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The Society For Protective Coatings

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Quality Assurance and Quality Control — We Do It, Too!

In today's world of complex coatings, contracts and certifications, there is a key consideration that ties together the total scope of the job: quality control (QC) and the related function of quality assurance (QA). What does this mean? In simple terms, quality control is the guarantee that contractors provide to ensure that they are meeting all of the contract quality requirements using their own personnel. Quality assurance involves facility owners or contract holders monitoring contractor quality control and accurately documenting observations.

How do we know who is responsible for which function? The contractor doing the work normally provides the QC personnel, while a representative of the facility owner typically performs QA. This person may be an employee of the facility or a third party contracted by the owner to protect their interests. Quality is so important that many companies have both quality control and quality assurance departments.

What qualifies someone to assume this role and responsibility? *Training.* In the coatings world, there are many training courses that qualify workers in various areas. For example, a person working on a Naval vessel may take the Navy Basic Paint Inspector (NBPI) certification program, and those working on bridges or on other industrial structures may take SSPC's Bridge Coating Inspector (BCI) or Protective Coating Inspector (PCI) certification programs to qualify for work in those areas.There are also training courses specifically designed for quality control personnel. Training is an essential element to the qualification process. It helps facility owners determine who is most capable to complete any industrial coatings work.

Successful quality control and quality assurance in coatings projects has a direct influence on meeting the contract goal. When the individuals responsible for quality effectively perform their roles, work is conducted safely and properly, and the owner is rewarded with a long-lasting paint job. Regardless of the type of coating or facility, the expectation is the same: the contractor must meet the facility owner's quality expectations as demonstrated by use of quality control and confirmed through quality assurance. Quality control and quality assurance constitute two components of the larger quality management systems (QMSs) that guide those involved in producing quality work consistently.

A quality management system encompasses the complete package of training documentation, quality manuals, health and safety manuals, methods of regulatory compliance and other evidence of a commitment to producing quality work. Establishing a QMS can be accomplished by a variety of different means and may be verified by an accreditation body. The SSPC QP programs are good examples of quality management systems that are verified and audited by an accreditation body. Contractors that have an SSPC-accredited quality management system can reassure facility owners that they have a system in place demonstrating documented training, policies, procedures and controls that meet industry standards of best practice. To an owner, this proves that a contractor is capable of meeting project goals through evidence of an established track record of successful work on similar projects, and a pattern of business conduct that has enabled them to be certified or accredited to specific industry standards of best practice.

An even broader goal for successful quality management systems involves having the accreditation entities themselves be certified or accredited by another governing body. Putting this in terms of quality control and quality assurance, you can consider SSPC to be the initial certifying authority and the

International Standards Organization (ISO) to be the governing body to which SSPC policies must adhere. The SSPC Painting Contractor Certification Program (PCCP) is now certified to the ISO/IEC 17020 standard. This means that we, as an organization, have a quality manual and are regularly documenting our internal quality control and quality assurance processes to support our own quality management system. In addition, the SSPC Qualification Program (QP) division must now undergo an annual audit to certify that it continues to meet the requirements of ISO/IEC 17020. Thus, SSPC itself now conducts business in the same manner that is expected of its PCCP- and QP-certified contractors.

Not being certified by an accreditation body does not mean that contractors are incapable of meeting owners' goals. However, being certified indicates to an owner that the contractor has met an industry standard, as verified by an outside source. Quality control and quality assurance play major roles in every aspect of the world we live in — from the clothing and toys we buy to the success of those coatings systems we apply to billion-dollar infrastructure assets. If we look at the importance of quality control and its quality assurance verification component from the asset owner's point of view, we can quickly agree that certifying quality control and quality assurance through quality management systems is a crucial aspect of good business practices. There are many domestic and international organizations that certify and accredit to recognized standards, including ISO, ANSI, ASTM and, of course, SSPC. All of these organizations verify — and, through audit programs, re-verify — that quality management systems are and remain in place for all of their certificate holders.

This brings us full-circle, back to the importance of quality control and quality assurance in our industry. Whenever you ask yourself, "How important is quality to a coatings project?" consider the entire quality process and how it affects the perception of companies to their customers.

For more information about SSPC's quality-related training programs, contact Joe Berish, SSPC corporate certification program manager, at berish@sspc.org; or call 412-281-2331, ext. 2235. Berish is an SSPC-certified Bridge Coatings Inspector (Level 2) and a NACE-certified Coating Inspector (Level 3). He has 12 years of experience as a coatings inspector, three years of experience as a quality systems auditor, and is SSPC C-3- and C-5-qualified.

Applications Open for 2016–17 SSPC Scholarships

SSPC is pleased to announce that the 2016–17 scholarship application is now available.

The program is open to any student who is beginning or continuing his or her education at an institution of higher learning in the U.S. or Canada. To be considered for the scholarship, each candidate must be a high school senior planning to enroll full-time or a student already enrolled full-time at an accredited institution of higher learning that has a three or four-year curriculum. He or she also must be a member of SSPC in good standing, or a child of an SSPC member in good standing.

To apply for the scholarship, candidates must submit a completed application form, two letters of recommendation, high school or college transcripts, a personal letter expressing why they deserve the scholarship and what they plan to do in their field of study, and finally a current senior picture or similar type of photo. Scholarship funds will be applied to the direct costs of the student's courses. Once awarded, SSPC will work with the financial aid offices of each institution to ensure proper use of the funds.

A panel consisting of three members of the SSPC Board of Governors (designated by the entire Board) will choose the scholarship recipients.

To apply, and for more detailed information please visit www.sspc.org, where you can download the application or fill out the online version. Applications must be received by April 30, 2016.

If you have any questions about the scholarship program or the application process, please contact Christine Lajzo at 412-281-2331 x2231, or email at Lajzo@sspc.org.

Free February Webinar Focuses on Oil and Gas Coatings

The second free, online webinar in the 2016 SSPC/*JPCL* Webinar Education Series will be available to participants in February.

"Protective Coatings Specified for the Upstream and Downstream of the Oil and Gas Industry," will be presented by Kristin Leonard of Bechtel Materials Engineering and Technology Group on Wednesday, Feb. 17, 2016, from 11:00 a.m. to noon, EST.

The upstream and downstream segments of the oil and gas industry present an array of unique challenges. Given the drive to cut capital costs and the need to adhere to strict environmental regulations that are inherent in this industry, the long life of a coating system and effective protection of assets is essential. This webinar will define several types of anti-corrosion coatings for the oil and gas industry, with performance properties such as intumescence and heat resistance, high levels of abrasion resistance and the durability to extend component life.

Kristin Leonard

Kristin Leonard earned a Bachelor of Science degree in polymer science and high-performance materials from the University of Southern Mississippi. After graduating, Kristin began working in Bechtel's Materials Engineering and Technology Group, where she serves as an engineering specialist for coatings and non-metallics. She is an SSPC-certified Protective Coatings Specialist and a Concrete Coatings Inspector. Kristin was also profiled in *JPCL*'s August 2015 bonus issue, *Coatings Professionals: The Next Generation*.

Registration, CEU Credits

This program is 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 this online presentation at paintsquare.com/webinars.

PaintSquare News Gets Revamp for 2016

As some readers may have already noticed, *PaintSquare News*, the daily online newsletter and *JPCL*'s sister publication, kicked off 2016 with a new, clean, responsive newsletter design geared to professionals on the go.

The changes for the revamped *PSN*, which include a new logo, larger images and fresh graphics, were rolled out with the Jan. 4 edition. The newsletter is now designed to make it easier for readers to enjoy content on mobile devices as well as desktops. The format will

provide readers with a clear, adapted view of the content no matter the access point.

Moreover, hyperlinks on phones and tablets will be more "thumb-friendly," making it easier to tap and view corresponding content on paintsquare.com as well as share with friends and followers via social media.

PaintSquare News offers more than 70,000 readers daily news and information on the marine and protective coatings industries. Topics covered include coating materials, coating application, surface preparation, quality control, health and safety, environmental controls, and program and project management.

For more information and to provide feedback, e-mail *PaintSquare News* Editor Amy Woodall at awoodall@paintsquare.com.

Outdoor exhibition area at World of Concrete 2015. Photo courtesy of World of Concrete.

Las Vegas Welcomes Back World of Concrete

The 2016 World of Concrete show and exhibition will return to the Las Vegas Convention Center from Feb. 1 to 5, 2016. This annual international event for concrete and masonry professionals will feature educational, safety and training programs; an exhibition with over 1,400 exhibiting companies; indoor and outdoor product and equipment demonstrations; networking opportunities and other special events.

The WOC technical program, which will comprise more than 100 skill-building seminars, will begin on the morning of Feb. 1, while the exhibition opens Feb. 2. Among the 675,000 square feet of exhibition space will be numerous companies with products and services that may be of interest to protective coatings professionals.

For complete, up-to-date information on the World of Concrete, including an exhibitor list, descriptions of the technical and educational sessions, and the 2016 WOC daily schedule, visit www.worldofconcrete.com.

Editor's Note

The article, "The Negative Influence of Fe_2P Pigments on the Anticorrosion Properties of Zinc Dust Primers" by Pascal Verbiest, Dr. Sc., in the December 2015 issue of *JPCL*, was based on a presentation given at the European Coatings Congress, Nuremberg, April, 2015. The acknowledgement was inadvertently omitted. We apologize for the error.

JPCL Publisher Picks New CEO

Brion D. Palmer, a media executive with 30 years' experience in the publishing industry, has been selected as the new CEO of Technology Publishing Company (TPC), the parent company of *JPCL*. Palmer began his term succeeding the company's founder, Harold Hower, as CEO on Jan. 13.

Palmer comes to TPC from Houston-based AtComedia, a global media company serving the oil and gas industry, where he held the post of president and chief operating officer. While there, he was responsible for the overall leadership, strategic planning and operational management.

Previously, Palmer was group publisher for BNP Media, a leading business-to-business media company serving industry professionals across more than 50 industries, where he managed business operation of four publications within the Food Retail Group. Palmer was also Hart Energy's vice president of publishing, where he established the strategic direction for the entire publishing operation, including its digital presence. Other publishing executive roles included vice president, group publisher of the Hospitality Group; vice president of E-Strategy; and publisher, Manufacturing Systems for Reed Business Information, a provider of data services, business information and workflow solutions to businesses.

Palmer holds a Bachelor's degree in business administration and economics from Culver-Stockton College and also earned a certification from at the American Business Media Kellogg/Medill School of Journalism's Advanced Management Forum at Northwestern University. He also served as a guest lecturer at Tuck School of Business at Dartmouth College for three years.

As CEO, Palmer will oversee the day-to-day operations of TPC, whose media properties include *JPCL*; *PaintSquare Daily News*, an e-newsletter which delivers news stories related to the protective and marine coatings industries; *D+D In Depth*, a monthly digest of technical articles related to architectural coatings; *Durability + Design News*, a daily e-newsletter which provides news and features to the architectural coatings community; and Paint BidTracker, a comprehensive business tool that provides construction project leads and market data to industrial painting contractors and suppliers.

Technology Publishing Company, founded by Hower in 1984, develops and publishes content about coatings and related construction materials in print and on digital platforms. The mission of the company is to advance the technology by disseminating information about best practices in the selection and use of these materials.

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Will LNG Exports Boost Shipbuilding? *(Dec. 17)*

Shipyards in the United States could see a major boost in newbuilding orders if a congressional mandate goes forward requiring all liquefied natural gas (LNG) exports to be transported on U.S.-built ships.

According to a new report from the Government Accountability Office (GAO), *Implications of Using U.S. Liquefied-Natural-Gas Carriers for Exports*, the U.S. is slated to transform itself from a net importer of natural gas to a net exporter. Five large-scale U.S. liquefaction facilities — necessary for converting natural gas to LNG to facilitate storage and transport — are currently under construction, the GAO says. Based on the facilities' estimates, at least 100 LNG carriers would be required to transport their full capacity. More than 30 companies have received approval for large-scale exports of U.S. LNG via specialized LNG carriers beginning in 2015 or 2016, the GAO reports, but no U.S. shipyard has built an LNG carrier since 1980, and none are registered to a U.S. operator.

With these production developments, Congress is considering legislative language to require U.S. LNG to be exported via U.S.-built-and-flagged carriers. Such a move could boost employment for U.S. mariners and shipbuilders alike. However, this optimistic view is tempered by questions regarding how the time and expense involved in constructing this number of specialized ships would affect the LNG export market.

Based on the current capacity of U.S. shipyards, building 100 carriers would likely take over 30 years, putting the shipbuilding far behind the timelines of the U.S. liquefaction facilities. Also, of the two shipyards that have sufficient space to accommodate the carrier construction, both already have orders booked that fill their production capacity through 2018.

According to industry representatives, U.S. carriers would cost about two-to-three times as much as similar carriers built in Korean shipyards and would be more expensive to operate. Based on the agency's analysis, these costs would increase the cost of transporting LNG from the U.S. (by about 24 percent, the GAO suggests); decrease the competitiveness of U.S. LNG in the world market; and may, in turn, reduce demand for U.S. LNG.

PSN TOP 10 *(as of Dec. 30)*

1. Contractor Gets $20M for Bribe Reports
2. Steel Issue Closes Forth Bridge
3. Clinton Targets Infrastructure, Jobs
4. Pipeline Blasts Lead to Jail Time
5. In $130B Deal, DowDuPont Unveiled
6. Obstacles Delay Bridge Opening 60 Years
7. Water Tower Fall Nets $180K in Fines
8. Coating Technology to Repel Water, Dirt
9. OH Contractor Nets $53M Bridge Job
10. Architect Rethinks Water Tower's Form

STUMPER OF THE MONTH

(PSN Daily Quiz, Dec. 7)

What general name is given to a coating that responds with corrective measures when corrosion is detected beneath the coating?

a. Photocatalytic coating
b. Smart coating
c. Biomimetic coating
d. Barrier coating

Answer: Smart coating. Read about various smart coating types, including anticorrosion coatings, in Cynthia Challener's *CoatingsTech* article, "The Intelligence Behind Smart Coatings."

On Selecting Coatings for New Concrete

WHICH FACTORS ARE MOST IMPORTANT IN SELECTING COATINGS FOR NEW CONCRETE?

Rodney White
Benjamin Moore & Company

Coatings must be selected to perform in the intended service environment. Is it an exterior, water-repellent finish for tilt-wall? Is it a shower wall? Is it a floor surface in a production facility? A clean room in a chip-making facility? These things must be considered before selecting any coating system — for concrete or any other surface, and each has its own set of most important factors.

Tom Murphy
VP Marketing LLC

This is a great question. I agree with Rodney that the selection process starts with determining the performance criteria. The next factor to consider is the surface condition and the surface prep required for the systems selected. The next challenges are the installation conditions and schedule requirements. Now that you have narrowed the field of options, you can determine which fits the budget and life cycle requirements for the intended use and maintenance.

Randy Nixon
Corrosion Probe, Inc.

I can only build on the comments from the other two experienced gentlemen by adding a few words to the wise based on a number of years of experience. The three things that must go into selecting coatings for success on new concrete are as follows.

1. The coating system must be able to meet the exposure conditions while being capable of curing under the actual field conditions. This will include the all-important moisture properties of the new concrete. Products with greater moisture tolerance during cure are therefore desirable for new concrete. This, of course, is provided they can be resistant to any chemical or physical exposures inherent to the specific application.

2. The coating system must be capable of achieving good film quality, meaning no pinholes, holidays or other types of discontinuities. This is particularly crucial for concrete due to its many non-homogenous properties, i.e. "bugholes" or entrapped air voids. This means the system must be capable of filling and surfacing the substrate sufficiently to prevent discontinuities from being created via the outgassing of entrapped air during coating system application. Film quality is simply more difficult to achieve on concrete than on steel. In this same line of reasoning, the coating's film thickness must be appropriate to assure good hiding properties to avert discontinuities.

3. The coating system must provide adequate adhesion to the concrete. This goes without saying, but is worth repeating because different degrees of cleanliness and wide variations in concrete surface profile can be appropriate for a wide range of coating products. Selecting the coating system which will provide good adhesion as necessary for the intended surface conditions is a worthy consideration.

Sporadic Interior Pipe Corrosion and Perforations

CORROSION CONTROL ON A PIPE INTERIOR CARRYING SALT WATER AT ALMOST TWICE THE CONCENTRATION OF THE OCEAN

By Warren Brand, Chicago Corrosion Group, LLC

The owner, an oil producer located in the scrub of the southwestern United States, has hundreds, perhaps thousands, of carbon steel risers scattered around hundreds of square miles of productive oil wells.

The pipes range in size from 4 inches to 8 inches in diameter and over the years, tended to perforate and leak in no predictable manner. Some of the locations of the risers were in exceedingly delicate environmental areas, occupied by barrel cacti, tumble weeds, scorpions, bats, lizards, coyotes and other varmints. Leaks here are very costly due to environmental cleanup requirements, even though the main liquid running through the pipe was a blend of mostly salt water and petroleum products. In fact, the chemical analysis of the water looked like the answers to a college chemistry test with the one constant being high concentrations of chlorides (salt) of around 55,000 ppm. As a reference, seawater has a concentration of around 35,000 ppm.

The water was also not consistent in terms of its constituents, as they could change over time. Further, while chlorides are always an issue from a corrosion perspective, they were even more problematic in this dynamic environment where, as any uncoated interior piping would rust, the rust would be quickly removed, exposing new, bare steel. In contrast, structural steel, for example, will rust when exposed to chlorides, but the rate of corrosion can sometimes drop as the rust builds up, protecting the un-corroded steel underneath. That was not the case with this pipe system.

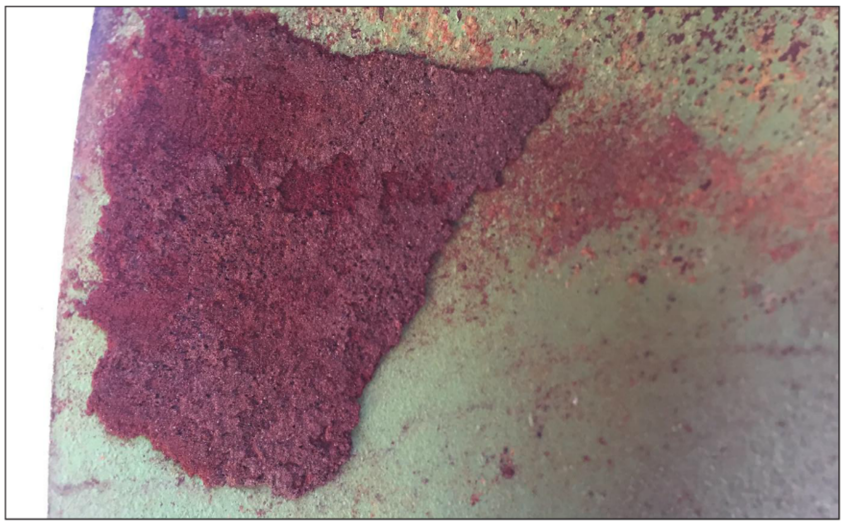

Fig 1: Residue on pipe interior.
Photos courtesy of the author.

To complicate matters further, there were solids running through the system, leading to some level of abrasive action on the pipe interior.

There was also paraffin wax in the water. Data indicated that on occasion, the paraffin wax would deposit onto the pipe wall interiors, providing some corrosion protection (the water was typically around 64 F and paraffin melts at approximately 115 F). It was not, however, possible to conclusively determine if that was the case — and, further, determining if it was would have been of no value to the owner.

Also of note in the water stream was iron content ranging from 24-to-112 ppm, likely contributing significantly to the adherent residue remaining on the pipe interior (Fig. 1). The owner also reported oxygen concentrations levels ranging from .04 to 2.0.

Further complicating inspection work was the length of the pipes, which varied from a few feet to more than 20, severely limiting access to areas beyond arm's-reach.

Observations

At first glance, much of the pipe interiors were coated with a dark, rusty-looking residue which made visual inspection of the existing coating system difficult. When damp, this residue was in some cases easy to remove (Fig. 2). However, in other areas, the residue was very difficult to remove, even with solvent.

In some cases, the owner had cut and removed several sections of piping that had perforated. From the pipe exterior, the perforation looked like one would expect — a slightly elongated hole. However, the owner was requested to cut the pipe along the diameter at the center of the perforation to get a side view. The side view of the perforation

Fig. 2: A dark residue on the pipe interiors was sometimes easy to remove and sometimes difficult to remove, even with solvent.

Fig. 3: Significant corrosion surrounded a perforation in the pipe.

revealed significant corrosion of the surrounding areas showing a clear "V" configuration (Fig. 3).

During inspection of the pipe interior, other areas were identified which had the exact same corrosion pattern but had not yet perforated, as if someone had scooped ice cream out of a 5-gallon tub.

The owner mentioned that the pipe interiors had been lined by two different shops using different materials. It was unknown which materials were used at all, and certainly not within each pipe.

In the same run of pipe which exhibited through corrosion, there were areas where the pipe had no coating at all, yet exhibited virtually no signs of corrosion. In these areas the iron oxide may have combined with the paraffin wax in the water to provide some type of corrosion resistance.

In all cases, where the paint remained, the coating appeared intact. In one set of pipes, the paint was largely intact and

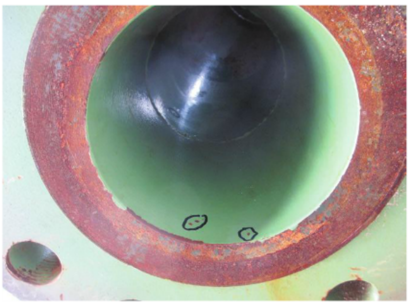

Fig. 4: Holidays were found in an area of pipe interior where the coating was otherwise intact.

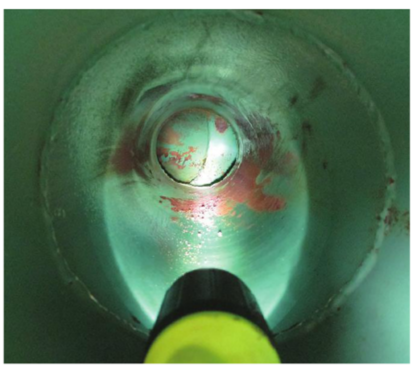

Fig. 5: A largely intact coating system despite a significant area of corrosion.

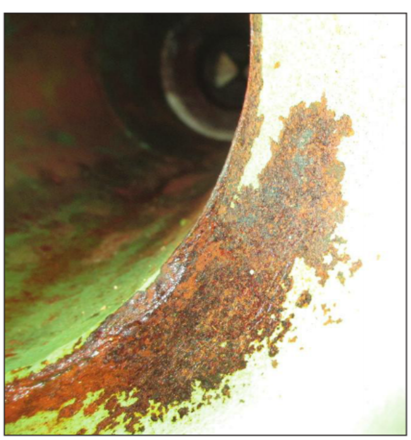

Fig. 6: A close-up of the corroded area referenced in Figure 5 above.

exhibited only small, isolated areas of corrosion. Even in these pipes, however, there were anomalies in terms of how the corrosion manifested. For example, Figure 4 (p. 17) shows a largely intact coating system with two holidays. The holidays exhibit only minimal, general corrosion with no apparent undercutting.

In contrast, Figure 5 (p. 17) shows a largely intact coating system other than a corroded area at the wye of the pipe (all of the other dark areas are sediment). A close-up view of this rusted area reveals active pit corrosion with progressive deterioration of the coating system (Fig. 6, p. 17). It is possible that the residue within the pipe system provided some coincidental corrosion resistant properties, except in areas where the water and suspended solids impacted the pipe wall, thus removing, or not allowing, the sediment to collect, and increasing the corrosion rate in those isolated areas

In other pipe runs, much of the coating system was gone and yet they exhibited little-to-no corrosion. In the same pipe run, however, there were areas of poorly applied coating with severe corrosion and undercutting (Fig. 7). The reason for these discrepancies remains elusive.

Neither coating system exhibited any apparent signs of chemical attack or degradation. There were no apparent blisters, cracking, crazing, blemishes, softening or any other visual evidence which would indicate that the coating system was incompatible with the salt water.

There were, however, other very serious concerns. In one case, the dry film thickness (DFT) at one end of a pipe varied around the internal circumference of

Fig. 7: An area of poorly applied coating with severe corrosion and undercutting.

Fig. 8: Pull-off adhesion testing wasn't possible due to the small diameter of the pipe.

the pipe from approximately 3 mils to 25 mils. At the other end of the same pipe, the coating ranged from 10-to-14 mils. The DFT varied on all of the pipes with some averaging in the mid-teens and other pipes averaging less than 10 mils. The lowest readings taken (in multiple locations) were 1-to-2 mils.

wasn't possible due to the small diameter of the pipe (Fig. 8). X-cut adhesion testing was performed where the coating appeared to be reasonably well-adhered (4A to 5A, as per ASTM D3359, Standard Test Methods for Measuring Adhesion by Tape Test) but was very brittle (it was not known what type of coating system this was) (Fig. 9). The test results may have also been compromised due to the difficulty in obtaining adhesion to the recently cleaned area. As mentioned earlier, an adherent residue remained on the pipes and even after chemical cleaning, some type of residue, possibly paraffin wax, remained.

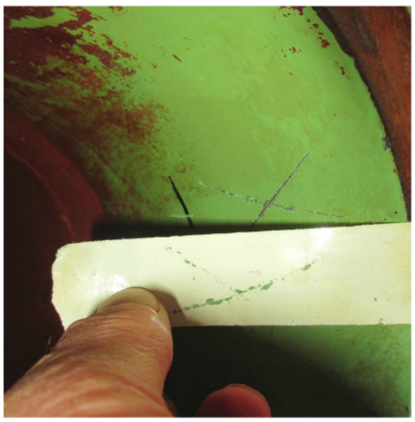

Fig. 9: X-cut adhesion testing was performed as per ASTM D3359 where the coating appeared to be reasonably well-adhered.

Fig. 10: Adhesion testing exposed a white coating or primer beneath the green coating.

As mentioned earlier, the owner had been shipping pipes to two different local vendors and wasn't sure what coating system was used by either one. In one case, they believed the coating was a liquid-applied epoxy. In the other case, it was a powder coating application. In either case, the owner was relying on the coating applicator not only for the material selection, but for all of the QA/QC as well.

Further testing was carried out with limited results. Pull-off adhesion testing

The appearance of a white coating or primer beneath the green coating discovered during the X-adhesion testing further confused determination of the type of coating system used (Fig. 10, p. 19). However, the white material was not evident in other areas, as noted when scraping other lose areas and when Tooke gauge readings were carried out.

Conclusion

Data increasingly indicated that the failure of these materials to prevent the pipe from perforating was due to application issues. Further, it appeared that the adherent residue, likely a blend of iron oxide and paraffin wax, might be providing some corrosion protection in those areas of the pipe which did not experience turbulence during operations. This might explain the frustratingly inconsistent perforating the owner had been experiencing.

Solutions

It was recommended to the owner to avoid additional testing and lab costs, and to simply move forward and focus on what was working. The data clearly supported that in each area where the coating was applied properly and well-adhered, corrosion was not an issue.

The owner hired a competent corrosion consulting firm to identify an optimal, internal corrosion mitigation material and develop application specifications for submittal to local shops. It was determined that one of the coating systems installed, a powder coating system, appeared to be performing better than the liquid applied material. The owner had a relationship and preference for a specific local contractor who was a powder coating applicator.

The consulting firm identified an epoxy-based powder coating solution and made some modifications to the manufacturer guidelines. For example, the initial specifications from the manufacturer required a DFT from 8-to-12 mils. With the approval of technical support staff from the material supplier, the consultant changed the specification to 8-to-20 mils. This allowed the applicator a greater range of freedom and the additional material on the pipe interior could only benefit the owner. The consultant also recommended that the coating system be brought up and onto the flange face to reduce the likelihood of undercutting as there were several areas within the pipe system that exhibited undercutting of the coating system at the flange.

The owner is in the process of developing an in-house quality assurance program including DFT readings, holiday testing and coating-cure determinations (either solvent wipe or hardness testing).

Prepare Hot-Dip Galvanized Coating Surfaces for Painting

By Dr. Thomas J. Langill, American Galvanizers Association

Hot-dip galvanized steel parts or assemblies are often required to be painted, either to identify a structure, for architectural reasons, to provide a particular type of protection, to prevent severe corrosion attack of zinc in an acidic environment, or to extend the service life of an existing structure. The combination of a paint system with a hot-dip galvanized coating is referred to as a duplex system[1]. When paint and galvanized steel are used together, the corrosion protection is superior to either protection system used alone[2].

The application of a paint system onto a hot-dip galvanized surface requires careful surface preparation and a good understanding of both corrosion protection systems. The margin for error is small when dealing with newly galvanized steel surface preparation. However, there have been many examples of paint adhesion problems on older or more moderately aged galvanized steel surfaces, and the most common cause is improper or incomplete surface cleaning and preparation[3].

The adhesion of paint onto galvanized steel can become a small problem when the galvanized coating has weathered for at least a one-year period. The zinc corrosion products form a very dense, insoluble protective layer that accepts a paint coat readily. A brand new galvanized coating also experiences few adhesion problems within the first 24-to-48 hours after coating. Although these two conditions can yield a sustainable duplex system, the most common timing for applying paint onto a galvanized part is between 2 days and 6 months after galvanizing, where there can be many preparation issues to be handled in order to obtain an intact duplex system.

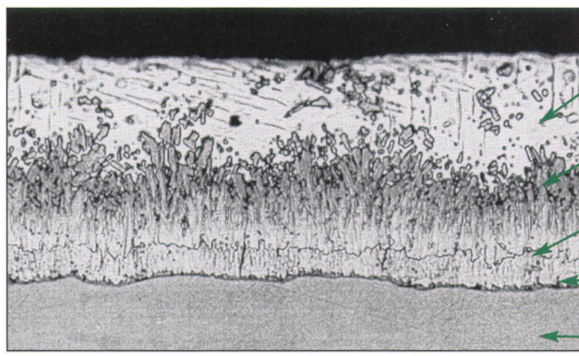

Fig. 1: Microstructure of hot-dip galvanized coating on steel. Figures courtesy of the American Galvanizers Association.

Galvanized Coating Application

Hot-dip galvanized coatings can be applied in two different ways. The parts can be fed into a liquid zinc bath in a continuous roller process, where the coating characteristics are highly dependent on the speed of the steel through the bath. The two most common steel products that are hot-dip galvanized using this process are sheet and wire. The objective of the continuous process is to deposit a zinc coating that is smooth, thin and composed of nearly all zinc-bath metal with very little zinc-iron intermetallic. The coating can be alloyed to form a dull gray intermetallic coating, which has a good surface profile and can be easily painted.

The second type of hot-dip galvanizing process is often called the "batch" process, because individual steel pieces or assemblies are dipped in a molten zinc bath as individuals or as groups. The coating is formed by the interdiffusion of zinc and iron. A micrograph of a typical batch hot-dip galvanized coating is shown in Figure 1. The coating forms four distinct layers or intermetallics. The first layer is called the gamma layer, which has 75-percent zinc and 25-percent iron. The next layer, the delta layer, has 90-percent zinc and 10-percent iron. The third layer is called the zeta layer, which has 94-percent zinc and 6-percent iron, and the final layer is called the eta layer and has 100-percent zinc and no iron. The coating growth depends on the chemistry of the steel to allow iron atoms to diffuse through the steel and the already formed zinc/iron intermetallic to interface with the zinc bath metal, forming additional coating. Figure 2 shows a typical coating on steel with reactive silicon chemistry. The coating consists of 100-percent zinc/iron intermetallic, and the surface is dull grey and rough after coating.

During the batch hot-dip galvanizing process, a number of variables can affect

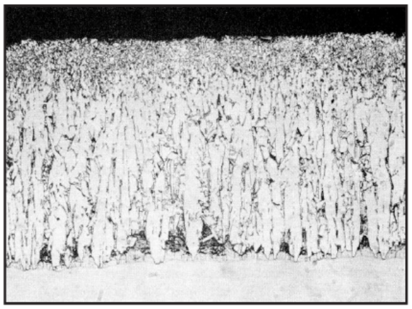

Fig. 2: Microstructure of reactive steel hot-dip galvanized coating.

the coating thickness, the primary factor of which is the steel chemistry, with the most influential elements being silicon and phosphorous. These two elements promote the interdiffusion of zinc and iron and cause the hot-dip galvanized coating to become thick and filled with intermetallic. Figure 3 shows the coating weight of two different types of steel versus the time spent in the molten zinc

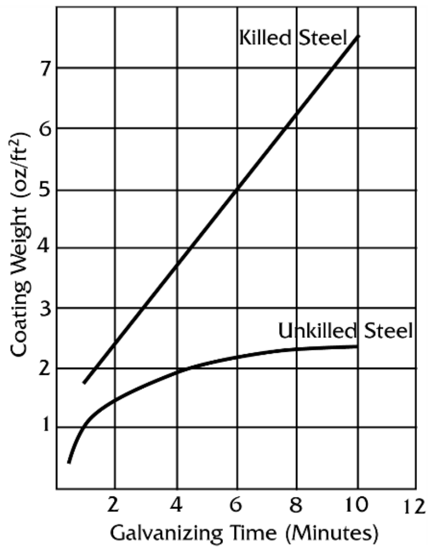

Fig. 3: Coating weight of hot-dip galvanized coating versus galvanizing time for two different steels.

bath. The normal steel curve shows the galvanizing reaction is self-limiting and will cease to increase the coating weight when the diffusion of zinc and iron becomes a very slow process whereas, with the reactive silicon steel, the reaction continues to add coating weight to the part as long as the steel is in the galvanizing bath. The reactivity of the steel is determined by the amount of silicon and phosphorous in the steel.

The coating produced when the steel is reactive contains intermetallics of iron and zinc. This means that the surface will not be bright and shiny, but rather dull gray and slightly rough. This intermetallic surface makes a very good anchor for paint systems. The main concern with reactive steel galvanized coatings is the thickness of the coating. If the coating is too thick, it may become brittle and will be susceptible to applied stresses that may separate the galvanized coating from the steel underneath. Knowing the silicon and phosphorous content is very important when producing a quality galvanized coating.

Galvanized Coating Surface

Many galvanizers apply post-treatments to their galvanized coating to prevent the formation of excessive zinc oxide and zinc hydroxide. Additionally, the galvanized part is sometimes quenched in a water bath to accelerate cooling. These treatments and quenching should be avoided if the galvanized part is to be painted. The post-treatments will change the surface chemistry of the coating. While some of these treatments (such as phosphating) produce better surfaces for painting, others (such as chromating) will produce a surface that is difficult to paint. Water quenching, in itself, is not harmful to the surface, but the quench bath often has small amounts of oil, grease or flux on the surface, which could interfere with paint adhesion. Consult with the galvanizer and the paint company before applying a post-treatment to galvanized steel that is to be painted.

A galvanized coating of zinc protects the steel by providing both a barrier to atmospheric elements and cathodic protection to the steel. The corrosion protection of the zinc originates from the dense, insoluble corrosion product layer that forms over time on the zinc surface. Newly galvanized non-reactive steel is bright and shiny, and is pure zinc on the surface. This surface is fairly smooth, so during the first 24-to-48 hours after galvanizing, only a slight roughening of the surface is needed to prepare the galvanized coating to be painted.

The first step in the transformation of the zinc coating surface is the combination of zinc-metal with oxygen and moisture to form zinc oxide and zinc hydroxide on the surface of the galvanized coating. The conversion of some of the zinc oxide to zinc hydroxide occurs soon after the zinc oxide is formed and depends on the amount of available water in the air, or as a result of dew or condensation. These corrosion products are water-soluble, so they are often washed off of the zinc surface in the presence of rain or condensation. This zinc oxide and zinc hydroxide formation occurs in the first couple of months after galvanizing.

The final step in the corrosion cycle is the conversion of zinc hydroxide and zinc oxide to zinc carbonate. This happens in the presence of freely flowing air across the exposed surface. The carbon dioxide from the air reacts with the zinc oxides. The resulting zinc compound, zinc carbonate, is insoluble in water and forms a very dense layer on the surface of the coating. This layer will erode very slowly over time, but it provides a barrier to the further consumption of zinc-metal from the galvanized coating. The corrosion rate of the overall system depends on the rate of zinc carbonate erosion or dissolution. Very basic (pH above 12.5) or very acidic (pH below 4.0) solutions can dissolve this layer more rapidly. The corrosion rate changes most rapidly in the low pH atmosphere because acidic solutions quickly dissolve the zinc carbonate layer.

The zinc carbonate layer is a very dense and slightly rough layer. Paint adhesion to this layer is extremely good with little-to-no surface preparation. Galvanized articles that have been exposed to the atmosphere for more than one year are completely covered with the zinc carbonate layer.

The two conditions of galvanized steel that need little-to-no surface preparation are the newly galvanized part that is less than 24-to-48 hours removed from the zinc bath and the weathered galvanized steel part that has been exposed to the atmosphere for more than one year. Galvanized articles that do not meet these two conditions need surface preparation to remove the zinc oxide and zinc hydroxide from the coating before applying a paint coating. Unfortunately, most galvanized steel articles fall into this last category — partially weathered galvanized steel — as few galvanizing facilities have painting capability in their galvanizing plant. As a result, the parts are galvanized and then shipped to a paint shop or to the field and painted some days after they have been galvanized.

Surface Preparation

Successful surface preparation is the key to producing adherent coatings on galvanized steel and realizing the benefits of a duplex system. The pole shown in Figure 4 (p. 30) has peeling paint as a result of poor surface preparation. The surface contained zinc oxides and hydroxides when the paint was applied. The coating appeared to adhere to the surface, but after two-to-three years in service, the zinc oxide began to separate from the underneath zinc metal. As paint was adhering to the zinc oxide, it separated from the pole surface at that time.

Surface Cleaning

When cleaning a galvanized surface prior to painting, the goal is to remove any organic contaminants such as dirt, grease or oils; any zinc compounds such as zinc oxide or zinc hydroxide; and salts deposited on the surface during part transportation. At the same time, care must be taken not to remove too much of the galvanized coating. Alkaline cleaning, ammonia cleaning and solvent cleaning are the most common ways of removing organics from a galvanized surface. As some cleaners may react differently with different paint systems, the paint manufacturer should be consulted for specific reaction problems.

Oil, grease and dirt can be removed by using an alkaline solution in the pH range of 11-to-12, but not greater than 13 as this will damage the zinc coating. Most alkaline cleaning solutions are nominally 2-to-5-percent sodium compounds with small additions of emulsifying or chelating agents. The solution can be applied through dipping, spraying or brushing with a soft bristle brush (preferably nylon, definitely not copper or steel bristle brushes). If dipping or spraying the solution, the temperature range that works best is between 140 and 185 F. For newly galvanized steel, a water-based emulsifier can be used to remove contaminants. After cleaning, thoroughly rinse the surface with hot water and allow it to dry; heated drying is preferred.

Mineral spirits, turpentine, high flash naphtha, and other typical cleaning solvents can be used to clean galvanized surfaces, provided they are applied with lint-free rags or soft bristle brushes. The rags and brushes must be changed often to prevent re-applying the contaminants. After cleaning, rinse thoroughly

Fig. 4: Galvanized pole with peeling paint.

with hot water and allow the surface to dry completely.

A solution of 1-to-2-percent ammonia applied with a soft bristle brush can also be used to clean galvanized surfaces, although this method is typically reserved for cleaning parts with zinc ash residue. As a piece of steel is removed from the galvanizing kettle, it may pick up particles of oxidized zinc from the bath surface, otherwise known as zinc ash, which must be removed prior to painting. After cleaning, thoroughly rinse the surface with hot water and allow it to dry completely.

The removal of organics using brushing will also remove the zinc oxide and zinc hydroxide as these compounds are loosely bonded to the zinc metal of the coating by electrostatic forces. The brushing motion will separate the zinc compounds from the zinc metal.

After cleaning and drying the galvanized part, if there are still areas that have a white powdery appearance on the surface, there may be salts of zinc that were not cleaned with the brushing and solutions and may need to be cleaned with a more powerful cleaner.

Surface Profiling

In order to provide a good adhesion profile for the paint, the galvanized surface must be flat with no zinc bumps, runs or spikes on the surface. During the removal of the galvanized article from the zinc bath, the excess zinc runs down the edges of the part and can sometimes build up at a protrusion or irregular edge. The zinc can also form spikes at the edge where it drains off of the part. These high spots and spikes must be removed before painting, as they will be very difficult to coat. The high spots and spikes are usually ground-off with hand-tools or power-grinders. Care must be taken to ensure that the galvanized coating is not removed when grinding or filing the surface. This step is typically done at the hot-dip galvanizer's facility before the parts are sent to the painter.

Once the parts reach the painter's facility and the surface cleaning is accomplished, the surface must be roughened to provide an anchor profile for paint application. In order to roughen the typically smooth galvanized surface after cleaning, an abrasive sweep or brush-blast may be used. Care should be taken to prevent removing too much of the zinc coating. Particle size for a brush-blast of galvanized steel should range between 200 and 500 microns. Aluminum/magnesium silicate has been used successfully in the brush-blasting of galvanized steel, as seen in Figure 5 (p. 32). Organic media such as corncobs and walnut shells or minerals such as corundum, limestone and sands with a Mohs hardness of 5 or less may also be used. Any blast media containing iron should be avoided, as this will react with the zinc surface and cause paint adhesion issues. The removal of less than 25 microns of zinc is the target for a brush-blast, with a final profile of 18.5 microns.

When blasting, the temperature of the galvanized part can have a significant effect on the finished surface profile. Brush-blasting while the galvanized part is still warm from the galvanizing process (175-to-390 F) provides an excellent profile for painting. Ambient conditions for brush blasting are recommended to be less than 50-percent relative humidity with a minimum temperature of 70 F.

The process of brush-blasting (SSPC–SP 16, "Brush-Off Blast Cleaning of Non-Ferrous Metals") should not be confused with "Near-White Blast Cleaning" (SSPC-SP 10/NACE No. 2) that is used to clean uncoated steel before applying paint systems. This "near-white" blasting will remove the galvanized coating and negate the corrosion protection afforded by the zinc. Brush-blasting is best performed by an experienced applicator. The blast angle to the galvanized part is recommended to be 30-to-45 degrees. If the blast angle is near 90 degrees, the blasting can quickly remove the protective zinc rather than the zinc oxide particles on the surface of the coating. At the conclusion of the brush-blasting, the part should be rinsed to remove any blast media on the surface and dried thoroughly (heated drying is preferred).

If the brush-blasting is not performed, or there are no skilled brush-blasters, then the following post-galvanizing treatments can be used to provide a paintable surface on partially weathered galvanized steel.

Penetrating Sealers

Two-part epoxy penetrating sealers are sometimes used to form a 50-micron-thick coating on the galvanized

Fig. 5: Sweep blasting of galvanized steel surface.

surface after cleaning. These products can be particularly effective as surface treatment methods on surfaces that have had zinc oxide and zinc hydroxide removed during the cleaning process. Follow the manufacturer's directions for application and always use a topcoat over the penetrating sealer.

Zinc Phosphate Treatment

Zinc phosphating is a conversion coating that passivates the zinc surface and blocks the formation of zinc oxides. The phosphate treatment can be applied by immersion, spray or soft bristle brush and should be left on the galvanizing surface between 3 and 6 minutes. The piece should then be washed with clean water and allowed to completely dry. This type of treatment is appropriate for most types of paints but does not perform well with zinc-rich paints.

Wash Primers

This treatment uses a metal conditioner to neutralize surface oxides and hydroxides, as well as etch the galvanized surface. Wash primers should be applied to the galvanized surface to form a protective layer of 7-to-13 microns thick. If the thickness exceeds 13 microns, paint adhesion can become a problem. The critical thickness layer dictates that this process is to be done in shop conditions. Field application of this treatment results in thick and irregular protective layers. When using wash primers, the manufacturer's directions should be followed for maximum performance.

Acrylic Passivation

This treatment uses an acidic acrylic solution to passivate the galvanized surface, as well as to roughen the smooth zinc coating. Acrylic passivation should be applied approximately one micron thick to a clean galvanized surface. The passivation layer should be dried completely before applying paint to the surface.

Paint Selection

The proper selection of a paint system for a certain engineering need is the province of the architect and the engineer. There are many options depending on the intended use of the duplex-coated part, the application method and place for the paint system, environmental concerns, and aesthetics of the total system. Many paint companies offer good paint systems that are designed to work with galvanized steel. Consult your paint manufacturer for the proper paint selection.

Conclusion

The increased lifetime that can be provided with a combination of paint over galvanized steel makes this type of corrosion protection system very attractive for structures designed to last a long time in aggressive atmospheres. The secret of good painting on galvanized steel is the surface preparation of the galvanized surface. Following the correct surface preparation procedures can give a satisfactory duplex system.

About the Author

Dr. Thomas J. Langill has been with the American Galvanizers Association for

21 years as technical director. He presents information on galvanizing to the corrosion protection and metal coatings industries and fosters relationships with technical organizations including SSPC, ASTM International, NACE and the International Standards Organization (ISO). Langill holds Bachelor of Science and Master of Science degrees in physics from John Carroll University and a Ph.D. in materials science and engineering from Northwestern University.

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2016 COATINGS INDUSTRY FORECAST

Major coating manufacturers and *JPCL* readers share their thoughts about what's ahead in 2016.

Brad Rossetto

President and General Manager
Sherwin-Williams Protective & Marine Coatings

Given the current state of infrastructure in the United States, you don't need a crystal ball to know that 2016 brings with it a heavy focus on extending the life of aging assets. Coatings will play a major role, particularly in bridge and water infrastructure enhancements.

Nearly 60 percent of the nation's bridges are concrete. Most are untreated and eroding due to salt, chemicals and weather. Many are also approaching or exceeding their design lives. However, bridge replacements will be rare, as current spending is far less than the billions of dollars the Federal Highway Administration estimates will be needed annually to update existing bridges over the next 16 years. That means transportation departments will rely more heavily on high-performance coatings to maximize bridge service lives and conserve public works budgets.

Municipal water facilities have similar goals. The U.S. population has more than doubled since 1950, yet people still live in the same concentrated areas. This population growth has taxed — and overstressed — water facilities, many of which have exceeded their planned lives by more than 20 years. Like the bridge market, tight budgets have curbed new water infrastructure construction spending. Therefore, municipalities are looking to coatings to economically restore cracks and corrosion to extend infrastructure life.

On a global scale, the issue of corrosion under insulation (CUI) will continue to drive opportunities for protective coatings. Mitigating CUI is a major expense for industrial facilities worldwide, costing the average chemical plant and refinery hundreds of thousands of dollars annually. More plants are learning that thermal insulative coatings can eliminate the hidden threat of CUI to help them stay up and running longer, while also protecting assets and personnel.

From bridges to water facilities to plants — and many areas in between — 2016 is ripe with opportunities for the coatings industry to extend the lives of infrastructure and assets.

Doug Moore

VP of Global Marketing & Business Development
Carboline Company

The upstream oil and gas market is in the process of contraction due to the decline in the price of oil. This affects global oil and gas producers, drilling companies and the marine operations that support them. There are exceptions, but they are few. The industry still presents a robust market for coatings long-term, but near-term outlook for coatings, linings and fireproofing products is slow.

The midstream and downstream oil and gas market segments certainly feel the impact of low oil prices, but they are much less affected. Transporting crude oil, natural gas and hydrocarbon products will continue to be a necessity and many LNG projects requiring coatings and fireproofing will continue. The pipeline segment will continue to require coatings for new construction, driven by a need for increased capacity, and coatings for maintenance activity which is driven by government regulations that require corrosion protection systems to be kept in good working order. The downstream petrochemical segment will continue to present global new construction and maintenance opportunities for coatings, linings and fireproofing. The demand for intermediate and finished chemical products continues to be stable.

Opportunity will continue for the coatings industry in the power market, particularly conventional power since fuel supplies are lower cost. We also expect infrastructure/public works activity to offer good opportunities for coatings, linings and fireproofing including bridges, commercial building, transportation segments, water, wastewater and more.

Oscar Wezenbeek

Managing Director – Marine Coatings
AkzoNobel

Protective and marine coatings markets face a number of challenges over the coming year.

Lower ordering at mayor shipyards, particularly in South Korea and China, and an oil and gas industry capital spending decline is having an effect on the markets.

However, this is being offset by continued strength in a number of key segments. These include the downstream oil and gas and power markets for protective coatings, and in sectors where sustainability is an important factor, such as marine fouling control. In both protective and marine markets, demand for maintenance and repair and associated services is also robust.

Lower oil prices have impacted mainly the upstream oil and gas sector, with some big projects cancelled or delayed. However, we are seeing more favorable conditions, and with those, opportunities in the downstream sector, including refining and petrochemical production. There is also continued opportunity in the power market, both in thermal power plants and the renewables sector, particularly offshore wind energy production.

In the marine business, the delivery of new ships increased last year for the first time in several years, and dry dock maintenance work is steady. We see some evidence that the bottom of the cycle has been reached in marine new-build, although new contracts are declining. However, the long-term outlook for marine remains strong, as wealth and international trade continue to increase.

Tim Knavish

Global Vice President
Protective & Marine Coatings
PPG Industries

We continue to see investment in liquefied natural gas and chemical processing facilities where both conventional protective coatings and fire protection coatings are applied. Additionally, while lower crude oil and natural gas prices have resulted in a reduction in exploration and drilling activities both onshore and offshore in 2015, existing assets need to be maintained and the maintenance sector will remain active. Also, downstream storage and refining of crude oil remain opportunities for coatings. It will be difficult to predict spending in civil infrastructure until the U.S. Congress acts on holistic infrastructure legislation. Finally, the rail segment in North America continues to build freight cars to service the chemicals industry, crude oil in the absence of pipelines where needed, and the agriculture sector, which represent additional opportunities.

The new-build global marine market remains depressed and has yet to recover from pre-2012 performance, but supporting sales for maintenance and repair work on ocean vessels, cruise liners and inland marine vessels is improving in the form of dry dockings and sea stock. The U.S. government has shown their intention to continue building new Coast Guard vessels and Navy ships as needed, so opportunities continue to exist with government-funded projects as long as funding levels do not shift. More sustainable technologies such as copper-free anti-foulants and products that further improve the fuel efficiency of vessels will continue to be an area of focus.

The primary challenge will be the continuation of low crude oil pricing and its impact on drilling investments and the supply chain of services and products that support this segment. This will have an impact on coatings sales into the oil and gas market segment. Due to increasing regulatory action targeting air emissions, we see the power industry shutting down coal-fired plants, which have historically required a considerable amount of protective and heat-resistant coatings. However, new combined-cycle power plants using heat recovery steam generator (HRSG) technology will reduce emission outputs and create new opportunities for protective coatings in the form of newly constructed plants.

MNDOT'S APPROACH TO IMPROVING BRIDGE MAINTENANCE PAINTING OPERATIONS

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The Minnesota Department of Transportation (MnDOT) conducted a one-day seminar on bridge maintenance painting strategy and project design in May of 2013. One outcome of that seminar was the realization that MnDOT needed a more uniform method to rate the condition of coatings statewide during biennial bridge safety (in conjunction with the new AASHTO Manual for Bridge Inspection) as well as a process to select and prioritize maintenance painting strategies. MnDOT assembled a Technical Advisory Panel to address the needs identified during the seminar and launched a multi-objective study in October of 2013. This article describes the outcomes of efforts undertaken and MnDOT's novel approach to improving statewide bridge maintenance painting operations.

OBJECTIVE 1: CONDUCTING A TRANSPORTATION RESEARCH SYNTHESIS

The first objective of the study was to conduct a Transportation Research Synthesis (TRS) of representative transportation agencies' policies, guidance and manuals related to best practices for bridge maintenance painting operations. Maintenance painting may be performed by agency-employed personnel or by contracting for these services. The TRS provided a vehicle by which to determine other agencies' operations and their effectiveness. A survey questionnaire was prepared and distributed

All images courtesy of the authors unless otherwise noted. Photo: Pamela Simmons to 52 transportation agencies to determine common practices they used for maintenance painting of steel bridges. Survey questions were developed for five topic areas including: 1) Coating Condition Assessments; 2) Bridge Coating Maintenance Strategies; 3) Surface Preparation Methods; 4) Coating Systems; and 5) Use of In-House Painting Forces versus Contractors.

The survey collected information from 42 agencies, an 81-percent response rate. The results of each topic area were presented in TRS 1404, published on www.mndot.gov/research.

OBJECTIVE 2: IDENTIFYING BEST PRACTICES

The second objective of the study was to identify the best practices appropriate for MnDOT bridge maintenance crews from the results of the survey in order to develop a more robust state-wide bridge maintenance painting program.

Best Practices for Conducting Coating Condition Assessments

Because the condition of an existing coating system drives the selection of the appropriate maintenance painting strategy, an accurate assessment of that coating condition is paramount. While SSPC-VIS 2 (Standard Method of Evaluating Degree of Rusting on Painted Steel Surfaces) and ASTM D610 (Standard Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces) can be used to rate the type and quantity of rusting present on a bridge structure, the amount and distribution of corrosion across multiple bridge elements can vary, is often not uniform, and can include coating deterioration in addition to corrosion. The preparation of a custom photographic guide containing actual images of bridge elements in various conditions is integral to consistently communicating the condition of the existing structure, selecting a maintenance painting strategy and prioritizing the work. While creating such a guide sounds rather straightforward, considerable planning was required to obtain the correct images.

As recommended by the study, MnDOT developed a standard coating assessment guide containing digital images of representative steel bridge elements depicting the four condition state categories (good, fair, poor and severe) for the new AASHTO bridge management element (BME) 515 Steel Protective Coating. The images contained in the guide include steel elements such as beam ends and bearings, cast-in-place pilings, steel elements beneath deck expansions, fascia beams, interior girders, hinge joints, pin and hanger assemblies, truss members, weathering steel and duplex coated railing. This approach was chosen to improve the consistency of the visual coating condition assessment data gathered across the state. The use of more detailed coating condition assessments may be warranted to establish condition thresholds for which maintenance painting strategies are appropriate, and determining risk of premature coating failure. Further, it aids in priority planning in relation to condition options and establishing bridge maintenance painting priorities.

Best Practices for Selecting Bridge Maintenance Painting Strategies

There are several strategies available for performing maintenance painting on steel bridges, such as spot touch-up, spot touch-up and overcoating, zone painting, and removal and replacement of the existing coating system. Apart from full removal and replacement, these maintenance painting strategies can serve to extend the service life of existing coating systems, postpone major painting projects and address aesthetic issues separate from corrosion. The condition of the existing coating system and underlying steel primarily drives the selection of an appropriate maintenance painting strategy.

Spot touch-up and overcoating can be a cost-effective maintenance strategy to prolong the life of the existing coating system. In this manner, the funding required to perform removal and replacement can be carefully budgeted and planned five-to-seven years ahead. However, the existing coating condition as well as the condition of the substrate beneath must be carefully assessed to reduce the risk of failure. The existing coating must also be analyzed (or historical records accessed) to determine the generic coating type for compatibility with the overcoat system. An Approved Products List (APL) for overcoat systems must be established, complete with surface preparation requirements and surface soluble-salt testing when an overcoating strategy is considered. Spot touch-up and overcoating could then be performed by contract or by using an in-house workforce. If the amount of coating deterioration is 10-to-15 percent of the total coated area, then removal and replacement of the coating system is a preferred strategy, as the amount of spot touch-up will likely not be economical, as per SSPC-PA Guide 5, "Guide to Maintenance Coating of Steel Structures in Atmospheric Service."

Best Practices for Selecting Surface Preparation Methods

Best practices with regard to surface preparation are based on the maintenance coating strategy selected. The active strategies include spot touch-up, spot touch-up and overcoat, and total removal and replacement. (An inactive strategy is to elect to do nothing.)

Spot Touch-Up

Surface preparation methods include cleaning and degreasing (SSPC-SP 1) and hand or power tool cleaning (SSPC-SP 2/ SSPC-SP 3). If a greater degree of surface cleanliness (and roughness) is desired, such as when heavy rust, pitting and pack rust are present, commercial-grade power tool cleaning (SSPC-SP 15) may be performed. The prepared areas should be transitioned (feathered) into the existing sound coatings. Chloride remediation may be performed during the surface cleaning

GENERAL RUSTING

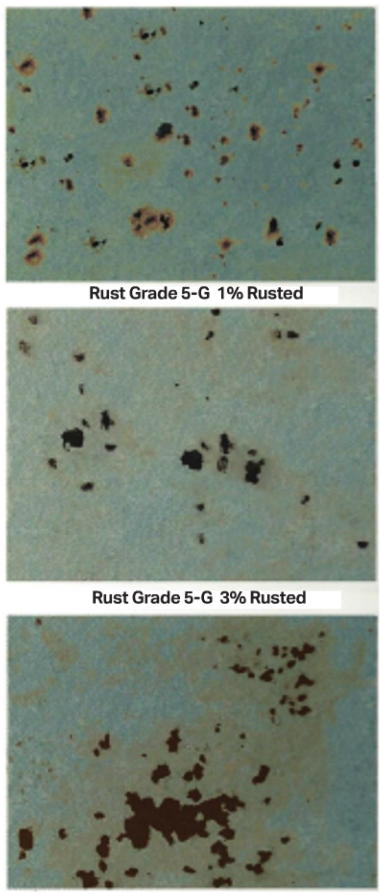

Fig. 1: Images from SSPC-VIS 2 show the appearance of a painted steel substrate exhibiting 1% general rusting (top), 3% general rusting (center) and 10% general rusting (bottom).

procedure followed by retesting. The current MnDOT threshold of 7 µg/cm^2 water-soluble chloride was determined to be reasonable for Minnesota bridges.

Spot Touch-Up and Overcoat

Surface preparation methods are identical to that described in the Spot Touch-Up section above. However, regarding overcoating of existing sound coating, additional surfaces to be coated are subject to cleaning and degreasing.

Total Removal and Replacement

Prior to abrasive blast cleaning, grease and oil contamination must be removed as per SSPC-SP 1 followed by chloride testing on representative surfaces. Chloride remediation testing should be performed following abrasive blast cleaning if chloride levels exceeded 7 µg/cm^2 prior to blast cleaning. Abrasive blast cleaning is performed to achieve an SSPC-SP 10/NACE No. 2, Near White Metal Blast Cleaning prepared surface and achieve the specified surface profile depth.

Industry experts recommend power washing as a key component of cleaning and chloride remediation. However, this method can be prohibitive to agencies such as MnDOT due to environmental regulations. Regardless of the surface preparation method selected, paint

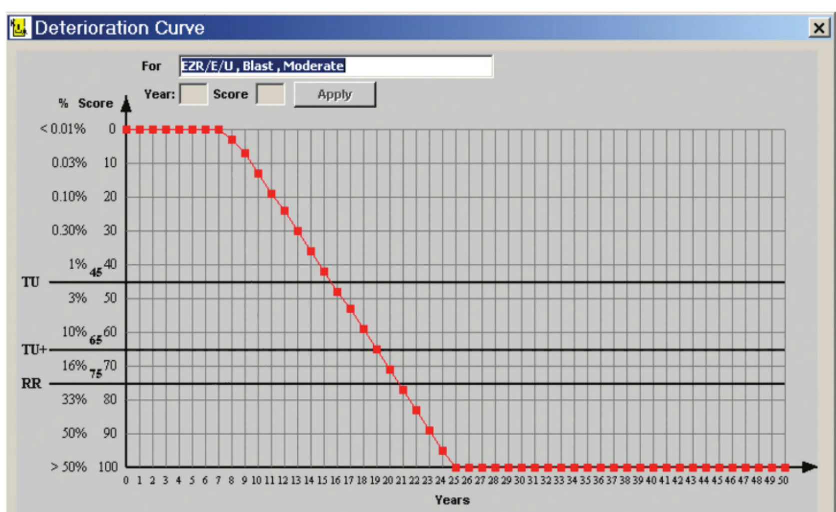

Fig. 2: Generalized coating deterioration curve based upon expected service life.

removal practices must be performed in accordance with the agency's environmental guidelines.

Best Practices for Selecting Coating Systems

Similar to best practices for selecting methods of surface preparation, the best practices for selection of coating systems are based on the maintenance painting strategy.

Spot Touch-Up or Spot Touch-Up and Overcoat

Epoxy mastic and polyurethane finish coats are often specified for this method, either with or without an epoxy penetrating sealer. When overcoating is not carried out, the visibility of the spot touch-up approach may impact whether or not a color match finish spot coat is applied. With overcoating, some additional barrier (and atmospheric) protection is provided as well as a uniformity of appearance.

Remove and Replace Existing Coating System

Typically, an organic (epoxy) zinc primer and epoxy mid-coat with a polyurethane or polysiloxane finish coat, or moisture-cured urethane (MCU) zinc primer with two coats of MCU finish are used for this method.

Best Practices for Determining Whether to Use In-House Crews or Contract Painting

Best practices relating to the use of in-house crews verses contract painting are based on whether bridge structures contain lead and/or other toxic metals as well as the total surface area requiring maintenance coating and the maintenance strategy selected.

Beyond worker safety and environmental protection, in-house crews should receive formal training on proper surface preparation techniques as well as proper coating mixing, thinning and application procedures. Assessment of environmental and safety considerations, worker skill sets, square footage, access and agency decisions regarding work planning and management of risk are appropriate to judge whether or not to use in-house crews or contractors.

OBJECTIVE 3: PREPARING A BRIDGE MAINTENANCE PAINTING MANUAL

The information obtained in Objectives 1 and 2 was used to establish a decision process and ultimately a revised Bridge Maintenance Painting Manual (BMPM) for MnDOT bridge maintenance crews. The BMPM addressed four subject areas including conducting a coating condition assessment, selecting maintenance painting

Fig. 3: Sample photos from the MNDOT "Steel Bridge Coating Condition Assessment Photographic Field Guide," developed to assist with performing coating condition assessments.

strategies, establishing priorities and executing the work.

Conducting a Coating Condition Assessment

Visual coating condition assessments are typically performed during the biennial or annual bridge inspection but may also be performed at the discretion of the MnDOT District that owns and manages the bridge. During the visual assessment, the steel bridge elements are assessed and classified into one of the four bridge element condition state categories explained earlier. Condition state guidance is provided for the protective coating system, the steel superstructure elements themselves and the section loss of steel elements. However, some deficiencies may not be visually apparent. When that is the case, a physical assessment may be performed to determine properties of the coating system such as adhesion, thickness and number of coating layers, and substrate condition.

Selecting a Maintenance Painting Strategy

The results of the visual coating condition assessment are used to determine whether maintenance painting is warranted and which strategies are likely to provide adequate preservation of the structure. There are five maintenance painting strategies that may be selected for any given painted steel bridge, including painted weathering steel. These include: do nothing, spot touch-up, spot touch-up and overcoating, removal and replacement in zones, and removal and replacement of the existing system for the entire structure. For weathering steel, maintenance options include abrasive blast cleaning, allowing the patina to reform, and coating application.

When the existing coating system will be overcoated, there are risks that must be assessed based on the condition of the existing coating system. The risk can be categorized as minimal (nil), low, moderate or high depending on the coating property being considered (Table 1, p. 53).

Determining when maintenance painting will be performed can be dependent on the visual threshold (tolerance) established for the degree of rusting on a surface (Fig.1, p. 46). There are also performance expectations that can aid in selecting the maintenance painting strategy, influenced by the service environment, coating products selected and degree of surface preparation.

Figure 2 (p. 46) identifies the generalized expected service life performance of different maintenance painting strategies based on three coatings systems. Table 2 provides estimates of the projected service life of the three coating systems until 3-to-5-percent coating breakdown and 5-to-10-percent coating breakdown occurs. Either of these scenarios may represent the visible threshold at which maintenance painting is performed.

The expected performance of various protective systems can influence the selection of a maintenance painting system when more than one option exists. An example is provided in the idealized service life (deterioration) curve for a coating system in Figure 2.

The importance of the deterioration curve in decision-making is related to the anticipated additional service life that may result from coating touch-up (TU), touch-up and overcoat (TU+) and from full removal and replacement (RR) is the appropriate maintenance painting strategy when the deterioration has progressed to that point. If touch-up occurs at the curve and TU lines intersect, the curve can be moved to the right (X number of years) since further coating breakdown is postponed. The same example exists when the curve and TU+ line intersect; the curve is moved to the right (X number of years) if touch-up and overcoating is performed. The slope of the curve is a function of the surface preparation performed, the coating system applied (products and layers) and the service environment (mild, moderate and aggressive).

An example of the influence of maintenance painting on service life based on Figure 2 is illustrated in Table 2. After initial painting, the practical service life is 18 years (intersection of 10 percent and the curve). Touch-up will be performed approximately six years later (at 24 years), 10-percent rusting occurs again and this time touch-up and overcoating is performed. Approximately 9 years later (33 years from

Table 1: Risk Assessment for Overcoating Based on Coating Physical Properties

Coating Repair Risk	Coating Deterioration	Adhesion Tape Test	Adhesion Pull-Off	Coating Thickness (mils)	Substrate Condition
MINIMAL (Nil)	1-3%	>3A >3B	>500	<10	Clean profile
LOW- Repair Likely	3-10%	3A 3B	>400-500 psi	>10 to 20	Clean & Profiled
MODERATE- Repair Possible	10-20%	2A	200-400 psi	20 to 30	No Active Rust
HIGH- Repair Unlikely	>20%	≤1A ≤0B	<200 psi	>30	Rust, Flaking Mill Scale

Table 2: Maintenance Coating Systems: Years of Anticipated Service until 3%–5% and 5%–10% Coating Breakdown Reoccurs

Coating Sytem	Coating Materials	Surface Preparation	Years to 3% - 5%	Years to 5% - 10%
One Coat Touch-Up	1 Coat Surface Tolerant Polyamide Epoxy	SSPC-SP 3	5	7.5
Two-Coat Touch-Up and Overcoat	1 Coat Surface Tolerant Polyamide Epoxy 1 Coat Aliphatic Polyester Polyurethane	SSPC-SP 3 SSPC-SP 6	7 9	10.5 13.5
New Three-Coat Replacement System	3 Coats - Zinc Rich Epoxy, High Build Epoxy and High Solids Polyester Aliphatic Polyurethane	SSPC-SP 10	14	21

the initial painting), 10-percent rusting will occur again.

The service life can also be dependent on service environment. Aside from the general service environment for the bridge, steel protective coating systems on specific elements generally begin to fail first under leaking expansion joints where the steel is exposed to chlorides, frequent wet and dry cycles and high humidity. Addressing underlying issues is crucial to preserving the protective coating system.

Establishing Priorities

Developing a priority list for a group of bridges that require maintenance painting may be easy if the extent of coating breakdown is widely dissimilar. The worst bridges are addressed first. However, there are other factors that should be considered when establishing priorities including structure integrity; social impacts (detours); safety and health (worker, public and environment); scheduling of other bridge work; remaining service life and distribution of budget. Alternatively, the priority ranking for maintenance painting may simply be based on the general rating of coating breakdown and degree of rusting.

Executing the Work

The MnDOT BMPM contains six flow diagrams that guide the user through the maintenance painting processes described in the Manual and guide the assessor through a series of questions, the answers to which lead them to the following series of questions, or even to another diagram. These diagrams require the user to

A. Examine the steel protective coatings;
B. Determine the maintenance painting strategy for painted steel elements;
C. Determine the maintenance painting strategy for unpainted weathering steel elements;
D. Risk assessment for overcoating;
E. Determine who will perform the work; and
F. Surface preparation and paint system options.

Maintenance Painting Procedures for MnDOT Personnel

The final section in the BMPM includes the maintenance painting procedures for agency bridge maintenance crews. Topics include:

- Safety and environmental protection;
- Quality control;
- Pre-cleaning and cleaning;
- Procedures for touch-up maintenance painting;
- Procedures for touch-up and overcoat maintenance painting;

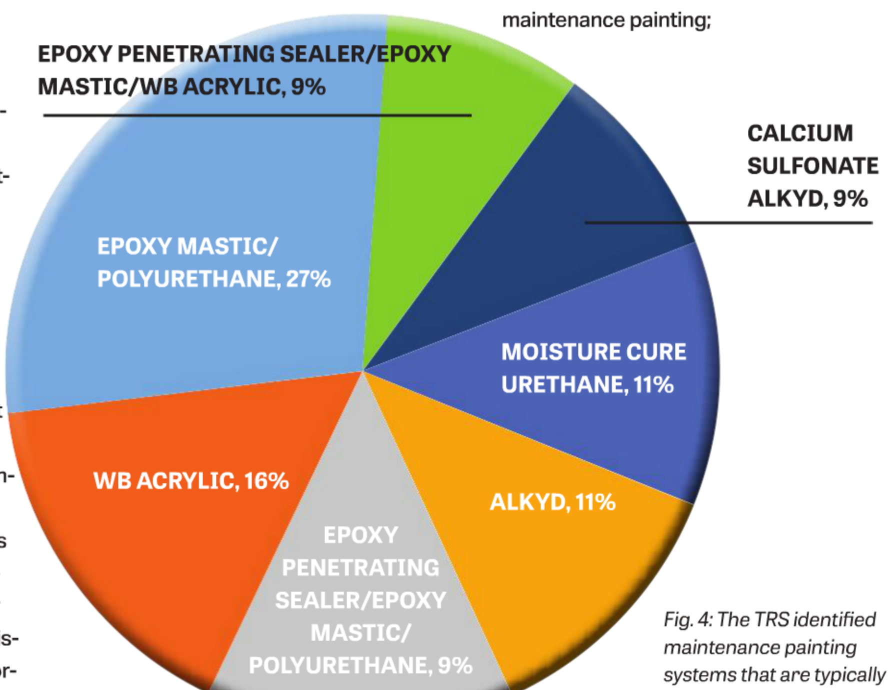

Fig. 4: The TRS identified maintenance painting systems that are typically used by other agencies.

- Procedures for zone removal and replacement of the existing coating system; and
- Weathering steel bridges.

OBJECTIVE 4: NEXT STEPS

The TRS and the updated BMPM served as the initial steps in the process to identify best practices for MnDOT's Bridge Maintenance Painting Program. The next steps included developing a custom coating assessment guide, conducting training and pursuing a bridge maintenance painting test site.

Training was conducted over two days in mid-April of 2015. Participants were introduced to the content and utilization of the BMPM and the Steel Bridge Coating Condition Assessment Photographic Field Guide (Fig. 3, p. 50). Beginning in 2016, MnDOT will perform visual coating assessments using the coating assessment guide and rate element 515 Steel Protective Coating. As inspectors become more familiar with the rating system and decision process, the BMPM will be evaluated and updated. Ongoing training, including field training on implementation of these practices, is paramount to the success of a bridge maintenance painting program.

Selecting optimum coating materials and corresponding levels of surface preparation are also critical in order to protect bridges from corrosion, especially in states with severe climates. The TRS identified maintenance painting systems that are typically used by other agencies (Fig. 4, p. 53).

To be able to more effectively select proper surface preparation methods and coating products for bridge maintenance painting performed in Minnesota, MnDOT initiated a bridge maintenance painting test site research project. In August of 2015, five maintenance coating systems, which were recommended by paint manufacturers based on MnDOT's goals and objectives, were applied to steel beam ends at a test site. The coating systems will be evaluated over a four-year period. Objectives of the study include identifying generic coating materials that can be effectively applied by MnDOT bridge crews to successfully extend the service life of the existing coating systems and provide a means of determining anticipated deterioration rates for maintenance painting strategies employed in Minnesota.

Ultimately, the data gathered from all of these efforts will provide valuable information and lead to better budgeting and planning of painting operations in Minnesota.

ABOUT THE AUTHORS

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TWO-COAT POLYASPARTIC URETHANE COATINGS PROTECT VIRGINIA STEEL BRIDGES FOR OVER A DECADE

BY AHREN OLSON AND C. TODD WILLIAMS, COVESTRO LLC; MARK HUDSON, THE SHERWIN-WILLIAMS COMPANY AND C. WAYNE FLEMING, VIRGINIA DEPARTMENT OF TRANSPORTATION

Protective coatings have been used for more than a century to protect steel bridges from corrosion. Oil-based coatings with lead and chromium pigments applied directly over mill scale were the industry standard for almost 100 years and providing excellent protection against corrosion at a reasonable price. In the mid-1960s, use of lead-based paints declined and zinc became the inhibitive pigment of choice[1]. Zinc-based pigments provide corrosion protection by galvanically coupling to the steel, sacrificing themselves.

For more than 40 years, zinc-rich primers in three-coat systems have been considered state-of-the-art technology for preventing corrosion of steel bridge structures. Typically the zinc-rich primer is topcoated with two additional coats to improve aesthetics and barrier properties along with chemical, corrosion and abrasion resistance[2].

From the 1970s to the 1990s, vinyl-based intermediates and topcoats were used over zinc-rich primers[3]. Vinyl coatings require high levels of volatile organic compounds (VOCs) in order to facilitate proper application and physical property development. When the level of allowable VOC emissions from industrial maintenance coatings was decreased in the 1990s, the use of vinyl coatings ceased in the bridge market[3]. After significant efforts in the 1990s to identify lower-VOC solutions, a three-coat system consisting of zinc-rich primer/high-build intermediate/light-stable polyurethane topcoat became the new industry standard[5-9]. This coating system is expected to last 20-to-40 years before significant maintenance of the coating is required, depending on

Photo: Pamela Simmons

the service environment[10]. For instance, a zinc-rich primer/epoxy intermediate/ polyurethane topcoat was applied to the Windgap bridge in Pittsburgh, Pa., and after 20 years of service, the steel exhibited less than 0.03-percent rusting over the entire surface[11]. Another example of the three-coat system that has demonstrated an excellent track record is a three-coat moisture-cure urethane (MCU) system consisting of zinc-rich urethane primer/ high-build urethane intermediate/moisture-cure polyurethane topcoat. This system has an expected life of 20-to-30 years[10, 12].

As bridge coating technology continued to evolve in the 1990s, advancements in binder technology allowed a reduction in the number of coating layers from three coats to two through the use of high-build, two-coat polyaspartic urethane (PAS) coating systems[13-14] (Fig. 1, p. 58). The main advantages of PAS coatings are increased painting productivity[15-20] and overall cost reduction [17,19] with corrosion protection equivalent to that of conventional three-coat systems[6, 21-24]. In 2003, the Connecticut Department of Transportation conducted a study to quantify the throughput and cost-savings potential of a PAS two-coat system versus a three-coat system. The study showed that a PAS two-coat system demonstrated a 31-percent increase in productivity and direct cost savings of approximately $6 per-square-foot, with indirect cost savings of $18 per-square-foot when the benefits of reduced traffic congestion were included[17]. PAS two-coat systems utilize a zinc-rich primer for galvanic protection and the epoxy and polyurethane layers are replaced by a high-build PAS topcoat.

The first generation PAS coatings commercialized in the early 2000s had relatively short pot lives and recoat window times in warm climates with high humidity. When touch-up of the topcoat was necessary after 24 hours from the initial application, abrading between coats was required and if the surface was not abraded, delamination of the second layer could occur. This issue necessitated the development of a second generation of PAS coatings. Recent advances in PAS resin technology addressed the aforementioned issues while also improving wet adhesion and corrosion resistance[25-27].

THE BRIDGES

Beginning in 2005, the Virginia Department of Transportation (VDOT) approved PAS two-coat systems to be used in lieu of three-coat systems. This research compares the field performance of PAS two-coat systems and MCU three-coat systems on steel bridges in western Virginia after 10 years of service. The service conditions include routine salt application during winter, and frequent freeze/thaw cycles during spring and fall seasons that stress the ability of coatings to protect the steel.

Eight PAS two-coat and 16 MCU three-coat systems were inspected to provide statistically significant performance data. The first project, BP-8C-04, consisted of eight structures and was completed using a PAS two-coat system (MCU zinc-rich primer/PAS topcoat). Table 1 (p. 58) lists the bridges by number, location, tonnage, deck material and design of this project. The bridge decks were made of hydraulic cement and two of the eight decks had asphalt overlays.

Projects BP-8A-04 and BP-06-968-101 were painted using MCU three-coat systems and 16 bridges were inspected. Tables 2 (p. 60) and 3 (p. 61) list the bridges that were inspected by number, location, tonnage, deck material and design.

All bridges were visually inspected in 2015 to evaluate the performance of the PAS two-coat system after being in service for approximately 10 years. In order to make a comparison against three-coat

Table 1: Bridges Repainted on Project BP-8C-04 with a PAS Two-Coat System

Structure Number	Route	Crossing	Approx. Tonnage	Deck Material	Design
1028*	RTE 39	Back Creek	39	Concrete	Cantilever w/ Suspended Span
2016	I-64	CSX Railroad	123	Concrete	Simple Span
2015	I-64	CSX Railroad	123	Concrete	Simple Span
2058	I-64	RTE 269 & Simpson Creek	372	Concrete	Simple Span
2059	I-64	RTE 269 & Simpson Creek	372	Concrete	Simple Span
2057	I-64 Ramp	RTE 269 & Simpson Creek	75	Concrete	Simple Span
1048*	RTE 11	RTE 60	52	Concrete	Simple Span
6038	RTE 608	Buffalo Creek	89	Concrete	Cantilever w/ Suspended Span

* Asphalt overlay

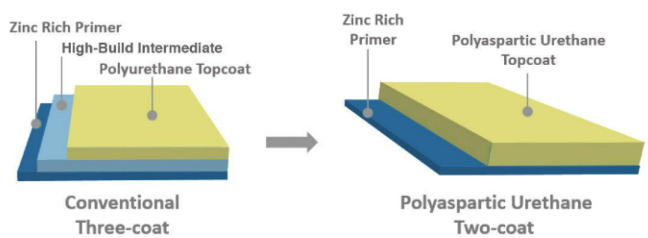

Fig. 1: Layers of the standard three-coat system and PAS two-coat system. Both systems have total dry-film thicknesses ranging from 9-to-14 mils.

systems, two bridge projects that utilized MCU three-coat systems painted in 2004 and 2005 were also evaluated.

THE INSPECTION PROCEDURE

Bridge structures were visually inspected and rated using the field guide from Myers et al. This visual guide provides pictorial examples of each category to aid the user in determining the percentage of rust on a steel bridge during field inspections[21]. The rating system is based on SSPC-VIS 2, Standard Method of Evaluating Degree of Rusting on Painted Steel Surfaces, shown in Table 4 (p. 61).

The rating system was used to rate the beam ends and mid-span. The beam end is the area from the end of the beam up to 12 feet away from the end, while the mid-span represents the remaining area between the beam ends (Fig. 2, p. 60).

A total of 24 bridges were visually inspected for rusting and overall coating performance and the average of three individual NACE-certified inspectors was used to tabulate the ratings.

MCU THREE-COAT SYSTEM WITH CONCRETE DECK

Overall, the MCU three-coat system performed well on the 16 inspected structures with four rated very good and 12 rated good. After eight years of service, Ault, et al. found similar performance of three-coat organic zinc-rich systems used in New Jersey. The referenced landmark study concluded that a successful coating system should be defined as exhibiting less than 0.3 percent of rusting after eight years, allowing it to be an overcoating candidate after 20 years[3]. Based on the current performance of MCU systems and the historical performance of three-coat organic zinc systems[3], after an additional 10 years coatings ranked very good and good are expected to exhibit between 0.1-and-10-percent rusting and can be candidates for spot repair and overcoat. Figure 3 (p. 61) shows photos of a very good rated bridge in this category.

PAS TWO-COAT SYSTEM WITH CONCRETE DECK

Overall, the PAS two-coat system also performed well on the eight structures inspected, with four rated very good, three rated good and one rated fair. The seven structures rated very good and good are expected to be excellent candidates for overcoating with only 1-to-10-percent rusting after 20 years, similar to the MCU three-coat bridges with concrete decks. The two-coat system performed as expected based on previous evaluations of these systems[6, 21-24].

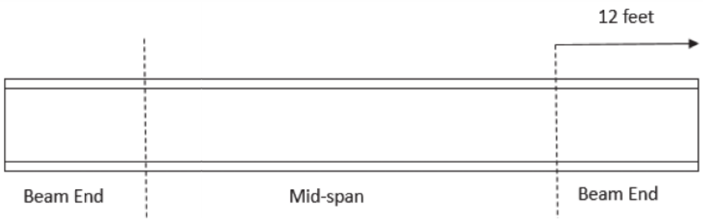

Fig. 2: Diagram illustrating the beam ends and mid-span areas.

Table 2: Bridges Repainted on Project BP-8A-04 with a MCU Three-Coat System

Structure Number	Route	Crossing	Approx. Tonnage	Deck Material	Design
1110	RTE 522	Back Creek	96	Concrete	Simple Span
1111	RTE 522	Back Creek	96	Concrete	Simple Span
1085	RTE 37	RTE 522	161	Concrete	Simple Span
1086	RTE 37	RTE 522	161	Concrete	Simple Span
1113*	RTE 37	RTE 50	172	Concrete	Simple Span
1114*	RTE 37	RTE 50	172	Concrete	Simple Span
2029	I-66 & I-81 Ramp 2	NBL I-81	96	Concrete	Simple Span
2028	I-66 & I-81 Ramp 3	NBL I-81 & Ramp 2	228	Concrete	Simple Span
6085*	RTE 606	I-66 EBL	55	Concrete	Simple Span
6084*	RTE 606	I-66 WBL	55	Concrete	Simple Span
6911*	RTE 628	Cedar Creek	99	Concrete	Simple Span
6331*	RTE 614	Mill Creek	73	Concrete	Simple Span

* Asphalt overlay

Of the eight PAS two-coat bridges, 50 percent were rated very good, while only 25 percent of the 16 MCU three-coat bridges with concrete decks were rated very good. The performance difference between the MCU three-coat and PAS two-coat bridges is narrow enough with a large data set to conclude that the PAS two-coat system has performed at least equivalently to the MCU three-coat system on similar structures. Table 5 shows all the ratings for the MCU three-coat and PAS two-coat bridges with concrete decks. Figure 4 shows two photos of a bridge rated very good in this category.

The one PAS two-coat bridge with a concrete deck that rated fair was Bridge 1028. This bridge had an asphalt

Table 3: Bridges Repainted on Project BP06-968-101 with a MCU Three-Coat System

Structure Number	Route	Crossing	Approx. Tonnage	Deck Material	Design
1067	RTE 55	I-81	237	Concrete	Simple Span
1034*	RTE 263	Stoney Creek	9	Concrete	Simple Span
1068	RTE 42	I-81	254	Concrete	Simple Span
6572*	RTE 649	S.F. Shen. River	220	Concrete	Simple Span

* Asphalt overlay

Table 4: Inspection Rating System for Field Evaluations[21]

Rating	Description	Degree of Rusting
Very Good	Rust grade 10 and 9	Less than or equal to 0.03%
Good	Rust grade 8	Greater than 0.03% up to 0.1%
Fair	Rust grade 7 and 6	Greater than 0.1% up to 1.0%
Poor	Rust grade 5 and 4	Greater than 1.0% up to 10%
Very Poor	Rust grade 3, 2, 1 and 0	Greater than 10%

Table 5: Rating Summary for MCU Three-Coat and PAS Two-Coat Systems

Rating	MCU	PAS
Very Good	4	4
Good	12	3
Fair	-	1
Poor	-	-
Very Poor	-	-

Fig. 3: Bridge rated very good with MCU three-coat systems and concrete deck.

Fig. 4: PAS two-coat coating system with a concrete deck. This bridge was rated very good.

overlay that had begun to deteriorate and crack along the joints, allowing road salts and water to penetrate to the steel, causing higher corrosion levels not observed on the other seven structures. Salt was visible on the bottom flanges throughout this structure. Mid-spans that were not under leaking joints were rated in good condition, while the beam ends were rated in poor condition.

CONCLUSION

This research confirmed the field performance of PAS two-coat coating systems and further validated the technology's excellent corrosion prevention noted in many previous investigations[6, 21-24]. With performance being generally equal, PAS two-coat systems can provide significant value to bridge owners in the form of overall cost reduction in painting operations, accelerated painting schedules, and milder traffic congestion headaches. Advancements in PAS resin technology have alleviated application complexities around short pot life and limited recoat windows that were experienced in higher temperature and humidity conditions[25-27]. As bridge coatings continue to evolve, PAS two-coat systems continue to have a bright future in the bridge market as a high-performance and cost-saving solution for long-term asset protection.

ABOUT THE AUTHORS

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C. Wayne Fleming has worked for the Virginia Department of Transportation for 27 years and in the central office, materials division, chemistry laboratory for 23 years. He oversees all structural steel coating system approvals, as well as ancillary coating systems. Fleming provides support in the execution of new construction and maintenance coating contracts. He is an instructor in Virginia's Materials Training/Certification Program and is currently a panel member on two technical committees for AASHTO/NTPEP, Protective Coatings and Pavement Marking Materials. Fleming is certified through SSPC in abrasive blasting, airless spray application, completed the Planning and Specifying Industrial Coatings Projects (C2) course and is a certified Level-1 Bridge Coating Inspector.

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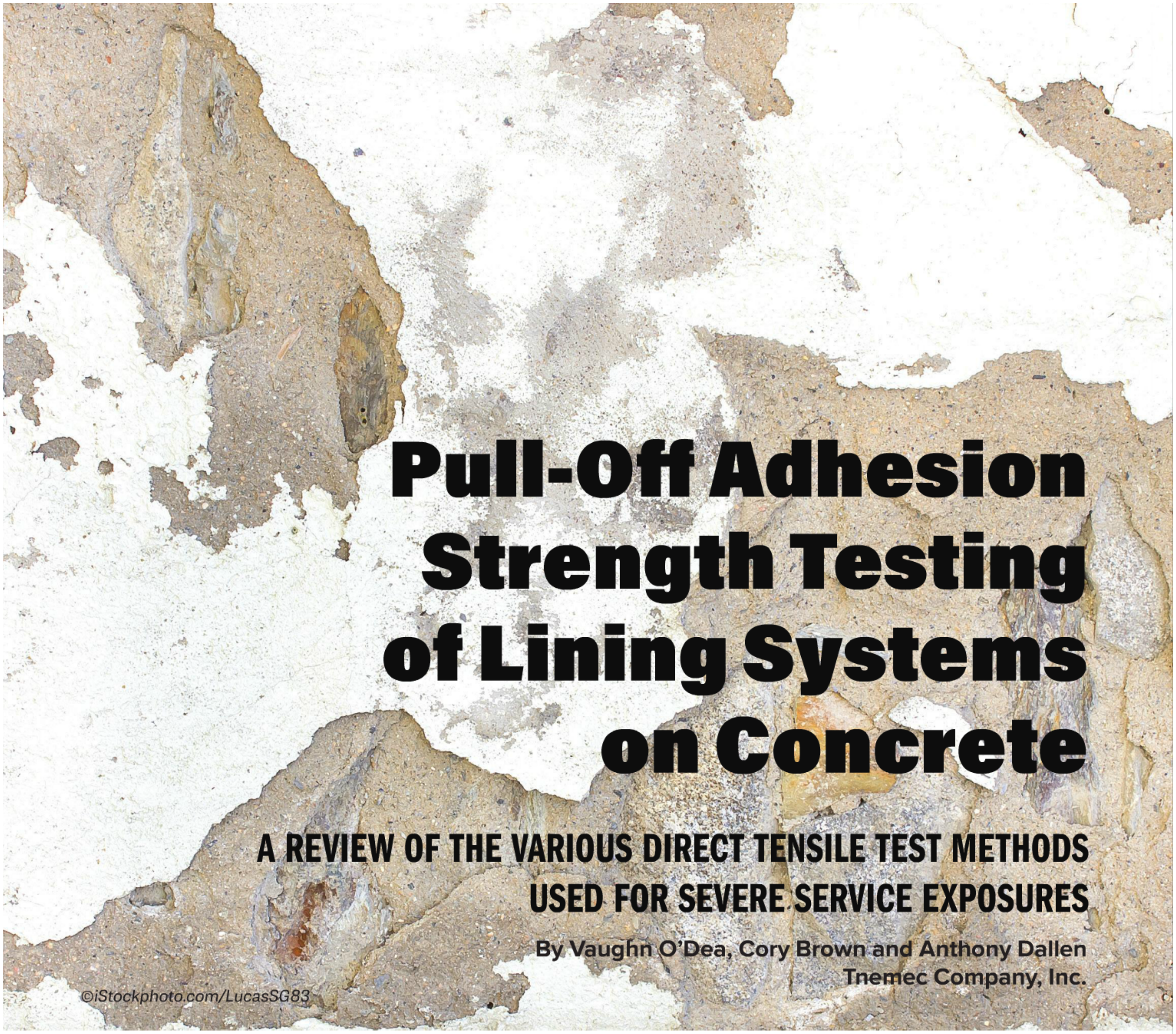

Pull-Off Adhesion Strength Testing of Lining Systems on Concrete

A REVIEW OF THE VARIOUS DIRECT TENSILE TEST METHODS USED FOR SEVERE SERVICE EXPOSURES

By Vaughn O'Dea, Cory Brown and Anthony Dallen
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Tensile pull-off adhesion testing is becoming a more frequent specification requirement for in-situ quality assurance testing to confirm proper surface preparation and adhesion of high-performance protective linings applied to concrete. It is also becoming a widely used test for forensic analysis of protective linings in existing installations. There have been numerous investigations leading to the development of different devices and pull-off adhesion test methods used to assess bond strengths of mortars and overlay materials. Fundamental differences exist between these methods that can dramatically impact tensile strength results. This article presents the common pull-off adhesion test methods used in the United States, as well as the results of experimental research investigating the results using two common tensile strength testers.

THE BACKGROUND

The rehabilitation and protection of concrete has consistently been a challenge in many chemical containment and severe service immersion environments. Although portland concrete is considered to be extremely durable, it is susceptible to concrete paste attack when exposed to acids, sulfates and some caustics. High-performance protective linings are commonly used to prevent attack of the portland cement paste or to protect against the ingress of carbonation or chlorides into the concrete. The old way of thinking was to simply apply a protective lining directly to concrete surfaces. Nowadays, it is understood that

Fig. 1: DIN 18555-6 calls for the use of a tapered ring to create cuts into freshly cast mortar.

resurfacing new concrete and repairing deteriorated concrete prior to the application of a protective lining is the only effective method of achieving a monolithic and pinhole-free application. Leveling the concrete substrate effectively first creates a paintable surface and significantly reduces the discontinuities and thin areas in the film otherwise encountered. This approach is economically beneficial by extending the service life of concrete structures.

In order to realize long-term performance in severe service environments it is essential that the protective lining adheres to the resurfacing or repair materials. Likewise, the resurfacing and repair materials should achieve sufficient physical properties and exhibit a sound bond to the concrete substrate. Most of the lining failures the authors encounter are due to the formation of a laitance layer or from cohesive splitting of the mortar due to insufficient physical strength gains, for example, having been applied below the minimum thickness. Ideally, for severe environments, the adhesion of the protective lining and the adhesion and cohesion of the cementitious repair mortar will exceed the tensile strength of the substrate concrete.

Tensile pull-off adhesion testing can be a good technique to measure bond strengths and to assess the weakest link in the system through observation of the failure modes. Tensile pull-off adhesion testing involves gluing a test dolly to the coated surface and then pulling the dolly by exerting a tensile force perpendicular to the surface in an effort to remove the dolly with the coating system attached, from the substrate. The force at which this occurs, and the type of failure mode obtained is recorded as a measure of the tensile strength properties.

Following are a variety of pull-off tests that are utilized throughout the concrete repair industry. ASTM D7234 is unique in that it specifically addresses protective coatings applied to concrete and it appears to be the most commonly referenced pull-off test in the U.S. when assessing the tensile strength of protective linings.

- ASTM D7234, "Standard Test Method for Pull-Off Adhesion Strength of Coatings on Concrete Using Portable Pull-Off Adhesion Testers."
- ASTM C1583/C1583M, "Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method)."
- ICRI No. 210.3R, "Guide for Using In-Situ Tensile Pulloff Tests to Evaluate Bond of Concrete Surface Materials."

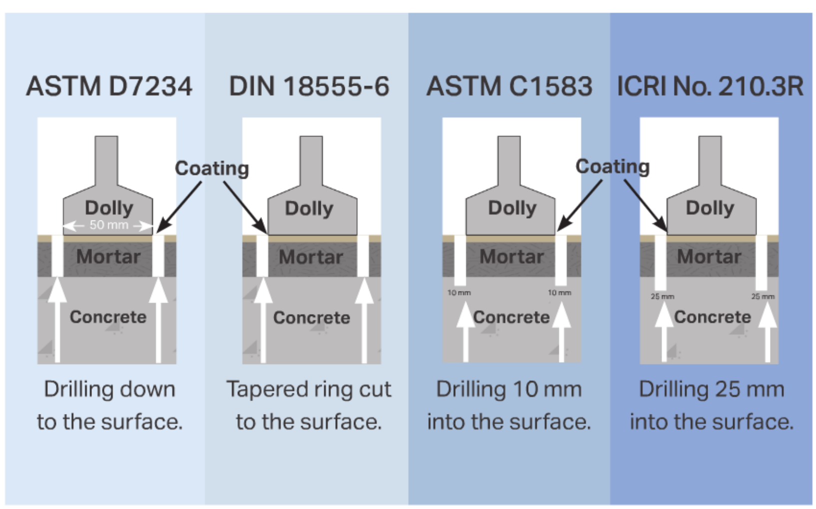

Fig. 2: This figure illustrates the different cut depths of the test methods examined.

- DIN 18555-6, "Testing of Mortars Containing Mineral Binders; Determination of Bond Strength of Hardened Mortar."

TENSILE STRENGTH TESTS EXAMINED

ASTM D7234

In the late 1990s, ASTM D4541, "Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers," referenced both steel and concrete. First published in 2005, D7234 was an offshoot of D4541 to specifically address pull-off adhesion testing of coatings on concrete substrates. In 2012, D7234 was republished to include a "Precision and Bias" section following the completion of an ASTM Interlaboratory Study Program (ILS). This standard is the only tensile strength test method with a Precision and Bias section.

According to this standard, pull-off adhesion is performed by scoring through the coating down to the surface of the concrete substrate at a diameter equal to the diameter of the loading fixture (i.e., dolly, stud), and securing the loading fixture perpendicular to the surface of the coating with an adhesive. After the adhesive is cured, a testing apparatus is attached to the loading fixture and aligned to apply tension perpendicular to the test surface. The force applied to the loading fixture is then uniformly increased and monitored until a plug of material is detached. The exposed surface represents the plane of limiting strength within the system. The nature of the failure is qualified in accordance with the percent of adhesive and cohesive failures, and the actual interfaces and layers involved. The pull-off adhesion strength is computed based on the maximum indicated load, the instrument calibration data and the surface area stressed. Pull-off adhesion strength results obtained using different devices may be different because the results depend on instrumental parameters.

Scoring the coating down to the surface of the substrate is required for all coatings thicker than 0.5 mm (20 mils) and for all reinforced or elastomeric coatings. While scoring is recommended for coatings less than 0.5 mm, the test may be performed without scoring with a noted exception. Scoring should be performed in a manner that ensures that the cut is made perpendicular to the coating surface and in a manner that does not twist or torque the test area and minimizes the heat generated and edge damage or microcracks to the coating and the concrete substrate. For thick coatings, it is recommended to cool the coating and substrate during the cutting process with water lubrication. When using a round loading fixture, scoring is performed before the loading fixture is attached. When using square or rectangular loading fixtures, scoring is typically performed after the loading fixture is attached. The core bit inside diameter should equal the diameter of the loading fixture. The core bit or saw blades should be diamond-tipped and, when required to minimize heat and suppress dust, supplemented with water lubrication. For the test procedures that use a square or rectangular loading fixture, a circular saw is required instead of a core bit and drill. Alternately, for thin or elastomeric coatings, a sharp knife or hole saw may be sufficient to score around the loading fixture. Any failure displaying 20 percent or more glue failure constitutes a "non-test" and should be disregarded.

ASTM D7234: Pros & Cons

ASTM D7234 is effectively intended for protective coatings and linings applied directly to concrete and does not mention resurfacing or repair mortars. Scoring through the coating down to substrate concrete would not be conducive for several of the outlined techniques when a resurfacing or repair mortar is present. However, it is possible to core through the coating/mortar down to the substrate concrete when using a diamond-tipped core bit.

ASTM C1583

Adopted in 2004, this test method determines the near surface tensile strength of concrete used as an indicator of the adequacy of surface preparation before applying a repair or overlay material. When the test is performed on the surface of a repair or an overlay material, it determines the bond strength to the substrate or the tensile strength of either the overlay or substrate, whichever is weaker. This test method is suitable for both field and laboratory to determine one or more of the following:

- The near-surface tensile strength of the substrate as an indicator of the adequacy of surface preparation before application of a repair or overlay material;
- The bond strength of a repair or an overlay material to the substrate; or
- The tensile strength of a repair or overlay material or an adhesive used in repairs after the material has been applied to a surface.

The test method specifies the use of a 50-mm (2-inch) inside diameter, diamond-impregnated core bit used to drill perpendicularly to the concrete surface to a depth of at least 10 mm (0.5 inches)

Fig. 3: A selection of 50-mm fixed and self-alignment dollies.

into the concrete substrate. A nominal 50-mm diameter dolly is then attached to the test area using an epoxy adhesive. At temperatures below 20 C (70 F) it is permitted to gently heat the dolly (not with a direct flame) to no more than 50 C (120 F) to facilitate spreading of the adhesive and accelerate curing.

The tensile loading tester is attached to the dolly and tensile loading is applied at a constant rate so that the tensile stress increases at a rate of 35 ± 15 kPa/s (5 ± 2 psi/s).

The failure load and mode are recorded as *(a)* in the substrate, *(b)* at the bond line between the substrate and the repair or overlay material, *(c)* in the repair or overlay material or *(d)* at the bond line between the repair or overlay material and the epoxy adhesive used to bond the dolly.

ASTM C1583: Pros & Cons

Although ASTM C1583 does not specifically mention a protective coating, there is no reason why this method cannot be employed when a resurfacing or repair material is present under a coating. One noted limitation is possible misalignment when coring through the coating/mortar and down into the substrate concrete at a minimum of 10 mm.

ICRI No. 210.3R

ICRI published this guideline in 2013 to provide information to the facility owner, concrete repair designer, contractor and repair material manufacturer about testing to determine the tensile/bond strength of repair materials and systems. This document also provides guidance on interpretation of test results, acceptance criteria and re-evaluation. The guide also discusses recommended time and frequency of tests of both trial and completed repairs.

ICRI recommends a minimum drilling depth of 25 mm (1 inch) or one-half the core diameter, whichever is greater, into

Fig. 4: A fixed-alignment adhesion tester.

Fig. 5: A self-alignment adhesion tester.

the existing substrate for both testing of the prepared concrete substrate and the repair composite. According to this guide, drilling deeper into the substrate results in more uniform stress contours within the core at the bond interface. This reduces the potential for fracture initiation at the interface. This can be particularly important where project specifications do not accept bond failures. As an option, the dolly may be attached to the test surface prior to coring as long as coring will not adversely affect or damage disc installation.

ICRI No. 210.3R: Pros & Cons

Although ICRI No. 210.3R does not specifically mention a protective coating, there is no reason why this method cannot be employed when a resurfacing or repair material is present under a coating. Possible misalignment from coring through the coating/mortar and down into the substrate concrete a minimum of 25 mm is a concern, especially on vertical surfaces in the field.

DIN 18555-6

This standard specifies methods for determining the bond strength of hardened mortar containing mineral binders to concrete. Although not commonly referenced in the U.S., this standard details an alternative method of establishing the cut around the dolly and into the mortar worthy of discussion. Like the others, this standard recommends a 50-mm diameter core bit to cut through hardened mortar and into the concrete substrate at a minimum depth of 5 mm (0.25 inches). Alternately, cores can be created in freshly placed mortar during the initial set phase using a 50-mm diameter tapered ring (Fig. 1, p. 65). The use of the tapered ring to create cuts into freshly cast mortar is unique compared to the other methods requiring core bit cutting.

DIN 18555-6: Pros & Cons

DIN 18555-6 does not specifically mention a protective coating. Coring through the coating/mortar and down into the substrate concrete a minimum of 5 mm is achievable with less of a concern of misalignment. The tapered ring method would be challenging, if not impractical to perform in the field when applying a protective coating. The annulus "cut" would have to be temporarily protected to ensure that no abrasive or coating material enters the space.

THE EXPERIMENT PROTOCOL

These tensile strength tests have many similarities, including the recommendation of a 50-mm dolly. One major difference between these tests, however, is the depth of the core drilling into the substrate concrete (Fig. 2, p. 65). A study by Bungey and Madandoust found that the shallower the drilling depth, the higher the measured tensile strength[1]. They concluded that by using finite elemental analysis, that restraint provided by the concrete was greater at the perimeter of the dolly rather than at the middle of the core. They also concluded that the deeper the core, the higher the net stress concentration will be, which corresponds to lower failure loads.

Selecting the appropriate tensile strength testing method becomes difficult due to the fact that none of the standards specifically address a protective coating applied over a cementitious resurfacer or repair mortar.

Given these differences, the authors carried out an experimental study to compare some real values of different direct tensile strength test methods using two commonly used pull-off adhesion testers. The study included the evaluation of the four different bond test methods described earlier. Substrate concrete material and mix proportion and were the same for all bond tests.

THE RATIONALE

In designing this experiment, much consideration was given to eliminating as many undesirable independent variables as possible. Concrete is a notoriously irregular substrate. If the outcome of the experiment yielded low and/or inconsistent results, the values would be difficult to conclude. The following measures were taken to mitigate the effects of an irregular substrate on test results.

- A precise, high-strength concrete design mix was selected to achieve more consistent and higher substrate tensile strengths.
- Wooden rails were glued around the perimeter of the test specimens to facilitate that an even thickness of each repair mortar was achieved.
- The number of loading fixtures used to calculate the average tensile strength was increased from three (common for field testing averages) to eight per-test-specimen.
- Loading fixtures were placed alternately (fixed vs. self-aligned) throughout the field of each test specimen (Fig. 3, p. 69).
- A drill press was used in lieu of a hand tool to ensure coring occurred perpendicular to the plane of the test specimen.

Some independent variables were designed into the experiment and included the following.

- The depth of the core was determined by the testing methods.
- Two types of loading fixtures and testing devices were used, one fixed alignment and one self-aligning.
- Two different repair mortar materials were selected, one epoxy modified cementitious and one hydraulic cementitious repair mortar.
- Control test specimens were also prepared.

TABLE 1: CONCRETE/CEMENTIOUS RESURFACER/100% VS EPOXY

Adhesion Method	Instrument Type	Dolly Pulls, psi									
		1	2	3	4	5	6	7	8	AVG	COV
DIN	FA	150	210	140	240	300	190	250	310	224	26%
18 555-6	SA	250	316	155	260	223	263	331	215	252	21
ASTM	FA	200	350	225	260	300	200	250	325	264	20%
D 7234	SA	473	477	419	440	392	480	345	471	437	10%
ASTM	FA	275	250	275	360	325	300	340	330	307	12%
C 1583	SA	455	480	430	480	480	480	473	480	470	4%
ICRI	FA	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
210.3R	SA	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT

TABLE 2: CONCRETE/EPOXY CEMENTITIOUS RESURFACER/100% VS EPOXY

Adhesion Method	Instrument Type	Dolly Pulls, psi									
		1	2	3	4	5	6	7	8	AVG	COV
DIN	FA	500	500	500	500	500	500	500	500	500	0%
18 555-6	SA	450	480	480	480	480	480	480	480	476	2%
ASTM	FA	500	500	400	500	500	500	500	410	476	9%
D 7234	SA	480	480	480	480	480	480	480	480	480	0%
ASTM	FA	400	300	200	225	275	260	325	375	295	24%
C 1583	SA	435	465	339	339	334	480	406	NP	400	16%
ICRI	FA	350	200	210	NT	NT	NT	NT	NT	253	33%
210.3R	SA	316	385	387	NT	NT	NT	NT	NT	363	11%

TABLE 3: CONCRETE/100% VS EPOXY

Adhesion Method	Instrument Type	Dolly Pulls, psi									
		1	2	3	4	5	6	7	8	AVG	COV
ASTM	FA	500	375	450	500	500	500	500	NP	475	9%
D 7234	SA	480	480	480	480	480	480	480	480	480	0%
ASTM	FA	260	275	310	325	300	275	240	NP	284	10%
C 1583	SA	480	413	462	449	480	457	400	466	451	6%
ICRI	FA	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
210.3R	SA	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT

THE SUBSTRATE

The concrete substrates were formed using a mixture of one part portland cement, one part sand and two parts pea gravel aggregate, and the blocks measured 16-inches-by-16-inches-by-2-inches. The concrete blocks were cured for a minimum period of 28 days. A total of 10 specimen blocks were cast and used for the different test methods and systems applied.

SURFACE PREPARATION

The test specimens were prepared by removing all loose materials, laitance and other bond-inhibiting materials from the surface in accordance with SSPC-SP 13/NACE No. 6, with a minimum surface profile of ICRI-CSP 5.

THE COATING SYSTEMS

System #1 was a cementitious repair mortar at ¼-inch DFT/100% SBV modified polyamine epoxy at approximately 20-mils DFT.

System #2 was an epoxy modified cementitious mortar at 1/16-inch DFT/100% SBV modified polyamine epoxy at approximately 20-mils DFT.

The control system was 100% SBV epoxy at approximately 35-mils DFT.

Each coating system was given seven days cure before testing.

THE TESTING EQUIPMENT AND TOOLS

The following equipment was used.

- One fixed-alignment adhesion tester (calibrated September 2015) (Fig. 4, p. 70).
- One self-alignment adhesion tester (calibrated September 2015) (Fig. 5, p. 70).
- 50-mm dollies, fixed and self-alignment.
- Adhesive - 100% SBV two-component epoxy – 48 hours cure time.
- 2-¼-inch outside diameter (OD) thin wall dry diamond-core drilling bit.

THE RESULTS

The tensile strength test results for Coating System #1, the cementitious repair mortar, are shown in Table 1 (p. 72). The tensile strength test results for Coating System #2, the epoxy cementitious resurfacer, are shown in Table 2 (p. 72). The tensile strength test results for the control system, a 100% SBV polyamide epoxy, are shown in Table 3 (p. 72).

Moisture Condition

The moisture condition of the substrate can have an effect on the bonding of a repair mortar. If the substrate concrete isn't adequately conditioned with water to a saturated surface dry (SSD) condition, the moisture imbalance will cause water to penetrate into the substrate concrete resulting in limited hydration in the repair mortar. Chorinsky reported that unmodified cementitious repair mortars applied to a dry concrete surface will suck part of the mixing water from the mortar before any soluble and reactive components in the cement paste are formed[2]. The repair mortar will not adhere firmly to the substrate concrete due to the limited penetration of the reactive components into the capillary pores. Chorinsky also maintained that similarly, too much water on the substrate concrete, for example a saturated surface wet (SSW) condition, will fill the capillaries with water and raise the water/cement ratio in the boundary of the fresh mortar creating a layer with a high water cement ratio. Austin and Robins also suggested that an SSD condition gave higher bond strengths than an SSW condition[3]. Regardless, the bond strength of a cementitious repair mortar can be weakened at the interface if the surface is too wet or too dry.

Alignment

Another potentially influential parameter of the direct tensile strength pull-off test that hasn't received much attention is test alignment. The primary requirement in any direct tension test is to ensure the pulling force is aligned with, and parallel to, the specimen axis at all times to avoid bending effects. According to Courard et al, the two main causes for misalignment are inclination of the core axis caused by inaccurate core drilling and inclination of the pulling forced caused by inaccurate positioning of the dolly[4]. They further stated that a reduction in core depth or increase in dolly diameter tends to minimize the negative effects of misalignment. A jig or other device should be used when coring to ensure proper alignment and prevent the bit from walking during drilling.

CONCLUSION

In general, it appears that the tensile strength values decrease as the partial core depths increase. Not all of the test result values are supportive of this conclusion, however; some precision discussion should be considered. Surface testing (for example ASTM D7234) tensile values were generally higher than the partially cored tests. The precision of the two loading devices are considered to be incomparable. The fixed-type adhesion tester yields consistently lower tensile strengths and higher values of coefficient of variation (COV) than the self-alignment adhesion tester on the same test specimens. It is believed that the higher values of COV may be due to the intrinsic heterogeneity of granular material like concrete, moisture conditions of the concrete and misalignment, as well as the possible lack of precision of the test methods.

The diamond-tipped core bit required to perform these test methods is not readily available from industry suppliers. Also, as core depths increase, so does wear on the core bit. It is for this reason that some of the testing planned for in the design of the protocol was not achieved. It is the authors' opinion that these facts make coring beyond the surface of the substrate impractical in field testing environments, especially when testing on vertical surfaces. Likewise, the DIN method using a tapered ring core is not realistic for field testing. The timing required to use the scoring ring may be problematic. In the field it would also be difficult to apply the lining material over the repair mortar without filling the annular space created by the scoring ring prescribed by the DIN method.

RECOMMENDATION

For these reasons, it appears the best method for performing this type of testing in the field is ASTM D7234 using 50-mm dollies. In light of these conclusions, we believe specifications requiring minimum pull-off adhesion values should be specific in the pull-off test method, instrument type (preferably make and model) and minimum bond strength values derived from an assessment of the existing concrete substrate.

ABOUT THE AUTHORS

Vaughn O'Dea is the director of sales for water/wastewater at Tnemec Company, Inc. and has 15 years of experience in the protective coatings industry. He is an SSPC-certified Protective Coatings Specialist (PCS) and a NACE-certified Coating Inspector. O'Dea is a contributing editor of the *JPCL* and was named a *JPCL* Top Thinker in 2012.

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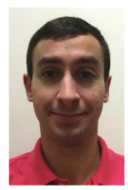
Anthony Dallen has spent the past year at Tnemec training in conducting and



analyzing test methods in the coatings industry. Being new to the industry, he has formed a solid foundation of the fundamentals of corrosion, various substrates and surface preparation, as well as a thorough understanding of the numerous types of coatings and their respective application properties and uses. Anthony is a member of SSPC, WEF and AWWA.

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