VOLUME 31. NUMBER 2

PAINTSQUARE.COM
jpcl
FEBRUARY 2014

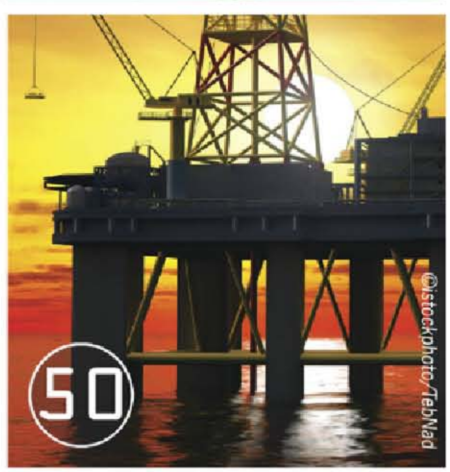
JOURNAL OF PROTECTIVE COATINGS & LININGS

SSPC The Society For Protective Coatings

The Voice of SSPC: The Society for Protective Coatings

Cover: © istockphoto/santiphotois

FEATURES



DEPARTMENTS

Also This Month

From the Offices of

SSPC The Society For Protective Coatings

Staff

Editorial:

Editor in Chief: Anita M. Socci / asocci@paintsquare.com
Managing Editor: Charles Lange / clange@paintsquare.com
Editorial Director: Pamela Simmons / psimmons@technologypub.com
Technical Editor: Brian Goldie / bgoldie@jpcleurope.com
Directory Coordinator: Mark Davis / mdavis@paintsquare.com

Contributing Editors:

Warren Brand, Rob Francis, Gary Hall, Robert Ikenberry, Alison Kaelin, Alan Kehr, Robert Kogler, Vaughn O'Dea, E. Bud Senkowski, Lloyd M. Smith, PhD, Dwight Weldon

Production / Circulation:

Director, Production Operations:
Milissa M. Bogats / mbogats@paintsquare.com
Art Director: Peter F. Salvati / psalvati@protectivecoatings.com
Associate Art Director: Daniel Yauger / dyauger@paintsquare.com
Production Assistant: Mikaela Longo/mlongo@technologypub.com
Circulation Manager: JoAnn Binz / jocbinz@aol.com

Ad Sales Account Representatives:

Publisher: Marian Welsh / mwelsh@paintsquare.com
Bernadette Landon / blandon@paintsquare.com
Bill Dey / bdey@paintsquare.com
Classified and Service Directory Manager:
Lauren Skrainy / lskrainy@paintsquare.com

PaintSquare:

Director of Operations: Andy Folmer / afolmer@paintsquare.com
Director of Technology: D'Juan Stevens / dstevens@paintsquare.com
Digital Media Production Manager: Tricia Chicka / tchicka@paintsquare.com
Vice President, Content and Marketing: Pamela Simmons / psimmons@technologypub.com

SSPC:

SSPC Individual Membership: Terry McNeill / mcneill@sspc.org
SSPC Organizational Membership: Ernie Szoke / szoke@sspc.org

Finance:

Accounting Manager: Michele Lackey / mlackey@technologypub.com
Andrew Thomas / athomas@technologypub.com

Assistant to the President: Larinda Branch / lbranch@technologypub.com
President and CEO: Peter Mitchel / pmitchel@technologypub.com
President, International Operations: Harold Hower / hhower@technologypub.com

Periodical class postage at Pittsburgh, PA and additional mailing offices. Canada Post: Publications Mail Agreement #40612608 • Canada returns are to be sent to: American International Mailing, PO Box 122, Niagara Falls, ON L2E 6S4 Canada The Journal of Protective Coatings & Linings (ISSN 8755-1985) is published monthly by Technology Publishing Company in cooperation with the SSPC (877/281-7772). Editorial offices are at 2100 Wharton Street, Suite 310, Pittsburgh, PA 15203. Telephone 412/431-8300 or 800/837-8303; fax: 412/431-5428

Copies of articles are available from the UMI Article Clearinghouse, University Microfilms International, 300 North Zeeb Road, Box 91, Ann Arbor, MI 48106. **Subscription Rates:** $90.00 per year North America; $120.00 per year (other countries). Single issue: $10.00. **Postmaster:** Send address changes to Journal of Protective Coatings & Linings, 2100 Wharton Street, Suite 310, Pittsburgh, PA 15203. Subscription Customer Service: PO Box 17005, North Hollywood, CA 91615 USA, Toll Free: 866 368-5650, Direct: 818-487-2041, Fax: 818-487-4550, Email: paintsquare@espcomp.com

Printed in the USA PAINTSQUARE www.paintsquare.com

Changes

This year, *JPCL* said goodbye to Karen Kapsanis, former Editor in Chief for the last 25 years. Karen's wealth of knowledge and unwavering commitment to the *Journal* helped make it what it is today: the journal of record not only for SSPC, but also for the protective coatings industry.

With that said, I know what you're thinking: Will there be any changes? The answer is "Yes" and "No."

Here's what won't change: the level of technical content authored by some of the greatest minds in the protective and marine coatings industry. Something else that won't change is our coverage of why paint fails and the innovative and new ways we can make it last longer.

We're keeping traditions alive, but at the same time, we're adding new content. Warren Brand's column, "Mind Your Business," will give coatings business advice on managing conflict, negotiating, and how to ask for the sale. The popular "Cases from the F-Files" will be tweaked to include mechanisms of failure; and these are just a few of the developments we have on tap. We will continue to disseminate information on industry advances and provide the solid technical information our readership has come to rely on for three decades.

Our Directories and Buying Guides will remain a staple in the *JPCL*. It's important to us that you're able to find the right company, tool, coating, or lining for your project—and it's also great that you can find those things in print and online at paintsquare.com.

The *JPCL* will always deliver respected content to our influential audience and I am looking forward to making that happen, along with you, our valued readers. And of course, my door is always open to your suggestions, comments, and feedback.

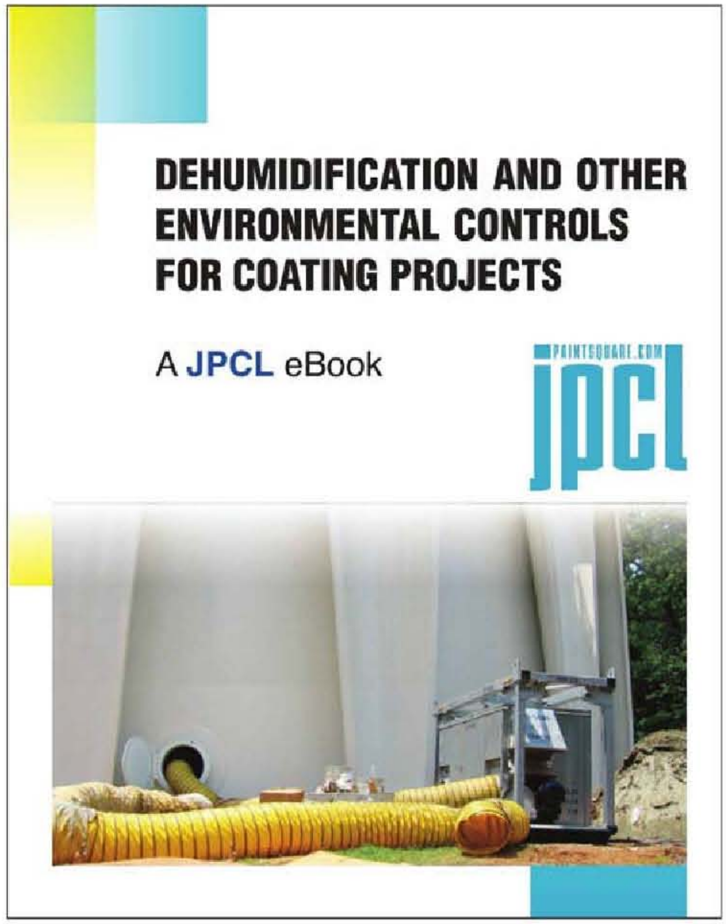
Anita M. Socci
Editor in Chief

JPCL Offers New eBook on DH, Environmental Controls

JPCL has released a new, free eBook designed to help guide users in employing dehumidification and environmental controls during protective coatings applications.

"Dehumidification and Other Environmental Controls for Coating Projects" consists of five articles published from *JPCL* on topics including advances in environmental controls, the basics of dehumidification, temperature and humidity control, sizing dehumidification for water tank lining, and setting up ventilation in confined spaces. Authors' affiliations are listed as they appeared when the articles were originally published in *JPCL*.

This eBook is sponsored by DRYCO and is available for download, free of charge, at paintsquare.com/store.



AkzoNobel CFO to Step Down

AkzoNobel has announced that Keith Nichols, the chief financial officer who led the company during a turbulent period in 2012 and oversaw its largest acquisition, will leave his position June 30, after eight years with the company.

No reason was given for Nichols' departure, although some reports noted that AkzoNobel is based in Amsterdam and Nichols' family is in the U.K. The company said it would mount an international search for his successor.

Nichols, 53, joined AkzoNobel, then the world's largest paint and coatings company, in 2005. He became CFO in 2008.

AkzoNobel CFO Keith Nichols (left) and CEO Ton Büchner (right)

His tenure has included AkzoNobel's $17 billion acquisition of Imperial Chemical Industries, its exit from the pharmaceuticals business, its billion-dollar sale of its North American decorative coatings business to PPG Industries, and other major changes. Nichols has also been a key figure in the company's multi-year restructuring effort.

In late-2012, he led the firm when AkzoNobel CEO Ton Büchner abruptly left for what was billed as a short rest but stretched into a medical leave of three months. Büchner had just joined the company four months earlier.

Before joining AkzoNobel, Nichols was group treasurer at the Corus Group plc. Prior to that, he had held a number of senior finance positions within the TNT Post Group.

PPG to Acquire Hi-Temp Coatings

Pittsburgh, PA-based PPG Industries has announced the acquisition of Hi-Temp Coatings Technology Co., Inc., a privately-owned global supplier of high-temperature resistant and insulative coatings.

Financial terms of the acquisition were not disclosed, but the transaction is expected to close in the first quarter, subject to customary closing conditions.

Hi-Temp, founded in 2001 and based in Boxborough, MA, specializes in coatings that withstand extreme temperatures to protect both carbon steel and stainless steel substrates. Its coatings are used in refineries, petrochemical plants, pulp and paper mills, and power plants. The company's product line includes coatings that may also be applied while equipment is hot and in operation, reducing downtime for maintenance.

"PPG looks forward to integrating Hi-Temp Coatings into our product offering," said Tim Knavish, PPG VP of Protective and Marine Coatings. "Hi-Temp's unique technologies bring multiple growth opportunities to PPG, particularly in the petrochemical segment.

"Combining their excellent corrosion-under-insulation coatings portfolio with PPG's legacy portfolio enables us to provide additional high-quality options to meet more of our customers' coatings needs," Knavish added.

Founded in 1883, PPG is a world leader in protective and marine coatings and specialty materials.

Two Coatings Groups Elect Directors

RadTech and the Powder Coating Institute have both named their new board members for 2014.

RadTech, based in Bethesda, MD, is the non-profit association for the advancement of ultraviolent (UV) and electron beam (EB) technologies. The association has more than 700 members in 32 countries.

RadTech President Don Duncan

PCI President Bob Allsop

Its new board members, effective January 1, are:

- Lisa Fine, Joules Angstrom, chair of the Environmental Health and Safety Committee;
- Beth Rundlett, DSM, co-chair of the UV LED Committee; and
- Aaron Smith, Kimball, chair of the Wood Committee.

The new board members join RadTech President Don Duncan, Wikoff Color Corp., and the other current board members, including:

- Peter Weissman, Quaker Chemical, president-elect;
- Paul Elias, Miwon NA, treasurer;
- Eileen Weber, Red Spot, secretary;
- Howard Ragin, immediate past president;
- Tony Carginano, Allnex;
- Jennifer Heathcote;
- Steve Lapin, PCT Engineered Systems;
- Im Rangwalla, ESI;
- Mike Sajdax, IMX International;
- Rick Baird, The Boeing Company;
- Joshua Lensbouer, Armstrong World Industries; and
- Chris Miller, Estron Chemical Inc.

The Powder Coating Institute (PCI), based in Montgomery, TX, was founded in 1981 to represent the North American powder coating industry. PCI's 2014 Executive Committee is:

- Bob Allsop, Nordson, president;
- John Cole, Parker Ionics, vice president; and
- John Sudges, Midwest Finishing Systems, secretary/treasurer.

The other members of the PCI Board are:

- Barry Keating, PPG Industries;
- Chris Merritt, GEMA USA;
- Chris Reding, DSM Resins;
- Dean Edwards, Trimite Powder;
- Paul West, Sun Polymers Inc.;
- Ron Cudzilo, George Koch Sons;
- Steve Kiefer, Akzo Nobel; and
- Shivie Dhillon, Sundial Powder Coatings.

The Buzz on PaintSquare.com

By Anita Socci, JPCL

HOT TOPIC

Know Your Rights When OSHA Calls

In a recent blog, Eric J. Conn discusses employer's rights when it comes to OSHA inspections, and the comments came flooding in.

Tony Rangus: *What rights do the poor employees have? There are far too many deaths, injuries, and detrimental health results to workers in the United States caused by companies who don't care. Look around at how many companies have multiple OSHA fines, etc., but continue to put employee safety way down the radar screen. We need to give OSHA much bigger teeth to take big bites out of companies who don't give a DAMN! OSHA should be able to shut down folks who kill & maim employees because safety is at the bottom rung of the company ladder...*

M. Halliwell: *Tony, I understand the sentiment and agree that OSHA should have bigger teeth...but just like the police, there have to be checks and balances to protect companies from anything malicious (vindictive ex-employees or over-zealous inspectors come to mind). I fully agree that recalcitrant employers need to be brought on board when it comes to safety or shut down and not allowed to simply "hang a new shingle." I also think that there needs to be some due process...*

Read more and join the conversation at www.paintsquare.com/blog.

PSN TOP 10

(As of Feb. 5)

- TBT Ban Lets Girl Snails Be Girls
- 'Willful' Citation in PPG Worker's Death
- Navy Likes Ike's New Paint Protocol
- Epic Fail: $195K Paint Job Washes Out
- Inquiry: Bay Bridge Concerns Quashed
- USAF Investigates Foam System Death
- Broken Bridge to Cost $170M Extra
- High Court: No Pay for Donning PPE
- Probe of 2 Bridge Deaths Underway
- Wage Hike Ordered for U.S. Contractors

Popular Poll

(Among Poll questions from Jan. 2 to Feb. 7)

A bill now before Congress would raise the federal minimum hourly wage to $10.10. Should Congress pass the bill, kill it, or pursue an amended version?

61%	32%	7%
Pass it.	Kill it.	Amend it.

MOST POPULAR QUIZ

(From Jan. 2 to Feb. 5)

What is the relationship between a polyol and a polyalcohol?
(Answer at bottom of page)

A. One is a resin, the other a curing agent.
B. They are synonymous.
C. They have no relationship.
D. They both start with P.

Quiz Leaderboard (As of Feb. 5)

Douglas Steitz 23/23
Parvez Shaikh 22/23
Doug Driscoll, Sr. 22/23
Michael Beitzel 22/23
Robert Cloutier 22/23

Results

Answer: B. They are synonymous.

Get the coatings industry buzz at paintsquare.com, or scan the QR code with your smart device for instant access!

On Overcoating Existing Tank Linings

When performing maintenance painting of tank linings, what are the pros and cons of overcoating an existing lining that appears to be in good condition?

From Christian Favennec, DCNS

In my opinion, it is not recommended to apply a new full coat over an old one in a tank, even if it is assumed that the old one is in good condition.

The only result you will have is to generate new risks of premature failure, including the risk of premature adhesion failure between the old coats and the new one, and the risk of damaging the old coat by generating mechanical stress during surface preparation, with the stress generated by the new coat.

In a tank, the only need for application of a new full coat over an old coating assumed to be in good condition is for cosmetic reasons, generally based on the asking of the customer, and not for technical reasons. If you can assume that the old coating is in good condition, there is no need to apply a new coat.

Some of the methods to define if the old coating is in good condition include visual inspection for blistering, cracking, flaking, etc., and repartition of these defects (localized or scattered); adhesion pull-off tests; thickness testing; and holiday detection.

Generally, on an old coating in a tank, you can detect the porosity by visual inspection. You can also damage the old coat if you use too high a voltage during holiday detection. If you only have localized defects or less than 10–15% scattered defective areas, it's generally better, both technically and economically, to only perform touch-up. If you have more than 15% of scattered defective areas, I generally suggest completely blasting the old coating and reapplying a new one.

From Tom Selby, Rodda Paint Corporation

The pros, of course, are the savings in time and money from not having to remove and dispose of the existing coatings. The con is whether or not there is enough adhesion to the substrate and the soundness of all existing coatings on the surface. Prior to making a decision, adhesion tests should be done. If a sweep blast is done per SSPC-SP 7, then adhesion tests should be done after the sweep blast to check and see if the adhesion of the old coating system has been compromised in any way.

From William Slama, International Paint/Ceilcote Products

This answer is in regards to internal tank linings and particularly thick, reinforced thermosetting systems. First, one must focus on the functional challenges to the lining system, simplified here as permeation, direct chemical attack, and mechanical (i.e., abrasion, etc.) Next, the percentage of intact film area must make the "repair and overcoating" approach worthwhile, as opposed to removal and reapplication of the same or a different lining system.

Basically, the existing lining system must be judged to have given and to be able to provide good protection in the tank environment (primarily chemistry and temperature). In those cases, the existing lining damage could be due to application variables or localized challenges due to cold wall areas or abrasion. The intact lining areas should be assessed for remaining thickness and for through-adhesion with emphasis on evaluation of underfilm condition of the (steel) surface. If tensile adhesion strength through the film is acceptable (generally more than ⅓ of a new film), and underfilm corrosion is slight or none, overcoating is a good prospect. We have seen this in many high-build, reinforced linings that can be expected to have a protective life of 10 to 25 years. In some cases, localized areas have been compromised and/or the surface layer (top coat) has been severely degraded over many years, but the underlying lining is still strong and well-bonded. The result has been that localized repair and reapplication of the top coat after abrasive blasting has resulted in 20-plus years of service without the much higher cost and down time of removal and relining.

JPCL

Problem Solving Forum questions and answers are published in *JPCL* and *JPCL*'s sister publication, *PaintSquare News*, a daily electronic newsletter. To subscribe, go to paintsquare.com. Occasionally, PSF questions and answers are republished, and participants' company affiliations are listed as they were when the answers were initially submitted.

Q&A with Frank Rea

By Charles Lange, JPCL

Frank Rea is the Director of Coatings Services and Chief Chemist for the southeastern coatings operations of Greenman-Pedersen, Inc. He is responsible for the promotion and marketing of GPI's coatings services, including writing proposals and developing presentations and fee estimates. He also provides project management services with consulting, specification writing, occasional failure analyses, and coatings inspection for steel and concrete during construction or maintenance—mostly on bridges. Before joining GPI, he spent seven years as Chemist Administrator with the Florida Department of Transportation.

In addition to his PCS certification, Frank is a NACE-certified Protective Coatings Specialist, a NACE Level 3-certified Coatings Inspector, an ANSI Level 2-certified Nuclear Coatings Inspector, holds SSPC's C-3, Deleading of Industrial Structures certification, and teaches several SSPC and NACE courses. He holds a bachelor's degree in chemistry from the University of Florida.

JPCL: How did you get your start in the protective coatings industry?

FR: I was fortunate enough that the Florida Department of Transportation hired me as their Chemist Administrator in 1994. In addition to supervising chemical testing of all of the materials used in road and bridge construction, I was told that I would be FDOT's "bridge paint guy." At that time, I thought, "how complicated can that be?" I immediately found out when I started the position and learned more about the coating of bridges.

JPCL: What was it like working for such a large and, presumably, busy state agency like the Florida DOT? Did the work you did with the DOT differ greatly from what you do now?

FR: It was exciting and, moreover, I was so blessed to have such a perfect opportunity to set the foundation for my career. It was not only a first step, but the perfect setting to learn so much. We tested concrete, galvanizing, bridge pads, traffic markings, raised pavement markers, limerock, reflective sheeting, paints, sealants...you name it, we were responsible for developing the specifications, testing the products for approval, and performing random QA/QC on project samples.

JPCL: GPI Southeast recently merged with its parent company, Greenman-Pedersen, Inc. Have you had any particular challenges in maintaining business as usual during this transition period? How did you work through these challenges?

FR: You don't know the half of it. In the middle of our end-of-year accounting, we not only merged into GPI, but also moved our office! The merger was essentially a name change, but it was hectic with having to re-write contracts; re-do insurance certificates; change all letterheads, business cards, etc.; pack and move. However, through teamwork and a great effort from our support staff, I feel the transition went smoothly without any consequences for our clients.

JPCL: Your background is in chemistry, and you have plenty of consulting and project management experience in the field, as well. Personally, which do you prefer more: working in the laboratory, or working out in the field or at a project jobsite?

FR: I would have to say I have a few favorite components of my job. I am a "people" person and therefore enjoy client interaction, doing presentations to win projects, and teaching classes. However, I am also a "mad scientist, techno-nerd" and therefore enjoy anything associated with chemistry.

JPCL: Is there a project or job that you worked on in the past that is particularly memorable or noteworthy? Can you describe what made the project stand out?

FR: Without a doubt, the complete rehabilitation of the Isaiah D. Hart Bridge in Jacksonville, FL. GPI provided turn-key services for this project from start to finish. I performed the coatings condition assessment, provided maintenance recommendations, and provided plan note consultation to the Engineer of Record. We were then fortunate enough to provide certified coatings consulting and inspection during the construction/maintenance phase. I also served as the Senior Coatings Consultant on the project.

The scope of work entailed steel repair and full coatings removal and replacement. Over 39.3 tons of steel and 9,000 bolts were repaired or replaced. Further, 5,500 tons of abrasive, 32,000 gallons of coatings, and 24 miles of caulk were used to protect the 1.2 million square feet of steel surfaces. The project won the SSPC George Campbell Award in 2012 for outstanding achievement in the completion of a difficult or complex industrial or commercial coatings project.

JPCL: What has been the highlight or proudest moment of your career thus far?

FR: SSPC 2000 in Nashville, TN. I was honored to serve as the General Session Chair, reviewing 72 papers, coordinating the presentations, and introducing the individual Session Chairs. I felt fully accepted in the coatings industry, but, moreover, I was giving back for all the help and advice I had gained from my mentors.

JPCL: What is your favorite part about the work that you do?

FR: Client relations are my favorite. I especially like educating clients on the importance of solid specifications and certified coatings inspection. It's rewarding to assist them in avoiding problems or helping them solve coatings problems should they arise.

JPCL: What are your interests outside of work? How do you like to spend your free time?

FR: I like to dabble in the kitchen as much as the laboratory. I enjoy inventing gourmet dishes and competing in local competitions. I sing the blues and classic rock with a local band from time to time and take out my boat in the Gulf when possible.

JPCL

Applying Coatings Outside of the Recommended Thickness Range

By Chrissy Stewart, PCS, KTA-Tator, Inc.

Rich Burgess, KTA-Tator, Inc., Series Editor

The manufacturer's Product Data Sheet (PDS) should always be consulted when recommending a coating or coating system for a specification or when coatings will be applied. The PDS typically contains information regarding appropriate uses and environments, performance characteristics, and application information, including mixing, application methods and equipment, and the recommended thickness range for the material. The information provided by the manufacturer should be followed closely to maximize performance of the coating material.

Coating materials are selected for application with a target application thickness in mind. The manufacturer's recommended range and the thickness indicated in the project specification should be in agreement. If a discrepancy exists, the specifier and the coating manufacturer should be contacted. When applied at the appropriate thickness, the physical and protective properties of the coating material are optimized. Often, a problem with coating performance can occur if not enough attention is given to the thickness at which the materials are to be applied.

This article will investigate the possible failure mechanisms that can occur if a coating is applied at insufficient or excessive thickness.

Insufficient Coating Thickness

Insufficient coating thickness can occur in a number of ways, but essentially, either the coating thickness was not specified or communicated correctly, the application was performed deficiently, or the volume solids content of the coating was not reported accurately. The quality of the coating application should not be judged on appearance (e.g., looks good enough). While coatings have a cosmetic advantage, the main goal is protection of the substrate from corrosion or other environmental factors. If a coating material is applied until it appears to cover completely, without regard to the manufacturer's specified thickness, the resultant dry film thickness could be lower than the target thickness for optimal coating performance in a specific environment. If an applicator

"Cases from the F-Files," a Change in Direction for 2014

Since 2009, *JPCL* has published nearly 50 "Cases from The F-Files." Up to this point, the series has focused on the investigation of real-world coating failures, specifically how the failures were investigated in the field and in the lab and how conclusions and opinions were reached. Identification of the "responsible party" was also provided, and the missteps were detailed.

This year, the "F-Files" series takes a different tack. The series, now known as "Cases from the F-Files: Mechanisms of Failure," will define various coating failures related to selection and application of coatings. It will provide examples that illustrate why a deficiency occurs and what causes it; describe how to determine that it occurred in the first place; and detail its potential effect on coating performance. Our first column in the series addresses coating thickness. Future articles will address entrapped solvents, incorrect mixing of coatings, coatings applied to alkaline substrates, and more. As always, reader feedback and questions are welcome. We hope you find the articles interesting and helpful.

tries to stretch the coverage area of the material with diluents, then the result will be a coating thickness that is below the acceptable threshold for performance.

When the specified range of coating thickness represents a thinner film, such as 1.0–1.5 mils, the importance of applying the coating within that range is magnified. If the coating is applied at 0.5 mils, then film thickness is reduced by 32–50%. Particular attention must be paid when applying thin films to ensure that the appropriate thickness is obtained. By comparison, if a range of 20–30 mils is specified and the actual film thickness is 19 mils, the 5% reduction in coating thickness will likely not present as significant a problem with the performance of the coating material.

Consequences of Insufficient Coating Thickness

Some of the problems that can occur when a coating film is applied at a range significantly below the recommended thickness range are discussed below.

Visibility of Substrate

When proper coverage is not achieved, the substrate or underlying coating may be visible through the coating material (Fig. 1). While this is not an ideal aesthetic condition, it may also leave underlying coating materials or substrates vulnerable to corrosion, degradation by exposure to solar radiation (sunlight), or other environmental effects. For example, if a urethane topcoat is applied over an epoxy coating and there are several scant areas present, the epoxy coating is more susceptible to chalking because of unintended exposure to ultraviolet light. The results include blotchy color and gloss and uneven erosion patterns, and a shorter time until maintenance painting may be necessary.

Pinpoint Rusting

Pinpoint rusting can occur when the thin film does not provide enough barrier or cathodic protection to the underlying metal substrate. For example, a zinc-rich primer applied to a substrate with a surface profile depth greater than the applied thickness of the coating will not adequately cover the tips of the anchor profile peaks. This leaves the tips of the steel with little or no protection. Failure to agitate zinc-rich paints during application can exacerbate the problem by not providing enough zinc material to effectively protect the steel from corrosion. Rusting will occur at the points with the least protection (Fig. 2).

Fig. 1: Scant coating coverage of wood siding. The substrate is visible through the thin coating material. Figures courtesy of the author.

Fig. 2: Pinpoint rusting through the topcoat

Cracked, Brittle Coating

When the coating film is applied below the target thickness range, the physical properties of the film itself may be jeopardized. For instance, a modified polyurethane lining that has an inherently high degree of cohesive strength will be more brittle than anticipated when applied at a thickness of 5 to 8 mils rather than a recommended thickness of 30 mils. The decreased flexibility of the coating corresponds to reduced cohesive strength of the film and can result in cracking or delamination (Fig. 3, p. 16).

Fig. 3: Cracked topcoat of a system applied approximately 20 mils below the minimum specified thickness range, viewed at 50x

Correcting deficient film thickness is not as simple as applying the next coat thicker. Inorganic zinc coatings generally have poor intercoat adhesion when applied in multiple coats. Corrosion inhibitive epoxy primers have drying and curing recoat intervals to consider, and the loss of primer thickness is also a decrease in primer function—something the next, thicker coat may not make up for. Finish coats are likely to require scarification prior to application of an additional coat.

Owners do not want to deal with the performance consequences resulting from a coating applied below the manufacturer's recommended minimum thickness. Contractors do not want to deal with correcting low film thickness. Both are good arguments for hitting the minimum film thickness required. The other side of this coin is failing to stay below the maximum coating thickness, which can have consequences as well.

Consequences of Excessive Coating Thickness

As with insufficient thickness, excessive coating thickness is also application related; however, the reason for the application error can vary. Often an applicator is not aware of the impact of excessive coating thickness on coating performance. Protective coatings are designed to perform at a specific thickness range based on the chemistry of the coating and the intended service. Therefore, with protective coatings, more is not equivalent to better. In fact, several additional issues or modes of failure are attributed to excessive coating thickness than those described for insufficient thickness. Several consequences of excessive coating thickness are discussed below.

Sagging and Running

If a coating material is applied in excess, the wet coating can run or sag, especially on vertical surfaces (Fig. 4). Coating materials with lower viscosities are particularly susceptible to sagging and running. The result is an uneven film surface with areas of excessive thickness as well as insufficient thickness.

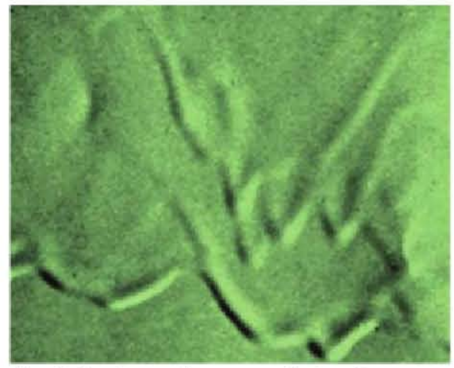


Fig. 4: Sagging coating on a vertical surface

Cracking and Delamination

Some coatings, such as epoxies, are susceptible to cracking and delamination when applied at a thickness above the manufacturer's recommended range. The high epoxide functionality of epoxies forms a highly cross-linked polymer network post cure that exhibits high temperature and chemical resistance, but low flexibility. The additional internal stress associated with excessive coating thickness often results in cracking of the material, which may subsequently result in delamination of the coating (Fig. 5). Typically, delamination occurs at the weakest interface. When a coating is applied too thick, the cohesive strength of the material is often compromised (Fig. 6, p. 20). A cohesive break in the coating layer that is applied too thick is not uncommon with cross-linked coatings. Additionally, a smooth substrate in combination with a coating applied thicker than recommended may cause delamination from the substrate, as the stresses introduced to the system are greater than the adhesive bond of the coating to the substrate.

Fig. 5: Stress fracturing or cracking caused by excessive film thickness, viewed at 50x

Wrinkling

In cases of excessive coating thickness, the top surface of the coating may dry or cure before the bulk of the coating. In these

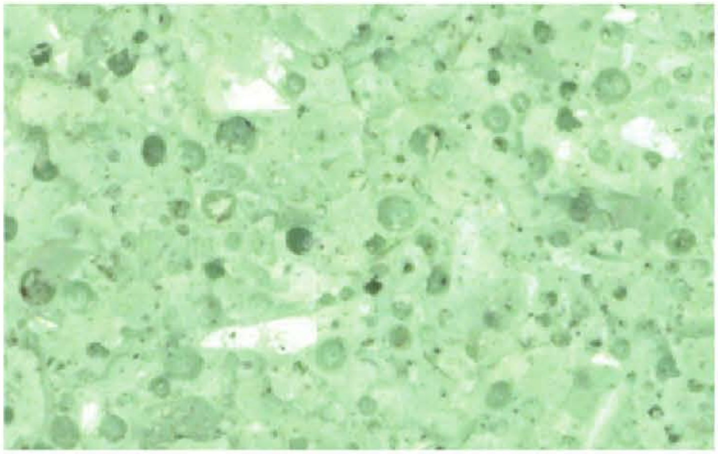


Fig. 6: Cohesive fracture of a coating layer, viewed at 50x. Notice the craters in the green coat split from the structure.

cases, the top surface creates a skin of stationary dry material over the flexible, soft uncured material, which can result in deformation of the surface upon movement of the underlying material. The ridges and valleys in the skin are seen as wrinkles (Fig. 7). Alkyd coatings are particularly susceptible to wrinkling when applied excessively because they cure by atmospheric exposure to oxygen. The oxidation process will occur first at the surface and continue throughout the coating thickness, but at a much slower rate. When films are applied excessively thick, the bulk of the film remains soft and uncured with less exposure to the atmosphere.

Increased Dry Time

The dry time and curing time of coatings are often directly related to the application thickness. If a coating is applied too thick, the delayed dry time can affect the recoat schedule, the rate of solvent release, and the likelihood for dirt and debris pick-up because of an unusually extended soft surface (Fig. 8). These factors may result in a poor surface for over-coating or an unwanted appearance.

Fig. 7: Wrinkles caused by a coating applied at four times the recommended thickness

Fig. 8: Washed coated surface. Dirt is embedded into the top coating layer.

Fig. 9: Blisters in a clear coat applied at three times the recommended thickness over wood substrate

Improper Curing

As with wrinkling and increased dry time, excessive film build may cause issues during curing. Some materials may not fully cure before being put into service, leaving a coating surface that is too soft, easily damaged, and unfit for service. Solvent entrapment may also occur if the top surface cures and the underlying material does not. Because a thicker film creates a thicker, less permeable barrier, any entrapped solvent or moisture would have a more difficult time permeating through the system. Solvent entrapment could lead to blistering of the coating (Fig. 9).

Methods of Coating Thickness Measurement

In a perfect situation, the wet film thickness of the coating material should be checked as application occurs to ensure that the specified thickness range is being met. This can be done at the time of application using a wet film thickness gage. If incorrect dry film thickness is suspected, several techniques or instruments can be used to measure the thickness of a coating system.

Tooke Gage

A Tooke gage can be used in the field or laboratory. To determine the film thickness with this instrument, an incision is made into the coating down to the substrate using an angled blade that is selected based on the expected thickness range. The incision is then viewed using the microscope (ocular) and scale that is visually evident through the ocular of the gage. A conversion using the selected cutting blade, as well as the scale reading, will provide the coating thickness for each visible coating layer. ASTM D4132, "Standard Practices for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive, Cross-Sectioning Means," describes the procedure for using this type of instrumentation.

Limitation—This is a destructive test. The cutting blade will expose a small portion of the substrate.

Nondestructive Coating Thickness Gage

A nondestructive coating thickness gage can be used in the field or laboratory. These gages are available in ferrous and non-ferrous models, and they can obtain coating thickness measurements on various coated metals. Ultrasonic gages are useful for measuring coatings on concrete or masonry surfaces. These gages send an ultrasound signal into the coating using a probe (i.e., a transducer) with the assistance of a couplant applied to the surface. Gages used to measure coatings on metal surfaces use eddy current and/or magnetic induction technologies. The gage is placed on the coated surface, and a digital reading of the total thickness of the coating system is provided. ASTM D7091, "Standard Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals," and ASTM D6132, "Standard Test Method for Nondestructive Measurement of Dry Film Thickness of Applied Organic Coatings Using an Ultrasonic Coating Thickness Gage," describe the procedures for using this instrumentation.

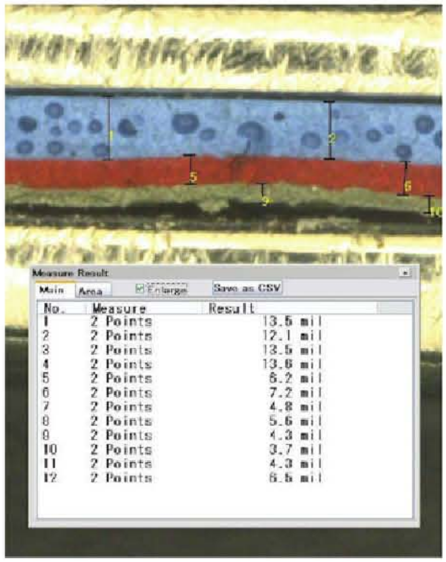


Fig. 10: Example of thickness measurements obtained from a digital microscope

Limitation—Only the total coating system thickness measurement can be obtained using this method; individual coating layers cannot be measured after they are applied. Note that some ultrasound gages can distinguish coating layers, but they may not be able to measure the thickness of coatings with air-entrained voids or coatings containing glass flake.

Microscope Equipped with Scale

The cross-section thickness of coatings is predominantly performed in the laboratory with samples collected from the field. Some microscopes have a scale fitted into one of the ocular pieces (similar to the Tooke gage, described earlier). Digital microscopes often have a measuring tool in which two points are selected in addition to the current magnification to calculate the coating thickness (Fig. 10). Coating thickness can be expressed in mils, inches, micrometers, millimeters, and other units. Photographs are often obtained through the microscope.

Multiple coating layers also can be measured by a microscope when the cross section of the sample is viewed. An advantage of the cross section view in the microscope is a magnified view of each coating layer. Splits between or within coating layers can be observed, as well as voids within the coating layers or other defects.

Limitation—Microscopes are typically not appropriate for field use. There is a possibility of viewing an incomplete coating system if samples are not removed cleanly from the substrate.

Conclusion

This article provides eight common examples of coating problems associated with insufficient or excessive coating thickness.

When investigating coating performance issues, the applied coating thickness as compared to the specification requirements and/or the manufacturer's recommendations is an important consideration. That is, if the material was applied outside of the recommended thickness range, it is reasonable to conclude that the performance of the product has been impacted to some degree and that impact should be evaluated. Note, however, that during a coating failure investigation, a thorough survey of coating thickness may reveal insufficient and/or excessive coating thickness in both failing and non-failing areas, so thickness alone may not be the sole cause of a coating problem. Nevertheless, an objective investigation that looks at all of the facts is critical to identifying the root cause and corrective actions. The dry film thickness should always be determined, if for no other reason to exclude it as contributory.

Chrissy Stewart is a Chemist in KTA's Analytical Laboratory, where she has worked for more than seven years. She is responsible for the testing of coatings to determine conformance to specifications and analytical testing to determine the cause of coating failures. Chrissy is currently the Vice President of the Pittsburgh Society for Coatings Technology (PSCT), and is a member of SSPC, ASTM International, and ACI. She is an SSPC-certified Protective Coatings Specialist. She has a B.S. in chemistry from Mercyhurst University. **JPCL**

Power Tool Cleaning

Surface preparation is the most important factor in a successful protective coating application. To achieve a properly prepared surface using power tools, extreme care must be taken in choosing the proper tool and abrasive. Some of the more common reasons to use power tools are as follows.

- **Spot repair of existing coating systems**

If only a few square feet on a bridge, tank, floor, or other structure requires repair or touch-up, it would not make economic sense to mobilize large, efficient blast rigs.

- **As an adjunct to abrasive blasting**

If abrasive or shot blasting is being carried out on a large structure, or if blasting has been completed, and water or other contaminant comes into contact with the clean surface, it would not make economic sense to remobilize. There also may be occasions where shot or abrasive blasting cannot reach certain areas.

- **In overcoating an existing coating system**

If an existing coating is in good condition, but simply needs another topcoat, applicators may choose to use hand sanders or other power tools instead of abrasive blasting.

- **Lead abatement**

Because of the numerous types of power tools and associated vacuum attachments, it may be economically more efficient to use these tools rather than other more popular, high-production types of systems.

- **In shop applications**

In many cases, it would be inefficient for items to be run through the blast unit again.

Editor's Note: This article is updated from the original version written by Ralph Fabian of DESCO and published in the October 2005 JPCL.

Vacuum-shrouded roto peening prep tool used on a vertical surface. Courtesy of Novatek Corp.

Common Surface Preparation Problems

Flaking, blistering, delamination, and chipping are some of the most common signs of coating failure resulting from poor surface preparation. There are two forms of contamination: visible and non-visible. The most common form of visible contamination is a corrosion byproduct—on carbon steel, it would be rust. The most serious form of non-visible contaminants on metallic surfaces is soluble salts. Because of their ability to draw in moisture through the coating, it is imperative to check for the presence of salts before the application of a new coating. None of the tools mentioned in this article will remove salts or other non-visible contaminants (chlorides, sulfates, etc.). Failure to remove these contaminants may result in premature coating failure.

Another cause of poor coating adhesion is inadequate surface profile. Surface profile is the measurement of the roughness of a surface. A proper profile is critical, as it provides the "anchor" pattern necessary for proper adhesion and bonding of most coatings. In general, the thicker the DFT of the coating system, the more aggressive or deeper the required profile should be.

Four Basic Forms of Power Tools

Although power tools come in a variety of shapes and sizes, they can be broken down into four basic categories: reciprocating sanders, rotary or impact tools (roto peening, scarifiers, bristle blasters), grinders, and reciprocating impact tools (needle guns and scabblers).

Because of their higher productivity compared to reciprocating sanders and orbital grinders, rotary impact tools are typically the best choice for removing coatings and creating an anchor pattern. For spots that are difficult to reach and areas not accessible to large rotary impact tools, needle guns, scalers, roto peening, or bristle blasters can be used. In short, an operator can look at large rotary scarifiers as the "paint roller" and smaller impact tools as the "paint brush." Like paint rollers, rotary scarifiers are used for larger, more accessible areas, whereas reciprocating or smaller impact tools, like paint brushes, are used for detail work such as reaching into corners and hard-to-reach areas. On average, one can expect a rotary impact tool's productivity to be at least 5 to 7 times greater than the productivity of a needle scaler for most applications.

Furthermore, for removal of hazardous coatings or other contaminated materials, impact and rotary impact tools will usually generate the lowest levels of airborne contaminants. The chipping action of these tools when removing coatings and other unwanted material typically produces larger and heavier waste, which is more easily contained. On the other hand, when sanders and grinders remove coatings, a very fine, dust-like material is produced. Because of the high revolutions per minute (rpms) generated by most grinders and sanders, the dust-like material produced combined with the velocity of the particulate can create containment problems if tools are not properly shrouded and operated.

All of the above-mentioned tool groups are available in portable, hand-held, and walk-behind configurations. Most hand-held power tools are available in both electric as well as pneumatic (air) power. Electric hand-held units typically require the standard 110 volts, while pneumatic units require 5 to 40 cfm of air (at 90 psi), depending on the tool. Reciprocating tools require the least amount of air supply, while larger sanders or rotary scarifiers consume the most air.

Larger, walk-behind machines are available in electric, pneumatic, gasoline powered, and propane powered. Electric machines usually require a higher voltage of 440 volts (three-phase power). Some smaller, walk-behind units are available in 110-volt versions; however, because of the power required to drive the abrasive media, most units will have larger motors requiring three-phase power. Depending on the size, most pneumatic units will require a minimum of 95 to 125 cfm, when operated at 90 psi.

Reciprocating Impact Tools

Examples of reciprocating impact tools include needle guns, chipping guns or hammers, and scabblers. These tools are most commonly characterized by an air-driven chisel or piston that is designed to strike a surface. Chisels and pistons come in a variety of shapes and sizes to adapt to varying applications. Needle guns are typically used for cleaning small areas or areas that are not accessible to rotary impact equipment because of limited clearance. Scabblers tend to be much more aggressive and are used for breaking up heavy rust, mill scale, coatings, or concrete. When using impact tools, an operator must take extreme care to avoid gouging or destroying the substrate.

Rotary Impact and Scarifying Tools

Rotary impact tools are characterized by any of a variety of rotating heads, which strike the surface at a 90-degree angle. These tools are not to be confused with grinders, which also have a circular motion but do not strike the surface.

Bristle blasters are one type of impact tool that can effectively remove coatings on hard-to-reach areas. Courtesy of MONTI-Werkzeuge GmbH, Hennef, Germany

Scarifiers use a drum with moving steel or carbide-tipped cutters that are available in a variety of shapes, depending on the application. Bristle blasters use heavy wire-type drums, while roto peening equipment uses smaller, circular steel tabs secured to a fabric wheel.

Sanders and Grinders

Sanders and grinders come in a variety of shapes and sizes. Smaller, palm-sized tools allow operators to perform detailed work in difficult-to-reach areas, whereas larger sanders can be used for heavier grinding and production work. The four primary cutting mechanisms used with these tools are coated abrasives, non-woven abrasives, wire brushes, and diamond-tipped wheels. Although wire brushes can remove coatings and loose mill scale, they will not completely remove rust. Wire brushes have a tendency to burnish or polish the rust, eventually resulting in rust-back and coating failure. Depending on the disc, coated abrasives can be used for removing paint, mill scale, and grinding rust. Unfortunately, coated abrasives have a tendency to load or clog up, requiring frequent change outs, and they can damage a substrate if not used properly. Non-woven discs can be used effectively for scuffing and feathering paint, as well as removing rust and corrosion from steel substrates. Because of their design, non-woven discs will not load up like coated abrasive discs and will provide more constant performance throughout the life of the disc. Diamond abrasives are very effective for grinding and finishing concrete.

The Right Tool for the Right Job

When choosing the best-suited power tool for any given job, certain factors should be considered, such as the level of cleanliness and profile required, the coatings to be removed, and environmental concerns.

Level of Cleanliness and Profile Required

Depending on the coating to be applied and the level of cleanliness it requires, most contracts that call for power tool cleaning will require a contractor to meet an SSPC-SP 3 (Power Tool Cleaning) or SSPC-SP 11 (Power Tool Cleaning to Bare Metal) level of cleanliness. With some projects, such as bridge repainting, it is not uncommon to see SSPC-SP 3 specified on some areas and SSPC-SP 11 on others.

SSPC-SP 3 essentially requires the surface to be free of any loose mill scale, rust, paint, or other foreign matter and is typically specified for coatings requiring minimal surface cleanliness before recoating. For those coatings requiring much higher levels of cleanliness, SSPC-SP 11 is specified. When viewed without magnification, the surface is to be "free of all visible oil, grease, dirt, dust, mill scale, rust, paint, oxide, corrosion products, and other foreign matter." SSPC-SP 11 also requires the contractor to impart a minimum profile of 1 mil (25 micrometers) to provide an anchor pattern for the new coating system.

SSPC-SP 15, Commercial Grade Power Tool Cleaning, also requires a minimum 25 micrometer surface profile. SSPC-SP 15 permits random staining to remain on a defined percentage of the cleaned surface, where SSPC-SP 11 requires removal of surface staining. The standard differs from SSPC-SP 3, in that a higher degree of surface cleanliness is required.

A critical point to remember when preparing any surface area to an SSPC-SP 11 finish is that the level of cleanliness acceptable is never the same in all cases. What is acceptable will depend on the original state of the steel substrate before initial coating application. For example, if the coating being removed was initially applied to a fresh, blast cleaned steel substrate, the level of cleanliness required is different from that for a substrate with heavy pitting and mill scale. To determine what is acceptable, SSPC has developed visual standards that provide pictures of acceptable levels of cleanliness under SSPC-SP 11. Unfortunately, not all inspectors are aware of the different visual standards and subsequently, may demand levels of cleanliness higher than what is actually required by SSPC-SP 11. Therefore, it is highly recommended that contractors have a copy of the visual standard on hand and prepare a test patch to be approved by the project inspector.

Coatings To Be Removed

Rotary impact tools are most often the best choice for removing coatings. Typically, rotary

A needle scaler is a reciprocating impact tool that works well on vertical as well as irregular surfaces. Courtesy of Novatek Corp.

impact tools are used for the bulk of the work, while reciprocating impact tools such as needle guns and chisels are used for detailed areas not accessible to the rotary impact tools. In addition to being faster, rotary impact tools can create a profile on the steel, which will allow the coatings to adhere. Sanders are typically used for removing residual surface contaminants, feathering edges, and repairing spot failures.

Rotary impact tools outfitted with roto peen abrasive hubs, or impact tools, such as bristle blasters, are often the first choice for removing fracturable coatings, such as epoxies up to 15 mils (375 micrometers) thick. An operator can expect to remove the majority of a coating, while leaving a 1 to 3 mil (25 to 75 micrometer) surface profile. Care must be taken not to run roto peen over protruding objects or off the edge of a substrate. Doing so will result in damage to the abrasive bit. It is critical that operators use these devices at the appropriate height adjustment and rpm. Failure to do so will result in significant reduction in life and damage to the abrasive. When used properly, roto peen can last 60 hours or more; when used improperly, the abrasive can be destroyed in minutes. It is not uncommon for residual primer to be left in the pits of the substrate. If SSPC-SP 11 is required, a secondary operation using a non-woven abrasive may be necessary to remove the residual primer.

For heavy, fractureable and non-fracturable coatings, rotary scarifiers and scabblers offer the best method of coating removal. These tools basically cut or shear the coating from the substrate. Certain urethanes and other coatings are so soft and flexible that roto peen, roto hammers, and needle scarifiers will do little more than bounce off the coating surface. With some coatings, such as self-leveling/cementitious coating systems used on concrete floors, the best method for removal is often through chipping hammers, scabblers, or scarifiers. The primary objective with these applications is again to shear or cut the coating from the substrate surface. Care must be used with these tools as it is possible to remove significant amounts of concrete substrate along with the coating.

Projects do not always require complete coating removal. Many applications simply require a contractor to scuff and feather coatings or remove loose coatings before applying a fresh coat of paint. Sanders outfitted with a variety of abrasives most often are the best choice for this type of surface preparation, as they are well suited for removing rust and corrosion and other surface contaminants. Wire cup wheels are often used for removing loose coatings from substrates. Unfortunately, because of their tendency to burnish the surface, the level of cleanliness and finish is not suitable for many types of coatings systems. Nylon non-woven abrasives are excellent for scuffing and feathering coatings while resisting the loading factor experienced with most coated abrasive products.

Environmental Concerns

Vacuum-assisted power tools provide an excellent option for removing hazardous coatings or in removing coatings in environments where nuisance dust is a concern. When used properly, vacuum-assisted power tools are capable of grinding, cleaning, peening, or scarifying in a virtually dust-free environment. When choosing a system, you must ensure that the vacuum used is appropriate for the application. A tool capable of operating well below the allowable level of airborne dust when 25 ft. (8 m) from a given vacuum source may emit airborne dust at very high levels when operated 50 ft. (15 m) from the same vacuum source.

Not all vacuum-assisted power tools are the same. Some offer very high levels of containment; others provide minor dust control at best. The factors affecting the efficiency of a vacuum-assisted power tool include the type of tool being used (i.e., impact tool, rotary scarifier, or grinder), the design of the dust collector attachment, and the vacuum system. Due to the volume of dust produced and rpms generated by sanders and grinders, these tools typically require more sophisticated dust-collecting attachments, as well as more powerful vacuums to achieve the same levels of containment as impact and rotary impact tools. Be sure the vacuum is in good working order and has been properly maintained. A dirty bag or filter can significantly affect a vacuum's performance, resulting in failure of the containment system. Last, verify that the vacuum performance specifications meet the minimal requirements for the power tools being used.

Further, vacuum attachments frequently require that the tool operator hold the power tool at a very specific angle to the substrate. This can be a very tiring process for the operator and typically reduces production rates significantly. This is less of a concern with devices that are designed to work on horizontal surfaces.

Maintaining and Servicing Equipment

The biggest contributors to pneumatic-tool failure are poor air supply and poor air quality. Tools must receive the appropriate amount of air to operate the equipment properly, and it is critical to make sure that the air is clean, dry, and receiving the appropriate amount of lubrication. Air hose assemblies with a built in filter/evaporator and lubricator are often provided with the equipment. To ensure maximum performance and tool life, these assemblies should be used at all times. For best performance, an inline dryer should be installed at the compressor to remove condensation that naturally occurs in the lines.

For maximum performance and longevity from power surface preparation tools, set up a periodic maintenance and servicing program. During maintenance intervals, tools should be lubricated per manufacturer specifications. They should also be taken apart and the bearings should be greased (where applicable) and inspected for wear in such areas as bushings, bearings, air motor veins, and other areas as recommended by the manufacturer. Proper maintenance will prevent costly repairs in the future.

Safety

When working with any type of tool that has moving parts, proper safety precautions must be taken to prevent operator injury.

Due to the dramatically different types and sizes of tools mentioned here, it would be potentially misleading to try and list all of the safety issues. Be sure to follow all appropriate safety precautions when operating power surface preparation tools and other pieces of equipment.

Conclusion

Surface preparation is a multi-faceted process. When selecting a tool for a job, take into account the coatings being removed, the surface to be prepared, the level of cleanliness required, surface profile required, and, most importantly, the protection of the worker and the environment. By taking these factors into consideration, an operator will have the necessary information to make the best choice in selecting the appropriate tool and abrasive for each application. Selecting the proper equipment will enable an operator to save time and money while achieving maximum performance from the new coating system.

JPCL

Polyurea "Loose" Liners

A Floating Fix For Cracked Concrete Secondary Containment

By Kristin Leonard, Materials Engineering Technology Group, Bechtel Corp.

While installing a typical thin-film coating system in a chemical plant in the Western U.S., extensive dynamic cracking was discovered in concrete chemical secondary containment structures. After multiple failed attempts to repair the cracks using standard thin-film coating products, the decision was made to proceed with process equipment installation in hopes of maintaining the construction schedule while the coating details could be evaluated.

With this additional hurdle, the challenge was made to develop a coating system that delivered chemical resistance while acting as a "band-aid" over the damaged concrete to provide 100% containment. After evaluating various options, a polyurea/geotextile liner was selected on a trial basis because of the system's flexible and chemical-resistant properties, as well as the relatively swift installation time.

This article outlines the trials and challenges of modifying the membrane liner to accommodate stringent chemical resistance criteria, poor concrete conditions, and hundreds of pre-installed obstacles. From detailed design to installation mock-up, the pros, cons, and lessons learned are discussed.

This article is based on a presentation given at SSPC 2013, the annual conference and exhibition of SSPC: The Society for Protective Coatings, in San Antonio, TX, Jan. 14–17, and it is available in the conference Proceedings.

Choosing the System

Project requirements outlined that all concrete secondary containment structures were to be coated using a chemical-resistant lining. Severe process conditions, as well as strict local environmental regulations, further emphasized the need for a relatively impenetrable system.

During the system selection process, potential coating materials underwent weeks of rigorous chemical testing, including monitoring for a number of failures that would eliminate a candidate. Different epoxy formulations were tested based on basic knowledge of their overall chemical resistance. Concrete test specimens were prepared in accordance with ASTM D5139, Standard Specification for Sample Preparation for Qualification Testing of Coatings to be Used in Nuclear Power Plants, and subjected to 24- and 72-hour immersion in chemical process fluid. Upon removal from the immersion bath, the specimens were allowed to dry and were inspected for discoloration,


©iStockphoto/ryasick

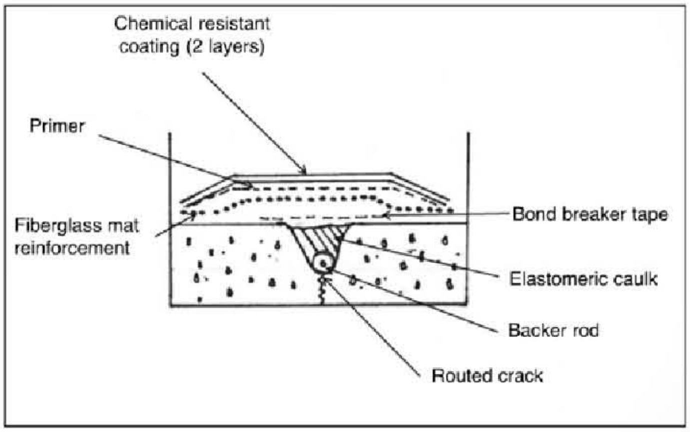


Fig. 1: Schematic of proposed crack repair method
All figures and photos courtesy of Bechtel Corp.

swelling, blistering, and loss of adhesion. After all test results were analyzed, an epoxy novolac system was selected because it provided the best chemical resistance of all the formulations tested.

The original application included the approved thin-film epoxy novolac system applied before the installation of equipment. The concrete was to be prepared by abrasive blasting in accordance with SSPC-SP 13/NACE No. 6, Surface Preparation of Concrete. Vertical and horizontal corners of the containment structure were coved using an epoxy filler. The concrete was to be primed using a penetrating primer followed by two coats of the approved thin-film epoxy novolac.

Dynamic Cracking Discovered

During surface preparation, the removal of laitance exposed extensive cracking in the concrete secondary containment structures. Assuming the cracks were caused by concrete shrinkage, application of the thin-film system continued. Within days of coating application, however, cracks through the coating system were evident. The project team made multiple attempts to repair the coating with rigid epoxy filler materials, but none were successful. Coatings work was stopped, and a concrete specialist was brought in to evaluate the defects.

Because the concrete containment areas were located outside, the structures were exposed to a dry climate, with average daily temperature swings between 30 F and 100 F, resulting in a temperature gradient of 70 F, depending on the time of year. Based on the size and characteristics of the cracks, and taking the environmental conditions into consideration, many of the cracks were determined to be dynamic (constantly moving). With this determination, the project team was faced with two options: revise the existing thin-film system to include rigorous, multi-step crack repair details; or develop a completely new system. Given that the thin-film epoxy system had already completed the chemical resistance testing, the project team requested a crack repair method be developed and evaluated.

Proposed Crack Repair Procedure

Numerous crack repair variations are used in the industry; however, due to the sensitivity of this project, it was decided to stay with a very comprehensive and conservative repair method.

The proposed procedure required cracks to be routed out to a minimum of one quarter-inch on either side of the crack. Once routed, a closed-cell foam backer rod would be placed in the crack and covered with an elastomeric caulk. Bond breaker tape would be installed to allow the crack to move as needed without disturbing the coating system above. Because of vehicle and forklift traffic in the immediate area, a fiberglass mat reinforcement would be required before application of two coats of the thin-film, chemical-resistant epoxy novolac (Fig. 1).

In addition to the crack repair process, a crack mapping procedure would be introduced. The mapping program would require field engineers to evaluate the cracks at various times during the day, measuring the crack width and length. The locations of the cracks were plotted on area design drawings, and measurements would be recorded in a database. This information would be provided to the facility owner for maintenance purposes.

A Faster Fix

Repairing all of the cracks per the recommended method discussed above could potentially take months. Therefore, research into alternative systems began. In an attempt to maintain the construction schedule during the time, the project team decided to proceed with installation of the equipment before coating application. However, this created new obstacles to coat around (e.g., pipe supports, skid-mounted equipment, sumps, and trenches).

Fig. 2: The polyurea/geotextile loose liner system contoured to surfaces to which it was applied.

Several containment systems were assessed before a polyurea/geotextile liner was selected. Commonly recognized as on-grade liners used on disposal sites, reservoirs, and tank farms, the polyurea/geotextile system was re-purposed for this application based on its chemical resistance, flexibility, and relatively swift installation.

Chemical resistance testing per the original requirements was performed on the polyurea system, as well as a slow-setting brush grade polyurea formulation and polysulfide caulk to be used as needed. Upon passing testing qualifications, the design and installation details began.

Design and Installation Details

The loose liner system, comprised of a 12-ounce geotextile fabric topcoated with a plural-component, spray-applied polyurea, would allow the system to float over the damaged concrete without requiring direct adhesion to, or removal of, the previously applied thin-film epoxy coating. Mechanical anchor bolts with washers and stainless steel batten strips were used to hold the geotextile onto vertical walls and also to prevent bunching of the textile on horizontal surfaces. The polyurea was sprayed directly over the textile, and it contoured to the surface on which it was applied (Fig. 2, p. 34).

Difficulty arose in designing the various tie-in details. Considerations had to be made regarding the distance between anchors, the distance of anchors from grout pads, termination details on base plates, and the development of a method for filling in unistrut. Because equipment skids were placed before the polyurea coating was applied, design details had to ensure that in the case of a leak, process fluids could not reach the bare concrete under the base plates. The geotextile was terminated along the concrete-base plate interface. For added protection, a bead of caulk was run along the perimeter of the base plate prior to coating application. The polyurea was then sprayed over the geotextile so that it overlapped onto the steel base plate at a minimum of 2 inches to encapsulate the base and contain any access to bare concrete.

Another area of concern was the interior area of unistrut where process fluid could become trapped. After several modifications, the final design required the interior lower six inches of unistrut to be filled with injectable closed-cell foam. Once filled, the edges of the foam were caulked, and the lower 6 inches of the interior and exterior unistrut were coated with polyurea (Figs. 3 and 4).

The most complex design detail developed was the installation of the system into sumps and trenches. These areas presented narrow access, causing difficulty in manipulating the textile and installing the mechanical anchors. Initial design details required the geotextile to run over the steel

Fig. 3: Polyurea-coated unistrut design detail

Fig. 5: Installation of liner in sump

Fig. 4: Close-up of polyurea-coated unistrut design detail and geotextile membrane

angle iron into the sump, creating a monolithic liner. This design would require fewer anchors to be installed, as the geotextile installed over the horizontal base mat would hold the fabric in place over the vertical walls of the sumps and trenches. However, the thickness of the fabric/polyurea system prevented the pre-fabricated sump grating covers from fitting the sump opening as designed. The final design detail included the use of 1-inch batten strips mechanically installed approximately 1 inch from the top of the sump wall to support the weight of the geotextile. The polyurea was then sprayed over the batten strips and angle iron to complete the sump coating (Fig. 5, p. 36).

An additional challenge arose when it was determined that ultrasonic dry film thickness gages would not provide accurate coating thickness measurements over the loose polyurea/geotextile coating. As confirmed by discussions with various gage manufacturers, the geotextile fabric scattered the ultrasonic pulse and produced inconsistent thickness values. Because of the owner's strict documentation and inspection requirements, standard material usage calculations were not permitted to be the sole acceptance criteria for coating thickness. Therefore, a secondary measuring technique was developed and tested.

The secondary technique included the use of 3-inch x 5-inch steel plates placed within the coated area at frequencies in accordance with SSPC-PA 2, Measurement of Dry Coating Thickness with Magnetic Gages. Each steel plate represented a "spot" measurement having three individual coating thickness measurements taken from each. After the coating was sprayed, the steel plates were cut from the liner, the coating thickness was measured using a standard magnetic thickness gage, and the liner

Fig. 6: Void at edge of mechanical anchor

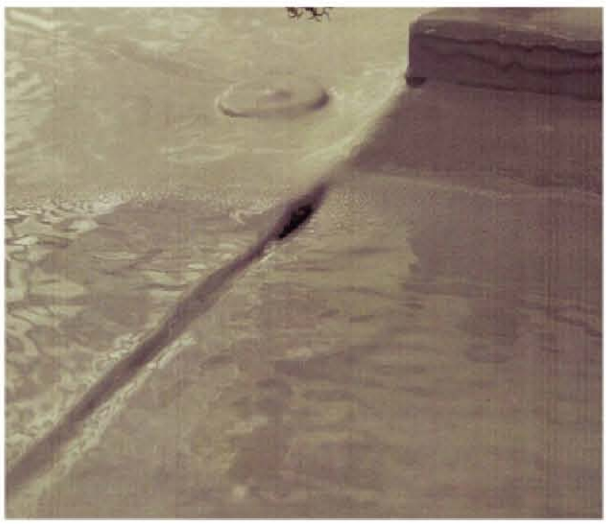


Fig. 7: "Bird mouths" at geotextile seams

was repaired. The steel plates were labeled with the date of coating application, coating thickness measurements, and the location of the plate within the coated area. This information was outlined on a master design drawing. After measurements were confirmed, the steel plates were placed in a box and retained as part of the final inspection records.

Design details were tested in a full-scale mockup of the system. All loose dirt and debris were removed from the concrete surface, and the geotextile fabric was laid. Seams were overlapped a minimum of 6 inches, and the geotextile fabric was cut to fit around the pre-installed equipment. Mechanical anchor bolts were installed, and the polyurea application began.

Lessons Learned After Applying the Liner

The mock-up exposed three main issues that needed to be modified. The first observed flaw was the formation of small voids around the edges of the anchor washers (Fig. 6). The simple solution was to add a bead of polyurea caulk to seal the edges of the washers prior to coating application.

The second challenge noted was the formation of "bird mouths," or puckers, along the fabric seams (Fig. 7). Heat created during the plural-component application of the polyurea lifted the top layer of the seam, which formed a gap and exposed bare concrete. Working closely with the coating manufacturer, the design was modified to seal the seams using a slow-setting, brush-grade version of the polyurea. A two-inch-wide line of polyurea was applied between the layers of the geotextile seam and then firmly pressed together using a smooth-seam roller.

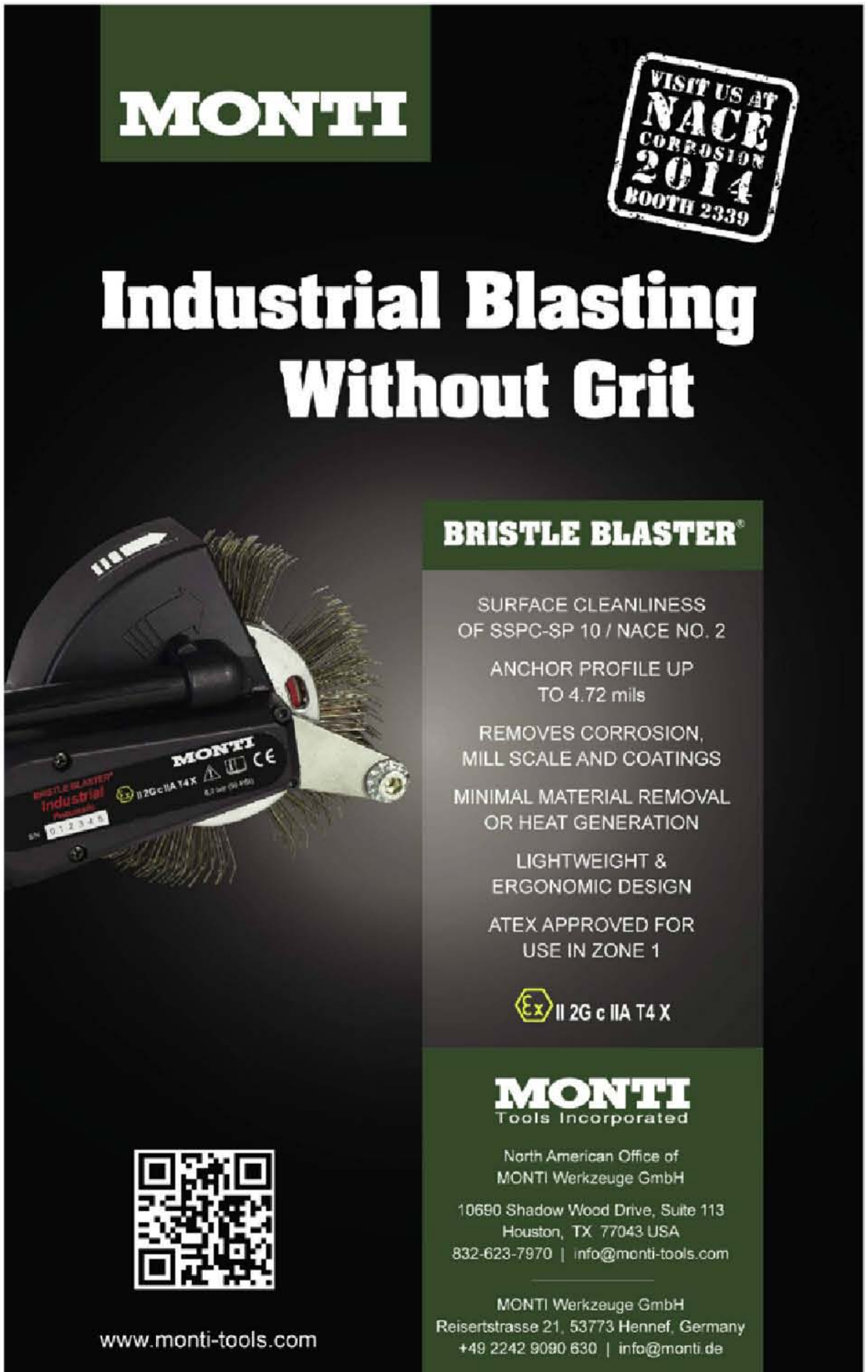


Fig. 8: Rupture in lining caused by fabric "tenting"

Full coating application proceeded after all seams were set.

The final challenge was fabric "tenting" away from the surface at the vertical/horizontal transitions. Originally, the order of installation outlined anchors to be installed on the horizontal base mat first. The geotextile would be supported on the vertical walls via temporary anchors and the final batten strips installed on vertical walls after full application of the polyurea coating. However, during the anchor installation on the horizontal surfaces, the geotextile shifted, creating the "tent." Unaware of this flaw at the time, the coating was applied, and the final batten strip was installed.

The tenting caused the fabric to be pulled taut, increasing stress in the immediate area. In one instance, the stressed location ruptured when a crewmember unknowingly stepped on the liner near the affected area, which caused a large tear (Fig. 8). The rupture was repaired by a cut made into the liner to release the tension. A small patch of geotextile fabric was added behind the existing liner to cover the small area of exposed concrete, and polyurea was sprayed over the area.

Preventing and Solving Delamination During Multilayer Pipeline Girth Weld Coating Application

By J. Alan Kehr, Alan Kehr Anti-Corrosion, LLC

Fusion-bonded epoxy (FBE) and three-layer polyolefin (3LPO—polyethylene or polypropylene) are the most common external coating systems for new pipelines. Multilayer coatings using polypropylene (MLPP) can be several inches thick, protect from corrosion, and provide thermal insulation. Both FBE and multilayer polyolefin coatings have long track records of successful use, but there are occasional issues that must be addressed as part of the pipe installation process. One of these issues is delamination between the FBE and the steel in the girth weld area of coated pipes.

The primary audiences for this article are pipeline owners, coating applicators, and inspectors. What can happen is that an issue like this is discovered and it appears to be new and not understood. Hundreds of thousands of dollars are then spent on studies, and millions are lost in delays while the issue is sorted out. An understanding of the phenomenon and a solution allows the project to move ahead. Even better, preventive measures are taken, and the issue does not happen.

All photos and figures courtesy of the author

Multilayer Coatings: End-of-Pipe Adhesion Issues

For FBE coatings, delamination in the cutback area of the girth weld is a rare occurrence, however, for multilayer systems, it is not uncommon (Fig. 1, p. 44). Chang, et al, evaluated the causes of disbondment for three-layer pipe coating systems.[1,2] One of the underlying causes is residual stress in the coating as a result of the application process. Application is typically done with the pipe and coating at temperatures in excess of 200 C. There is a significant difference in the coefficient of thermal expansion (CTE) between the steel and the

Fig. 1: Occasionally, for multi-layer polyolefin systems, the FBE disbonds from the steel in the girth weld area.

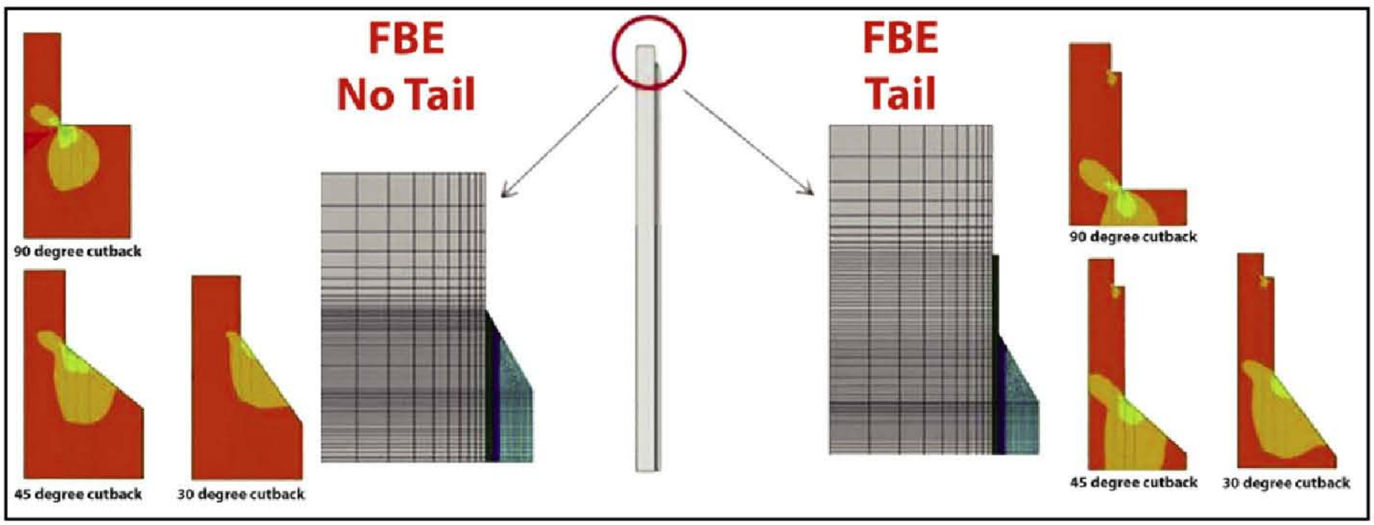


Fig. 2: Finite element analysis shows that the coating configuration in the cutback area significantly determines the amount of stress at the FBE/steel interface. Utilizing a chamfer angle of 30 degrees and an FBE toe reduces the stress.[1]

coating materials, as shown in Table 1.[1] As the pipe cools, the coating wants to contract more than the underlying steel, but is held in place through adhesion, creating stress.

Table 1: Thermal Expansion Coefficient of Coating Layers and Steel

Material	CTE – SI Units
FBE	$3.18x10^{-5}/°C$
PP Adhesive	$1.1x10^{-4}/°C$
PP	$1.1x10^{-4}/°C$
Steel	$1.1x10^{-5}/°C$

Finite element analysis shows an intensified level of stress at the interface of the FBE and the steel at cutback areas. Pipeline experience shows that the stress is insufficient to pull well-applied FBE from the steel surface (Fig. 2). However, if there is adhesion reduction, these forces can result in disbondment. A reduced angle in the chamfer area of the coating and an FBE toe significantly reduces stress and the likelihood of delamination.

Adhesion Loss Mechanisms

For stand-alone FBE, the residual stresses are relatively low and a significant amount of that stress relaxes when the FBE is wet. In that case, stress is unlikely to delaminate the coating from the steel substrate (Fig. 3, p. 46).

For three-layer coatings, the situation is different. The high coefficient of thermal expansion for polyolefin generates high residual stresses in the 3LPO coating system. Polyolefin has low water absorption and permeability, which means that stress levels remain

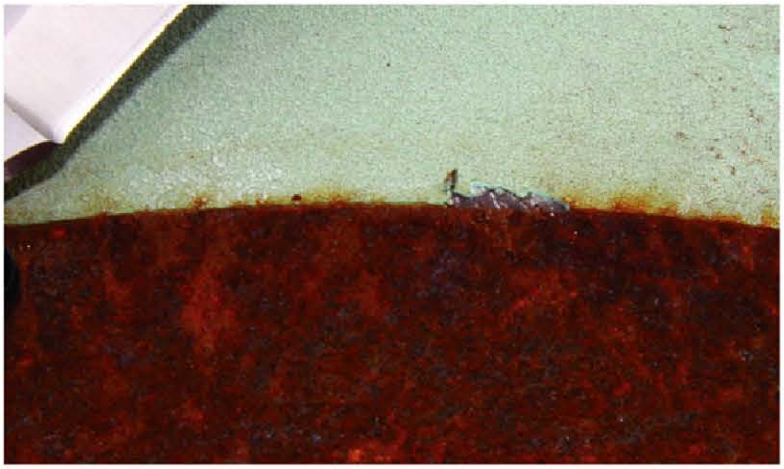


Fig. 3: Residual stress is unlikely to cause delamination of single-layer FBE coating.

Fig. 5: For larger disbondments, there are often growth rings with alternating cathodic and anodic areas. This suggests that wet and dry cycles play a part in the rate of disbondment.

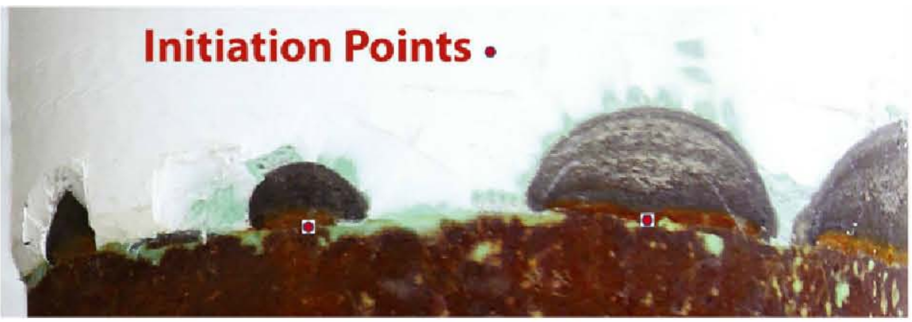


Fig. 4: Disbondment begins at an initiation point and grows in a semicircle.

high even after environmental exposure. At the cutback, peel stresses (principal stress) and in-plane shear stresses are high for these, types of coatings. If there is a reduction in adhesion between the FBE and the steel, the stress can cause delamination.

Mechanism of Bond Loss

Poorly formulated or applied FBE can lose its bond to steel when exposed to water. However, the girth weld disbondment phenomenon has been seen with high-performance, well-applied materials as part of 3LPO systems. The disbonded area looks like half of a blister or half of a cathodic disbondment. The semicircle begins at the interface between the FBE and the steel in the cutback area. The shape of the disbonded area implies that there is an initiation point where an electrochemical reaction begins and creates the disbondment (Fig. 4).

In some cases, there are growth rings, indicating an electrochemical reaction with anodic areas (corroded) and cathodic areas (clean-steel, Fig. 5). They begin as small rings near the initiation site and become larger farther away, suggesting wet and dry cycles and repeated corrosion events during disbondment growth. Multiple initiation sites can result in disbondments growing together and loss of adhesion around the circumference of the pipe.

The alternating cathodic and anodic areas (growth rings) in the disbonded areas suggest two possible mechanisms. The anodic and cathodic reactions within the cell drive a front that disbonds the FBE coating from the steel substrate.

For one mechanism scenario, the anodic reaction occurs at the interface of the bonded/disbonded coating, and the corrosion products take up a larger volume than the steel, physically forcing the coating from the substrate. In this scenario, we're looking at crevice corrosion. Crevice corrosion is characterized by a configuration in which the cathode reactant, oxygen, readily gains access to the metal surface outside the crevice but has less access to the crevice. The metal within the crevice is therefore anodic to the surrounding steel and suffers preferential corrosion and the resulting adhesion disruption (Fig. 6).

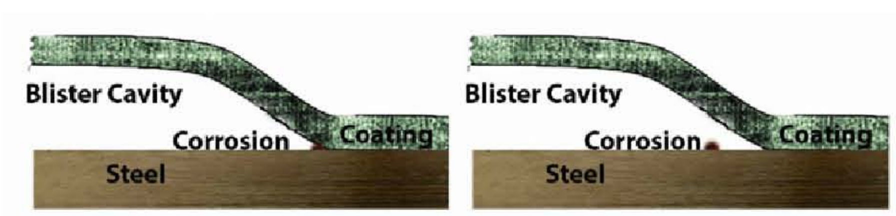


Fig. 6: Illustration of anodic delamination scenario on the left; cathodic on right.[3]

On the other hand, if the anode is remote (mm to cm), then a cathodic disbondment front causes the adhesion loss, as is typical of the cathodic blister growth. Cathodic delamination is produced by the formation of

OH^- ions at the metal/coating interface due to the cathodic reaction(s). The formation of OH^- disrupts the bond between the coating and the metal surface. However, OH^- ions are mainly produced during impressed-current cathodic protection, where the rate of the cathodic reaction is increased. At the metal free potential, the production of OH^- due to the cathodic reaction may be scarce under

Fig. 7: To make a suitable girth weld coating application, the delaminated coating must be removed back to well-adhered mainline coating.

the coating, since it is limited to the bare portion of the pipe surrounding the coating (Fig. 6, p. 46).

However, as will be discussed in the next section, the mechanism—whether the disbondment front is cathodic or anodic—is not critical. The solution is to prevent the formation of the electrochemical cell.

Adhesion Loss Prevention

The key element in avoiding coating disbondment at the pipe end is preventing corrosion at the interface of the FBE and the steel at the cutback area. This is particularly true for storage near the ocean. One way is to minimize the time between coating application, pipe assembly, girth weld coating application, and installation. For long storage times, preserve the FBE toe/steel interface with a suitable technology, such as a wrap, peelable coating, or vapor phase inhibitor.

Adhesion Loss Solution—Cut Back to Well-Adhered Coating

While there have been examples of poor application quality that resulted in general adhesion loss along the length of pipe, that is a different situation. The type of delamination under discussion is of finite size. The solution is to remove the parent coating back to the point of sound adhesion (Fig. 7), then apply the girth weld coating of choice. This may create a problem if the delamination is so extensive that the size of the girth weld coating area exceeds the size of existing application equipment or materials. In that case, specialized equipment may be required, or a pipe might even need to be cut out and rewelded.

Summary

The leading cause of coating disbondment in the cutback area is environmental exposure, particularly exposure to a marine environment. The degradation process initiates at a damaged area of the FBE/bare steel interface and a corrosion cell starts. The underlying mechanism is likely an electrochemical reaction—either anodic or cathodic. Other factors such as residual stresses may act as intensifiers once the adhesion is reduced by environmental exposure.

To minimize the possibility of coating delamination in the cutback area:

- utilize world-class coating materials and application processes;
- minimize the time the cutback interface is exposed to the atmosphere without protection;
- in case of prolonged storage time, implement suitable protective measures such as wraps, peelable coatings, or vapor phase inhibitors;
- include an FBE tail to minimize the influence of stresses; and
- keep the chamfer angle down to 30 degrees.

In any industry, new issues occur. However, once they are understood, steps can be taken to prevent them or, failing that, remedies can be implemented.

References

1. Chang, Benjamin T. A., Hung-jue Sue, Han Jiang, Dennis Wong, Alan Kehr, Meghan Mallozzi, Fabio Aquirre, Ha Pham, William Snider, "Residual Stresses in 3LPO External Pipeline Coatings – Disbondment and Cracking," BHR Group, 17th International Conference on Pipeline Protection, Antwerp, Belgium, November 2009.
2. Chang, Benjamin T. A., Shu Gho, "Residual Stresses in 3LPP Pipeline Coatings," NACE Paper 11025, NACE CORROSION 2011, Houston, TX, March 2011.
3. Chuang, J., T. Nguyen, and S. Leet, "Micro-Mechanic Model for Cathodic Blister Growth in Painted Steel," *JCT*, Vol. 71, No. 895, August 1999.

About the Author

Alan Kehr is the Managing Consultant of Alan Kehr Anti-Corrosion, LLC (Lakewood, TX), which offers worldwide consulting on fusion-bonded epoxy (FBE), pipeline and rebar coatings, and several other services. Alan has more than 40 years of experience in the pipeline and reinforcing steel coatings industries. He has been active in SSPC and was instrumental in standards development for ASTM, ISO, and other industry associations. He was also a 2012 *JPCL* Top Thinker. **JPCL**

High-Solids Epoxy Systems for Protective and Marine Coatings

By Daniel Totev, Air Products and Chemicals Europe B.V., and Marcelo Rufo, Air Products Brasil Ltda.

Epoxy systems have a long and successful track record in marine and protective coatings, mainly driven by their excellent barrier properties, corrosion, and chemical resistance.

There is a continuous trend in this industry to move the technology from the so-called conventional paint to high-solids coatings and, more recently, to ultra-high-solids coatings.[1] This change not only brings some technical challenges that need to be addressed by the formulators, but it also brings benefits such as lower VOCs, improved cure under adverse conditions, and the possibility to increase dry film thickness without having issues of solvent entrapment.

This article will review the basics of high-solids epoxy coatings compared to conventional epoxy technologies, and describe the fundamental technical differences.

Background

Epoxy coatings for ambient temperature cure are available as two-component systems. The epoxy resin base is typically referred to as "Part A" and the curing agent as "Part B." The resin and the curing agent form the coating's binder and determine most of its properties and performance.[2] Pigments, fillers, additives, and suitable solvents that may be also part of the formulation can be added to

Table 1: Example Formulation and Properties of Conventional and High-Solids Epoxy Coatings

Components	Conventional Solvent-borne Epoxy Coating	High-Solids Epoxy Coating
Part A	**kg**	**kg**
Liquid epoxy resin (equivalent weight = 190)	-	34
Solid Epoxy Resin (Type I, equivalent weight = 500) at 75% solids in xylene	33	-
Reactive diluent (equivalent weight = 175–190)	-	4
Additives	2	3
Solvents	20	15
Pigments	7	6
Fillers	38	38
Total Part A	**100**	**100**
Part B		
High molecular weight polyamide curing agent (70% solids in xylene, equivalent weight = 340)	13.2	-
High solid curing agent (equivalent weight = 95)	-	15.3
Accelerator	0.3	
Solvent	4.5	1.7
Total Part B	**18**	**17**
Paint Properties		
% solids by weight	68	85
% solids by volume	52	75
VOC (g/L) as supplied, calculated	415	200
Drying time, stage III Byk recorder (hours)	7	12
Pot life (hours)	6	1
Mixed viscosity (cPs)	1,500	1,500

either side, allowing the formulators to adjust the pigment volume concentration (PVC), gloss, and mixing ratio between Parts A and B. Solvents are used to reduce viscosity and facilitate manufacturing, handling, and application. The solvent level may change according to the application method and equipment used to apply the coating. In conventional solvent-borne epoxy coatings, a high molecular weight epoxy resin and a high molecular weight curing agent (most typically polyamide or aliphatic amine adduct types) are used to formulate a system with volume solids of ca. 50% and volatile organic compounds (VOC) level of ca. 400–450 g/l (Table 1).

When formulating at higher solids (>70 vol.%; VOC ≤250 g/l)[3], the most significant change in the composition above is the replacement of high molecular weight polymers, epoxy resin and curing agent, by low molecular weight alternatives, which naturally have lower viscosity. The paint viscosity can be brought further down by including some mono- or di-functional epoxy-terminated diluents in the formulation.[2] As a consequence, less solvent is required to adjust to application viscosity, resulting in coatings with higher solids by volume. Another important change is the use of pigments and fillers with lower oil absorption, because they will have a lower impact on the paint viscosity. Using pigments and fillers with lower density also will have a positive effect on the volume solids.

Increasing the solids not only affects the VOC levels, but also affects the coating's properties and performance. Table 2 (p. 54) shows the generic differences between conventional solvent-borne and high-solids coatings.

Discussion

Historically, the most commonly used curing agents in marine and protective epoxy coating industries for ambient temperature cure are the polyamides. They are reaction products of a polyethyeleneamine with a dimer fatty acid and have relatively high molecular weight.[3] Their fatty acid backbone provides good corrosion resistance and good flexibility but at the expense of high viscosity and reduced solvent and

Table 2: General Properties of Conventional Solvent-borne Epoxy Coatings vs. High-Solids Epoxy Coatings

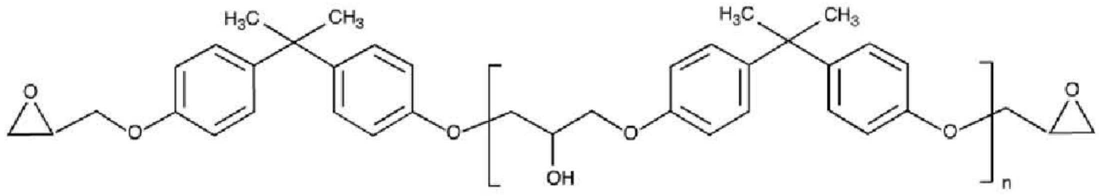
Typical Properties	Conventional Solvent-borne Epoxy Coatings	High-Solids Epoxy Coatings
Dry film thickness	Low	High
Drying time	Fast	Slow
Pot life*	Long	Short
Barrier property	Good-Excellent	Excellent
Chemical resistance	Good	Excellent
Flexibility	Excellent	Moderate
Solids by volume	Low	High
VOC	High	Low
Typical curing agents	Polyamides High molecular weight aliphatic adducts	Cycloaliphatic adducts Amidoamines Phenalkamines Mannich bases
Typical epoxy resin	Solid Bisphenol-A diglycidyl ether (EEW 450–550)	Liquid Bisphenol-A diglycidyl ether (EEW 185–192)
Typical reactive diluents		Cresyl glycidyl ether Glycidyl ether of C_{12}-C_{14}- Aliphatic Alcohol Hexane diol diglycidyl ether

Table 3: General Benefits and Limitations of the Different Curing Agent Types

Curing agent type	Benefits	Limitations
Polyamides	High flexibility Long pot life	High viscosity Poor low temperature cure
Aliphatic adducts	Fast dry	High viscosity
Cycloaliphatic adducts	Low viscosity Good low temperature cure	Low flexibility Require plasticizers to fully cure
Amidoamines	Low viscosity Long pot life	Poor low temperature cure Poor blush resistance
Phenalkamines*	Good low temperature cure	Poor blush resistance Poor overcoatability
Mannich bases	Fast dry	Low flexibility Labeling (contain phenols)

chemical resistance. Polyamides show excellent adhesion and offer long pot life, typically up to 6 hours. The pot life is defined as the time for the paint to reach a viscosity which is no longer suitable for the application. Because polyamides react relatively slowly with the epoxy, typically they are used with a solvent-based solid epoxy resin (Bisphenol-A diglycidyl ether with an average molecular weight of ca. 1,050; n=2–2.5; Fig. 1, p. 56). This normally results in coating formulations with low solids and VOC content well above 250 g/L. Because both the resin and the curing agent have high molecular weight, once most of the solvent evaporates and perhaps a small amount of chemical reaction has occurred, the film will become dry-to-touch. Such drying is referred to as lacquer dry.

Generally speaking, the main obstacle to formulating a curing agent and an epoxy resin into a high-solids coating is the mixing or application viscosity. In order to keep the latter to practical values, while using less solvent, formulators need to switch to curing agents and epoxy resins with lower viscosity.[2] In practice, this means complete or partial replacement of the polyamides and the solid epoxy resins with lower molecular weight technologies such as (cyclo-) aliphatic amine-based curing agents and liquid epoxy resins (Figure 1, p. 56).

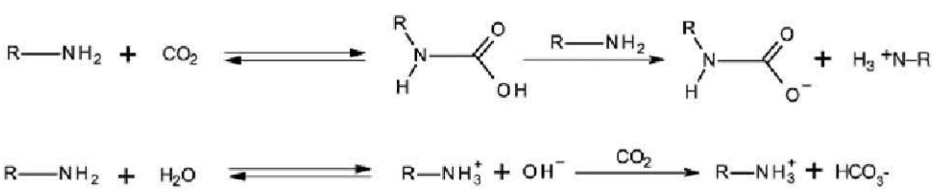


Resin Type	n	Average Molecular Weight	Epoxy Equivalent Weight (EEW)	Viscosity, Pa.s 25°C
Standard liquid resin	<1	380	185–192	11–14
Solid resin (Type I)	2–2.5	1,050	450–550	solid

Fig. 1: Bisphenol-A-based epoxy resins

Offshore oil production platform showing storage tanks that are typically protected with high-solids epoxy coatings. Photo: © iStockphoto/Frogman1484

Scheme 1: Amine blush chemical reactions



The general benefits and limitations of the different curing agent types are summarized in Table 3 (p. 54).

The use of different chemistries for formulating high-solids epoxy coatings has lead to a number of additional performance benefits. Depending on the technology used, the new systems provide improved low temperature cure as (cyclo-) aliphatic amine curing agents typically react faster and have better compatibility with epoxy resin than polyamides. The overall effect is improved application robustness. The lower VOC content contributes not only to reduced solvent emissions, but also to improved worker safety.

Another advantage derived from the different chemistry of the curing agent and the use of liquid epoxy resin is the increased chemical and temperature resistance of the coating. The higher solids also help achieve a higher film build per coat and may contribute to reducing the coating cost per square meter.

On the other hand, formulating at high solids also brings challenges. The reduced amount of solvents decreases the transfer efficiency and leads to poor atomization during spraying. This, together with the reduced flow and leveling of the paint, can cause poor surface appearance of the coating.

As mentioned above, the use of lower molecular weight curing agents and liquid epoxy resin improves the chemical and temperature resistance of the coating. This is primarily attributed to the higher cross-link density of the cured film. A higher cross-link density can also lead to reduced flexibility[2] and can potentially increase coating brittleness. Because of the tighter network in the thermoset, the stress relaxation is hindered and the probability of a coating failure during its service life is increased. This is especially pronounced at areas with high surface energy, such as edges and welding joints, or at higher film build.

Another consequence of the high cross-link density is a limited overcoat window, defined as the time from which a second coat can be applied and still achieve good adhesion. These challenges must be addressed when formulating at high solids. Epoxy diluents can be a useful tool. These are diluents—usually glycidyl ethers of mono- or di-alcohols (or phenols) that efficiently reduce the system viscosity and thus facilitate formulation at higher solids. The mono-functional materials act as chain stoppers and can be used as a means to control the cross-link density. The di-functional diluents introduce some flexibility because of their less rigid backbone compared to that of the Bisphenol-A epoxy resin. Another positive effect of the reactive diluents is a prolonged pot life, compared to the unmodified systems, and improved wetting and adhesion.[2] The reactive diluents are typically used at levels of 5–15% of the resin, depending on the application and the desired coating's properties.

The low molecular weight (primary) amines from a curing agent used in high-solids coatings are typically hygroscopic. They tend to easily migrate from the body of the coating to the coating surface, where they react with the carbon dioxide and moisture from the air to form ammonium salts (Scheme 1, p. 56). This phenomenon is known as carbamation, or blushing, and is a process that competes with the amine-epoxy reaction. It is favored at lower temperature and high humidity and manifests itself as haziness, reduced gloss, or white crystals at the surface. Carbamation is highly undesirable because it not only diminishes the visual aspect of the coating, but may also lead to poor intercoat adhesion.[2] That is why when a curing agent is designed, special attention is paid to this aspect to insure its tendency to blush is minimized.

A kinetic study[4] of the amine-epoxy reaction shows that increasing the solids in solvent-borne epoxy formulations leads to a shorter pot life, while the time for the coating to appear dry would be prolonged. As discussed earlier, the pot life depends on the rate of the viscosity increase, which in a two-component thermosetting coating is a function of the degree of conversion of the reactants. In otherwise identical conditions, increasing the solids of a paint leads to increased concentration of the epoxy and amine groups. This causes a faster conversion rate (shorter pot life), in accordance to the kinetics of the cross-link reaction.

The most common resin used in epoxy coatings is the diglycidyl ether of Bisphenol-A. It has a functionality of two glycidyl groups per molecule independently of its molecular weight (see Fig. 1, p. 56). This means that lower molecular weight epoxy resins have higher concentrations of reactive sites per mass unit. Similarly, lower molecular weight curing agents also tend to have higher functionality (per mass unit). As a result, the concentration of reactive groups in high-solids formulations becomes significantly higher than the concentration in conventional epoxy coatings, which leads to even further reduced pot life. Understanding this phenomenon allows the curing agent producers and paint formulators to address it and develop a coating system that provides sufficient time for its application. Furthermore, if

High-solids epoxy coatings can protect substrates from many of the challenges present in marine and offshore environments. Photo: © iStockphoto/TebNad

conventional spray technology is not optimal, the applicators can use plural-component equipment that eliminates the difficulties associated with a short pot life.

Ultimately, dry speed can also be related to increased viscosity. In the conventional polyamide-based coating, the lacquer dry effect is the primary contributor to fast drying. In high-solids systems, the viscosity build is mainly attributed to the cross-link reaction. This is usually slower than the solvent evaporation, hence longer dry times are observed.

Often, in order to solve one or more of the described challenges, the curing agents and the epoxy resins are formulated with plasticizers or non-reactive diluents such as benzyl alcohol and hydrocarbon resins. They not only reduce viscosity and ensure a high degree of cure at ambient temperature, but also may help improve compatibility, dry speed, and adhesion. Under certain conditions, these modifiers have the potential to leach out during the service life of the paint.[2] This affects the mechanical properties of the coating, leading to reduced flexibility and stress build-up. As a consequence, the potential for a coating to deteriorate in performance is increased depending on in-service conditions, a factor which needs to be addressed when formulating coatings based on this technology. Furthermore, due to recent changes in VOC definitions, benzyl alcohol is now viewed as a VOC,[5,6] and as such, it is difficult to achieve low-VOC targets using this diluent.

Conclusion

The stringent emission regulations and increasing need for more robust technologies with improved performance under adverse cure and service conditions are continuously driving new developments in marine and protective coating sectors. Because the final coating's properties and performance are mainly determined by the binder system, the choice of the right resin and curing agent is essential for achieving the specific application requirements. In epoxy coatings, a well-designed curing agent will address the above described difficulties and will provide a good balance of pot life, dry speed, viscosity, and flexibility. Although combining these with full elimination of non-reactive modifiers and solvents still remains a challenge, innovative technologies are already available on the market.[7,8]

References

1. Müller, B., Poth, U., *Coatings Formulation: An International Textbook, 2nd Revised Edition,* Vincentz Network, Hanover, Germany, 2011, p. 17–18.
2. Hare, C.H., *Protective Coatings—Fundamentals of Chemistry and Composition,* Technology Publishing Company, Pittsburgh, PA, 1994, p. 1; p. 199; p. 210; p. 398–400 and references therein.
3. Bianchini, G., Dyer, R., Fream, A. J., Heffer, P., McOwan, S. P., Oldring, P., Royston, I., Tuck, N., *Waterborne & Solvent Based Surface Coatings Resins and Their Applications, Volume II: Waterborne & Solvent Based Epoxies and Their End User Applications,* SITA Technology Ltd., London, UK, 1996, p. 339; p. 324; p. 210–215.
4. Dubowik, D.A., Walker, F.H., Starner, W.E., Air Products and Chemicals, Inc., *Novel curing agent technology for high solids epoxy coatings,* International Waterborne, High Solids, and Powder Coatings Symposium, February 1999.
5. http://ec.europa.eu/environment/air/pollutants/stationary/solvents.htm
6. http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:143:0087:0087:EN:PDF
7. Totev, D., Vedage, G., Raymond, W., Rufo, M., Cook, M., Air Products and Chemicals, Inc., *High Performance Polyamide Curing Agents Offering Low Emissions and Long Term Performance,* SLF Congress, Helsinki, May 2012.
8. Rasing, R., Vedage, G. A., Air Products and Chemicals, Inc., "Epoxy systems: Clearing the air," *ECJ,* 2011 (6), p. 20–27.

About the Authors

Daniel Totev has a Master of Science degree in chemistry and a Doctorate degree in homogeneous catalysis. Since joining Air Products and Chemicals in 2007, he has specialized in development of new curing agent technologies for epoxy resins. His primary area of focus is marine and protective coatings.

Marcelo Rufo is a senior application chemist for the coatings business of Air Products and Chemicals Inc., where he is responsible for new product development, application development, and technical service related to curing agents for epoxy coatings. He has more than 25 years of experience in the coatings industry. JPCL

SSPC Issues QP 9 Revision

SSPC's C.8.5 committee (Commercial Contractor Qualification), chaired by Jeff Theo of Vulcan Painters, Inc., has revised SSPC-QP 9, Standard Procedure for Evaluating the Qualifications of Commercial Painting and Coating Contractors.

First published in August 2008, the standard is intended to establish benchmarks for evaluating the qualifications of painting contractors applying architectural paints and coatings on commercial or institutional structures. Facility owners can use this standard to pre-qualify contractors bidding on projects. Contractors who have been qualified to the requirements of SSPC-QP 9 have demonstrated a history of satisfactory job performance and have established and implemented quality control procedures, worker health and safety programs, environmental compliance programs, and craft worker training and assessment programs.

The 2014 revision of SSPC-QP 9 has added specific requirements for training of craft workers, requires formal training for quality control and safety supervisory personnel, and contains specific language regarding use of subcontractors. Recent changes include the following.

• Introductory qualification categories have been eliminated. The initial version of QP 9 contained 4 qualification categories based on a contractor's experience and the level of detail of its quality program. The 2014 revision eliminates the 4 qualification categories by requiring all painting contractors certified to the QP 9 standard to meet the same requirements. Painting contractors who previously met the requirements of Category 1 through Category 3 now have the option to seek full QP 9 certification or

Training and Certification

Four students recently completed SSPC's Protective Coatings Inspector (PCI) Level 3 exam. Instructor Muniandi Dewadas (center) proctored the exam, which was held in Batam, Indonesia.

apply for "introductory qualification" under SSPC-QP 7 until they gain enough experience to qualify for QP 9.

• A revision to SSPC-QP 7 will address introductory qualification for all of the SSPC contractor certification categories, including QP 9 preliminary qualification.

• A requirement that contractors have procedures for selecting and using subcontractors has been added. A QP 9-certified painting contractor is responsible for maintaining all program requirements when delivered directly by subcontractors.

• Contractors must have a written craft worker assessment program.

• Definitions of Quality Control Inspector, Quality Control Supervisor, and Safety Manager have been added, as have requirements for the position of Safety Manager.

• Formal training requirements for QC Supervisor and Safety Manager have been added.

Beginning on July 1, 2014, applicants for certification to SSPC-QP 9 will need to meet the requirements of the January 2014 revision. Contractors already qualified to SSPC-QP 9 will need to meet the requirements of the January 2014 revision when their current certification period expires.

SSPC Members can download the new standard for free at sspc.org/market-place/standards/qualification-procedures-qp/sspc-qp-9-application-of-architectual-paints-coatings.html. Non-members can purchase the standard for $25 via the same link. The current version is also available through the SSPC App.

SSPC Board Seeks Nominees

SSPC is now seeking nominations for two seats on its Board of Governors in the categories of Facility Owners and International Delegate. There is one opening in each category.

The Facility Owners category is defined in the bylaws as "individuals who are employed by public or private sector owners of assets who are responsible for the maintenance of coatings of heavy or light industrial structures and surfaces."

The International Delegate is defined in the bylaws as "a member from any demographic. An international delegate can be from any country outside North America."

Candidates may be nominated to be representatives on the Board of Governors by a written nomination signed by an Individual Member in good standing. All nominees must be SSPC Members and meet the criteria set forth in the bylaws. Self-nominations are not accepted. To nominate a candidate, SSPC asks that individuals submit a brief statement detailing the nominee's qualifications by March 1, 2014, to SSPC, Attn. Bill Shoup, Executive Director, 40 24th St., 6th Floor, Pittsburgh, PA 15222-4656; fax 412-281-9992; email: shoup@sspc.org.

San Antonio Welcomes CORROSION 2014

CORROSION 2014, NACE International's 69th annual conference and exhibition, will take place March 9–13 at the Henry B. Gonzalez Convention Center in San Antonio, TX.

A technical program with more than 40 symposia, committee meetings, seminars and lectures, training opportunities, networking venues, and an exhibition with more than 380 exhibiting companies will be available for the 6,000-plus corrosion professionals expected to attend. Industries involved include coatings and linings, infrastructure, marine, military, oil and gas production, petroleum refinement, pipeline systems, and others.

The following information describes sessions that may be of special interest to persons involved in corrosion control through coatings. Information is current as of press time. For more information, visit nace.org.

Technical Sessions

Sunday, March 9

- TG 404, Nuclear Buried Piping
- TEG 424X, Liquid-Applied Thermal Insulative Coating for Atmospheric Service at 0 to 375 F
- TG 170, Offshore Steel Platforms—Corrosion Control: NACE SP0176 (review)
- TEG 267X, Pipelines: In-Line Inspection
- TG 460, Testing and Evaluation of Corrosion on Steel-Framed Buildings
- TG 290, Reinforced Concrete: Design Considerations for Corrosion Control
- TEG 474X, Nanotechnology and Corrosion
- TEG 314X, Pipelines: Liquid Petroleum Industry Corrosion Control Issues Forum
- TG 087, STG 33 Standards and Technical Committee Reports (review)

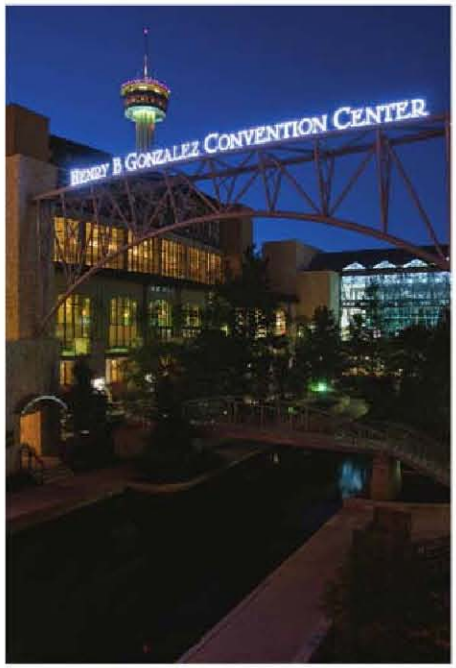


Photo courtesy of Al Rendon, San Antonio Convention & Visitors Bureau

Monday, March 10

- TG 012, Pipelines, Steel-Cased
- TEG 311X, Coatings and Methods of Protection for Threaded Fasteners Used with Structural Steel, Piping, and Equipment
- TG 031, Pipeline Coating, Plant-Applied Fusion-Bonded Epoxy: NACE Standard RP0394 (review)
- TEG 208X, Pipeline Crossings: Steel-Cased, Thrust-Bored, and HDD
- TG 148, Coatings for Protection of Threaded Fasteners Used with Structural Steel, Piping, and Equipment
- TG 041, Pipeline Direct Assessment Methodology
- TEG 145X, Vapor Corrosion Inhibitors and Rust Preventives for Interim (Temporary) Corrosion Protection: Advances and Novel Applications
- TG 261, Vapor Corrosion Inhibitors and Rust Preventives for Interim (Temporary) Corrosion Protection
- TG 352, Coating Systems (External) for Pipeline Directional Drill Applications
- Corrosion Issues in Military Equipment and Facilities
- TEG 126X, Materials, High-Temperature: Current Issues
- TEG 428X, Hot-Dip Galvanizing for Steel Corrosion Protection
- TG 249, NACE Standard RP0402-2002 (review/revise)

Tuesday, March 11

- TG 470, Cathodic Disbondment Test for Coated Steel Structures Under Cathodic Protection
- High Temperature Issues and Materials for the Process Industry
- Performance of Engineered Polymers and Nonmetallic Materials in Oil and Gas
- Direct Assessment Course
- Corrosion in Nuclear Systems (Day 1)
- TG 339, Railcars: Coating Application on Exterior Surfaces of Steel Railcars
- TG 437, Maintenance Overcoating of Railcar Exteriors
- TG 169, ANSI/NACE SP0607-2007 (review/revise)
- TG 260, NACE Standard TM0304-2004 (review)
- TG 263, Review of NACE Standard

TM0104-2004

- TG 264, Offshore Exterior Submerged Coatings: Standard Test Method
- TG 312, Offshore Platforms: Coatings for Atmospheric and Splash Zone New Construction
- TG 379, Surface Preparation by Encapsulated Blast Media for Repair of Existing Coatings on Railcars
- TG 057, Reinforced Concrete: Corrosion-Resistant Reinforcement
- TEG 118X, Failure Prevention Case Histories
- TG 332, NACE SP0386-2007 (review/revise/reaffirm)
- TG 394, Guidelines for Qualifying Personnel as Abrasive Blasters and Coating and Lining Applicators in the Rail Industry
- TG 456, Coating Thickness Measurement, Methods, and Recording—Specific to the Railcar Industry

Wednesday, March 12

- TEG 080X, Well Casings, Corrosion Control: Information Exchange
- TEG 159X, Building Fire Protection Systems: Corrosion and Deposit Control
- Corrosion in Nuclear Systems (Day 2)
- STG 33, Oil and Gas Production—Nonmetallics and Wear Coatings (Metallic)
- Pipeline Integrity (Day 1)
- Oil/Gas Coating Technology (Day 1)
- Marine Corrosion
- TG 061, Revision of NACE SP0592 (formerly RP0592), Application of a Coating System to Interior Surfaces of New and Used Railway Tank Cars in Concentrated (90-98%) Sulfuric Acid Service
- TG 333, NACE SP0295-2008 (review/revise/reaffirm)
- TG 366, Railcars: Corrosion Under Tank Car Insulation
- TG 381, Fire Protection Systems
- TEG 368X, Electric Utility Transmission and Distribution Corrosion and Grounding: Discussion of Issues
- TG 067, SP0302-2007 (review/revise/reaffirm)
- TEG 053X, Reinforced Concrete: Design, Evaluation, and Remediation
- TEG 291X, Land Transportation: Information Exchange on Corrosion and Coating-Related Issues
- TG 444, Guidelines for Data Collection and Analysis of Railroad Tank Car Interior Coating/Lining Condition
- STG 40, Military and Aerospace Systems and Facilities
- TG 451, Corrosion-Resistant Non-Skid Surfaces for Railcar Exteriors

Thursday, March 13

- Pipeline Integrity (Day 2)
- TG 461, Standard for Hull Roughness

Measurements on Ship Hulls in Dry Dock
- TG 146, Coatings, Thermal-Spray
- TG 212, Pipeline Inspection: In-Line Nondestructive—Review of NACE SP0102-2010
- TG 490, Review/revise API 5L2, Recommended Practice for Internal Coating of Line Pipe for Non-Corrosive Gas Transmission Service
- TEG 224X, Nuclear System Corrosion
- STG 10, Nonmetallic Materials of Construction
- TEG 181X, Marine Vessel Corrosion
- Oil/Gas Coating Technology (Day 2)
- TEG 469X, Surface Preparation Issues
- TG 271, Removal Procedures for Nonvisible Contaminants on Railcar Surfaces
- TG 019, Pipelines: Cathodic Protection of Concrete Pressure and Mortar-Coated Steel
- TG 237, Microbiologically Influenced Corrosion on External Surfaces of Buried Pipelines: Detection, Testing, and Evaluation—Standard
- STG 43, Transportation, Land
- STG 01, Reinforced Concrete
- STG 35, Pipelines, Tanks, and Well Casings
- STG 41, Electric Utility Generation, Transmission, and Distribution
- STG 44, Marine Corrosion: Ships and Structures

Exhibitors

The following is a list of exhibitors at CORROSION 2014, as of press time, that may be of interest to protective coatings professionals.

3M Infrastructure Protection Products.....1227
Accoat A/S 1338
Advanced Polymer Coatings 2431
American Society for Nondestructive Testing, Inc..................................1239
Anticorrosion Protective Systems.......1946
Axalta Powder Coatings 1347
AZZ WSI..2649
BASF 3111
Binks 1132
Blair Rubber Company......................2527
Brand Energy & Infrastructure Services..1207
Canusa CPS 1113
Carboline Company..........................1013
CHLOR*RID International Inc. 2439
Clemco Industries Corp. 2947
CoatingsPro Magazine.......................3223
Cold Jet Dry Ice Cleaning/Farrow Abrasive Blasting 3220
Controlled Dehumidification/CDIMS 1140
CorrLine International, LLC 3103
Cortec Corporation 1033
Curran International..........................1228
D.E. Stearns Co................................1521
Dampney Co., Inc. 1532
DeFelsko Corporation........................1321

Dehumidification Technologies 1204
Denso North America 1221
DoD Corrosion Prevention and
Control 3239
DuPont Teflon Industrial Coatings 1849
DuraSeal Nanocoatings Company 1748
Elcometer 1213, 2311
Enviropeel USA 1747

Evonik Corp. 1445
Farwest Corrosion Control Co. 1613
Fischer Technology Inc. 1939
Front-Line Coatings LLC 2149
GMA Garnet Group 2546
Grace Distributing 1348
Graco Inc. 2739
Greenman-Pedersen, Inc. 1526

Hempel USA 2839
Heresite Protective Coatings 1005
Hi-Temp Coatings Technology 1104
Highland International, Inc. 1203
HoldTight Solutions Inc. 2033
IBIX Surface Technologies LLC 1139
International Paint 1531
International Thermal
Spray Association 3110
ITW PolySpec/Futura 1806
Jotun Paints USA 2745
KTA-Tator, Inc. 2021
Lone Star Specialty Products LLC 3121
Mascoat 3015
MATCOR, Inc. 1121
Materion (Brush Wellman) 2443
MONTI Werkzeuge, GmbH 2339
Montipower Inc. 1428
Novatek Corporation 2907
Oxford Instruments 2634
Paint Technology Solutions Ltd. 3043
Pipe Wrap, LLC 1702
Pipeline Inspection Co. Ltd. 1333
PK Technology 3021
Platt Brothers & Company 1739
PolyCorp Ltd. 1728
Polyguard Products, Inc. 2827
PPG Protective & Marine Coatings 1021
Rema Tip Top North America Inc. 1832
Safety Lamp of Houston, Inc. 3214
Sauereisen 2528
The Sherwin-Williams Company 1421
Simpson Strong-Tie 1546
Southwestern Paint Panels 2448
Specialty Polymer Coatings Inc. 2639
Sponge-Jet Inc. 1433
SSPC: The Society for
Protective Coatings 1803
Stronghold Coating Systems 1242
Sulzer Mixpac USA Inc. 1845
Superior Products International Inc. ... 2807
Temp-Coat Brand Products, LLC 2608
Tesla NanoCoatings Inc. 2247
Thomas Industrial Coatings 2711
Tinker & Rasor 2121
Tnemec Company Inc. 2933
Trenton Corporation 1811
TruQC 2712
Tubacoat, S.L. 1241
U.S. Coatings 3212
Wasser Coatings 3243