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The Society for Protective Coatings
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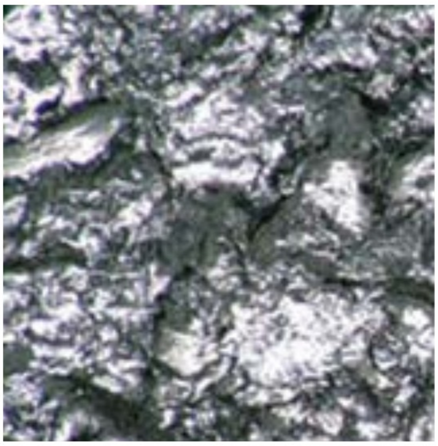
FEATURES



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SSPC Introducing Two New Training Courses at SSPC 2018

SSPC will debut two new training courses, which will be available to the public throughout 2018, at the SSPC 2018 conference in New Orleans this month.

THERMAL SPRAY INSPECTOR

Want to become a thermal spray coatings inspector? This new course is the only place to get this unique type of certification. This program covers the inspection of thermal spray from pre-surface preparation through coating application. The classroom session consists of an 8-hour lecture and is supplemented by workshops in which students learn how to navigate the NAVSEA Standard Item on thermal spray and a DOT specification and complete a four-station exercise of common thermal spray inspection tests, including profile, film thickness, tensile pull-off and mandrel bend test.

THERMAL SPRAY INSPECTOR PUBLIC COURSE SCHEDULE:

Jan. 17: SSPC 2018 Show (New Orleans, La.)
Jan. 31: Sponge-Jet, Inc. (Newington, N.H.)
March 16: KTA-Tator, Inc. (St. Petersburg, Fla.)
May 23: Mega Rust 2018 Show (San Diego, Calif.)
Nov. 12: KTA-Tator, Inc. (St. Petersburg, Fla.)
Dec. 14: Vigor Industrial LLC (Portland, Ore.)

INDUSTRIAL COATING SAFETY MANAGEMENT TRAINING

Nothing is more important on a jobsite than ensuring the safety of the workers. This new course provides the tools and knowledge needed to help contractors accomplish this goal on every job. The goal of this training program is to provide the safety director/manager the necessary knowledge to manage corporate safety and health programs and develop, implement and manage safety and health plans at the project level. This three-day Instructor-Led Training (ILT) will provide participants with knowledge and skills necessary to manage a safety and health program in industrial painting operations. This course will be delivered in 17 units featuring lecture, participant engagement exercises and workshops.

INDUSTRIAL COATING SAFETY MANAGEMENT TRAINING PUBLIC COURSE SCHEDULE:

Jan. 14 to 16: SSPC 2018 Show (New Orleans, La.)
March 13 to 15: Greenman-Pedersen, Inc. (Grand Rapids, Mich.)
May 22 to 24: SSPC Headquarters (Pittsburgh, Pa.)
Oct. 16 to 18: Greenman-Pedersen, Inc. (Annapolis Junction, Md.)
Dec. 4 to 6: SSPC Headquarters (Pittsburgh, Pa.)

To sign up and take advantage of either of these unique new training opportunities, visit www.sspc.org.

SSPC Employee Earns PCS Certification

Jim Kunkle, manager of business development with SSPC, has earned the Society's highest level of certification for industrial coatings professionals, the Protective Coatings Specialist (PCS).

The PCS certification recognizes industrial coating professionals for their extensive knowledge in the principles and practices specific to industrial coatings technology. Each individual has been evaluated for his or her mastery of coating type, surface preparation, coating application and inspection, contract planning and management, development of specifications and the economics of protective coatings.

Kunkle has been with SSPC since 2013 and in his current position works with facility owners and specifiers to incorporate SSPC programs into protective coating specifications and project requirements. Kunkle also holds SSPC Protective Coatings Inspector (PCI) and Concrete Coatings Inspector (CCI) certifications.

For more information on the PCS and other SSPC training and certification programs, visit www.sspc.org.

Coming Up: SSPC CoatingsConnect e-Newsletter

The second edition of CoatingsConnect, SSPC's new quarterly online e-newsletter, will hit inboxes in mid-January with a focus on the SSPC 2018 conference as well as recent standards development efforts.

Designed to keep SSPC's members informed on the latest news and developments from SSPC and the protective coatings industry, CoatingsConnect features updates about SSPC's ongoing initiatives, upcoming events, standards and regulations, products and more. The first CoatingsConnect newsletter was released in the fall and can be viewed at www.naylornetwork.com/sspc-nwl/newsletter.asp?issueID=61850.

To sign up for CoatingsConnect, visit www.sspc.org and enter your email address in the bottom right-hand corner under "Newsletter Sign Up."

New *PaintSquare Press* to Highlight Projects, Products and Personnel in Print

Spring 2018 will bring a new addition to the coatings-industry media landscape: *PaintSquare Press*, a new quarterly print publication from Technology Publishing Co., publisher of *JPCL* and *PaintSquare Daily News*.

PSP will feature engaging content related to coatings projects, products and personalities. From case histories and personnel updates to product comparisons and announcements, the new tabloid-size publication will provide the information PaintSquare readers have said they want.

Regular features in *PSP* will include the following.

- Case studies that highlight the successful use of specific products and techniques.
- New-product announcements.
- Product roundups, comparing offerings from various suppliers and manufacturers in specific niches.
- Round table discussions with respected industry professionals.
- Profiles of industry figures and companies.
- Industry news briefs such as personnel moves, facility expansions, regulation changes, mergers and acquisitions.
- The PaintSquare Prestige Awards, a new series honoring excellence in protective coating projects.

PaintSquare Press, distributed free to PaintSquare readers, will arrive in the mailboxes of industry professionals beginning in March; the first issues will include features such as a discussion between specifying engineers about their decision-making processes and approach to new products, and a preview of the inaugural Prestige Awards.

Submissions of story ideas and content for potential publication can be directed to *PaintSquare Press* editor Andy Mulkerin at amulkerin@paintsquare.com.

In addition to *JPCL* and *PaintSquare Daily News*, Technology Publishing Co., publisher of *PaintSquare Press*, provides the Paint BidTracker contract-lead service, *Durability + Design News*, and industry events such as Contractor Connect.

OSHA Issues New Silica Rule Guidelines, Renews Alliance with Women's Trade Group

The U.S. Occupational Safety and Health Administration recently released more than a dozen fact sheets related to the respirable crystalline silica standard for construction, with a focus on informing employers on how to properly implement controls, respiratory protection and work practices.

The fact sheets cover more specific topics such as handling dust controls for crushing machines, dowel drilling rigs and drivable saws. This feeds into the overall theme of these fact sheets — controlling silica dust in construction.

The new fact sheets also include information on heavy equipment used during demolition; heavy equipment used for grading and excavating; small and large drivable drilling machines; rig-mounted core saws; vehicle-mounted drilling rigs and walk-behind milling machines and floor grinders.

©iStockphoto.com/livertoon

The revised fact sheets cover handheld and stand-mounted drills; handheld grinders for mortar removal and other functions; handheld power saws; handheld powered chipping tools; stationary masonry saws; and walk-behind saws.

Controlling silica dust when it comes to crushing machines should involve the use of mist for dust suppression, notes OSHA in the related fact sheet. Other wet spray methods can help reduce the silica exposure levels of those working near the machine. The crusher must also be maintained to manufacturer specifications for the best safety performance.

Dowel drilling rigs for concrete need to be equipped with a vacuum dust-collection system (VCDS), which can help reduce silica exposure. VDCSs include a dust collector, vacuum, hose and filters.

As for drivable saws, OSHA advises the use of wet cutting to reduce exposure to silica dust. Slurry must be cleaned up before it dries. If this is not done, dried slurry can release silica dust into the air.

Further information is available at www.osha.gov.

OSHA-NAWIC ALLIANCE

OSHA also announced on Dec. 15 that it has renewed its alliance with the National Association of Women in Construction (NAWIC) in an ongoing effort to safeguard women working in the building trades.

OSHA and NAWIC will continue working together for the next five years, aiming to protect the health and safety of women in the construction industry, focusing especially on personal protective equipment selection, sanitation and protection against intimidation and violence.

Personal protective equipment can often be too large to correctly fit female workers, workplace-safety experts say. Construction sites often don't have sufficient restroom facilities, a factor that can adversely affect women in particular on a male-dominated site, and lead female workers to avoid properly hydrating in order to reduce the need for restroom facilities.

Female workers are often subject to harassment or a hostile work environment, experts note, which can lead to distraction that may bring about a workplace injury.

According to NAWIC, women make up about 9 percent of the construction workforce in the U.S., with a total of 939,000 women in the industry in 2016. Of those, 423,000 held sales and office positions, with 293,000 in professional and managerial roles. Less than a quarter of women in the industry worked natural resources, construction and maintenance jobs — about 196,000 total — while a small percentage worked service occupations and transportation and material moving jobs.

"Women represent a small, but growing segment of the construction workforce," said Deputy Assistant Secretary of Labor for Occupational Safety and Health Loren Sweatt. "OSHA's renewed alliance with NAWIC will continue to promote innovative solutions to safety and health hazards unique to female construction workers."

NAWIC was formed in 1955 and offers education and career development for women in the industry.

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SSPC, AASHTO, NSBA Issue Joint Standard

SSPC: The Society for Protective Coatings is now offering a new standard, issued jointly with the American Association of State Highway Transportation Officials and the National Steel Bridge Alliance, on the application of thermal spray coatings to steel bridges.

SSPC-PA 18/AASHTO-NSBA S.82, developed by committee C.3.19, SSPC/AASHTO/NSBA Thermal Spray Coating Application, complements the existing standard SSPC-CS 23.00/AWS C.2.23/NACE No. 12, Specification for the Application of Thermal Spray Coatings of Aluminum, Zinc, and their Alloys and Composites for the Corrosion Protection of Steel. The C.3.19 committee was chaired by Jeff Carlson of the National Steel Bridge Alliance.

The new standard is made to be adopted by transportation departments by reference in their standard specifications. It includes information on pre-production procedures, equipment, materials, surface preparation and application, as well as aspects like repairs and inspection.

The new standard is available online via the SSPC Marketplace at www.sspc.org and on the SSPC mobile app.

FTC Challenges Titanium Dioxide Merger

The U.S. Federal Trade Commission has moved to challenge a proposed $1.67 billion merger between two major suppliers of titanium dioxide, a raw material widely used in the paints and coatings industry as a pigment to provide hide, durability and whiteness characteristics.

Tronox Limited of Stamford, Conn., announced in February that it intended to acquire the TiO_2 business of Cristal of Jeddah, Saudi Arabia. At the time, the companies expected the deal to close by the first quarter of 2018, and said the new entity would have 11 TiO_2

production facilities, with a total annual capacity of 1.3 million metric tons. The acquisition gained approval from Australian regulators in August, but now faces a stumbling block in the United States in light of the FTC's complaint, announced Dec. 5.

Tronox is currently the world's sixth-largest TiO_2 maker. The company operates three plants in the U.S., Netherlands and Australia and employs 3,400 people worldwide. Cristal is the second-largest TiO_2 producer in the world, behind the DuPont spin-off company Chemours.


Photo courtesy of Tronox.

The FTC says if the merger were to go through, the new Tronox-Cristal entity and Chemours would together control "the vast majority of chloride titanium dioxide manufacturing capacity in the North American market." The agency asserts that the TiO_2 market "is already dominated by a few large players with a history of seeking to support higher prices by restricting production."

Proprietary technology and the cost of building titanium dioxide manufacturing facilities makes barriers to entry in the industry great; the likelihood of new players entering the market to offer further competition is not high.

Tronox responded quickly and publicly to the challenge, arguing that the FTC's view of the TiO_2 market is limited and that the agency did not take into account titanium dioxide produced via the sulfate process. But the FTC said in its complaint that sulfate TiO_2 generally exhibits less of the durability and appearance properties desired for coating formulation than chloride TiO_2, and that coatings companies and other customers would be unlikely to switch to the sulfate product.

While the FTC argues that the small number of players in the TiO_2 market could move to cut production and drive up prices, Tronox argues that in fact, the merger will only benefit the company if production remains at full capacity.

The FTC's suit is set to go to trial in May 2018.

PAINTSQUARE COMMENTS

In Response to "'Or Equal': Fairness or Failure?"

JPCL Special Report, July 2017

Commenters debated the use of the often-dreaded "or equal" clause in coatings specifications and discussed some strategies to help avoid confusion when the stipulation pops up in a spec.

Gary Siler

"I found that the best way to avoid confusion of product equivalence, as well as who makes the equivalence determination, was solved by always using the phrase 'or engineering approved equal.' This phraseology removed the ambiguous nature of product substitution from the process and placed the responsibility into the hands of the responsible engineering entity who specified the original item(s)."

David Kenyon

"Gary: I can agree with you wholeheartedly. My language is similar: 'or architect/engineer approved substitute.' When I specify a coating system I research the products, make the appropriate phone calls and attempt to provide coating systems from three different manufacturers that are in essence similar or equivalent — not always an easy task and sometimes impossible ... Most of our clients are government agencies which require the 'or equal' clause. I personally despise that clause — it opens up the specification to every Tom, Dick and Harry and puts the liability on the specifier to accept or reject some other manufacturer's products. Who pays for this extensive review? Most of the time the client, as part of the shop-drawing process. Other times we eat that cost.

Eugene Doerr, III

"It seems to me that this discussion is happening one step too late, probably because everyone in the discussion comes from a technical background. As an attorney, I have looked at this matter one step earlier in the process and advise clients not to get out of their lane and properly allocate the risk to those who have the most competency in each area. All seem to agree that the engineers and owners of the world are for the most part ill-suited to make the determination and that even an independent consultant may be swayed by relationships. I think we can agree that the entity most knowledgeable of any given product is the entity that created and manufactures it. So how do you get that entity to specify the best and most appropriate material for a given project? I advise owners and engineers to provide all of the pertinent data about the asset (heat ranges, particulate size and flow, chemical composition of stored materials, etc.) and then require bidding manufacturers to put forth the material they certify will meet the intended use for the intended service life. I even have the manufacturers sign a separate document that they have read everything supplied about the asset use and certify the product they are submitting meets the requirements. And if a contractor is adamant that a particular product is great for a certain situation, I will even have them sign a similar document. What this method does is it properly allocates the risk to the party with the most knowledge."

In Response to "NASA Develops Test Tool for Icephobic Coatings,"

PaintSquare News, Nov. 30, 2017

©iStockphoto.com/simonbradfield

NASA announced that its researchers have created a new tool to evaluate icephobic coatings on aircraft: the Icing Research Tunnel (IRT) at the NASA Glenn Research Center in Cleveland, which can help address ice-related issues that can be caused in the air.

VCBud Jenkins

"It would have been nice to see the ice not sticking to one of the panels."

Michael Halliwell

"VCBud, I think that's the whole point — they are testing icephobic coatings. Not every one of them will be successful. Nice to see a good number of them were successful, though."

Tom Schwerdt

"Presumably the one being iced is the control, used to validate the conditions in the test chamber would produce icing on a normal coating."

Problem Solving Forum

www.paintsquare.com/psf

How should a conflict between requirements, such as film thickness, on a product data sheet and the specification be resolved?

Javier Jimenez

"A good specification should respect the recommendations described on the product data sheet by the manufacturer. If the specification demands a certain thickness and the product is not able to resist it, the result will be a disaster."

Michael Halliwell, Thurber Engineering Ltd.

"This is a simple one: communication. It is a matter of talking to the person who did the spec to find out why it was spec'd the way it was. Sometimes, they copy and paste from another spec (using a different material) and numbers were carried over instead of matched to the project. Other times, they are trying to achieve something different and may not be aware of the product recommendations/limitations. Communication is needed to get to the bottom of the different spec and to find the appropriate solution."

Sean Newhall, Newport Fab

"The manufacturer's data sheet will always win in these cases as there will be no warranty on the coating if the DFT is out of spec. Any time I have seen this issue, I present them (the customer) with this information backed by an email from the manufacturer and the discrepancy goes away. Always go with manufacturer's specs."

Dennis Kelley, Kelly Moore Paint Company

"I agree with Michael that it must be communicated to the person producing the spec that it is very important that the technical data sheet provided by the manufacturer be followed in order to give the product the best chance to succeed. Since different raw materials are used in products from different manufacturers, it is important to apply the product to the manufacturer's specification in order to protect from failures due to over- or under-applying the specific product."

Erik Andreassen, CPS

"Many times this happens because the specifier has little or no contact with the coating supply companies. Their technical people are there to assist the client when proposing materials and systems and to provide the specifier with the product data for his recommended materials. Based on this cooperation, it should avoid any conflict at a later date."

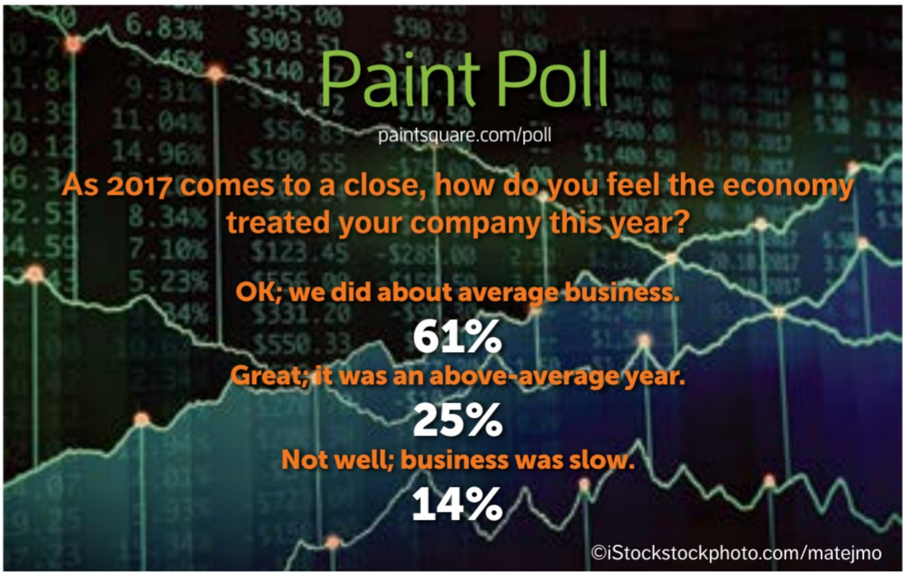
Tom Schwerdt, Texas DOT

"Sometimes a 'conflict' isn't actually a conflict. Let's say my specification (which allows a variety of organic zinc primers from different manufacturers) requires a DFT of 4-to-10 mils. The painter selects a material off the list with a manufacturer data sheet DFT requirement of 3-to-5 mils per coat. The painter therefore needs to keep the paint to a DFT of 4-to-5 mils in a single application, or select a different material from the approved list which allows a thicker DFT, or apply the primer in more than one coat to achieve the required DFT."

PAINTSQUARE NEWS TOP 10

paintsquare.com/news

1. 'Lazy' Tech Sentenced in Concrete Scandal
2. FTC Challenges Titanium Dioxide Merger
3. DIY Painter Hits the Road
4. Coating Damage Eyed in Keystone Spill
5. Boring Company Reportedly to Dig in MD
6. Tractors Threaten Bridges in IN County
7. Lawmakers Propose New SF Bridge, Tunnel
8. GA Regulators Weigh Nuclear Project's Fate
9. NE Rejects Keystone XL Firm's Change Request
10. CA's First Cable-Stayed Bridge Tops Out



Strengthening Concrete and Steel Bridges Using FRPs

BY GREGG BLASZAK, P.E., MILLIKEN INFRASTRUCTURE SOLUTIONS, LLC

Crumbling concrete and rusting steel bridges are a common sight for anyone traveling America's highway system. Of the 614,387 bridges in the United States, almost 40 percent are 50 years or older and about 10 percent are posted with a load restriction[1]. In its 2017 Infrastructure Report Card, the American Society of Civil Engineers (ASCE) issued a grade of C+ for the condition of the country's bridges. The nation's backlog of bridge rehabilitation needs is estimated at $123 billion. The report specifically states that most bridges were designed for a lifespan of 50 years, so an increasing number will soon need major rehabilitation[1].

The challenges facing every state Department of Transportation (DOT) include how to get more done with less, and minimize the impact to the local community and economy. Rehabilitating to extend the life of a structurally deficient bridge is preferred over replacement. In addition, when it comes to rehabilitating bridges, many DOTs are considering cost-saving, nontraditional methods and materials to help get more done with less. Fiber-reinforced polymer (FRP) strengthening is one nontraditional method where use has grown steadily during the last 30 years and is now being adopted by more and more DOTs.

FRPs are externally bonded to, or wrapped around existing concrete structural members to provide reinforcement where additional reinforcing bars are desired. FRPs are used to restore or increase the load-carrying capacity of bridges or to improve their ability to withstand earthquakes.

FRP STRENGTHENING SYSTEMS

FRPs, also known in the aerospace industry as advanced composite materials, are routinely used in the manufacture of aircraft. Nearly half of the airframe of the Boeing 787 Dreamliner comprises carbon fiber and other composite materials[2]. Carbon fiber is lightweight, corrosion resistant and has superior mechanical properties compared to traditional building materials. Figure 1 compares the properties of carbon fibers with those of traditional reinforcing steel and post-tensioning steel. These properties have contributed to the growth of FRPs as a strengthening technique for concrete, masonry and steel structures. Even though the FRP materials are more expensive than traditional building materials such as steel and concrete, the total construction cost is often less.

FRP strengthening systems are defined by the American Concrete Institute's ACI 440.2R, "Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures," as the fibers and resins used to create the composite laminate, all applicable resins used to bond it to the concrete and any coatings used to protect the FRP[3]. Carbon fibers and epoxy resins are used in most strengthening or retrofitting applications (carbon fiber-reinforced polymer, or CFRP). E-glass fibers are used by some DOTs to provide additional protection (glass fiber-reinforced polymer, or GFRP). FRP systems can be categorized by how the fibers and resins are combined.

ACI 440.2R and the American Association of State Highway and Transportation Officials (AASHTO), "Guide Specifications for Design of Bonded FRP Systems for Repair and Strengthening of Concrete Bridge Elements" publish the design equations for FRP strengthening projects. ACI is typically used for building structures, but since it has been around since 2002 it is often utilized for bridge projects as well. The AASHTO Guide has been available since 2012[4]. Both guides limit the amount an existing structure can be strengthened with FRPs for both safety and practical reasons. Therefore, FRPs may not be a candidate for every project.

WET LAYUP FRP SYSTEMS

Wet layup FRP systems are the most common FRP form used in the United States. Dry, unidirectional fabrics made with continuous carbon fibers are wet out with a saturating resin in the field and adhered to or wrapped around an existing concrete member. The fabrics may be wet out directly on the member being strengthened or pre-saturated by hand or by machine before being applied to the member. Heavier-weight fabrics may need to be pre-saturated to ensure sufficient impregnation of the fibers. Wet layup FRP systems are flexible and can easily conform to the member making it ideal for applications like column wrapping.

PRE-CURED FRP SYSTEMS

Pre-cured FRP systems consist of composite plates, bars or other shapes manufactured off-site and adhesive used to bond them to the concrete. Pre-cured FRP systems are rigid and cannot be bent or wrapped around a member. In the United States, pre-cured systems are commonly used to reinforce the tops of bridge decks in a near surface-mounted (NSM) configuration to protect the FRP reinforcement from vehicles and snowplows. Shallow slots cut into the surface of the concrete are filled with an epoxy adhesive and an FRP bar or strip. Since FRPs do not corrode like reinforcing steel, they can be placed very close to the surface of the concrete.

FRP STRAND SHEETS

FRP strand sheets are a relatively new form used to strengthen concrete or steel members. Assembling small diameter pre-cured carbon fiber micro-rods into an open sheet like a bamboo blind allows the strand sheet to be uniformly bonded to an existing structure. Ultra-high modulus carbon fiber micro-rods are used for steel strengthening applications.

BRIDGE APPLICATIONS OF FRPS

FRPs have been used to strengthen thousands of bridges, buildings, parking garages and other structures around the world since their introduction nearly 30 years ago. The number of projects has grown faster in the private sector but recent activity suggests DOTs are starting to embrace the many advantages offered by using FRPs. Additionally, the recent publication of the AASHTO Guide specification has given many DOTs confidence to specify FRPs on their projects. Below are some examples of where FRPs are commonly used on bridges.

Bridge Columns

FRPs are used by many DOTs to improve the seismic behavior of bridge columns by providing additional confinement or shear reinforcement. Older bridges with inadequate confinement steel can easily be retrofitted to meet current seismic codes by simply wrapping the columns with CFRP. Compared with encasing the existing columns in reinforced concrete or installing and welding steel jackets followed by grouting, it is not hard to see how FRPs offer cost benefit. DOTs often require a minimum steel jacket thickness for handling and welding that can be more than required to meet the structural loads. In these cases, FRPs are almost always the most cost-effective solution. Some DOTs also use GFRPs to provide additional protection from de-icing salt splash. Once the FRP cures, an epoxy or latex acrylic topcoat can be applied for aesthetic reasons and UV protection.

Bridge Piers

Many older bridges were designed to carry much lighter trucks than those using our highway system today. While the condition of the substructure (i.e., piers) may be in good condition with little deterioration, it may be undersized to carry today's trucks. Replacing the substructure is tantamount to replacing the entire bridge and can be very disruptive to communities. As older bridges are slated to have their decks replaced, DOTs have used

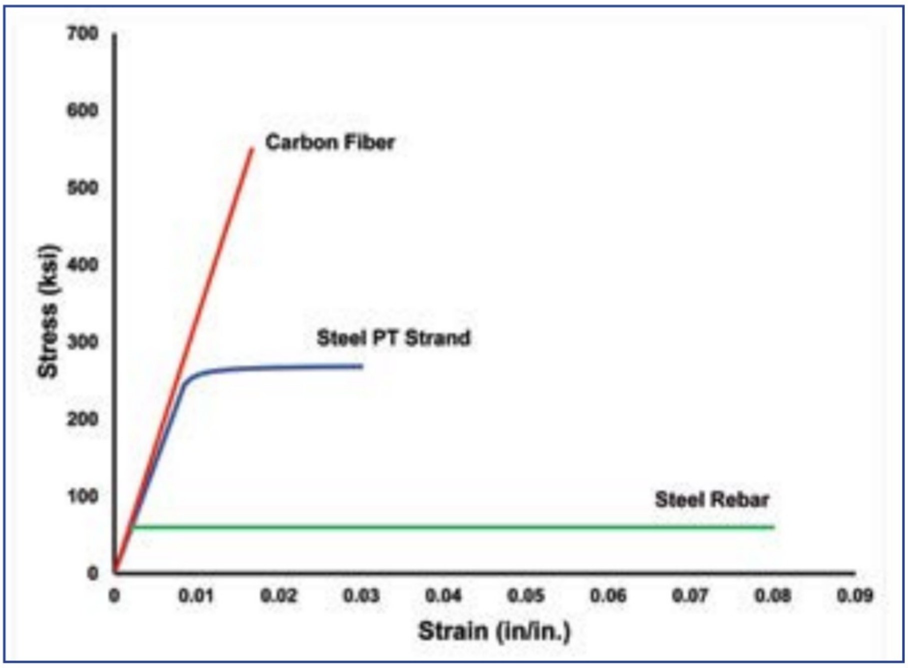


Fig 1: Properties of FRPs compared to traditional reinforcing materials. Figures courtesy of the author.

CFRPs to upgrade the strength of the piers to support the new decks and the new truck loads. It is becoming increasingly common to use CFRPs to provide additional flexure and shear strength to the pier caps. CFRPs are bonded to the bottom or sides to provide additional flexure strength and wrapped around the pier cap (fully or three-sided) to provide additional shear strength.

Bridge Girders

DOTs utilize FRPs to address a wide range of deficiencies in AASHTO-style precast, prestressed concrete girders.

- Increase flexure strength to restore lost capacity or support higher loads.
- Increase shear strength to restore lost capacity or support higher loads.
- Confine concrete repairs made to corrosion-damaged girder ends.
- Confine concrete repairs made to girders hit by trucks.

Each state has its own standard details for CFRP girder repairs. Some wrap just the bottom flange of the girder while others wrap the complete height of the girder. Some require one layer with the fiber aligned vertically on the sides while other require two layers, one aligned vertically and one aligned horizontally. A standard detail for confining concrete repairs with FRPs is likely to emerge in the coming years as more and more DOTs employ this technique.

Bridge Decks

Wet layup FRP systems applied to the bottom of a bridge deck and FRP bars installed in near surface-mounted (NSM) slots on the top of a bridge deck have been successfully employed to provide supplemental flexural strength. In addition, when the barrier/rail systems of older bridges are upgraded, it usually requires the edge of the deck to be strengthened for additional tension forces which can be done using NSM techniques.

Steel Bridge Elements

The use of FRPs to strengthen concrete structures is well established. Do FRPs offer similar cost-effective solutions for the strengthening of deteriorated steel structures? With the introduction of ultra-high modulus carbon fiber fabrics and strand sheets, FRPs are now a promising technique competing with bolting or welding additional plates. Where access is difficult or welding is dangerous (e.g., industrial facilities) bonded FRPs offer a cost-effective alternative.

In steel bridge structures CFRPs are used in the following cases.

- To restore section loss of tension and compression members such as flanges, bracing, truss chords and more.
- To provide additional compression/bearing strength to girder ends.
- To provide additional shear strength to webs.
- To reduce service stresses in existing steel members to improve fatigue behavior.

CONCLUSIONS

1. FRPs are routinely used to strengthen many different types of structures and use in bridge structures is increasing.
2. The superior mechanical properties, corrosion resistance and light weight of FRPs often leads to lower installation cost over cheaper, more traditional materials.
3. ACI and AASHTO published guides to assist engineers with the design of FRP projects.
4. Bridge columns, pier caps, girders and decks can be strengthened using FRPs.

ABOUT THE AUTHOR

Gregg Blaszak is a licensed engineer with over 15 years of experience with the design and construction of fiber reinforced polymer materials (FRPs) for civil/structural applications. He holds a Bachelor of Science degree in aeronautical engineering and an Master's degree in civil engineering, both from the University of Illinois.

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PREVENTING CREVICE CORROSION IN NEW AND EXISTING STEEL STRUCTURES

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Steel structures are often fabricated by bolting (or riveting) structural components together. Bolted joints result in multiple crevices between the bolted members and fasteners. These crevices are typically more susceptible to corrosion than flat surfaces because they tend to retain water/contaminants, they are difficult to properly coat and crevice geometry tends to support electrochemical phenomena that accelerate corrosion. This article will evaluate the effectiveness of various coating practices at mitigating corrosion around these joints.

For new structures, the state-of-the-art approach is to apply zinc-rich primer to mating surfaces prior to assembly and to use galvanized fasteners during assembly. Unfortunately, there are cases where this is not always possible. Obviously, it is typically unrealistic to disassemble, prime and re-assemble existing structures. During maintenance painting, stripe coats and caulking are often used to provide added protection to crevice areas. Though effective, caulking can be expensive and may not be necessary on all surfaces.

The authors will discuss the results of a laboratory study investigating the degree of crevice corrosion protection provided to bolted joints using different coating schemes. Forty different combinations of surface preparation, fastener coating, caulking extent and coating sequence were evaluated on aged and new steel assemblies. The test assemblies were exposed to cyclic accelerated corrosion testing and evaluated for rust staining, blistering and pitting within the crevice area. The data presented will help quantify the benefits of alternative approaches for corrosion mitigation in fabricated steel joints.

THE TEST APPROACH

Panel Design

Complex panels were assembled to replicate various geometries and include various materials that are seen on steel structures. A steel panel 6-inches-by-12-inches-by-⅛ inch had three 4-inch-by-2.5-inch-by-⅛-inch-steel plates fastened to them with ½-inch nuts and bolts (10 black-oxide and 10 galvanized). A 4-inch-by-2-inch-by-⅛-inch steel angle was also bolted to the panel. The panels were made in such a way that they had both vertical and horizontal water travel paths and a representation of bolted bridge structural geometries that contain crevices.

There were a total of 20 panels for this project. To compare the effects of new steel versus aged steel, half of the test panels were weathered prior to surface preparation and coating application. The following four surface preparation methods were evaluated in this project.

Table 1: Study Test Matrix.

System	Panel Condition			
	Assembly and Surface		Stripe Coat	Caulk
1	New - Primed After Assembly	SP-10	No	None
2			Stripe Coated	
3				Top
4				3/4
5				Full
6	New - Primed Before Assembly		No	None
7			Stripe Coated	
8				Top
9				3/4
10				Full
11	Weathered		No	None
12			Stripe Coated	
13				Top
14				3/4
15				Full
16		SP-11	No	None
17			Stripe Coated	
18				Top
19				3/4
20				Full

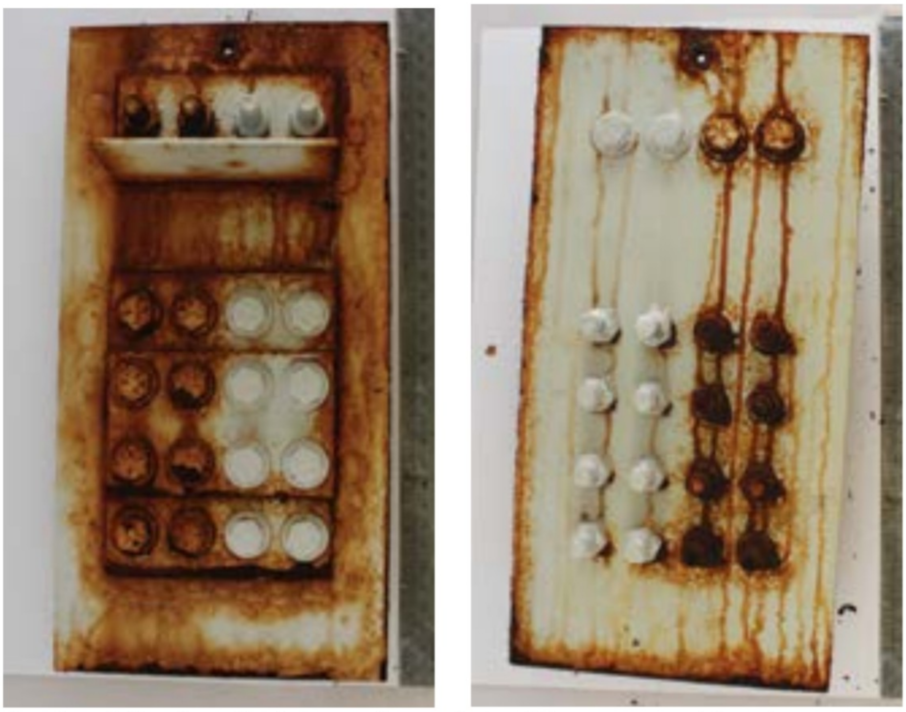

Fig. 1: Front (left) and back (right) of panels after weathering. All figures courtesy of the authors.

- New Steel – Assembled then abrasive blasted per SSPC-SP 10/NACE No. 2, “Near-White Blast Cleaning.”
- New Steel – As abrasive blasted per SSPC-SP 10/NACE No. 2 as individual parts, zinc-primed then assembled
- Weathered Steel – As abrasive blasted per SSPC-SP 10/NACE No. 2 prior to coating.
- Weathered Steel – Power tool cleaned per SP 11, “Bare Metal Power Tool Cleaning” prior to coating.

Table 1 shows the test matrix for the study. The existing steel, new steel and caulking methods are described in the following sections.

Weathered Steel

Prior to exposure, panels were coated with a light layer of epoxy coating (1 to 2 mils) over bare steel with no surface profile. Panels were exposed for 150 hours of salt-spray exposure per ASTM B117, “Standard Practice for Operating Salt Spray (Fog) Apparatus” and nine months of outdoor exposure in an industrial setting. Figure 1 shows the panels after weathering but prior to surface preparation procedures.

After weathering, the panel surfaces were prepared for coating by one of two methods. Most panels were abrasive blasted per SSPC-SP 10/NACE No. 2 using 30-grit aluminum oxide to achieve a nominal 1-to-2 mil profile. One set of weathered steel was prepared to SSPC-SP 11 using a combination of needle gun and angle grinder to achieve a nominal 1 mil profile. Figure 2 shows representative weathered steel panels prepared by each scenario.

New Steel

The second set of the test panels represented new steel assemblies. Half of these panels were assembled prior to abrasive blasting and priming with a zinc-rich primer. The other half was abrasive blasted as individual components, primed using the same zinc-rich primer and then assembled. Figure 3 (p. 22) shows representative new steel panels after assembly and preparation. All abrasive blasting was SSPC SP-10/NACE No. 2 blast cleaned using 30-grit aluminum oxide to achieve a nominal 1-to-2 mil profile. The fasteners on the panels were primed prior to assembly hand-sanded prior to additional painting.

Coating Application

The coating system used for this project was a standard three-coat system currently used on

Fig. 2: Surface preparation after weathering (SSPC-SP 10 left, SSPC-SP 11 right).

Fig. 3: New steel panels (assembled prior to blast, left; post-SSPC-SP 10 blast, center; and SSPC-SP 10 blast and primed, then assembled, right).

structural bridges today. One panel from each scenario did not receive stripe coats and two of each surface preparation scenario did not receive caulking. The coating application sequence was as follows.

- Perform designated surface preparation (e.g., SSPC-SP 10/NACE No. 2 or SSPC-SP).
- SSPC-SP 1, Solvent Cleaning (using isopropyl alcohol).
- Zinc primer (3 to 5 mils).
- Zinc stripe (3 to 5 mils).
- Intermediate coat (3 to 5 mils).
- Intermediate stripe (3 to 5 mils).
- Caulk application.
- Finish stripe (3 to 5 mils).
- Finish coat (3 to 5 mils).

Caulking Methods

Three panels from each surface preparation scenario had caulk applied to determine its effectiveness at preventing crevice corrosion. With each of the three panels, the caulk was applied in a different way to determine the amount needed to prevent crevice corrosion. Figure 4 illustrates the various caulking scenarios.

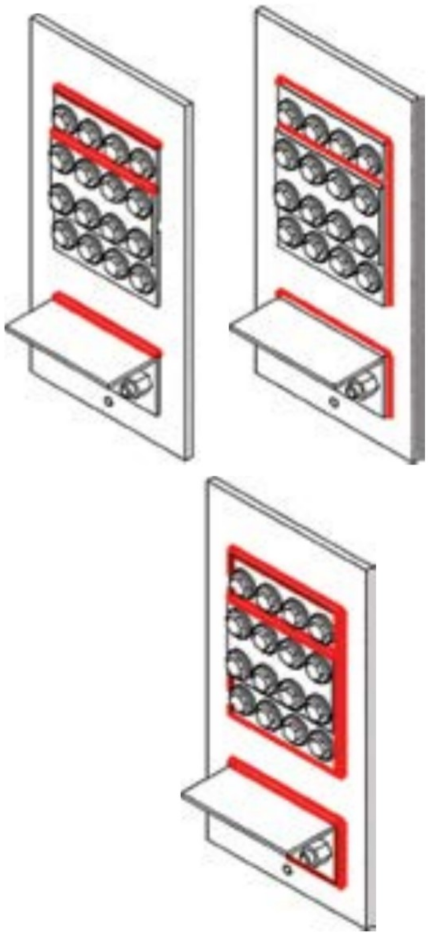

Fig. 4: Caulking scenarios, side view (full method, top left; ¾ method, top right; and top method, bottom).

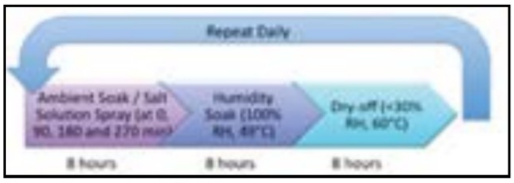

Fig. 5: One cycle of GMW 14872.

Corrosion Testing

After coating application and following a full seven-day cure, the panels were exposed to 120 cycles of GMW 14872 Cyclic Corrosion Laboratory Test (Fig. 5).

Inspections were carried out at 20, 40, 80 and 120 cycles. Each panel was inspected for rust through (using ASTM D610, "Standard Practice for Evaluating Degree of Rusting on Painted Steel Surfaces"), blistering (ASTM D714, "Standard Test Method for Evaluating Degree of Blistering of Paints"), crevice corrosion and the percentage of bolts with corrosion. Following 120 cycles of corrosion testing, the panels were disassembled to determine the extent of pitting in each crevice.

RESULTS

Figure 6 shows the new steel panels that were primed after assembly. Overall corrosion of these panels at each cycle was very minimal with the exception of rust bleed from the crevices in three scenarios. Crevice corrosion could be seen along the sides and top of the L-channel and built-up assembly throughout the exposure testing for three conditions: no stripe or caulk, stripe with no caulk, and stripe with top caulk.

Figure 7 (p. 26) shows the new steel panels that were primed before assembly. The black-oxide bolts on these panels showed the most corrosion of the conditions evaluated and the panel that received no stripe coating showed the greatest bolt corrosion. These bolts were only protected by the epoxy intermediate coat. The remaining systems received a stripe coat of zinc-rich primer on the black-oxide bolts but still experienced corrosion much earlier than any of the other types of surface preparation systems evaluated.

Other than the black-oxide bolts, crevice corrosion was less evident on the panels that were primed before assembly.

Figure 8 (p. 26) shows the abrasive-blasted panels and Figure 9 (p. 27) shows the power-tool-cleaned panels from the weathered steel scenarios. Not surprisingly, the abrasive-blasted repair system had less bolt and crevice corrosion than the power-tool-cleaned system. With both types of surface preparation, the best overall performing system was that of the full caulking; running rust was not evident after corrosion testing. Varying degrees of running rust can be seen from the crevices on the remaining panels. As expected, crevice corrosion was reduced with additional caulking. Interestingly, stripe coating alone had a minimal benefit for reducing crevice corrosion.

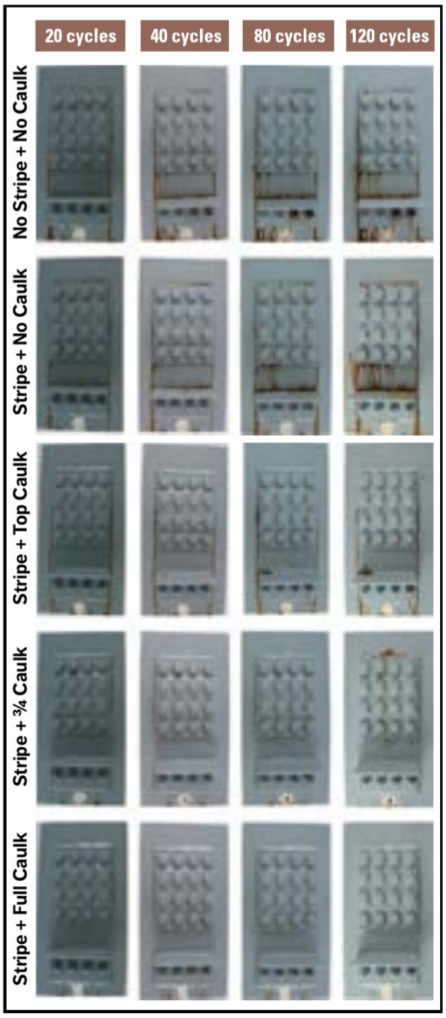

Fig. 6: New steel primed after assembly.

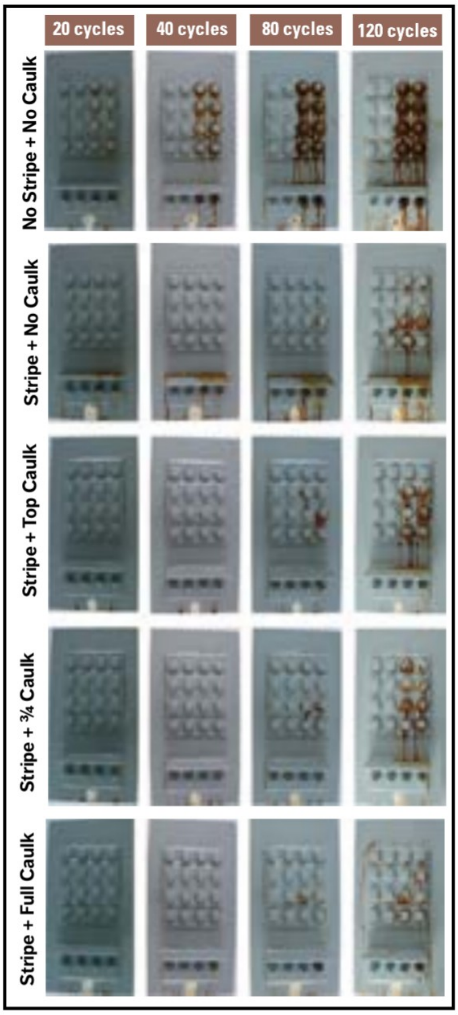

Fig. 7: New steel primed before assembly.

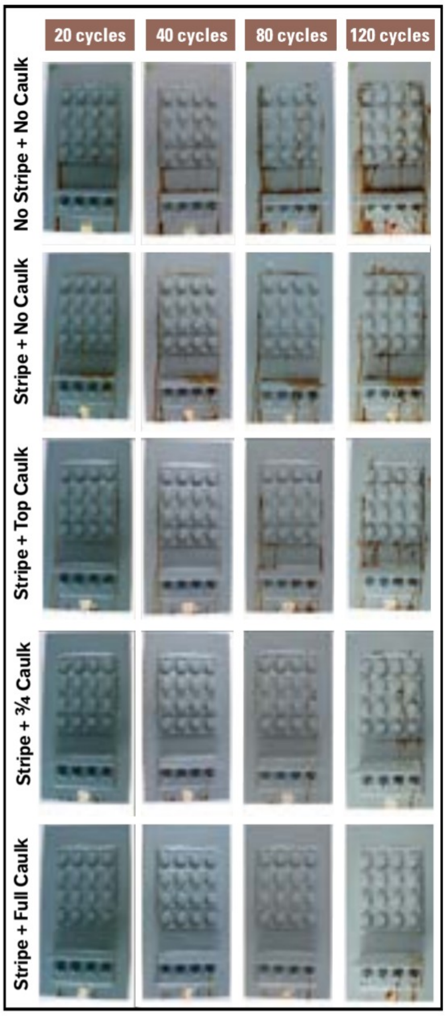

Fig. 8: Weathered steel, SSPC-SP 10 remediation.

Table 2: Crevice Corrosion Inspection at 120 Cycles of GMW 14872.
Red indicates corrosion was present.

System	Panel Condition				Running Rust at Crevices: Coupon Assembly			Running Rust at Crevices: Angle		
					Top	Sides	Bottom	Top	Sides	Bottom
1	New-Primed After Assembly	SP-10	No	None	Green	Red	Green	Red	Red	Red
2			Stripe Coated		Green	Red	Green	Red	Red	Green
3				Top	Green	Red	Green	Red	Green	Green
4				3/4	Green	Green	Green	Green	Green	Green
5				Full	Green	Green	Green	Green	Green	Green
6	New-Primed Before Assembly		No	None	Red	Red	Red	Red	Red	Red
7			Stripe Coated		Green	Red	Green	Red	Red	Green
8				Top	Green	Red	Green	Green	Red	Green
9				3/4	Green	Green	Green	Green	Green	Green
10				Full	Red	Green	Green	Green	Green	Green
11	Weathered		No	None	Red	Red	Red	Red	Red	Red
12			Stripe Coated		Red	Red	Green	Red	Red	Red
13				Top	Green	Red	Green	Red	Red	Green
14				3/4	Red	Green	Red	Green	Green	Green
15				Full	Green	Red	Green	Green	Green	Green
16		SP-11	No	None	Red	Red	Red	Red	Red	Red
17			Stripe Coated		Red	Red	Red	Red	Red	Green
18				Top	Red	Red	Red	Green	Green	Green
19				3/4	Red	Green	Red	Green	Green	Green
20				Full	Green	Green	Green	Green	Green	Green

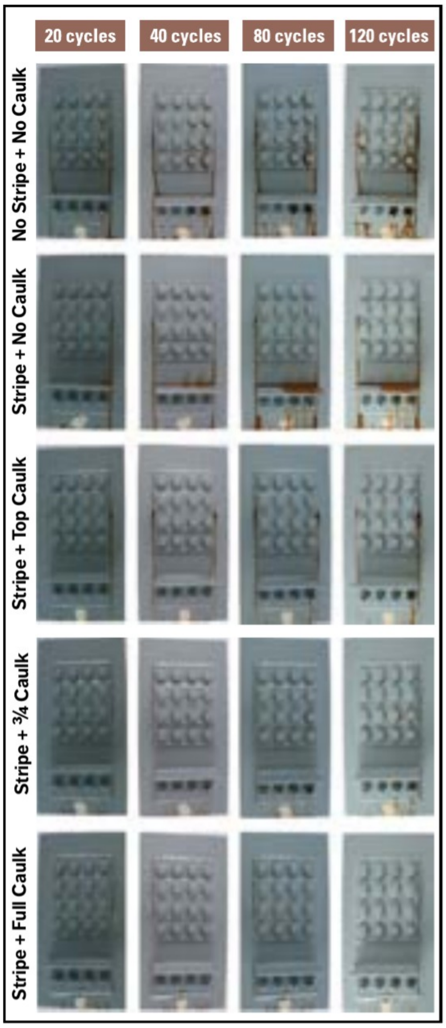

Fig. 9: Weathered steel, SSPC-SP 11 remediation.

Crevice Corrosion

The extent of crevice corrosion was noted at each inspection during the exposure testing. The top, sides and bottom of the three-coupon assembly, along with the top, bottom and sides of the angle, were inspected for evidence of running rust or rust through of the coating at these areas. Table 2 shows the extent of crevice corrosion after 120 cycles of exposure testing (red indicates that corrosion was present).

The only panels that did not display some form of crevice corrosion were those from the ¾ and full-caulking scenarios. It was interesting to note that the new steel panels that were primed after assembly displayed less crevice corrosion than those that were primed before assembly though this may be influenced by running rust from the poorly coated black-oxide bolts.

Table 3: Corrosion of Black-Oxide Bolts on Panels.

Panel Condition				20 Front of Black Bolts	20 Back of Black Bolts	40 Front of Black Bolts	40 Back of Black Bolts	80 Front of Black Bolts	80 Back of Black Bolts	120 Front of Black Bolts	120 Back of Black Bolts
New - Primed After Assembly	SP-10	No	None	60%	100%	10%	100%	100%	100%	100%	100%
		Stripe Coated	None	10%	0%	30%	10%	30%	10%	40%	50%
			Top	10%	40%	10%	40%	20%	40%	30%	80%
			3/4	40%	20%	50%	20%	50%	20%	50%	50%
			Full	20%	0%	20%	0%	30%	0%	40%	40%
New - Primed Before Assembly	SP-10	No	None	100%	100%	100%	100%	100%	100%	100%	100%
		Stripe Coated	None	0%	0%	0%	0%	80%	0%	90%	100%
			Top	20%	0%	30%	30%	70%	30%	100%	100%
			3/4	0%	0%	40%	30%	70%	30%	100%	100%
			Full	10%	0%	20%	10%	70%	10%	90%	100%
Weathered	SP-10	No	None	70%	100%	70%	100%	70%	100%	70%	100%
		Stripe Coated	None	0%	0%	0%	0%	0%	0%	0%	30%
			Top	10%	20%	10%	10%	20%	10%	20%	20%
			3/4	0%	10%	10%	10%	10%	10%	20%	10%
			Full	20%	0%	20%	0%	20%	0%	20%	0%
	SP-11	No	None	40%	100%	80%	100%	90%	100%	100%	100%
		Stripe Coated	None	20%	0%	30%	0%	30%	0%	30%	70%
			Top	10%	40%	30%	40%	30%	40%	30%	80%
			3/4	20%	20%	50%	40%	60%	40%	80%	100%
			Full	0%	20%	20%	50%	20%	50%	20%	70%

Bolt Corrosion

To explore the effects of the coating techniques on galvanized and black-oxide bolts, the percentage of bolts experiencing corrosion was documented at each inspection cycle. Table 3 shows the percentage of black-oxide bolts displaying corrosion at each inspection. Table 4 (p. 28) shows the same data for the galvanized bolts. A comparison of these tables clearly shows the value of galvanized bolts in any scenario.

The panels displaying the greatest bolt corrosion were panels primed prior to assembly. The black-oxide bolts that did not receive a zinc primer or zinc stripe coat displayed corrosion at the first inspection (cycle 20). Epoxy and polyurethane do not sufficiently protect the black-oxide fasteners for even a short period of time. If black-oxide bolts must be used, they should receive full and stripe coats of zinc primer, epoxy intermediate and finish coat.

Corrosion of the weathered black-oxide bolts was less evident on abrasive-blasted panels than on the power-tool-cleaned panels. This is not surprising, as existing rust in crevices was more thoroughly removed using abrasive blasting than power tools.

When comparing Tables 3 and 4, it is worth noting that the extent of corrosion on individual

Table 4: Percentage of Galvanized Bolts Displaying Corrosion per Panel.

Panel Condition				20		40		80		120	
				Front of Galvanized Bolts	Back of Galvanized Bolts	Front of Galvanized Bolts	Back of Galvanized Bolts	Front of Galvanized Bolts	Back of Galvanized Bolts	Front of Galvanized Bolts	Back of Galvanized Bolts
New – Primed After Assembly	SP-10	No	None	0%	0%	50%	100%	70%	100%	70%	100%
		Stripe Coated	None	0%	0%	0%	0%	0%	10%	20%	10%
			Top	0%	0%	0%	10%	0%	30%	10%	30%
			3/4	0%	0%	0%	0%	10%	10%	20%	10%
			Full	0%	0%	0%	0%	20%	0%	30%	10%
New – Primed Before Assembly		No	None	0%	0%	10%	10%	100%	100%	100%	100%
		Stripe Coated	None	0%	0%	0%	0%	0%	0%	20%	40%
			Top	0%	0%	0%	20%	0%	30%	20%	40%
			3/4	0%	0%	0%	20%	20%	50%	20%	50%
			Full	0%	0%	30%	20%	50%	40%	20%	40%
Weathered		No	None	0%	0%	20%	80%	40%	100%	40%	100%
		Stripe Coated	None	0%	0%	10%	0%	10%	0%	10%	30%
			Top	0%	10%	0%	10%	0%	20%	0%	20%
			3/4	10%	0%	10%	10%	10%	10%	20%	10%
			Full	0%	0%	0%	0%	0%	10%	0%	20%
	SP-11	No	None	0%	0%	20%	70%	30%	90%	20%	60%
		Stripe Coated	None	0%	0%	20%	0%	80%	0%	30%	10%
			Top	0%	0%	0%	10%	0%	10%	0%	10%
			3/4	0%	0%	20%	0%	20%	0%	20%	10%
			Full	0%	0%	0%	0%	0%	20%	0%	30%

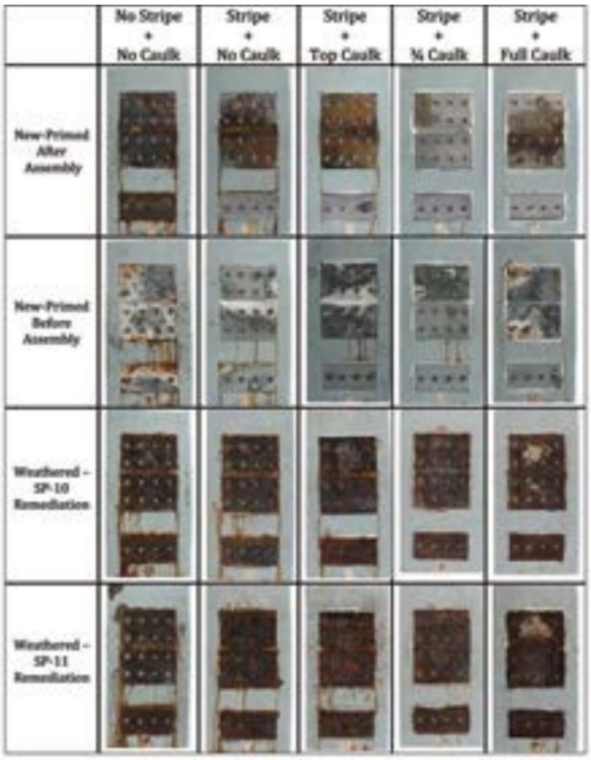

Fig. 10: Panels disassembled after application.

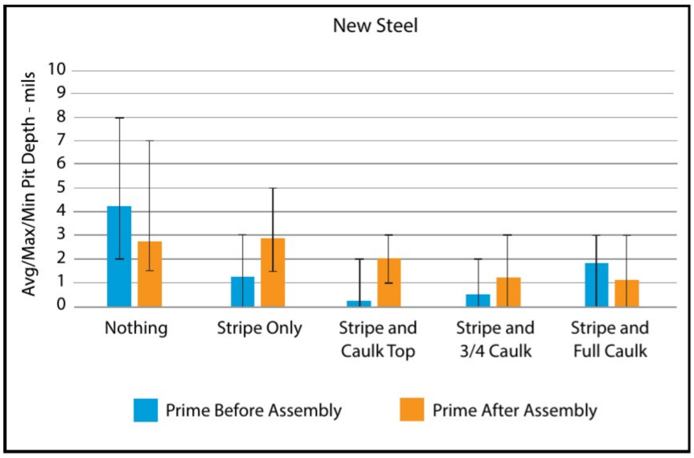

Fig. 11: Minimum, average and maximum pits measured on the crevice face of the angle for panels representing new steel coating systems.

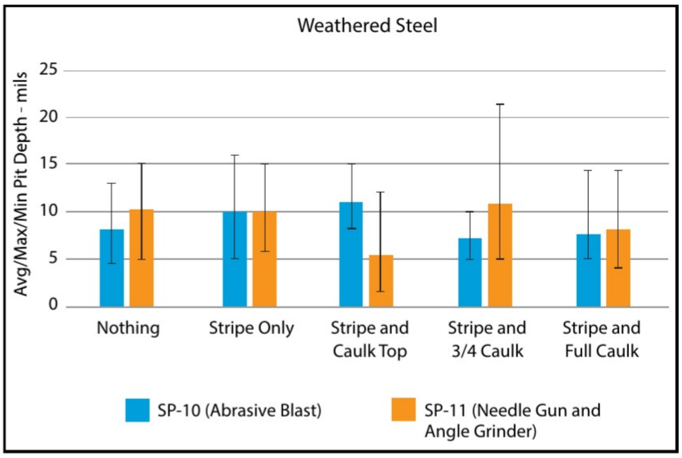

Fig. 12: Minimum, average and maximum pits measured on the crevice face of the angle for panels representing weathered steel coating systems.

fasteners was less on the weathered galvanized bolts than the weathered black-oxide bolts. Even though galvanized bolts had significantly less corrosion than the black-oxide bolts, Table 4 shows the clear benefits of stripe coating the galvanized bolts, especially on the threaded end of the bolt.

Disassembly

After accelerated corrosion testing, panels were disassembled for analysis of corrosion in the crevices. Figure 10 (p. 28) shows each panel dissembled.

Figure 13 shows that ¾ caulking applied to new steel that is primed after assembly is the best way to prevent corrosion in these crevices. In one of the two crevice areas, the full caulking appears to hold moisture within the crevice of the new steel panels. As expected, the panels with neither a stripe coat nor caulking experienced the most crevice corrosion. The remaining three scenarios (stripe coat, top caulk and full caulk) had visually similar crevice corrosion on the new steel assemblies.

For weathered steel under repair conditions, the benefits of a full caulk system are evident. The remaining caulking schemes visually appear better than the schemes without caulking.

Pit Depth

In an attempt to better quantify the crevice corrosion, pit depths were measured on the surface of the angles that were mounted onto the larger panel. After disassembling the

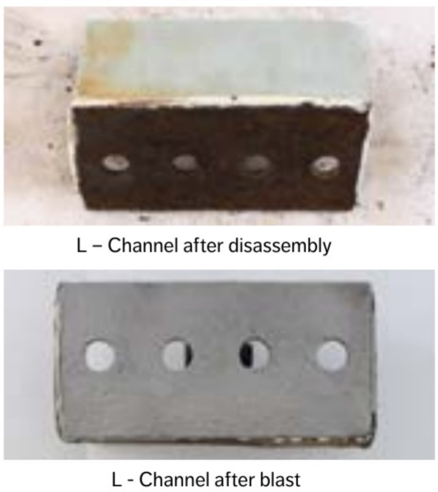

Fig. 13: L channel before and after glass-bead blasting.

panels, all corrosion products were removed from the crevice surface of the steel angle using abrasive glass-bead blasting. Figure 13 shows the crevice surface of an angle before and after glass bead blasting.

Once the surface was cleaned, the ten deepest pits were measured using a pit- and crack-depth gauge. The instrument has a measuring range of 0 to 500 mils and a resolution of 0.5 mils. The minimum, average and maximum measurement are used for the analysis presented in this article. Figure 11 shows the data for the panels representing painting of new steel and Figure 12 shows the data for the panels representing maintenance painting of weathered steel.

Comparing the two graphs, it is clear that deeper pits were measured on the panels representing maintenance painting of weathered steel. However, a certain portion of that pitting occurred when the test panels were being weathered (i.e., pre-rusted). For any given panel, it is not possible to know how much of the pitting occurred prior to the maintenance painting. Analysis of the remaining crevice surfaces may provide sufficient statistical data to get additional insight, however this article focuses on the two data sets individually.

For the new steel painting scenarios, the pit-depth data corroborates the visual observations (Fig. 12). Pitting is clearly reduced by striping and caulking. The caulking scenarios that left at least one edge un-caulked had the least amount of pitting. Priming prior to assembly was also beneficial in these scenarios. Interestingly, priming prior to assembly led to greater pitting than priming after assembly for the scenarios that did not have a stripe coat or were fully caulked. Standard industry practice of priming surfaces before assembly and incorporating stripe coats was among the best performing scenarios, though the practice would benefit by adding limited caulking to reduce water ingress.

For the weathered steel maintenance painting scenarios, the observed pitting is probably dominated by what occurred during the pre-weathering exposure (Table 4). However, by comparison to the "nothing" set of data, there is some evidence that the following four scenarios will result in less pitting.

- Stripe and full caulk for abrasive-blasted panels.
- Stripe and full caulk for power-tool-cleaned panels.
- Stripe and ¾ caulk for abrasive-blasted panels.
- Stripe and top-caulk for power-tool-cleaned panels.

The benefit of all caulking scenarios is corroborated by the visual observations. The panel geometry contains 11 unique crevice surfaces. Analysis of the remaining crevice surfaces may provide sufficient statistical data to obtain additional insight.

CONCLUSIONS

The following conclusions were formed based on the results of the study.

- Galvanized bolts perform better over time than do black-oxide bolts.
  - If black-oxide bolts are utilized, abrasive blasting, application of a zinc-rich primer, and stripe coats for each coating in the system will help prevent corrosion from occurring.
- Stripe coats and caulking of crevices directly exposed to water or moisture will help prevent crevice corrosion on new steel.
  - When caulking newly applied steel, consider leaving the bottom crevice uncaulked to allow moisture to escape.
- When working with weathered steel, full stripe coats and caulking of all crevices provide the best results in regards to reducing crevice corrosion and pitting.
- As a best practice, mating steel surfaces should receive a primer coating prior to assembly.

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ON THE CORROSION EFFECTS OF REBLASTED STEEL

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It is not uncommon during the course of abrasive-blast surface preparation of steel substrates to over-blast and create a blast profile that is over and above the defined specification. A profile is defined as the series of valleys and peaks and their commensurate height created during the abrasive-blasting process. Profiles that exceed specification are usually caused by using blast media that is too large for the intended purpose. Other factors that affect excessive blast profile include the air pressure of the blast, the distance of the nozzle to the substrate, the hardness of the substrate and the type and hardness of the blast media.

Excessive blast profile can lead to performance issues such as the early onset of erosion-induced corrosion if the DFT gauge is not properly validated to the blast profile[1]. It is, therefore, important that for any particular job, the proper profile is specified and that it is not exceeded.

Corbett et al. have recently studied the nature of out-of-specification blast profiles[2]. For the situation where the profile exceeds specification, they concluded the following.

1. Reblasting with a smaller abrasive blast media will reduce the overall profile.
2. Reblasting slightly increased the peak count versus the original over-blast peak count.
3. The peak count of reblasted profiles was less than the profile of surfaces blasted with the smaller blast media.

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The logical next step in the study of remediation of over-blasted surfaces is to investigate the effect of the blasted and reblasted profiles on corrosion performance. A coating is the primary method of corrosion protection and the surface profile plays a significant role in how well this protection is manifested.

The purpose of this study is to take a closer look at the topography of the surface (before and after reblasting an over-blasted profile) and how this topography might affect the corrosion protection of a protective coating.

EXPERIMENTAL

To study the effect of the reblasting of an over-blasted substrate, i.e., a substrate that was abrasive blasted in excess of a specification, four panel sets were prepared. The panels used were 3-inch-by-6-inch-by-⅛ inch, hot-rolled carbon steel. Following are the descriptions of the blasting programs.

Panel Set 1 (S1) – Panels were abrasive-blasted with coal-slag blast media to a profile of 4 mils as measured with replica tape. This is the original over-blasted condition.

Panel Set 2 (S2) – Panels were abrasive-blasted with coal-slag blast media to a profile of 4 mils as measured with replica tape. The panels were then reblasted using G40 steel grit to reduce the profile of the over-blast condition. The profile was measured with replica tape. The reblasting was conducted at a 90-degree orientation (Fig. 1).

Panel Set 3 (S3) – Panels were blasted with G40 steel grit and the profile was measured with replica tape. This is the optimum, in specification condition.

Panel Set 4 (S4) – Panels were abrasive blasted with coal-slag blast media to a profile of 4 mils as measured with replica tape at a 90-degree orientation. The panels were then reblasted with coal-slag blast media at an oblique angle, approximately a 20-to-30-degree orientation (Fig. 1). The resulting profile was measured using replica tape.

After the blasting program was complete, a representative panel from each panel set was measured for topography using a stylus-type surface profilometer. Both Rt (maximum valley depth to peak height of the evaluation length) and Rpc (peak count per linear length) were measured; ten separate evaluation lengths were measured for each panel set and averaged.

A representative panel from each panel set was imaged using both digital optical microscopy (DOM) and scanning electron microscopy (SEM). The surfaces of the panels were analyzed for elemental composition using energy dispersive x-ray spectroscopy (EDS).

To study the potential difference in corrosion properties of the various surface preparations, three panels from each panel set were coated with two coats of a phenalkamine-cured epoxy coating. The total film thickness of the coating was a nominal 11 mils DFT. The panels were scribed with a 2-inch scribe using a pencil-type scribing tool and were placed in an ASTM B117 (Standard Practice for Operating Salt Spray [Fog] Apparatus) salt-spray cabinet for 960 hours. After exposure, the panels were evaluated for scribe creep, cathodic delamination and any visual defects.

RESULTS AND DISCUSSION

Surface Topography

The four panel sets each showed different topographical characteristics because of the manner in which they were abrasive cleaned.

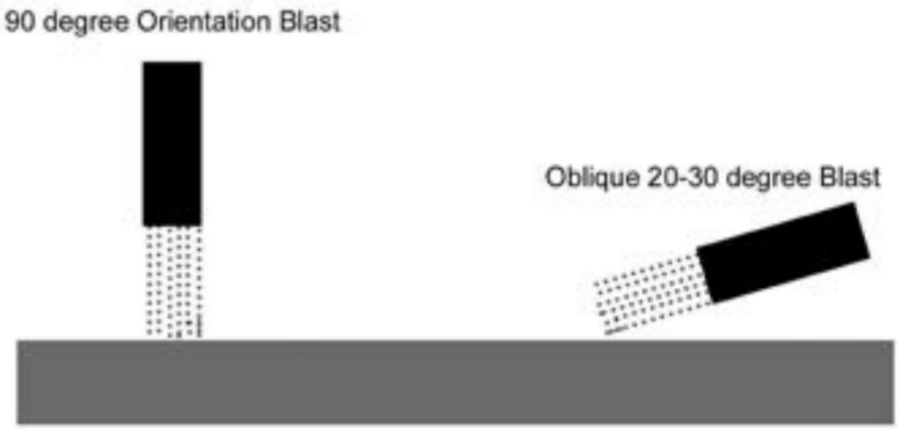

Fig. 1: Orientations of reblasting. Figures courtesy of the authors unless otherwise noted.

Table 1: Observed Profile Characteristics of the Four Test Panel Sets.

Panel Set	Profile (Replica Tape) mils	Rt, mils	Rpc, peaks/inch
S1	4.0	3.4 ± 0.5	66 ± 8
S2	2.8	1.8 ± 0.4	69 ± 19
S3	2.8	2.3 ± 0.2	86 ± 11
S4	3.8	3.5 ± 0.9	62 ± 8

Fig. 2: Effect of reblasting a profile with a secondary blast cleaning. Original blast profile (left) and same profile after blasting with a smaller steel grit (right).

Table 1 (p. 35) shows the profile characteristics measured from each panel set. Profile is the maximum valley-to-peak distance as measured with replica tape. Rt represents the average of 10 evaluation lengths of the maximum valley-to-peak distance as measured using a stylus profilometer. Although theoretically measuring the same property, the Rt values in all cases are less than what was observed using replica tape, which runs counter to an interlaboratory study conducted by R. Stachnik[3]. Rpc is the number of peaks per inch.

Table 2: Accelerated Corrosion Testing Results of the Coated Panel Sets.

Panel Set	Scribe Creep (mm)	Cathodic Delamination (mm)	Freckles
S1	0.4 ± 0.1	4.7 ± 1.0	Yes
S2	0.5 ± 0.3	9.7 ± 1.5	Yes
S3	0.3 ± 0.1	9.0 ± 1.8	No
S4	0.3 ± 0.1	8.9 ± 0.8	Yes

Panel Set 1 is the starting point of this study. The profile characteristics of this panel set (the set that was chosen as arbitrarily exceeding a specification) is compared to the results of the other panel sets. Panel Set 2 is composed of the panels that were reblasted with smaller steel grit to reduce the profile of the original blast. The valley-to-peak distance was reduced as shown in the profile and Rt measurements. It was speculated that the mechanism of this reduction in valley-to-peak height was due to the peaks of the original blast being smashed from the reblasting using the smaller steel grit (Fig. 2).

The average peak counts of both Panel Sets 1 and 2 are similar, but there is a substantial difference in the standard deviation of the average peak counts. The larger standard deviation of Panel Set 2 is due to the variability of smashing the peaks of the original blast. Figures 3 and 4 (p. 38) show microscopic evidence of this peak smashing mechanism.

The SEM micrographs clearly show the large peaks of the original blast of Panel Set 1 and the smashed peaks of the reblasted panels of Panel Set 2. Of interest is the metallic-looking features appearing as white areas found in Figure 3b. An EDS analysis revealed these white areas to be non-conductive coal slag from the original blast media that is embedded into the steel. This feature does not appear in Panel Set 2 because the reblasting by the steel grit has removed this embedded

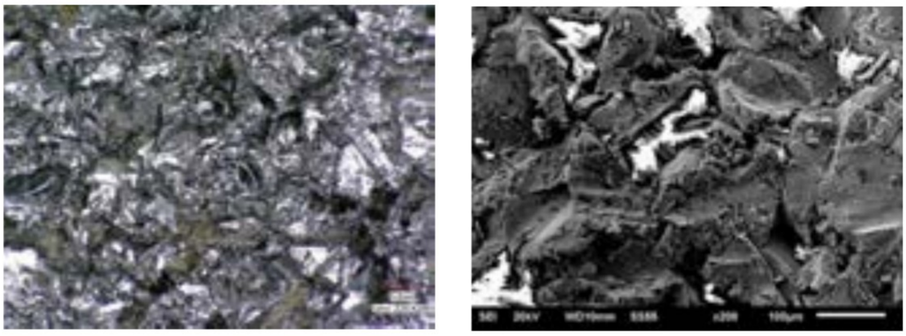

Fig. 3: Panel Set 1 — Digital optical micrograph (left) and scanning electron micrograph (right) at a magnification of 200 times.

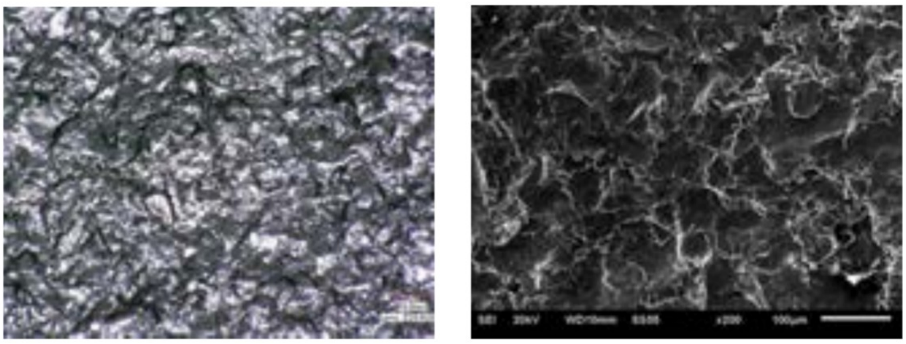

Fig. 4: Panel Set 2 — Digital optical micrograph (left) and scanning electron micrograph (right) at a magnification of 200 times.

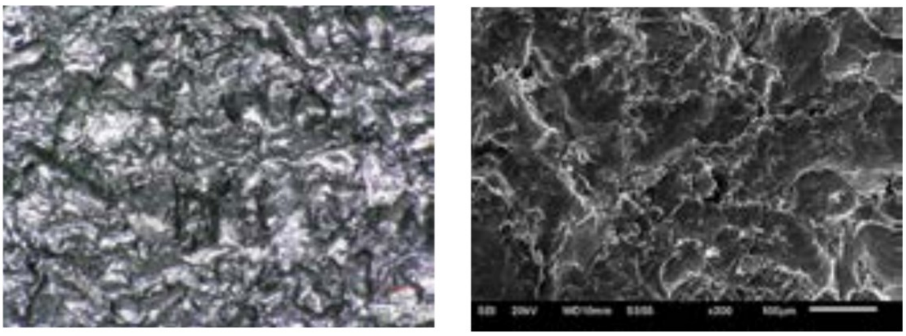

Fig. 5: Panel Set 3 — Digital optical micrograph (left) and scanning electron micrograph (right) at a magnification of 200 times.

coal slag (Fig. 4b). It has not escaped the notice of the authors what effect this embedded material may have on the performance of a coating applied to the substrate. This is an area that warrants further study, as there is potential of a significant effect on performance.

Figure 5 shows the photo micrographs of Panel Set 3 which was abrasive blasted once with the same-sized steel grit that was used to reblast Panel Set 2. The effect shown in this figure is similar in appearance to Panel Set 2. The average peak count for Panel Set 3 was significantly larger than Panel Set 2. This is because it is easier to build peaks from a flat surface (as was the case with Panel Set 3) as compared to smashing pre-existing peaks (as was the case for Panel Set 2).

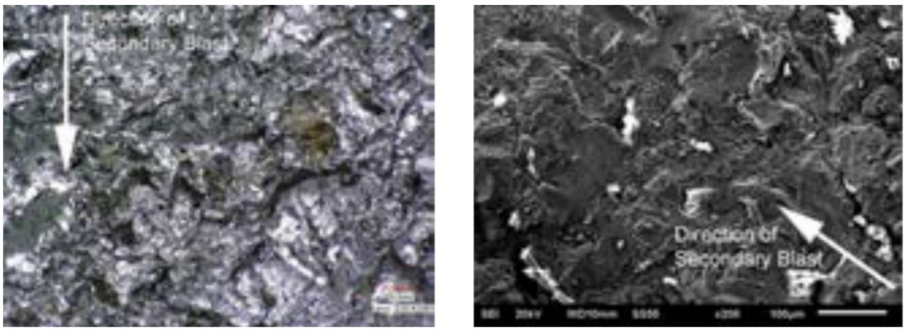

Fig. 6: Panel Set 4 — Digital optical micrograph (left) and scanning electron micrograph (right) at a magnification of 200 times.

Figure 6 shows the photo micrographs of panels that were reblasted with the same coal slag, but at an oblique angle. It was thought that the action of this reblasting would cause bending of the original peaks, as depicted in Figure 7a (p. 40), along with the commensurate lowering of the valley-to-peak height. The digital optical micrograph would seem to suggest that (Fig. 6a). However, the scanning electron micrograph shows a different reality. As shown in Figure 6b and depicted in Figure 7b, the peaks are pushed to the side instead of bent over. This results in similar valley-to-peak height between the original blast and the reblasted surfaces, hence the lowering of that height did not happen.

Accelerated Corrosion Performance

To determine if there is an effect of a reblasted surface on corrosion protection, the panel sets were coated with two coats of a phenalkamine-cured epoxy coating, scribed, and placed in an ASTM B117 accelerated corrosion cabinet for 960 hours. The panels were measured for scribe creep and cathodic delamination as indicators of corrosion protection. The presence of anodic corrosion also results in cathodic activity nearby, which generates alkalinity at the cathodic half-cell. This alkalinity, if of a certain strength and concentration, will result in the interruption of the Lewis acid-base interactions between the coating's polymer and the surface of the steel resulting in delamination of the coating in the area around the scribe. Scribe creep is commonly used as the evaluator for accelerated corrosion testing because it is readily visible to the observer. It is actually cathodic delamination that is the more severe and

Fig. 7: Possible orientations of peaks after oblique reblasting. Rolled over peaks from reblast (left) and pushed peaks from reblast (right).

important characteristic for evaluating corrosion resistance in neutral environments because of the potential for much more expansive corrosion that will be developed once the substrate is exposed to the elements[4].

The accelerated corrosion evaluation results are found in Table 2 (p. 36). The scribe creep results for all four panel sets are minimal and essentially equivalent. This is not surprising because in a neutral ionic environment such as found in an ASTM B117 cabinet, the cathodic action generates alkalinity as described previously, and this alkalinity tends to inhibit corrosion on the steel.

Cathodic delamination is shown to be much more extensive than scribe creep, wherein lies the potential corrosion problem. After the film has delaminated from the steel, as the coating is worn away by the elements, in particular UV radiation from the sun and water from rain, the steel under the delaminated coating will eventually be exposed and corrosion on this much larger exposed area will occur. Thus, a larger degree of cathodic delamination is an undesirable characteristic for a coating/steel substrate system to have.

In this study, Panel Sets 2, 3 and 4 all have similar cathodic delamination characteristics. Panel Set 1, on the other hand, has a significantly lower amount of cathodic delamination. It is not altogether clear why this panel set should show much better cathodic delamination characteristics than the others, especially Panel Set 4, which is very similar to Panel Set 1 in topography. The only difference is the "push" peaks caused by the oblique reblast. One possible explanation for the improved cathodic delamination in Panel Set 1 is that the tortuosity of the profile is greater in Panel Set 1 than in the other sets. Tortuosity is the ratio of actual interfacial-diffusion length to the apparent length or the evaluation length. Weinell et al. has shown

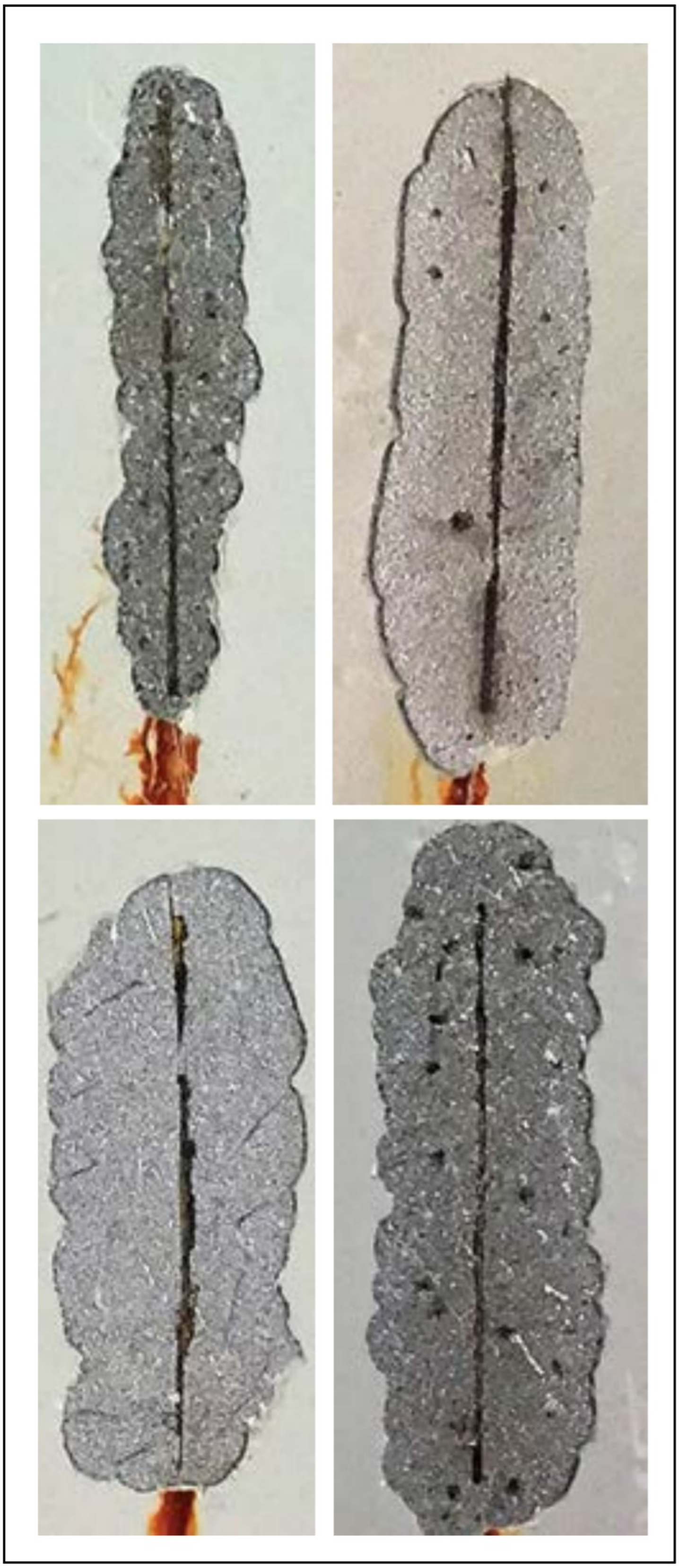

Fig. 8: Corrosion and cathodic delamination at the scribes of the panel sets (clockwise from top left: Panel Set 1, Panel Set 2, Panel Set 4 and Panel Set 3.)

the overall profile and slightly increase the peak count versus the original over-blast peak count. The peak count of reblasted profiles was less than the profile of surfaces blasted with the smaller blast media.

2. Reblasting an over-blasted substrate with smaller grit at a 90-degree orientation will smash the peaks to a lower height and push peaks horizontally when blasted at an oblique angle with the original blast media.

3. In an ASTM B117 accelerated-corrosion environment, the over-blast/reblasting scenario does not significantly affect scribe creep. An over-blasted substrate provided for significantly less cathodic delamination, likely due to the increased tortuosity of the surface profile.

4. An over-blast scenario can lead to freckle corrosion occurring under a cathodically delaminated coating in an ASTM B117 environment perhaps because of cavities formed in the profile during the blasting process allowing for the formation of black iron oxide in an oxygen-deficient environment.

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THIN-FILM COATINGS FOR PROTECTING REINFORCED CONCRETE BRIDGE ELEMENTS

BY BOBBY MEADE, GREENMAN PEDERSEN, INC.; DERRICK CASTLE, THE SHERWIN-WILLIAMS COMPANY; AND THEODORE HOPWOOD II AND SUDHIR PALLE, UNIVERSITY OF KENTUCKY

Bridges have three primary components: decks, substructures and superstructures totaling more than 1,830,000 elements. About 1,600,000 of those components are constructed of reinforced concrete. Many of those reinforced concrete components are exposed to repeated wetting with salt-contaminated water either from a marine environment or deicing salts. The presence of salt can cause corrosion of reinforcing steel and spalling/cracking concrete (Figs. 1 and 2). This results in huge maintenance and rehab concerns for bridge owners. The generally accepted action levels for chloride contamination of concrete that result in steel corrosion are as follows.

- 0.03 percent chloride to weight of concrete equals the initiation of corrosion.
- 0.08 percent chloride to weight of concrete equals accelerated corrosion.
- 0.18 percent chloride to weight of concrete equals major section loss of steel[1].

Fig. 1: Deteriorated pier cap under a leaking expansion joint. Figures courtesy of the authors.

The Kentucky Transportation Center (KTC) has investigated the deterioration of concrete bridge components[2], the effectiveness of penetrating sealers for concrete[3] and the effectiveness of thin-film coatings for concrete[4] for the Kentucky Transportation Cabinet (KYTC). Those investigations concluded that the presence of salts, primarily chloride, is a leading cause of concrete deterioration; that penetrating sealers are somewhat effective in retarding chloride intrusion into concrete; and that thin-film coatings are much more effective in retarding chloride intrusion.

KYTC sampled bridge deck concrete, at top reinforcement mat depth (2 inches), on several bridges in central Kentucky in 2002. All tests indicated chloride contents in the 0.01-percent range (by weight of concrete). By 2011, reinforced structural concrete in KYTC bridges showed visible signs of deterioration, with increasing deck and substructure damage. That same year, KTC collected concrete powder samples from 24 KYTC bridges in central Kentucky. Samples were taken from bridge deck wheel paths, deck gutters, abutments, and where accessible, pier caps. The concrete samples were taken at a depth of 1.5 to 2.0 inches and tested using a rapid chloride test (RCT) kit.

Testing revealed that chloride contamination had greatly increased from 2002 to 2011. As shown in Figure 3, many samples exceeded the 0.03-percent chloride level which initiates rebar corrosion. Chloride contamination at the upper mat level in some bridge decks had increased to 0.20 to 0.30 percent. Additionally, samples taken from pier caps and abutment seats revealed even higher levels of chloride contamination in the 0.30-to-0.40-percent range. The increase in chloride contamination is likely caused by the increased use of deicing chemicals, particularly the use of pretreatment with liquid calcium chloride. Higher chloride content in substructure elements is likely caused by the use of a different concrete mix in those elements and a much longer time of wetness on those elements.

Fig. 2: Deteriorated pier column under a leaking expansion joint.

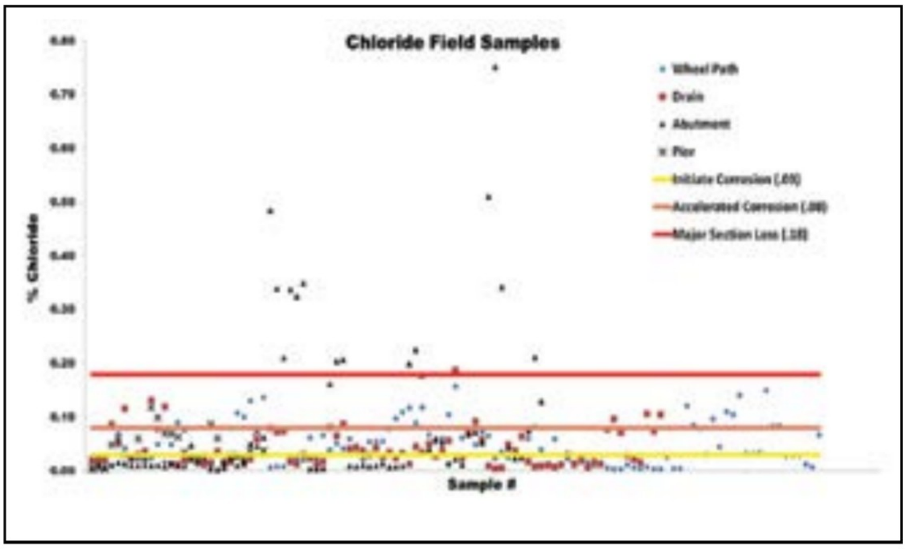


Fig. 3: Chloride content of KYTC bridge components in 2011.

As a result of the high chloride levels, KYTC authorized an evaluation of penetrating sealers for bridge deck preservation. A total of 24 products were evaluated with resistance to chloride penetration being a characteristic of primary concern. The products were applied and tested in accordance with AASHTO T259, "Resistance of Concrete to Chloride Ion Penetration," and AASHTO T260, "Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials." Samples were split and tested by the KYTC Division of Materials and KTC using both AASHTO T260 Method I and the RCT kit. Results from both methods were essentially the same. About one-third of the sealers tested reduced chloride penetration by approximately 75 percent, but most were far less effective. A conclusion based on these results is that the use of penetrating sealers can be a cost-effective preservation method for bridge decks but a more effective product is needed for other reinforced-concrete bridge components.

Fig. 4: Pier where thin-film concrete coatings were field tested.

THIN-FILM CONCRETE COATINGS FIELD TESTING

In the spring of 2013, eight thin-film coatings were applied to concrete columns of Pier 3 on the I-75/I-64 bridge over U.S. 68 in Lexington, Kentucky. Seven of the coatings tested were two-coat systems (Table 1, p. 50). The two-coat systems were a combination of urethane, epoxy, acrylic, silane, siloxane, silicon and methyl-methacrylate chemistries. The remaining system was a single-coat system based on a castor oil/gypsum mix.

This site contained a leaking expansion joint that had allowed water and deicing chemicals to spill onto the pier (Fig. 4). Before the coatings were applied, the concrete surfaces were pressure washed at 4,500 to 5,000 psi with a 0-degree oscillating tip and from a distance of roughly 1 foot. The tip was oriented approximately perpendicular to the surface. The washed concrete surfaces dried for a minimum of 24 hours prior to coating application. Air temperature ranged from 65 to 75 F, while relative humidity ranged from 45 to 68 percent during the application of all coatings.

Coatings were applied by roller. A brush was used to fill spalls or bug holes larger than one inch in diameter. Minimal effort was made to repair pinholes that developed with the roller application (Fig. 5). That effort was limited to an additional pass with the roller. Based on this field work, it is likely that most coatings applied to concrete will develop many pinholes unless special care is taken to eliminate them. The field-applied coatings were evaluated with pinholes since this would likely occur in project application.

The concrete substrate was sampled at a depth of 1⁄16 to ½ inch and 1-½ to 2 inches for

Fig. 5: Thin-film concrete coating in the field, Spalls are coated but pinholes remain.

initial chloride content and the field-applied coatings were monitored for adhesion. After one snow and ice season, there was no increase in chloride content under any coating.

Adhesive strength of the coatings was evaluated six months after their application. An automatic adhesion tester was used with 20-mm dollies. Coating adhesive strengths ranged from 478 to 1,635 psi (Table 2, p. 54). Breaks of the epoxy primer systems (1, 2 and 6) were cohesive failures within the concrete, while the other systems broke in cohesive failure of the coating or adhesive failure of the coating to the concrete.

THIN-FILM COATING LABORATORY TESTING

Laboratory testing consisted of applying coatings to concrete specimens (panels and blocks) and evaluating coatings using various performance criteria. Concrete blocks were cast for performing AASHTO T259 and T260. Blocks (12 inches by 12 inches by 6 inches) were cast using the standard KYTC AA concrete mix. After the concrete had cured for 28 days, the ponding surfaces of the blocks were blast-cleaned to an ICRI CSP3 condition. The coatings were applied to the ponding surfaces by roller and cured for 10 days prior to ponding as per AASHTO T259 (Fig. 6, p. 50).

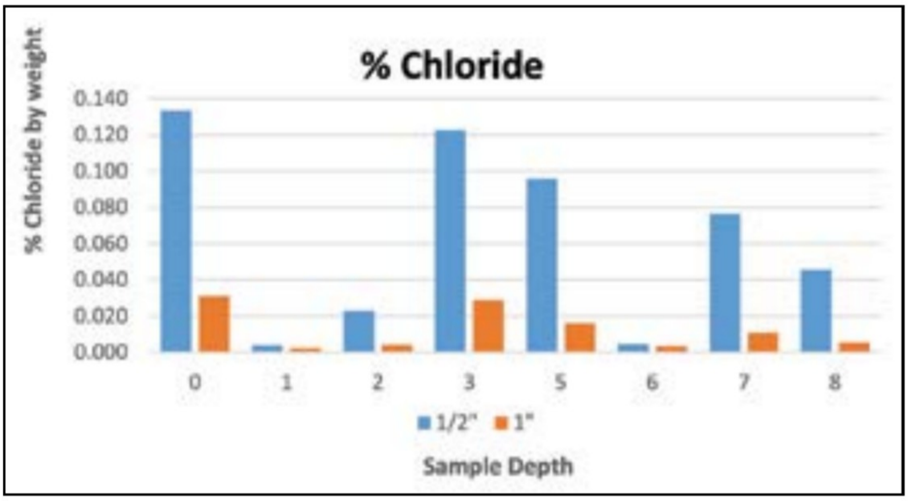
All coatings were applied by roller. It was difficult to achieve consistent film build with System 8 and it did not fill bug holes. System 4 was applied in the field but was not evaluated in the laboratory because the manufacturer insisted on restrictions that would make it unlikely that KYTC crews would use that product. All other systems could be applied in one day under normal painting conditions.

Fig. 6: Coated salt-ponding block with pinholes remaining.

Fig. 7 (Below): Chloride levels for each coating system after salt-ponding test.

Table 1: Types of Thin-Film Concrete Coatings Tested.

System	Description
1	Two component, high-solids, high-build, polyamide epoxy, applied in one coat. Two component, polyester modified, aliphatic, acrylic polyurethane, applied in one coat.
2	Two-component, high-solids epoxy, applied in one coat. Single-component, waterborne acrylic, applied in one coat.
3	Single-component, waterborne acrylic sealer, applied in one coat. Single-component, elastomeric high-build acrylic, applied in one coat.
4	Single-component, waterborne blend of silanes, siloxanes and acrylics, applied in one coat. Single-component, waterborne, silicon resin coating, applied in two coats.
5	Methyl methacrylate-ethyl acrylate copolymer sealer, applied in two coats.
6	Two-component, cycloaliphatic amine epoxy mastic, applied in one coat. Two-component, aliphatic acrylic-polyester polyurethane, applied in one coat.
7	Single-component, waterborne acrylic, applied in one coat. Single-component, modified acrylic terpolymer, applied in one coat.
8	Two-component castor oil/gypsum coating, applied in one coat.



One block was not coated prior to salt ponding to serve as a control and establish a baseline for unprotected concrete. After ponding, three locations of each block were sampled by drilling the concrete, collecting the dust and combining it into one sample. Samples were collected at depths of ¼ to ¾ inch (reported as a ½-inch depth) and ¾ to 1-¼ inches (reported as a 1-inch depth). The concrete samples were analyzed for chloride content; test results were corrected for chlorides in the concrete mix. Systems 1, 2 and 6 were more effective than the others at reducing chloride penetration (Fig. 7).

Panels at 6 inches by 12 inches by ¾ inch were cast and cured according to ASTM D1734-93, "Standard Practice for Making Cementitious Panels for Testing Coatings." The mix design called for a 0.43 water-to-cement ratio but that mix proved difficult to mold into thin panels and was then modified to a 0.53 ratio. After an 18-day cure, the panels were prepared by abrasive blasting to an ICRI CSP3 condition, the edges were smoothed with a finishing stone and coatings were applied by roller. Panel coatings cured for 20 days before initial adhesion testing. Panels were coated on their front and back sides to enable adhesion testing on the back, with color and gloss monitoring on the front (Fig. 8, p. 50).

Coating adhesion was measured according to ASTM D4541-02, "Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers." Adhesion was measured after a 20-day cure prior to weathering exposure and at 1,000-hour intervals of exposure, up to 3,000 hours (Fig. 8). Weathering exposure proceeded according to ASTM D4587-11, "Standard Practice for Fluorescent UV-Condensation Exposures of Paint and Related Coatings." Coating adhesion tended to increase with weathering exposure, which indicates additional coating curing. All weathered coating adhesion tests, with the exception of System 8, resulted in cohesive failure of the concrete substrate.

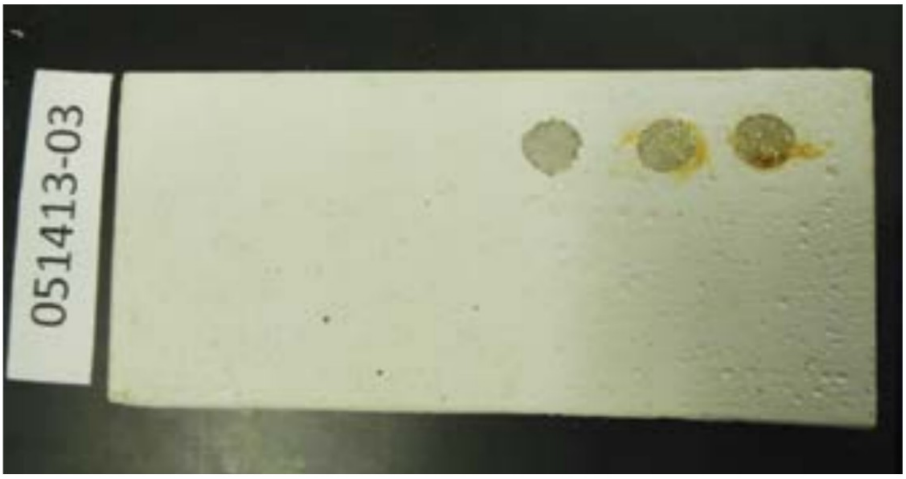


Fig. 8: Coated concrete panels for weathering testing.

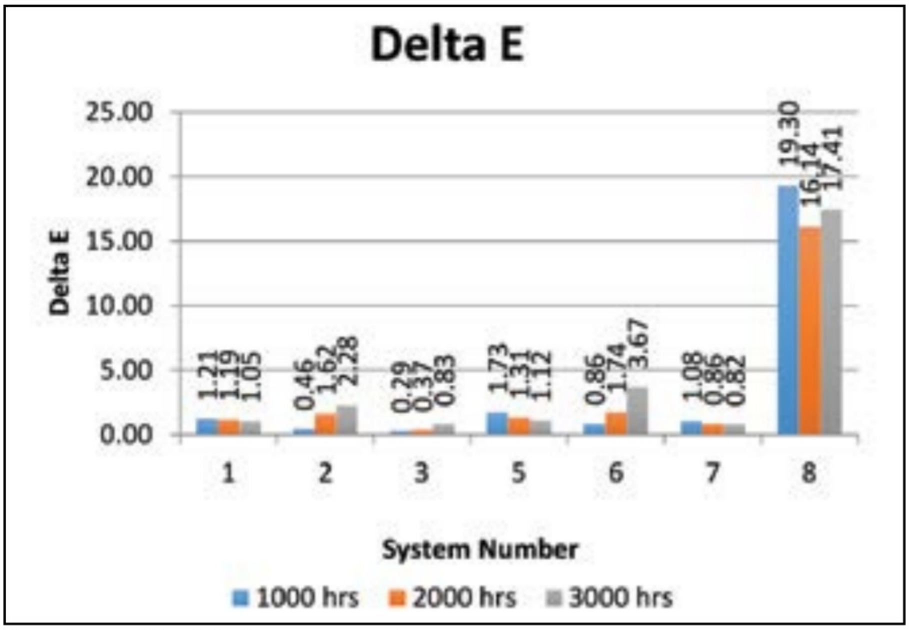


Fig. 9: Color stability of thin-film concrete coatings.

Coating adhesion test results are shown in Table 3 (p. 54).

Color and gloss retention are important characteristics to monitor when gauging coating performance[5]. Changes in these characteristics indicate degradation of the coating at a basic level, even though protection of the substrate may still be available. A 45/0 spectrophotometer was used to measure L*a*b* (three dimensional) color values and calculate a Delta-E, or change in color. One Delta-E is the color change least discernable to the human eye.

Gloss is measured by shining a known amount of light on a surface and quantifying the reflectance. Down-glossing occurs in all weathered coatings and is indicative of micro-fracturing or other degradation. A 60/20 gloss meter was used to record the 60-degree measurement. The measurement scale of a glossmeter (gloss units [GU]) is a scaling based on a highly polished reference black glass standard, which has a defined refractive index, having a specular reflectance of 100 GU at the specified angle. This standard is used to establish an upper point calibration of 100, with the lower end point established at 0 on a perfectly matte surface.

Color and gloss baseline values were established before the coatings were weathered. Those characteristics were evaluated at 1,000-hour intervals thereafter. Seven of the

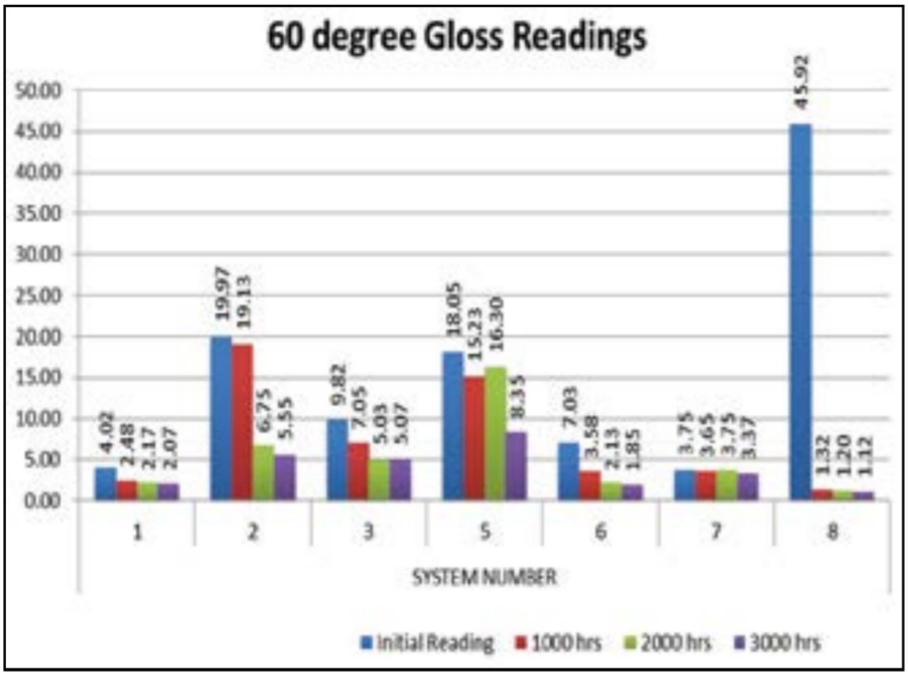


Fig. 10: Gloss retention of thin-film concrete coatings.

Fig. 11: The 2016 condition of thin-film (two-coat epoxy primer) concrete coating applied in 2004.

Table 2: Adhesive Strength and Failure Mode of Field-Applied Coatings.

System Number	Psi	Failure Mode
1	493	100% Cohesive Concrete
2	1452	100% Cohesive Concrete
3	549	100% Cohesive Coating
4	679	100% Adhesive Concrete/Coating
5	1128	90% Adhesive Concrete/Coating 10% Cohesive Concrete
6	1635	100% Cohesive Coating
7	551	90% Adhesive Concrete/Coating 10% Cohesive Concrete
8	478	100% Cohesive Coating
8	519	100% Cohesive Coating

Table 3: Adhesion of Laboratory-Applied and Weathered Coatings.

System	Pre-Exposure Psi	Post-Exposure (1,000 hrs) Psi	Post-Exposure (2,000 hrs) Psi	Post-Exposure (3,000 hrs) Psi
1	738	798	811	1,005
1	744	665	825	975
2	1,029	915	1,120	860
2	n/a	597	732	782
3	300	601	668	576
3	288	640	707	636
5	798	697	746	810
5	915	1,055	624	733
6	1,032	638	779	706
6	1,150	723	858	754
7	505	625	758	767
7	445	707	816	775
8	283	255	230	619
8	253	503	n/a	558

systems had good color stability, with Delta-E less than 4 (Fig. 9, p. 52). System 8 had a color change of nearly 20 Delta-E. Three of the systems had gloss changes of less than 5 GU but System 8 down-glossed by 45 units (Fig. 10).

SUMMARY

Steel reinforced concrete bridge components are deteriorating prematurely especially in marine and snow/ice zones of the U.S. The primary cause of the deterioration is chloride intrusion into the concrete in marine locations and where deicing chemicals are used.

Research has shown that penetrating sealers can provide some protection to the concrete but are not as effective as thin-film coatings in retarding chloride intrusion. The better performing penetrating sealers are approximately 75 percent effective in reducing chloride intrusion, while the better-performing, thin-film coatings are more than 95 percent effective.

Seven concrete coatings were applied and tested in both field and laboratory applications. Both application scenarios were by roller with minimal effort made to eliminate pinholes in the coating. Field coatings were evaluated for adhesion and the resistance to chloride penetration. Laboratory coatings were applied on concrete specimens and evaluated for resistance to chloride, adhesion, color retention and gloss retention of weathered coatings.

Adhesion of all products in both field and laboratory application was sufficient to provide a durable coating and ranged from approximately 500 to 1,600 psi. Color and gloss changes, which are early indicators of coating degradation, varied. Laboratory salt-ponding tests indicated that Systems 1, 2 and 6 have significantly better resistance to chloride penetration than do other coatings. Field testing indicated no chloride intrusion but it occurred after only one snow and ice season.

The adhesion of coatings to the substrate and their ability to resist chloride penetration are the two characteristics most important for concrete coating performance. Two-coat systems with an epoxy primer and either a urethane or acrylic topcoat performed better in these characteristics than other systems tested. Previous work conducted in 2004 also indicates the durability of two-coat, epoxy-primer systems. Figure 11 (p. 56) shows the current condition of such systems applied in 2004.

ABOUT THE AUTHORS

Bobby Meade retired from the Kentucky Transportation Center (KTC) at the University of Kentucky in 1999 with 29 years of service and accepted a position with the Kentucky Transportation Cabinet. Meade was responsible for the Cabinet's bridge maintenance painting program from which he retired in 2007. Since 2007, he has worked part-time for the KTC in the Bridge Preservation Program and part-time for Greenman-Pedersen, Inc. providing project development, project management and inspection services for the Cabinet's bridge painting program.

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$123 Billion

The estimated backlog of U.S. bridge rehab needs.

See page 16.

2

New SSPC training courses – Thermal Spray Inspector and Industrial Coatings Safety Management Training – that will be introduced at the SSPC 2018 show in New Orleans and available to the public throughout the year.

See page 4.

GMW 14872

The cyclic corrosion laboratory test employed in a study to determine the effectiveness of various corrosion prevention methods for crevices in bolted joints.

See page 20.

1,600,000

The number of components (decks, substructures and superstructures) in the Federal Highway Administration's bridge inventory that are made of concrete.

See page 46.

90 and 20-30 degrees

Two blast angles compared for evaluation of retaining peak height after reblasting.

See page 34.

86%

Percentage of PaintSquare Poll respondents who said that their company did average or above-average business in 2017.

See page 12.