a coating's tensile strength, or its resistance to a perpendicular pull. Pull-off testing was the primary means of adhesion testing used for this project (Fig. 4), but supplemental testing was also done using the knife test (Fig. 5).

When documenting pull-off adhesion test results, record the pull-off value and the location of the break. An adhesive break is a clean split between coating layers or down to the concrete surface. A cohesive break is a split within a single coating layer or within the concrete substrate itself. Adhesive or cohesive failures of the glue used to affix the loading fixture to the coating may necessitate that additional tests are performed.

*Fig. 4: Pull-off adhesion testing using a hydraulic adhesion tester (ASTM D7234).*

*Fig. 5: Knife adhesion testing (ASTM D6677).*

Note that while concrete has tremendous compressive strength, it often does not possess good tensile strength, so the location of the adhesion test break is oftentimes within the concrete itself. When this occurs, little information about the adhesive or cohesive properties of the coating system is revealed, other than the fact that the coating adhesive/cohesive strength exceeds the tensile strength of the concrete substrate.

For the work on this project, the pull-off adhesion in a typical non-failing area measured 525 psi with the break as follows: 15 percent glue, 20 percent cohesive in the concrete and 65 percent cohesive within the red primer coat of the original coating system. These results indicate that the new system adhered well to itself and to the original floor coating. Failing areas were not tested because there was obvious visual blistering and peeling on the coating surface.

Knife testing in failing areas produced poor results with the clear outer urethane layers detaching in large chips (¼-inch and larger) immediately upon insertion of the knife blade. Continued probing of the underlying layers revealed that those layers (both the new beige and original layers) were sound, intact and adherent. Knife tests in non-failing areas showed all coats to be very difficult to remove. The adhesion was excellent.



## Step 5: Field Microscopic Examination, Sample Collection and Photographic Documentation

### Field Microscopic Examination

When examining coating problems on concrete floors, one of the key tests often performed in the field is a microscopic examination. A low-power microscope with 20X-to-50X magnification can be used to identify flaws or deficiencies that would otherwise go undetected. A microscope with a large field of view is also a plus, especially one that has an opening in its base to allow for a knife to be used to probe the surface while viewing under magnification (Fig. 6).

Microscopic analysis also helps to focus the direction of the investigation by identifying the types of field samples that should be collected for subsequent laboratory analysis. For example, the microscope might show the presence of a contaminant between coats or that separation is occurring at different planes within the coating system, thereby influencing the type and number of samples that should be collected.

*Fig. 6: Field microscopic examination of a failing area.*

In this case, the microscopic analysis revealed that the separation was occurring between the beige epoxy layer and the first clear urethane layer, with a slight beige discoloration visible on the underside of the disbonded clear coats. Contamination between coats was not visible.

### Sample Collection and Photographic Documentation

The removal of samples must be done methodically and with planning, with consideration of the following.

1. Failing samples — The samples must be representative of the problems observed. Oftentimes, the failure is not the same across the entire surface. For example, the failure of a coating system to the substrate must be treated differently than a failure between coats. In the end, the cause may be the same, but when conducting field analysis and sampling, they must be treated as two separate problems. If more than one type of failure is occurring, representative samples of each type must be collected.
2. Non-failing samples — Non-failing samples are as important as failing samples so that comparisons can be made. Again, they should be representative of non-failing areas, such as both thin and heavy areas.
3. Sample locations should be known. The source and exposure (contamination) of detached coating chips lying on the ground are not known and should not be used.
4. The integrity of a sample must be maintained. For example, peeling/lifted paint on the surface can be contaminated from environmental exposure and should not be used if possible. Collect samples adjacent to failing areas where the poorly adhered paint is still weakly attached to the surface, so that the interface has not been exposed.
5. When possible, sample the failing coating and the underlying remaining coating, material or substrate. Oftentimes, key evidence is on the surface of the coating that remains attached to the substrate, or on the substrate itself.
6. Samples should include the complete coating system and substrate whenever possible. This allows for the sample to be separated in the laboratory so that the interface between layers can be examined. These types of samples can be obtained by cutting a core sample with a concrete core saw (dry) or by chipping the concrete (i.e. using a sharpened masonry chisel).
7. Immediately place each sample in a sealable plastic (polyethylene) bag or in a septum-capped vial and clearly label the sample. Septum-capped vials are particularly useful for preserving coating samples that may be suspected to contain retained solvent. In the absence of septum vials, double- or triple-bagging of samples can also be effective.
8. Prepare a chain of custody for samples for traceability purposes. The form should document information such as the type and location of the sample, laboratory analytical testing required and signature sections acknowledging the person who obtained, transferred or received the samples.
9. Photographic documentation throughout the evaluation process is of vital importance. Photographs of typical failing versus non-failing areas show the type and extent of the defects (for example, concentrated versus randomly scattered and general locations). Handwritten notations on the surface being photographed can enhance the value of the picture and aid in recall when preparing the report. A ruler or some other reference to size is also helpful as shown in Figure 7.

## Conclusion

In summary, the field investigation revealed that the floor was dry in both failing and non-failing areas. The field

*Fig. 7: Investigator photographing a sample site. Note that some of the blisters have been circled to better show patterns, information is written on tape, and a ruler is included for size.*

measurements of the coating showed that the thicknesses generally complied with the coating manufacturer's requirements, and more importantly, that there was no difference in thickness between failing and non-failing areas. For the work on this project, the pull-off adhesion evaluation in the intact areas showed that the new system adhered well to itself and to the original floor coating. The knife adhesion evaluation revealed that failing areas of coating were predominately the result of detachment of the clear outer layers, and that the underlying layers were sound, intact and adherent. Conversely, the knife adhesion tests in non-failing areas revealed that the adhesion was excellent. The field microscopic analysis of failing areas revealed that the separation was occurring between the beige (epoxy) layer and the first clear (urethane) layer, with a slight beige discoloration visible on the underside of the disbonded clear coats. Contamination between coats was not visible.

The documented field data, notes and observations were combined with the laboratory sample analysis to determine the cause of the coating failure. The laboratory forensic investigation and the conclusions regarding the cause are the focus of Part 2 of this series.

# Maintaining an Old Icon with a New Technology

By Greg Peters, SABRE Autonomous Solutions and Dr. Gavin Paul, University of Technology, Sydney

*Photos courtesy of Greg Peters unless otherwise noted.*

The Sydney Harbour Bridge is one of Australia's most photographed landmarks. Tourists climb to its peak, New Year's Eve revelers wait for hours for the best view of the annual fireworks launched from its structure, and for many it marks a significant part of young Australia's history. The Harbour Bridge is also a vital artery in Sydney's transport system featuring eight lanes of traffic carrying 160,000 cars per day, two train lines and countless people on its dedicated bicycle and pedestrian paths.

The bridge enlists a full-time maintenance crew as blasting or other works are always ongoing. There is an urban myth that by the time painters finish one end to the other, it is time to start again. In fact different sections are managed in different ways, with work ongoing. Some sections have not been repainted since construction. Other exposed surfaces must be repainted every five years and some can last 30 years without a new coat.

Recent planned maintenance involving abrasive blast-cleaning of the old paint back to bare metal has provided an opportunity for robotic technology to be used to assist maintenance workers. For the past two-and-a-half years, two autonomous robots named Rosie and Sandy have been performing some of the more repetitive and straining blast work on the southern side approach spans under the road deck.

Roads and Maritime Services (RMS) is the Australian government department responsible for building, maintaining and delivering a large range of transport infrastructure and services in New South Wales (Australia's most populous state), including the famous icon.

RMS have an Occupational Safety and Health (OSH) policy statement of "safety first, work second" and in 2006 formed a partnership with the University of Technology, Sydney (UTS) to investigate systems which could reduce worker exposure to the potential hazards of abrasive blast cleaning of steel bridges.

The robotics research group, the Centre for Autonomous Systems from the UTS, was tasked with a world-first challenge: create a robot capable of scanning and modelling a complex structural environment in real time without human intervention, and use this model to plan and safely control a robot's motion so as to grit-blast the structure. This was completely unlike any other robot used in grit-blasting, as it required the robot to operate in an unstructured environment, and with minimal prior knowledge of its surroundings.

The project involved professors, Ph.D. and Masters candidates, and undergraduate students working in collaboration with the RMS team of abrasive blasters, painters and engineers. Following a "proof of concept" phase where the scope was identified, a seven-year collaborative development project began. The two autonomous robots have remained in use since the project delivery in February 2013. Meanwhile the original design team has been busy readying the technology for a range of global applications.

*Workers slide the robot into position for the next blast. Photo: Roads and Maritime Services (RMS)*

## The Sydney Harbour Bridge

At 1,149 meters (3,770 feet) long the Sydney Harbour Bridge or the "Coat Hanger" as it is known locally, is the world's

*The Sydney Harbour Bridge enlists a full-time maintenance crew and work there is always ongoing. Some sections are painted every five years while others have not been recoated since original construction. © iStockphoto.com/WestLight*

largest steel arch bridge. Construction started in 1924 and employed a 1,400-strong workforce before finally being opened to traffic in 1932. An estimated 52,800 metric tons of steel and six million hand-driven rivets were required for its construction as well as 272,000 liters (71,854 gallons) for its initial three layers of paint.

Fast forward 83 years later, RMS have an objective to develop new ways of improving operational effectiveness, including the safety of their work environment. Protecting the intricate web of steelwork from corrosion is the most important factor in conserving the Sydney Harbour Bridge's arch and spans.

A full-time crew of riggers, painters, carpenters, electricians and ironworkers are required to conduct inspections and preventative maintenance. Abrasive blasting is a standard approach for bridge maintenance across the network with environmental containment being a top priority.

As with many bridges of the era, this bridge was coated with lead-based paint and a final coat of micaceous iron oxide (MIO) alkyd which later became the official 'Sydney Harbour Bridge Grey,' a registered trademark color. In 2003, RMS started repainting the city side southern approach spans, some 90,000 square meters (968,751 square feet) of steelwork. The specification called for a complete strip back to clean steel before application of a more modern high-performance, fade-resistant and lead-free paint.

A three-floor modular traveling work platform was designed for the task. It allowed riggers to install the upcoming section of environmental containment while adjacent work was ongoing. Within the environmental containment on the lower-level, modified boom lifts were used to access the wind braces, vertical and diagonal elements which make up the Warren truss spans. Closer to the road deck, two floors of work platforms allowed the work crews close access to the intricate structure which included main stringers, box sections, corrugated roofing and lattice box wind bracing. The robots were to be deployed in areas which were subtly differing in each location. The size, position and style of structural members varied from position to position eliminating the option of a preprogrammed solution.

## In-Field Robotics – The Challenges

When most people think of robots they tend to think of traditional industrial robots, like those found in car factories, or of fictional systems with super-human, "Terminator-like" capabilities. In reality, while technology has come a long way, few robotic systems have been deployed on real worksites outside of factories.

Typical industrial robots require a well-planned purpose-built environment. Industrial robots, for the most part, execute pre-planned paths which have been created using detailed prior knowledge well in advance of hitting the "start" button. The position of the robot with respect to the task is precisely known and carefully selected based on the intended motion.

While industrial robots can move at super-human speeds with high precision, their heavy construction makes it impractical for them to be used as mobile machines. To work successfully onsite, field robots must be moved many times a day; transported up ladders, through manholes and more, often without the use of assisted lifting equipment. While small robot arms do exist, they lack the strength and reach required to perform tasks such as abrasive blasting on large structures.

For robots to function in unknown, unstructured environments, a more sophisticated sensing and control solution is required. For the challenge of developing a robot that can carry out abrasive blasting in the complex, highly variable environment found on bridge structures, a new approach needed to be developed. Once grit-blasting commences, the air is quickly filled with dust, significantly reducing visibility, and meaning that remote control of a robot by a human operator is unrealistic. Hence, an autonomous solution is required.

The team at UTS recognized that research and development were needed to generate algorithms for exploration and mapping, collision avoidance and path planning. Then the software-implemented algorithms had to be paired with innovatively designed and developed robotic hardware.

*The 3-D sensor and blast gun.*

### Scanning: Sensing and Mapping the Environment

As both accurate and up-to-date, 3-D computer-aided design (CAD) data does not typically exist for bridge structures, the robot must be able to operate without detailed prior knowledge of the structure. This means that the system must generate its own 3-D map of the environment and use this data to plan an optimum blasting trajectory based on the information it has available.

The robot uses an inexpensive RGB-D camera capable of taking photos overlaid with depth data. It projects an eye-safe infrared-light structured grid pattern onto surfaces within its field of view allowing an image containing depth pixels to be generated that represent the distances from the camera to the reflecting surface. From each of the almost half a million distance values, 3-D "points" can be computed and captured at a frame rate of 30 per second.

An exploration algorithm is used to automatically select safe locations where the robotic arm can position the camera to take 3-D images of the surrounding environment. An algorithm stitches those point clouds together to form a 3-D model of the environment. Unlike traditional vision approaches such as stereo or structured visible light, this approach is tolerant of the dusty, vibration-affected work platform, environment lighting variation, and in fact, can even work in the dark.

The 3-D point cloud which is created during scanning is sufficient for the robot to perform blasting of many structures. However, as this point cloud can only contain points from surfaces that could be seen in each photo, for complicated environments exploring the location and capturing each surface from every angle can be time-consuming.

*Each robot is controlled by a portable safety controller and rugged computer, shown here installed next to the blast pot.*

Instead, engineers developed templates which are parametric structural primitives typically found within the environment. These templates included I-beams, box sections, rivets, the corrugated profile of the road deck surface, and more. The robotic software automatically scales, rotates and positions the templates over the point cloud, appending it to quickly and efficiently provide a complete picture.

## Plan: Autonomous Robot Control

The project team knew that even with state-of-the-art air extraction systems, once blasting starts, visibility would be poor. Remote-controlled cameras would not be a viable long-term solution and furthermore, accurately controlling the six-axis arm in confined and cluttered environments is non-intuitive and difficult for the most experienced human operator. An autonomous planner was developed that could use the point cloud and the template map to create the entire blast trajectory without any human intervention. This also frees up the robot operator to perform other tasks, controlling multiple robots at one time or manual blasting and painting in other areas.

The algorithm employed considers parameters for optimal blasting including maximum and minimum distance, the blast stream's angle of incidence with the surface, the speed, and the size of the blast spot. These parameters vary based on the desired surface cleanliness, the initial state of the surface coating including its thickness, type, condition, and the blasting equipment in use, such as the abrasive media, nozzle size and air-pressure. Millions of possible trajectory combinations are then evaluated to find the optimal path that matches the selected parameters while minimizing the blasting time necessary to cover all reachable areas.

An operator can also interact with the system via an intuitive user interface, which allows for areas to be virtually marked as "do not blast" if sections of steel surface are already in good condition, or to manually exclude utility infrastructure such as water pipes and electrical conduit.

## Blast: Deploying Rosie and Sandy

Following seven years of design iterations and field trials, delivery and deployment of two robots occurred in February of 2013.

Each robot consists of a 25-kilogram (55-pound), six axes robotic arm custom-built for abrasive blasting. The robot sits on a structurally simple frame tailored to each blasting application. For safety reasons, the robot was limited to 24-volt DC power within the abrasive area. This allows the system to be run from portable battery packs or from mains power via a power supply unit.

Workers first place modular sections of aluminum rail within the work site. To change location, the robot can either move along the tracks to another location onsite or be dismantled into compact units and moved by hand. The unique combination of mobility, robustness, power and lightweight construction make the system well-suited to the task.

The system was designed to use existing blasting equipment. A quick release system allows the human-operator to remove the standard nozzle coupling and perform manual blasting where necessary. The robot is protected by multiple layers of abrasive-resistant materials which are positively pressurized and temperature-controlled. The blast stream is activated automatically using either an electronic or pneumatic dead man's switch.

The robot operator uses a handheld touchscreen panel to safely monitor and control the robot from up to 30 meters (about 100 feet) away from the blasting area. Each day an operator first positions the robot and then presses "SCAN." Once scanning is complete the operator has the option to blast everything in the environment or only selected items. The operator then presses "BLAST" and the autonomous planner controls all robot motion.

At the Sydney Harbour Bridge the robot blasts for approximately 50 minutes in each location, producing an SSPC-SP 5/NACE No. 1, "White Metal Blast Cleaning" surface cleanliness. The blast worker then has the choice of repositioning the system for further blasting or performing any necessary manual touch-up and painting.

## Using Robotics in Other Blasting Jobs

The major repainting works of the Sydney Harbour Bridge southern side approach spans were completed in July of 2015. Over the two-and-a-half-year period the robots became a tool for blasters to use in specific areas of the bridge, thus freeing up valuable human resources to work in other sections, reducing OSH risks and improving efficiency. Following handover of the robots to the RMS bridge team, the project received many awards including a finalist for three awards: the 2013 Australian Engineering Excellence Award, the 2013 International Invention and Entrepreneurship in Robotics and Automation Award, and the 2013 Australian Museum Eureka Prizes.

Since 2013, the technology has been undergoing commercialization by SABRE Autonomous Solutions in Australia, a team that includes many of the original researchers and engineers. The challenge has been to "blast anything, anywhere," a process that has involved refining the software and hardware to work in a range of environments including bridges, ships, petrochemical tanks, pressure vessels, and towers and gantries (highway sign holders).

## About the Authors

Greg Peters is the engineering manager at SABRE Autonomous Solutions, headquartered in Sydney, Australia and specializing in autonomous solutions for hazardous tasks. His qualifications include a Bachelor of Engineering degree in mechanical and mechatronics and a Master's de-

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Dr. Gavin Paul is a postdoctoral research fellow at the Center for Autonomous Systems at the University of Technology, Sydney. His qualifications include a Bachelor of Engineering degree in computer systems and a Ph.D. in robotics from UTS. Dr. Paul's research interests lie in the fields of sensing, perception and planning for robotic manipulation. Dr. Paul has been a member of the autonomous bridge blasting robot project since 2006.


# Railcar Coatings From a Railcar Lessor's Perspective

By Maria Betti, GATX Corporation

*Photos courtesy of GATX Corporation.*

## Why Apply Coatings and Linings to Railcars?

Coatings have been applied to railcars since railcars were first manufactured from carbon steel. They are applied for a variety of reasons and may have different functions depending on whether they are applied to the exterior or interior of the railcar.

### Railcar Exteriors

The main purpose of an exterior coating from a railcar lessor's perspective is to protect the asset (including the steel tank and all steel components attached to the tank) from continued exposure to environmental factors such as ultraviolet (UV) rays, corrosive environments such as salt spray and also from exposure to the commodity that is being transported in the railcar. Commodity spillage is mainly encountered on a tank car where liquid products are transported and can impact the coating around the manway area where loading and unloading operations are performed. This effect is increased if the commodity is corrosive, and the area that is affected is typically referred to as the centerband area of the tank car as shown in Figure 1 (p. 34).

While the main reason exterior coatings are applied to railcars is to protect the steel, some shippers of the commodities that are transported by the railcars require a more aesthetically pleasing appearance. Shippers of food-grade products fall into this category as well as widely recognized chemical manufacturers. These shippers consider the railcar to be a billboard for the products they sell and therefore an aesthetically pleasing exterior is important. Shippers of highly hazardous commodities also want an aesthetically pleasing exterior to give the impression that the commodity is packaged well. Another reason that shippers coat the exterior of railcars is to visually communicate what commodity is loaded in the tank car. For example, some shippers apply a different color from the tank's base color to the manway nozzle or the centerband area, or the centerband area plus the lower one-third of the railcar. This last paint scheme is commonly referred to as a "saddle shoe."

### Railcar Interiors

Application of linings to the interior of railcars (mainly tank and hopper cars) is performed to satisfy two main needs: to protect the asset from corrosion or to protect the purity of the commodity being transported in a railcar (Fig. 2, p. 36). Sometimes both apply, for example, with phosphoric acid. The Department of Transportation (DOT) regulations define a commodity that is corrosive to a tank as one that corrodes steel at a rate of 2.5 milli-inch per year (mpy) or, .0025 inches per year. Typical liquid commodities that are transported in lined tank cars for protection of the tank include sulfur, sulfuric acid, fertilizer solutions, ammonium, sodium bisulfite and many more. Commodities that require sheet rubber linings are highly corrosive and the most common are hydrochloric and phosphoric acid. Fewer solid commodities require linings for protection of the railcar, but more typical examples include sodium chloride, potash, ammonium nitrate and some plastic pellets that can create acidic compounds when exposed to moisture, for instance terephthalic acid. Boxcar linings are typically used in those that transport packaged food commodities or shippers that require a bright, clean interior.

## Coating Types for Railcar Exteriors

The types of coatings used for railcars have changed over the years primarily due to evolving environmental and safety regulations and advances in coating technology and application equipment. Before the enactment of regulations governing coatings applied by the railcar industry, typical coatings for railcars contained lead and were high in solvent content, primarily volatile organic compounds (VOCs). Some coatings, and particularly linings, also contained asbestos and other ingredients which presented a safety issue for the applicator. As environmental regulations developed, the VOC content in coatings has decreased, and the solids content increased. Today, many coatings used are close to 100%-solids, particularly interior coatings.

Most railcar lessors currently choose one-coat epoxy polyamide coating systems for railcar exeriors. The common use of epoxy coatings began in the railcar industry approximately twenty years ago, when plural


*Fig. 1: The "centerband" area of a railcar is where loading and unloading operations are performed and is susceptible to spillage. Exterior coatings can be damaged if corrosive materials are involved.*

component (PC) application equipment became easier to use, maintain and more affordable. PC equipment is designed to automatically mix the two components at their correct ratios, and also has the ability to heat the coating material. With the addition of heat, it then becomes possible to apply epoxy coatings with higher viscosity and higher solids content. The high-solids epoxy coatings (typically at least 70-percent-volume-solids volume solids) are particularly advantageous for railcar maintenance shops that have air permit limits on VOCs. In addition, higher solids coatings can be more economical than lower volume solids coatings as less material is required and less time is spent on building the required coating film thickness. Finally, epoxy coatings are also advantageous from an asset protection perspective because they have good, broad chemical resistance (Fig. 3, p. 38).

One major disadvantage of an epoxy coating is its susceptibility to UV rays. Epoxy coatings will chalk with exposure to sunlight and the color will dull in a very short time frame. The loss of gloss may not be a concern to all railcar lessors since the coating continues to provide protection to the asset. However, gloss retention may be important to some shippers, particularly those who are sensitive to aesthetics, such as shippers of food-grade commodities or widely recognized chemical manufacturers. For these shippers, a two-coat epoxy/polyurethane coating system can provide an excellent solution as the epoxy base coat delivers the corrosion resistance and the polyurethane topcoat helps with gloss retention.

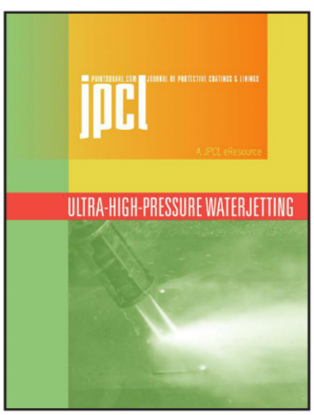
*Fig. 2: Newly applied interior lining in a tank car.*

While epoxy coatings are the most commonly used on the railcar exteriors, other coating types are also used. Some railcar maintenance shops don't have the equipment to automatically mix and heat two-component epoxy coatings and don't want to hand-mix components on a regular basis. To keep VOCs low and avoid mixing, they may instead use one-component, water-based coatings. These coatings make equipment cleanup easier since water is used as the clean-up solvent. Some acrylic exterior railcar coatings also provide extra corrosion protection for corrosive cargos such as sulfuric acid. For these tank cars, a two-coat, graphite-impregnated waterborne acrylic system is used. The main disadvantage in using these coatings is their low volume solids, which increases material and labor costs.

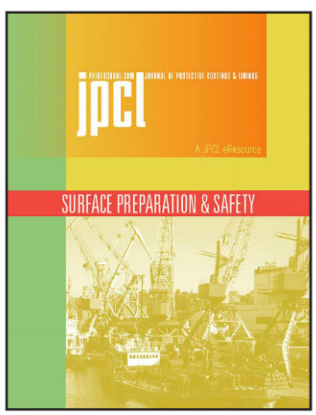
### Coating Types for Railcar Interiors

Interior coatings or linings in tank and freight cars have also evolved over time, not only to comply with environmental and safety regulations, but also to reduce the time and effort spent on applying linings. Forced curing of linings can have a significant impact on the time a railcar remains at a maintenance shop, which is commonly referred to as "throughput time." Throughput time is important to

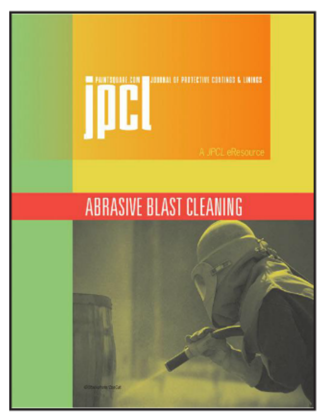








a railcar lessor because the longer the railcar remains in the shop for maintenance, the longer the car is off-lease and not generating income. This is especially important when the lessor has a full-service lease agreement, which means that they are responsible for all railcar maintenance. Throughput time also impacts the shipper's ability to use the railcar for the need that it was intended — to ship commodity.


*Fig. 3: Newly applied exterior epoxy coating on a tank car.*

The type of lining material used in both tank and hopper cars is somewhat varied, but the industry workhorse has been epoxy coatings. They have a healthy amount of volume solids (usually greater than 70 percent), are applied in one or two coats and are considered to be medium-thick-film — 12 to 15 mils, dry film thickness (DFT). High-bake phenolic linings are also commonly applied. These have a broad range of chemical resistance and are also suitable for food-grade commodities. High-bake linings are typically applied in three coats, and require intermediate curing (or baking) as well as a final bake at a very high temperature in the range of 375 to 425 F, depending on what commodity the lining will be exposed to. In addition, if the tank car is not insulated and jacketed, a layer of insulation must be applied to the tank car to ensure that the car retains the required amount of heat to properly cure the lining. Applying insulation to a tank car in this manner is both time-consuming and labor intensive.

Additionally, the exterior coating on a non-jacketed tank car can become compromised during the final high-bake process, and a new exterior coating application may be required. This can significantly increase the cost of applying a high-bake phenolic lining.

Advances in coating technology have led to the development and use of alternate coating systems that also have good chemical resistance. Single-coat linings, high- or 100%-volume solids coating materials and coatings that require only a low bake or air-dried final cure are examples of new coatings that are being used with increased frequency. Many of these coatings are novolac phenolic epoxy coatings. The main advantages of using these coatings for a railcar lessor are decreased throughput time in the shop and decreased application costs.

Other less commonly used linings are vinyl ester coatings. Vinyl ester linings are thick-film coatings (up to 40 mils DFT on average), have multiple components and are expensive to apply. Also, they require a deep surface blast profile to assure mechanical adhesion of the coating. Most railcar shops use metal grit media for their blast operations, and since metal grit is expensive, it is recycled/recovered. To achieve the deep profile, a different grit size is needed than one that creates a shallower profile required by most other lining systems. This means that the blast media must be changed when applying a vinyl ester lining. Changing blast media in a grit recovery system can be a significant process for shops and is disruptive to their operations. For this reason, very few railcar maintenance shops apply vinyl ester linings.

Rubber sheet linings are also used in the railcar industry, mainly for tank cars shipping hydrochloric and phosphoric acid, and for those also shipping ferric and ferrous chloride. Natural rubber is used for applications to hydrochloric acid cars, while chlorobutyl rubber is used for all other applications. Due to the expertise required to properly apply sheet rubber linings to the interior of tank cars, only a handful of railcar shops apply them.

## Trends in Railcar Coatings

Today, many railcar lessors provide application and maintenance of coatings as part of their full-service lease contract. Railcar maintenance is performed on a regularly scheduled basis and is both costly and time-consuming. As a result, railcar lessors are continually looking for methods to reduce coating application costs and throughput time, while improving the quality of the applied coating. Some efficiencies can be realized operationally through continuous improvement processes, while others through improvements in coating technology. Plural component equipment, high-solids content coatings and single-coat applications are examples of some of the efficiencies that have been utilized over the past several years.

Reduction of exterior coating costs and throughput time has led some lessors to overcoat the existing coating on a railcar versus blasting the tank surface to a commercial blast cleanliness level. This coating technique can reduce application costs by as much as 30 percent, and slightly reduce the surface preparation time; however it should only be performed when certain criteria are met. Some of these criteria include basic surface preparation such as brush blast cleaning or high-pressure waterjet cleaning, good adhesion of the existing coating, absence of corrosion, and the use of an epoxy coating as the overcoat material, since epoxy coatings have inherently good adhesion properties. Overcoating of existing coatings is particularly effective on boxcars where completely blasting the large boxcar, with its side stakes and varied surface features, to a commercial blast cleanliness level requires many labor hours to achieve. The subsequent coating application of such a boxcar is also time-consuming and requires significantly more material to build the required coating thickness.

The more significant impact in reducing coating application costs and throughput time comes from tank car lining applications. For tank cars, one of the greatest impacts is expected to be the replacement of high-bake phenolic linings with one-coat, 100%-solids novolac epoxy coatings. Since this is a recent development, the effect on both cost and throughput time has not yet been fully realized.


### About the Author

Maria Betti is a senior chemical engineer with GATX Corporation. She holds a Bachelor of Science degree in chemical engineering from the University of Illinois, Chicago, and has over 25 years of technical experience. Her career at GATX began over 20 years ago within the operations group concentrating on environmental issues. She has been part of GATX's engineering group for the past 15 years mainly focusing on tank car coatings, linings and material compatibility. ***JPCL***

A successful tank relining project requires four simple components for success. There are so many horror stories about projects that went off the tracks, blew up or degenerated into controversy, but that is not this story. This story is about a fairly complex tank relining project that went exactly the way it should have, simply because it had these four components: an owner who was supportive, cooperative and interested in having the project done right (the Gulf Coast Waste Disposal Authority [GCA]); a specification that was clear, complete, thorough and exact, yet flexible enough to work around problems or obstacles that popped up during the project and an approachable subject matter expert if changes in the specification were needed (Bill Goulette of GC&S); an experienced contractor who was interested in getting the job done according to the specification, correctly and on time (Blastco); and an experienced non-confrontational third-party inspector who communicated well with the owner and contractor (your humble author). So everything was easy, right?

**NOT SO FAST ...**

This project had an added twist. The product specified was vinyl ester, an older-style and somewhat complicated coating system, which has some very narrow surface preparation, application, recoat and inspection requirements. But we're getting ahead of ourselves here.

**THE OWNER**

GCA is an industrial wastewater treatment operation created by the State of Texas in 1969. It is a unique Texas entity allowing certain Houston-area industrial wastewater generators to pipeline their waste to a central location without requiring each individual member industrial plant in the system to install and operate costly water treatment facilities at their own sites. Savings to individual users from the use of the consolidated GCA system is considerable.

GCA's Bayport Industrial Wastewater Treatment facility, located in Pasadena, Texas, just southeast from Houston, serves more than 60 industrial customers and two neighboring municipalities, processing wastewater and contaminated storm water runoff. This facility has a 30-million-gallon-per-day maximum capacity and treats an average of 18 million gallons of industrial and municipal waste each day.

Tank 2003 at the GCA Bayport facility, called a "first step" tank, receives incoming wastewater and is one of four 110-feet diameter by 30-feet-tall domed tanks on site. First step tanks aerate and oxygenate received wastewater before sending it on for further processing in other portions of the facility. When GCA initially put the Bayport facility into service, a decision was made to use vinyl ester linings in all first step tanks. The incoming industrial wastewater stream could vary widely in chemical content and concentration, and unforeseen chemical combinations could form from the comingled waste of diverse industrial plants. Vinyl ester was the most chemical-resistant, air-dry system available at the time that could be spray-applied.

At the inception of this project, the vinyl ester lining in Tank 2003 was more than 15 years old. Most of the lining was still performing well, but the tank needed to be emptied for unrelated structural repairs and rather than patching the old lining, a decision was made by GCA management to replace it entirely.

Switching Tank 2003 to a 100%-solids epoxy novolac lining was discussed. The excellent chemical resistance of such linings had been proven elsewhere in the

# ADVENTURES IN TANK LINING

BY PETER BOCK, ADVANCED POLYMERICS, INC.

*(Left) The tank side shell was completely scaffolded for safe, easy access during surface preparation, lining application and inspection. Scaffolding was removed before the start of work on the tank floor.*

*(Top) Sunrise at Tank 2003, awaiting the safety crew to certify the tank as safe for entry. Exterior temperature was 83 F, 75 percent relative humidity, with rain quickly approaching from the south.*

*(Right) The blast/paint crew held daily safety meetings each morning before start of work. This photos shows a midmorning safety meeting about halfway through the project. Photos courtesy of the author.*


past 15 years since Tank 2003 had been lined with vinyl ester, but GCA had no track record of epoxy novolac for their own waste stream. It was decided to continue with vinyl ester for Tank 2003, but to place test coupons of 100%-solids epoxy novolac lining in the relined tank and to evaluate them for future relining of GCA first step tanks.

## VINYL ESTER TANK LINING

Vinyl ester was originally a trowel-applied system requiring as much as ¼-inch (250 mils) dry film thickness (DFT). Thinner-film, sprayable versions of vinyl ester became available in the 1970s, but the process and product were still very complex. Vinyl ester is cured by an exothermic catalysis reaction — precisely measured amounts of catalyst chemicals are added to the vinyl ester base to start a chemical crosslinking and heating of the vinyl ester material. In effect, the catalyzed, applied vinyl ester film cures by baking itself hard during the drying process. Usable pot life of vinyl ester is determined by the amount of catalyst added and by the temperatures of the vinyl ester material, the substrate


*The Tank 2003 side shell and floor were 100-percent high-voltage holiday detector-tested after application and curing of the second coat of vinyl ester lining.*

to which it is being applied and the air temperature in the application area.

**Vinyl Ester Resin**

Even without the addition of catalyst, vinyl ester resin can "kick over" and cure hard if enough heat is applied. The manufacturer's quoted shelf life on vinyl ester coatings is purposely short (usually 3 months from date of manufacture) because the resin is relatively unstable; storage in hot conditions can cause the material to actually harden in the can, and storage in relatively cool conditions (for an extended period) can bring about unwanted chemical changes in the coating. Vinyl ester coating materials are usually shipped in temperature-controlled trucks and are kept at the job site in an air-conditioned paint storage building or container.

**Vinyl Ester Fillers**

Vinyl ester resin shrinks significantly in the curing process and dries to a fairly inflexible film. To reduce shrinkage separation from the substrate during curing, and to increase flexibility of the dried film, vinyl ester lining materials are highly filled with fairly coarse and highly chemical-resistant flake or powder additives. These additives are very helpful with the applied film, but they are damaging to the fluid system metal parts of the application equipment. Airless pump packings, balls, spray tips and the high-pressure lower ends of airless pumps used to apply vinyl ester wear at much faster rates than the same equipment used to apply epoxy or urethane, and must be replaced or rebuilt constantly during a vinyl ester application project.

The ratio of catalyst to vinyl ester resin must be precise; too much catalyst and the material exotherms too quickly and hardens in the spray pump, hose and gun before it can be sprayed out. Too little catalyst and the vinyl ester lining never hardens after being sprayed onto the surface.

**Vinyl Ester Application**

Plural component spray pumps have been tried for vinyl ester application and were found to be unsuitable because of the very


*Initial test blasting of side shell areas showed that the abrasive being used was too fine to produce the specified anchor profile. Switching to coarser abrasive solved the problem.*

low catalyst-to-coating ratio and because of the possibility of uneven catalyst distribution. The traditional application method used for catalyzed vinyl ester is "hot pot" spraying by either conventional or single-component airless equipment.

The temperatures of the vinyl ester coating material before being catalyzed, and of the substrate to which it is applied, will both affect the rate and quality of cure, so they must be controlled or compensated for. In a hot summer environment, fluid lines feeding from an airless pump outside the tank to the gun inside must be insulated; otherwise sunlight or radiated heat from the ground might heat the hose enough to kick over and harden the vinyl ester inside before it ever reaches the spray gun.

Once a batch of vinyl ester is catalyzed, the exothermic reaction cannot be stopped. While the catalyzed material is in mass in a bucket or spray pot, the heat generated is concentrated, speeding the process. Any interruption of the spray-out can cause a very quick kick-over and hardening of the catalyzed material. If a painter can't spray out catalyzed vinyl ester, he and an assistant must immediately reduce pressure, push the vinyl ester out of the lines and spray equipment and flush everything with solvent. Otherwise, at best, the application equipment will turn into sculpture, filled with rock-hard vinyl ester and at worst, there is a possibility of fire or a small explosion caused by overheating the material.

Spray-applied vinyl ester is usually a two-coat system with minimum and maximum recoat intervals determined by the ambient and substrate temperature of the applied first coat as it dries and cures. In south Texas, on sunny days, the sunny side of a tank shell may reach 125 to 130 F, while the shady side is barely above ambient (typically

mid-90s F). The recoat interval for the sunny side of the tank shell will be much shorter than for the shady side or for the tank floor, which always stays cooler because of the heat sink effect. Of course, on a rainy day, the recoat interval for any area of the tank will be longer because the entire shell will be at exterior ambient temperature, which may be as low as the mid-70s F. Applied vinyl ester must be over 70 F for the material to cure. This is why temperature control and dehumidification of the tank interior are mandatory in a vinyl ester lining project.

A painting contractor unfamiliar with the distinctive characteristics of vinyl ester who bids and expects to do a vinyl ester lining project on the basis of experience with application of 100%-solids plural component epoxy linings, could be in trouble from the first day of application. Painters unfamiliar with vinyl ester would have a very difficult time completing  a safe and successful vinyl ester project.

*Another balmy day inside Tank 2003 — 99.5 F and about 40 percent relative humidity assured proper curing of the applied vinyl ester, regardless of weather conditions outside the tank.*

**THE SPECIFICATION**

A single-source industrial plant wastewater treatment facility has the luxury of scheduled turnarounds and plant outages, during which there will be no wastewater generated, and during which maintenance can be performed on the plant's components. With so many facilities sending waste to GCA, there is no such luxury.

Normal flow patterns were analyzed and the relining of Tank 2003 was scheduled for July 17 through November 1. Although this period includes the hottest part of the Houston summer, as well as its tropical storm season, it was understood to be the least disruptive to the Bayport facility's normal processes.

GCA management was familiar with the complexities of vinyl ester tank relining from past projects at the Bayport facility. There is an old Texas saying: "This isn't our first rodeo." A comprehensive bid package and coating specification document for the relining of Tank 2003 was prepared by a third-party consultant.

The bid package and specification is a bound document 1-5/8-inches thick. Tabs A through P cover the legal, financial and documentation portions of the bid and subsequent contract. Tabs L, M and O cover the working relationship of the contractor with the facility and others onsite. Tab N is the quality assurance/quality control document — three pages of required tests specifying who is responsible, when the tests are to be done, how the tests are to be done, and whether the tests are a hold point and/or require witness by the owner's representative.

Tabs Q through Z and two add-in documents from the selected contractor make up just over an inch of the bid package's thickness and constitute the actual surface preparation and coating specification. Tabs Q, R and U detail required meetings, communications, and coordination for the project. Tab T is a linear graph of the expected project timeline.

Tab W, somewhat misleadingly called the "Lining Specification" (because several other tabs also contain significant information pertaining to the lining specification); is a 19-page document listing the contractor's required process. Individual sections of this document detail the required atmospheric conditions within the tank, access, work progress and scheduling, pre-preparation cleaning, surface salt testing, surface preparation, testing of prepared surfaces, lining application, testing of each coat of the applied lining, spot re-preparation and spot lining re-application where needed, and completion of the project. The Tab W lining specification originated in 2007, and was revised or modified in 2008, 2010 and 2013.

Tab X is the coating manufacturer's material safety data sheet (MSDS) and application recommendations for the specified vinyl ester lining system.

GCA does not have onsite emergency tank-entry and rescue capability because their employees do not enter the tanks while in service. A third-party safety and emergency response company was contracted to provide a crew and the necessary equipment onsite when work was being done inside the tank. Together with GCA and the contractor's safety personnel, the emergency team would also test the atmosphere inside the tank to certify safe entry before entry and the start of work for each shift, and at the intervals specified in the Bid Package/Lining Specification. Actual confined space entry and exit logging would be handled by the contractor.

The Tank 2003 relining project pre-bid meeting was scheduled for April 30; the project was to be awarded to the successful bidder on June 14, and the contractor was expected to be on site August 5. Site work was expected to take 57 days, with final inspection scheduled for October 22. Wastewater would be back in the newly relined tank on October 30 at the latest, and the tank would be back in full operation on November 1.

**THE INSPECTOR**

Ideally, a tank lining project's third-party inspector should be selected based on experience, competence, reputation and familiarity with the lining system to be applied. Although the individual inspector or inspectors are critical, it is also important that they are employed or indemnified by a company with adequate insurance for both medical and professional liability. There should also be a formal structure for collecting, submitting and safeguarding inspection data for possible future reference. For specialty systems such as vinyl ester tank lining, an inspector with experience with that system or — if possible — with the exact product to be used, can help to ensure competence, adherence to the specification and accurate decisions when decisions need to be made.

The project spec writer and the author served together as inspectors on the project. They have known each other professionally for many years and have crossed paths on a number of projects involving a wide variety of coatings and thermal spray aluminum; sometimes on the same side of the QA/QC fence, sometimes on opposite sides. There have been technical disagreements, but never a major controversy in more than two decades.

As inspector, the author had the backing of a midsized inspection company with extensive experience in tank-coating work for major petroleum companies, among others. This backer provided professional insurance coverage, relief inspectors as needed and long-term record keeping services for the project.

Inspection was handled on a scheduled and as-needed basis rather than full-time onsite. This allowed one inspector to follow coating for two shifts if two shifts were needed (they never were) and also provided full coverage without a lot of dead time. The schedule involved being onsite at the start of work every morning to observe and record atmospheric conditions and check the previous day's work inside the tank, and again at lunch break or end of shift every evening when work was done that was ready for inspection. Additional onsite time involved required testing, witnessing testing done by the contractor, and meetings with the owner, inspectors and the contractor. When not onsite during working hours, the inspector was available within one hour of notification.

Since the tank location was reasonably close to the primary inspector's home, he could be onsite quickly if needed. This is a luxury not available on remote-site projects, but not that much of a luxury — a standby inspector has to be ready to drop whatever he or she is doing and head to

*A midday view of the east side of Tank 2003 after completion of the lining work and removal of the contractor's equipment and supplies.*

the jobsite immediately if requested. At major hold points and inspection milestones, the second inspector was also onsite to witness the inspection or — in some cases — to do the tests himself.

## THE CONTRACTOR

The GCA Tank 2003 pre-bid meeting was held on schedule and the successful bidder had previous experience using vinyl ester to reline first step tanks at the Bayport facility. The contractor had also worked with the spec writer before.

Several items in the bid package/lining specification were amended after the contract was awarded. Hydroblasting was removed and blasting and coating of the tank side shell and bottom were separated out. As discussed and agreed upon by GCA, the inspectors and the contractor, the tank side shell would be dry abrasive blasted and coated as two halves, and after completion of the side shell coating, the tank floor and floor beams would be dry blasted and coated, also as two halves. Overlap of the side and floor coating would be two feet up the side shell. Hold points for inspection, touch-up and high-voltage holiday testing were included after each of the four sections of work was completed.

The contractor also included a detailed response to Tab N, the GCA QA/QC inspection plan. The response described how each of the required tests would be done, how the completed tests would be documented, and included the contractor's corporate forms to be used to record testing before the results were submitted to the owner and inspector.

## THE PROJECT

Scaffolding erection and pressure-washing of the old lining began in mid-August and did not require third-party inspection. Some structural welding repairs were done after washing, and the backing inspection company provided an API 653-certified welding inspector (American Petroleum Institute's "Above Ground Storage Tanks Inspector Program"). At the same time, the pressure-washed old vinyl ester coating was tested for salt contamination prior to the start of abrasive blasting.

Abrasive blasting of the side shell began on August 21. Progress was slow, and after approximately 300 square feet had been blasted, surface profiles were found to be in the 2.5-to-4.0-mil range, well below the 3.5-mil minimum in the specification and the 4.0-mil-or-higher profile recommended by the lining manufacturer. Depth of anchor profile was checked using a combination of profile replica tape and electronic depth profile gauges. The electronic gauge was faster but gave readings of only a single pit. The project

*Because of effective dehumidification, small amounts of rain leakage on the blasted tank floor did not "turn" adjacent areas of white metal blast. The small rusted areas were reblasted.*

specification called for replica tape and after a requested change, the inspectors allowed use of both electronic gauges and replica tape, providing the electronic gauges were used to take relatively large numbers of anchor profile readings, in a fashion similar to those dictated in SSPC-PA 2, "Procedure for Determining Conformance to Dry Coating Thickness Requirements." On the test-blasted areas, electronic gauges and profile tape were both used and compared. Readings matched, but both showed the anchor profile to be too low. The contractor arranged for the abrasive being used to be replaced by a coarser grade of garnet which solved the problem and blasting resumed on August 22. Anchor profile readings of 4-to-5 mils and above became the norm for the remainder of the project.

When blasting at the top of the side shell, the contractor used plywood masking and took extra care not to damage the aluminum beams and sheets forming the dome roof of the tank. Anodes and nonmetallic piping inside the tank which could not be removed, were similarly protected during blasting and lining work. The tank had continuous dehumidification, but only one shift was blasting and painting, unless something unexpected delayed the schedule or hot surface temperatures required the application of the second coat of vinyl ester in less than 24 hours. Having a single shift allowed the contractor to use the same crew for the entire project. This crew had a long work history together and most of them had worked on the previous vinyl ester project at GCA.

At the same time the surface profile issue arose, another problem developed. Exterior temperatures at start of work in the morning were in the mid-80s, with relative humidity of about 80 percent. The existing dehumidification setup was running at full capacity but could not keep relative humidity inside the tank below the specified 50-percent level. There was no visible turning of the bare blasted steel yet, but existing exterior conditions could not be depended upon. Meetings with owner and inspectors determined that additional dehumidification capacity was mandatory. The uninsulated aluminum dome roof of the tank most likely leaked air on dry days, but during a period of rain or 100-percent relative humidity outside, the present dehumidification system would not be able to maintain satisfactory conditions inside the tank, and the contractor would lose the blast.

On the following day, additional dehumidification (DH) equipment arrived, effectively doubling the capacity of the system onsite. Once the additional units were installed and brought online, relative humidity measured at the DH air inlets at the tank side shell was in the 30- to 40-percent range. After some adjusting of the new DH equipment and as soon as the entire volume of air in the tank had been conditioned, relative humidity in the tank could be reliably kept under 50 percent (when measured at the center of the floor, away from the air inlets) regardless of conditions outside. Subsequently, there was a lot of rain later on and the aluminum dome roof did leak a bit, but the only lost blast was in areas where water from the roof leak actually landed on blasted steel. The surrounding areas maintained an SSPC-SP 5/NACE No. 1, "White Metal Blast Cleaning" condition.

The vinyl ester coating material arrived onsite and was immediately placed in an air-conditioned portable building. Manufacturer's batch codes were checked and indicated that all received material was well within the three-month shelf life; in fact some of the product was so new it may have been manufactured specifically for this project.

After abrasive blasting had been completed a transparent adhesive tape test was done on blasted areas to confirm they were dust-free and ready for coating. The contractor's dust collector unit and the crew's good housekeeping paid off — the tank side shell was dust-free enough to allow the start of coating application.

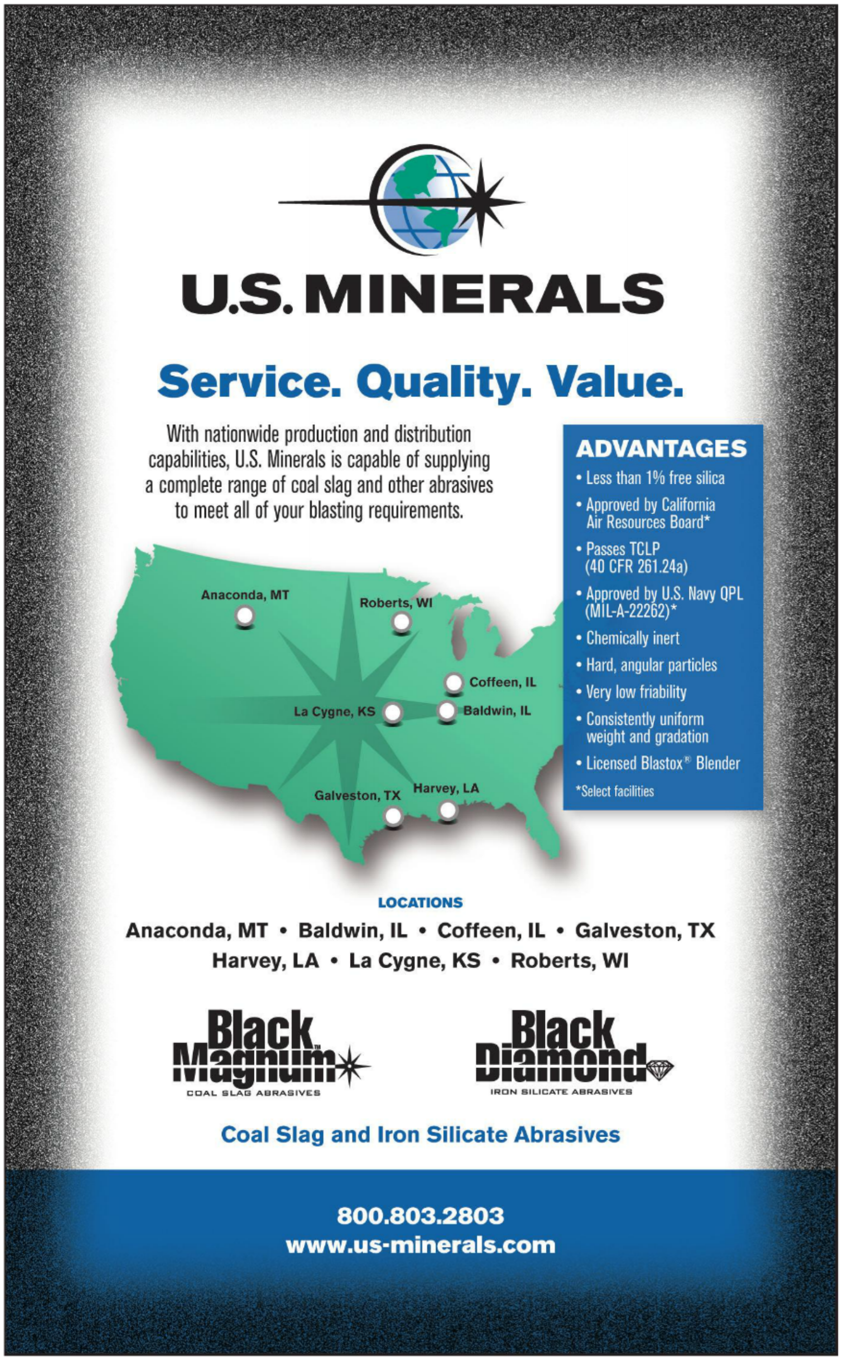
Vinyl ester spray application began on August 31; vinyl ester was catalyzed and fed into airless pumps located outside the tank, adjacent to the air-conditioned paint storage building. Fluid lines from the pumps into the tank were insulated to prevent heat buildup. All spray application was done with single-component airless equipment, rather than with conventional spray as originally listed in the specification.

At the time, surface temperatures on the west side of the tank side shell, which received direct afternoon sun and included the hottest portions of the tank side shell area to be coated, were under 130 F, so the manufacturer's recommended 48-hour maximum recoat interval could be used. The painters used 535 reversible tips, catalyzed material temperature at the gun was 79 F, observed pot life for material in a small cup was just under one hour, and everything went smoothly.

September 1 and the morning of September 2 were spent scraping and sanding rough spots in the first coat of vinyl ester and then checking and marking DFT in preparation for applying the second coat of vinyl ester. DFT testing was done according to SSPC-PA 2, with additional spot readings taken once an area of low DFT was discovered. Areas of low DFT were marked and outlined, giving the painters a road map of areas where additional film thickness needed to be applied during the second coat. A 30-minute methyl ethyl ketone (MEK) contact test was done to assure the vinyl ester had cured but not so fully as to prevent proper adhesion of a second coat. After the appropriate drying time, the second coat was applied without any problems.

DFT testing was again done, using SSPC-PA 2, again with additional spot readings taken once an area of low DFT was discovered. Low areas were marked and outlined and then hand-sanded and additional vinyl ester was applied.

On September 6, three high-voltage (HV) holiday detectors were onsite, calibrated and cross-checked against each other. All of the applied vinyl ester was 100-percent holiday checked at 3,500 volts, as required for the lining DFT, using two-person crews — one person operating the HV holiday detector, the other marking any areas of sparking. On the same day, adhesion tests of the applied vinyl ester were done, and observed by the owner and inspectors. Adhesion values ran from 950 to 1,500 psi, well above the specified minimum of 750 psi. After adhesion testing, the dollies were heated to disbond the glue used, so the dollies could be removed without leaving adhesion test holes to be repaired. The crew spot-sanded and spot-coated the few holidays that had been found.






Blasting of the tank floor beams which support the fiberglass-reinforced nonmetallic pipe that comprises the air and oxygen injection system started on Monday, September 9. A quality blast and anchor profile were achieved on the beams, but spray application of the vinyl ester was still difficult. The configuration of the beam edges, rough cut-offs and complex angles created a challenge when it came to applying adequate vinyl ester to the beam edges without getting too much on adjacent surfaces. SSPC-PA 2 was abandoned here, replaced with an "every square foot" and sometimes "every square inch" approach to DFT checking, followed by liberal use of markers, so that the sanders and painters could see exactly where additional vinyl ester was needed. Some areas took several tries before passing, but eventually the beams passed and blasting of the open floor areas began on September 13, after the nonmetallic pipe sections had been moved from the tank floor to their permanent location atop the floor beams.

Compared to the beams, blasting the floor was uneventful but slow, because spent grit had to be removed as the floor was being blasted. And of course the rains came, and of course there was moisture leakage. Fortunately, the leaks were localized and their sources could be identified from inside the tank. GCA maintenance personnel plugged the leaks from outside the tank as soon as it was safe to scale the tank roof. The total area of blast lost to the unexpected leaks was less than 20 square feet. At 102 F and 30-percent relative humidity, the augmented DH system was simply cranked up to compensate for the moisture leaks and the water inside the conditioned area.

By September 23, the tank floor was finished and had passed testing, except for some minor touchup areas, which were left for later in anticipation that during installation of the piping and sensors inside the tank there might be some mechanical damage, which would also require touch-up. Manway flanges and covers were blasted, inspected, coated, inspected, sanded where needed, and then coated with the second coat of vinyl ester. Low spots found were hand-sanded and spray-coated with vinyl ester.

Final touch-up was not done until October 17 and by then the contractor's crew had packed up all nonessential equipment, cleaned up the jobsite and all but completely demobilized. The only task left at that point was to provide the necessary reports, forms and photographs in order for the contractor to complete the "Project Book" final report, incorporating all daily reports, inspection results and photographs from the entire project.

After more than two months of watching the sunrise behind Tank 2003 just about every morning (except, of course, on days when it was raining too hard to see the sunrise), it was time to move on to the next project with a hope that the players would be as professional and the project run as smoothly for next one as had been the case on Tank 2003.

## ABOUT THE AUTHOR

Peter Bock is the executive vice president of Advanced Polymerics, Inc., in Salem, N.H. He is a U.S. Air Force veteran and holds degrees from Tulane University and the University of Northern Colorado.

Bock has 37 years of management, technical service, inspection and sales experience in oilfield and petrochemical heavy-duty coatings, in the United States, Canada, Mexico, Venezuela, Indonesia and Taiwan.

He has experience with on- and offshore production, drilling and workover rigs, shipyard work, natural gas and LNG, pipelines, terminals, refineries and chemical plants. Bock is a recognized expert on carbon steel passivation and corrosion under insulation, and teaches annual courses on corrosion under insulation.

Bock is a past-president of NACE New Orleans Section and of the Houston Coating Society. He is a NACE-certified Coating Inspector (Level 3). He has been published in a variety of industry journals and has presented papers and symposia at the SSPC, PACE, NACE and NAI conferences as well as at many regional and local coatings and corrosion control events. ***JPCL***

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# Basics of Corrosion in Reinforced Concrete

By Fred Goodwin and Frank Apicella, BASF Construction Chemicals

*Photos courtesy of the authors unless otherwise noted.*

Concrete, in some fashion, has existed for thousands of years. Reinforced concrete began to make an appearance in various structures in Europe and the United States in the mid-1800s, which is also when many of our current problems with concrete began.

Steel used for reinforcing concrete wants to corrode. It begins as iron ore and a great deal of energy is required to reduce the ore to form iron, which is then used to produce steel. This process results in a material at an elevated energy state which is basically unstable, and which wants to return to its original lower-energy state causing corrosion. Fortunately, concrete initially has a high pH which creates a passivating layer on steel in contact with concrete, preventing corrosion from occurring. But, unfortunately, this passivating layer can be destroyed by a reduction in pH of the concrete, through the presence of chloride or other ions, by an electrical charge imposed on the steel, or a combination of these factors. This article will discuss the properties of concrete, the causes of concrete damage and deterioration, issues related to corrosion of reinforcing steel in concrete, and options to reduce the effects of concrete deterioration (Fig. 1).

## Concrete Properties

There are two truisms about reinforced concrete: concrete cracks and steel rusts. There is no escaping the inevitability of these facts; eventually both will happen. Concrete cracks because it is comparatively weak in tensile strength but it is comparatively strong in compressive strength. Steel has a high tensile strength. The combination of these two materials is synergistic, in that they provide a superior composite material and both have the capability to destruct through their respective deterioration mechanisms.

When steel rusts, the oxide formation creates an expansive force within the concrete that causes cracking, spalling and eventual section loss. When concrete cracks, the steel is exposed to a combination of factors that accelerate its corrosion leading to further cracking of the concrete, and if allowed to continue will lead to destruction of the structure.

## Concrete Composition

Concrete can be thought of as a hard wet sponge. Technically, it is a complicated composite material consisting of aggregates, water and a mixture of cement hydration products that are mainly calcium silicates, calcium aluminates and other trace materials. The hydration products consist primarily of calcium silicate hydrate (called gel), calcium hydroxide (called portlandite) and ettringite. Water is chemically bound in the gel as well as within pores around and between the portlandite and aggregate particles. The pore water is saturated with calcium hydroxide and other soluble minerals such as sodium and potassium salts and is free to evaporate or move within the concrete. The size of the pores, the number of pores, and the connectedness of the pore structure that forms during hydration of the cement depends on the amount of water added to the cementitious binder system. The binder system can consist of cement and pozzolan. Pozzolan is a material that reacts with the portlandite from hydraulic cement as it hydrates to produce additional calcium silicate hydrate (CSH) gel, the binder that holds the concrete together. Desirable smaller pores are formed as the mixing water content decreases, provided there is sufficient binder to coat and fill the spaces between the aggregate particles.

*Fig. 1 (left): Corrosion of reinforcement can cause surface scaling down to the level of the reinforcement. Typically this sort of corrosion, called general or uniform corrosion, is caused by carbonation.*

Concrete needs water for the cement to hydrate to form these minerals; however, water in excess of the amount required for proper hydration dilutes the performance properties of the hardened material. Admixtures are additives that are added to freshly mixed concrete to modify both the hardened and unhardened concrete. These can include pozzolans that react with the portlandite to reduce the porosity of the concrete, water reducers that reduce porosity through improvement of the dispersion of ingredients, and corrosion inhibitors that help stabilize the passivating layer between the reinforcing steel and the concrete to extend the time until corrosion begins.

In addition to these improvements in the concrete properties, how deeply the reinforcing steel is embedded within the concrete is a significant factor in the amount of time before corrosion begins. This is called "cover." Cover is necessary for the composite action of steel within the concrete to properly function as designed. Furthermore, cover insulates the steel from exposure to fire and deterioration from aggressive materials in the external environment. Two of the most common aggressive materials are carbon dioxide and chloride ions (Fig. 2).

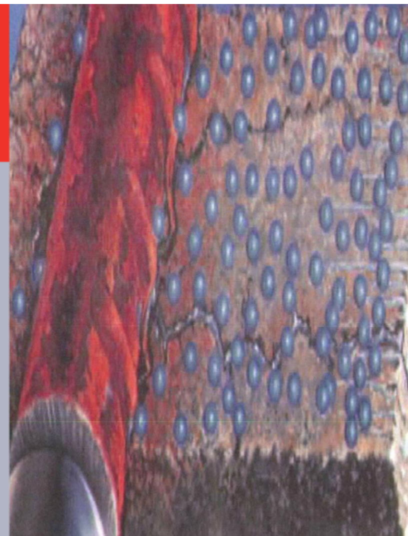


*Fig. 2: The penetration of chloride ions, carbon dioxide and moisture can cause surface rusting of the reinforcing steel, which then occupies a larger volume than the original metal.*

## Carbonation

Both CSH gel and portlandite are strongly alkaline. Steel in such an alkaline environment forms an insoluble, protective, passivating oxide layer that is one of the synergistic benefits of combining concrete with steel. The high pH of concrete will fall as the concrete ages, mainly due to reaction of the portlandite with carbon dioxide ($CO_2$) in the humid environment of concrete. This process is known as carbonation and occurs either as acid rain, or by the $CO_2$ gas diffusing into the concrete and reacting at the surface of the pores causing the passivating layer at the steel surface in the concrete to dissolve and corrosion to initiate.

Carbonation is a slow process depending on the porosity of the concrete, the thickness of the cover, the concentration of pH-reducing materials, and the amount of moisture in the concrete. In very wet concrete, the diffusion of acidic materials into the concrete occurs within liquid-filled pores and is quite slow compared to the movement of gaseous carbon dioxide through air-filled pores. In extremely dry concrete there is insufficient moisture at the surface of the concrete pores for the formation of carbonic acid and its reaction with portlandite to form calcium carbonate and water at a measureable rate. The maximum rate of concrete carbonation occurs at an internal relative humidity of about 60 percent. Wetting and drying of the concrete may accelerate carbonation; however, the formation of calcium carbonate may also tend to block some very fine pores reducing this rate.

## Chlorides and Other Aggressive Ions

The presence of chloride (or another halide) and aggressive ions also destroys the passivating film on the surface of the steel; however, this process is much more localized than the corrosion due to carbonation. Chlorides may be present from the materials used to make the concrete or migrate into the concrete from applied road salt or airborne chlorides from nearby salt water. Some chloride is captured by the concrete hydration products and may remain bound until the pH or temperature reaches some threshold. The chloride ions react with the steel and are not consumed. They can therefore continue to activate further corrosion.

By remaining present to react further, a pitting type of corrosion can then occur. As the pit grows deeper, the acid formed in the reaction further accelerates corrosion, causing pits to form deeper and deeper into the reinforcing steel.

## Cracks

Most deterioration, damage or failure of concrete is seen by cracking. Cracks are both the cause of these issues and the observable effects. Since concrete is comparatively weak in tension, expansive forces within it or tensile stress imposed on it, can easily exceed its ultimate tensile strength. Cracks follow the path of greatest weakness through the concrete beginning at small defects and propagating as stress increases. New cracks form once the initial crack meets sufficient resistance, the path of the stress changes, or the ingress of deleterious materials causes new stress to develop. Once a crack forms it becomes a "freeway" for deterioration by funneling water and dissolved minerals deeper into the concrete. When water freezes in the crack, the expansion of ice formation forces the crack faces to become wider. When water evaporates from a crack, the dissolved minerals (such as chlorides) are left behind. Road salt, dust and debris also accumulate within the crack, keeping it open to further infiltration. When the crack inevitably reaches the reinforcing steel, corrosion begins in a localized area. The expansive forces from the reinforcement corrosion further widen the crack and create new cracks.

## Corrosion Principles

Corrosion is an electrochemical process. This means that both chemical reactions and

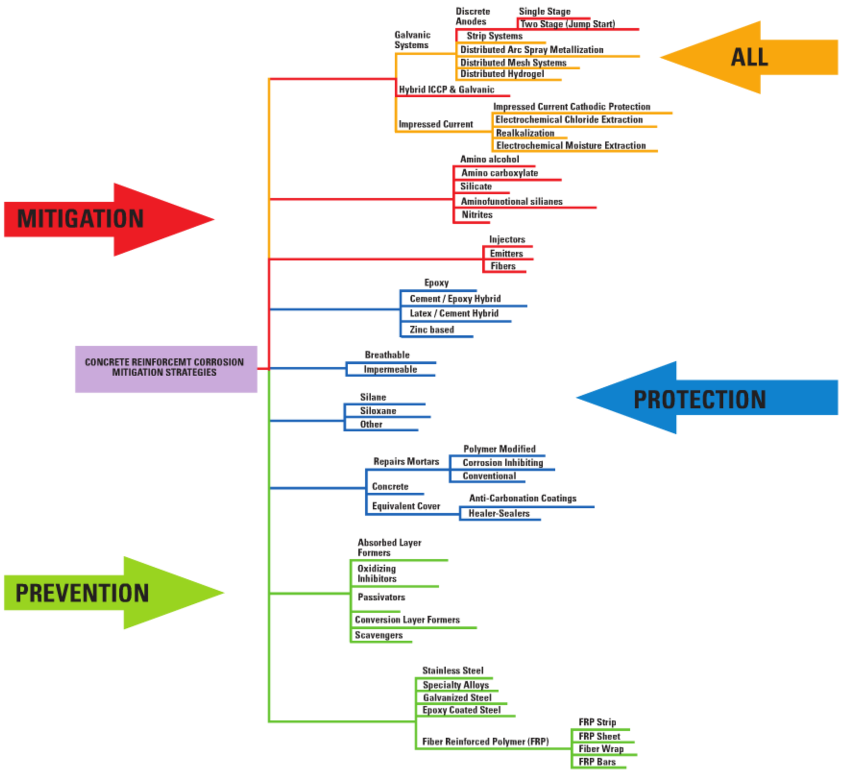
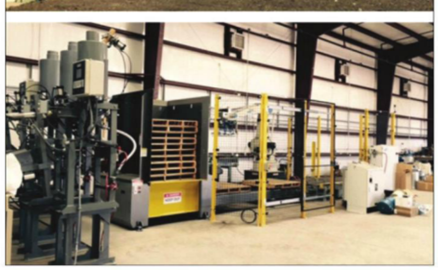



*Fig. 3: This diagram illustrates various approaches used to address corrosion of reinforcing steel in concrete. The yellow arrow indicates cathodic protection (both impressed current and galvanic). The green arrow designates corrosion prevention by way of changing the nature of the reinforcement, making it more resistant. The blue arrow denotes protection by way of creating a barrier between the reinforcement and the corrosive environment, and the red arrow represents mitigation treatments.*





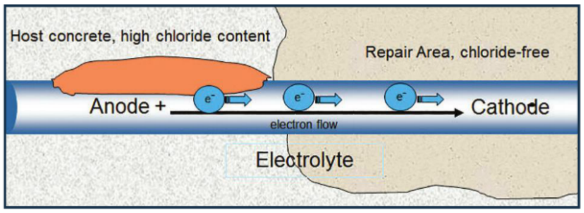



*Fig. 4: This figure shows a corrosion cell generated from the ring anode/incipient anode/halo effect. The originally corroding area was repaired with a chloride-free repair material causing the anode to shift from its original site to an area immediately adjacent to the repair after the repaired area became cathodic.*

electrical processes occur simultaneously. Usually, the electrical process involves ions changing their valence state (gaining and losing electrons, also known as oxidation and reduction or redox reactions). Chemical reactions form new chemical compounds.

For corrosion to occur, four components must be present: an anode, a cathode, an electrical path and an ionic path. In reinforcing steel, rust forms at the anode where electrons move away and oxidation occurs. An equal reaction must also be present at the cathode where the electrons are attracted and reduction occurs. The electrons formed at the anode travel through an electrical path to the cathode, in this case the reinforcing steel. External sources of current, such as from dissimilar metal corrosion of more noble metals in contact with the steel, or stray current leakage, can also drive reinforcing steel corrosion reactions. Likewise, ions migrate through an electrolyte, in this case the water in the concrete pores. Steel is a very good conductor of electrons, and concrete can readily conduct ions if it is moist, with many pores, or poorly if it has low internal relative humidity and a very dense pore structure (such as from a low water to cementitious material ratio and the use of pozzolanic materials). The anode and cathode in a corrosion cell may be adjacent to each other, have different surface areas, or be widely separated. Both the anode and cathode are free to move to different locations depending on the conditions of the reaction. The ratio of the anode area to the area of the cathode is also very important in the rate of the corrosion reaction, with small anodes and large cathodes creating a much more intense oxidation of the steel in a small area. Like most other chemical reactions, elevated temperatures accelerate the reaction and greater concentrations of materials such as chlorides, moisture and oxygen also increase the rate of corrosion. Ionic movement essentially ceases during freezing and corrosion therefore stops.

## Anti-Corrosion Treatments

Interruption or restriction of any of these four corrosion components will slow down the rate of corrosion and this is the basis for all of our treatments which address corrosion of reinforcing steel in concrete (Fig. 3, p. 62).

### Alternative Reinforcement

The most effective method in addressing reinforcing steel corrosion is to substitute a reinforcement material that is less prone to corrosion than mild steel, such as stainless steel or other specialty alloy bars or fiber reinforced polymer (FRP) materials. With no material to corrode, the root cause of corrosion is removed. Far too often, the steel that is used for reinforcing concrete is already significantly corroded or has sufficient residual mill scale from manufacturing to create cathodic and anodic areas before installation. While a light surface rusting on reinforcing steel is usually not detrimental, heavy rusting gives corrosion a head start.

### Electrochemical Treatments

An external source of electrical power can reverse the corrosion reaction by changing the direction of electron flow through the steel to reverse the flow of ions from the anode to the cathode. This is the principle of both galvanic and impressed current cathodic protection.

In galvanic cathodic protection, a competing corrosion reaction is used to outpace the oxidation of the steel through the use of a sacrificial anodic material that makes the steel the cathode. Galvanic cathodic protection comes in many forms, from discrete galvanic anodes which provide localized protection from changes in the anode and cathode locations caused by repairs (also known as the incipient anode, ring anode or halo effect), from distributed galvanic anodes where a mesh (or other form) of galvanic anode material is installed next to the reinforcing steel, or metallization where a galvanic material is sprayed onto the surface of the concrete to sacrificially corrode (Fig. 4). In all cases the galvanic material must be in electrical contact with the reinforcing steel as well as an electrolyte being present to permit the passage of ions between the anode and the resultant cathodically protected steel. With galvanic systems corroding due to many of the same factors influencing the corrosion rate of the reinforcing steel, these systems, although consumable, are relatively maintenance-free throughout their lifecycles.

In impressed current cathodic protection (ICCP), an external electrical source of direct current is applied to anodes to force the steel to become cathodic. The voltage and current of this process may also be optimized to repel chlorides from the steel (known as electrochemical chloride extraction) or generate alkaline conditions at the steel to reform the naturally occurring passivating layer (known as electrochemical re-alkalization). ICCP systems must be connected to all metallic objects in the concrete to prevent them from corroding. They must be designed to produce a relatively uniform current distribution throughout the concrete structure in changing environmental conditions or otherwise some areas of steel may corrode and other areas experience issues from excessive current flow (such as anode consumption or excessive alkalinity). The ICCP systems must be robust to remain operational throughout the lifetime of the structure. For these reasons, ICCP systems must be designed, installed, maintained and monitored correctly to ensure that corrosion is prevented or controlled and are somewhat expensive throughout their operation.

**Surface Treatments**

Most deterioration mechanisms of concrete involve the presence of water such as freeze/thaw deterioration, alkali aggregate reaction, sulfate attack and corrosion. Materials may be applied to dry the concrete and increase the resistance to ion flow (characterized as resistivity) followed by application of penetrating sealers or breathable coatings, to prevent further water ingress. Because chlorides move through the concrete with liquid water, further ingress of these deleterious ions also slows as the concrete dries and further water penetration is inhibited. Barrier materials such as waterproofing membranes and anti-carbonation coatings may also be used to stop water or carbon dioxide from penetrating into the concrete, but may also be sensitive to the amount of moisture present in the concrete during application. Non-breathable barrier materials may trap water in the concrete leading to deterioration from other causes. Any sealer, coating or membrane is subject to deterioration and should have an inspection and maintenance program to ensure continued effectiveness.

**Corrosion Inhibitors**

Inhibitors may be added to the concrete either as admixtures when the concrete is placed or surface-applied to the steel reinforcing bar to make the passivating film on the steel surface more resistant to chloride attack, dissipation from carbonation or otherwise more durable in adverse conditions. The inhibitor concentration required for effectiveness is often dependent on the extent of corrosive conditions for the steel.

#### Reinforcing Steel Coatings

Coatings may also be applied to the reinforcing steel to create a barrier between the steel and the concrete. If perfectly applied over the entire steel surface these materials can be quite effective. However even a small defect in the coating can create strongly concentrated corrosion from the small anode to large cathode area ratio, causing rapid deterioration. The same situation exists with reinforcement coatings applied during repairs where the reinforcement continues through the repair into the original concrete. Corrosion in this case may be accelerated at the bond line of the repair material to the original concrete, further enhancing the ring anode effect.

#### Oxygen Availability

Lack of oxygen availability can also inhibit corrosion such as in deeply immersed structures or where treatments are applied to the reinforcement surface, or can completely encapsulate the concrete. Once the available oxygen is consumed by corrosion, the rate of the reaction will reduce and be controlled by the ingress of oxygen. However, areas immediately adjacent to these inhibited areas may experience accelerated corrosion, since the oxygen-depleted areas are cathodic compared to the exposed sections that become anodic.

### Conclusion

In summary, sound practices using low-permeability concrete, proper cover in new construction and maintaining existing structures to mitigate corrosion before significant deterioration occurs are well known. However since corrosion develops years after a structure goes into service ignoring the problem until it is too late is likely to continue.

### About the Authors

Fred Goodwin, fellow scientist, product development, BASF Construction Chemicals, is a chemist with over 30 years of experience in the construction chemicals industry, including cement manufacture, research, develop-ment and technical support of grouts, adhesives, coatings, shotcrete, stucco, flooring and concrete repair materials. He has been with BASF and its predecessors for 25 years and is an active member of ICRI, ACI, ASTM, NACE, SDC and SSPC. Goodwin is a fellow of ACI and ICRI; an Honorary Member of ASTM C1 and C9; current chair of the ICRI Technical Activities Committee (TAC), ACI 515 Protective Systems, ASTM C09.41 Cement Based Grouts, SSPC 8.3 Commercial Floor Coatings; and a member of ACI TAC. Goodwin was awarded the *JPCL* Editors' Award in 2006, 2010 and 2012 as well as the ACI 2011 Delmar Bloem Distinguished Service Award. He holds multiple patents and was named a Top Thinker in *JPCL*'s Annual Bonus Issue of 2012. Goodwin also frequently speaks at national conventions.

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| **Sept. 26–30** | WEFTEC 2015, Chicago, Ill., weftec.org |
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