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The Society for Protective Coatings

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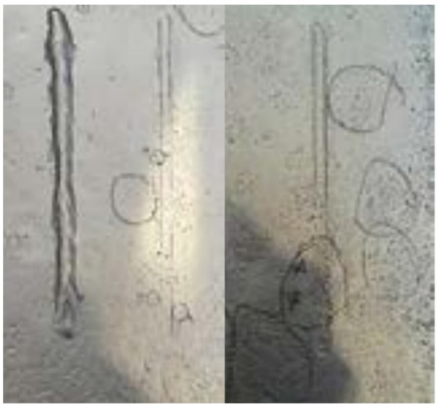
FEATURES



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SSPC Winter Training: Train the Trainer Takes Off

SSPC has completed four successful rounds of its newest training course, Train the Trainer (TTT), thus far in 2018.

Train the Trainer is a two-day class designed to prepare experienced coatings professionals to properly teach their craft workers the skills and knowledge needed in the industry. The course is centered around training and teaching techniques, adult learning concepts, a review of surface preparation and coating basics, and a guide to navigating SSPC's Trainthepainter portal.

SSPC 2018, Jan. 13-14 (Bottom row, L-R): Instructors Jennifer Buzzatto and Eric Piotrowski; Ben Spiegel, Chris Lucy and David Kinee; (top row, L-R): Robert Cloutier, Jayes Matthew, Jeferson da Dilva, Dirk Pohlmann, Thomas Fink, Richard Freyling, Richard Bayer, Fabio Krankel and Emilio Castro. Photos courtesy of SSPC.

The largest TTT class to date convened Jan. 13 to 14 at the SSPC 2018 conference in New Orleans. Instructors Jennifer Buzzatto and Eric Piotrowski of SSPC led the curriculum for the 12 attendees from five different companies.

Buzzatto also visited PPG offices in Atlanta for on-site training of four PPG employees on Feb. 12 and 13.

PPG, Feb. 12-13: Tom Higginbotham, Carl Sabo, Ron Watts, Buzzatto and Gilles Masse.

SSPC, March 5: Chris Gatian, Buzzatto, Andrew Mayerchak and Dejin Feng.

On March 5, three attendees – from as close as Ohio to as far away as China – traveled to Pittsburgh for a condensed, one-day TTT session led by Buzzatto at SSPC world headquarters.

Kiewit Offshore in Corpus Christi, Texas hosted TTT for its employees on March 16 and 17. Buzzatto instructed the course's seven students.

Kiewit Offshore, March 16-17: Michael Gutierrez, Chris Hodgson, Jason Garcia, Buzzatto, Juan Mendiola, Brandon Garcia, Cory Davis and James Mann.

SSPC Certification Update

NINE EARN PROTECTIVE COATINGS SPECIALIST

SSPC's highest level of certification, the Protective Coatings Specialist (PCS), recognizes industrial coating professionals for their extensive knowledge in the principles and practices specific to industrial coatings technology. Each individual has been evaluated for his or her mastery of coating type, surface preparation, coatings application and inspection, contract planning and management, development of specifications and the economics of protective coatings. SSPC congratulates the following individuals for their achievements.


Mike Abraham, AEIS (Rahway, N.J.)


Peter J. Engelbert, Job Safety Associates LLC (Hammond, Ind.)


Charles Katsuhiro, PPG Industries (Chino Hills, Calif.)


Troy Blatchford, KTA-Tator, Inc. (Austin, Texas)


Jack A. Jackson, Northwest Coating Inspection Service (Rock Island, Wash.)


Richard Leber, Robinson Engineering (Chicago, Ill.)


Judy Cheng, Pacific Gas & Electric (San Francisco, Calif.)


Charles Jamison, Huntington Ingalls Industries – Newport News Shipbuilding (Newport News, Va.)


Guillermo Loayza, Tecnocreto Cia. Ltda. (Ecuador)

TWO MASTER COATINGS INSPECTORS CERTIFIED

The Master Coatings Inspector (MCI) certification recognizes and honors individuals whose experience and training has afforded them the prestige of multiple inspector and coating specialist certifications. To reach the MCI level, one must qualify for certification as a Concrete Coating Inspector (CCI) as well as qualify for two of the four other SSPC certification programs: Bridge Coating Inspector (BCI); Protective Coatings Inspector (PCI); NAVSEA Basic Paint Inspector course (NBPI), which SSPC administers on behalf of Naval Sea Systems Command; or the SSPC Protective Coatings Specialist (PCS) program. SSPC congratulates the following recently certified MCIs.

Mohamed Elhamalawi, Alfa Egypt (Cairo, Egypt)

Gene Wells, Huntington Ingalls Industries – Newport News Shipbuilding (Suffolk, Va.)

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AkzoNobel to Sell Specialty Chemical Business

In the culmination of a process announced last spring, global coatings manufacturer AkzoNobel announced March 27 the 10.1 billion-euro ($12.5 billion) sale of its Specialty Chemicals business to The Carlyle Group and Singapore's sovereign wealth fund GIC.

The transaction, announced in April 2017 and expected to be completed by the end of this year, results in the creation of what the company calls two focused businesses — AkzoNobel Paints and Coatings, and Specialty Chemicals, now owned by Carlyle and GIC. The transaction is still subject to customary closing conditions as well as relevant regulatory approvals.

The separation of the Specialty Chemicals business has been discussed for some time, but the formal announcement was seen as a response to rival PPG Industries' repeated attempts at a takeover, which began in March 2017 and were at times contentious.

Photo courtesy of AkzoNobel.

Until this most recent announcement, it was unclear whether the separation would take the form of a sale or a demerger. According to AkznoNobel, its Board of Management and the Supervisory Board concluded that a private sale of the Specialty Chemicals business was in the best interest of the company and Specialty Chemicals itself, along with respective stakeholders.

"Today is a key milestone in creating two focused, high performing businesses, to generate value for all stakeholders," said Thierry Vanlancker, CEO of AkzoNobel. "We delivered on our commitment to separate the Specialty Chemicals business and did so ahead of schedule." According to Vanlancker, the deal leaves Akzo as "one of the top [three] largest paints and coatings companies in the world."

On March 8, just weeks before the announcement of the sale, AkzoNobel reported positive volumes and earnings for 2017 in its fourth-quarter and year-end report.

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Revenue was up 3 percent at 14.5 billion euros ($17.9 billion) on the year, with both Decorative Paints and Performance Coatings contributing 2 percent growth. For Q4, the respective subdivisions pulled in a 3 percent growth and a 2 percent dip over the same quarter in 2016.

Though listed as discontinued operations, AkzoNobel did list numbers for its Specialty Chemicals division and noted that revenue was up 4 percent (4.9 billion euros over 4.8 billion), volumes were up by 3 percent and EBIT was up 10 percent.

EIFFEL TOWER REPAINTING COULD RESTORE OLD COLOR

The iconic Eiffel Tower in Paris is due for its latest coat of paint, and French officials are debating bringing the monument back to its original color, a bright red. The three-year project, slated to begin in October and continue through 2021, is also part of a larger endeavor that will also see the addition of safety amenities to the monument.

According to The Local, after an original "Venetian red" coating (composed of bright red iron minium from Venice and linseed oil) was shop-applied on its iron structure, the Eiffel Tower was painted orange-yellow at its base and light yellow at the top in 1899, and from 1907 to 1954, the monument was a yellow-brown. In 1968, it was repainted brown-

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red. To date, the structure has had 19 different paint jobs; currently, the structure is painted a specially designed shade of brown.

In addition to the original red, older colors on the structure will also be uncovered and investigated to determine which color should be chosen for this project. If an older color is chosen, experts hope they will be able to recreate it.

According to Traveller, the Eiffel Tower is repainted every seven years, and will take 60 tons of paint to cover the 10,000-ton structure. The last repainting, which began in 2010, reportedly used an iron-oxide pigment to color a two-coat urethanized alkyd system.

According to the monument's website, the structure was built out of puddle iron, a material with a long lifespan that only requires regular repainting in terms of upkeep. When repainting is required, techniques dating back to Gustave Eiffel's day — namely painting by hand — are used; the use of spray guns is ruled out, as is remote work, and 25 painters complete the work. For previous paint jobs, the budget has been around 4 million euros ($4.9 million).

PAINTSQUARE COMMENTS

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In Response to "NIOSH Links Noise, Heart Disease" (PaintSquare News, April 2)

National Institute for Occupational Safety and Health researchers recently released a study that analyzed data showing a possible correlation between occupational noise exposure, hearing difficulty and heart conditions within U.S. industries.

Thomas Van Hooser:
"This is very informative. Government should make these findings more frequent to the public and to employers."

Michael Halliwell:
"High noise is a stressor, which induces high blood pressure. Not a stretch to see that chronic exposure to high noise could have a link to heart disease."

Donald Flynn:
"Need more research as correlation does not really indicate causation. My experience (more than 20 years, including as site safety officer) is that folks in the industries with high noise exposure tend to lead lifestyles (such as smoking) and have eating habits that lead them into high blood pressure and heart conditions. Of course, loud noise is an additional stressor but…"

Problem Solving Forum

paintsquare.com/psf

What is the correct gauge type and probe for measuring coating thickness of a super duplex stainless steel system with epoxy and polyurethane?

David Lemke, Team Industries, Inc.:
"Regardless of the type of stainless steel (SS), a Type-2 gauge with a non-ferrous eddy current lock must be used. Then the gauge must be zeroed using the same material (and blasted, if that is how the substrate has been prepared) onto which the coating has been applied. All carbon content is not the same in the various types of SS. Even with the non-ferrous lock on, the gauge will read different mil thicknesses from type to type of SS while the film thickness is exactly the same. I have had gauges that are supposed to automatically select the type of material go bananas because of the amount of carbon in the SS and the gauge didn't know what to do. Also, the carbon content in some of the duplex SS is not always evenly distributed in the manufacturing process. This will in turn show an erroneous (many mils off) reading and then less than an inch away show a reading that corresponds with the rest of the readings. As far as type of probe, there are different ways the probes are wired and the jury may be out. I have had discussions with one gauge manufacturer and they were not sure which one works the best. Not a lot of research has been done with the different types of probes and which one works best with this or that type of SS. Our company has seen more SS and types of SS being coated than ever before and it will remain that way into the future. Most of the time SS was not painted in the past and taking DFT measurements on SS is going to be new for a lot of folks."

Tom Swan, M-TEST:
"To add to the above answer, the reason the NF-type gauges get confused is some of the lower grades of SS, especially out of China, have enough magnetism to fool the gauge into thinking it is ferrous, so the gauge tries reading in F mode. The N lock prevents this from happening. As an alternative, but slightly more expensive, some of the newer UT gauges will read coating thickness over metal whether the substrate is carbon steel or SS. The various carbon content in the SS will not affect the coating thickness readings."

David Zuskin,
EXCET/U.S. Naval Research Laboratory:
"I suggest using a dedicated, non-ferrous probe versus the auto- sensing ferrous/ non-ferrous probes."

Considerations for Reconstruction of a Bridge Exhibiting Staining

BY CYNTHIA O'MALLEY, PCS, KTA-TATOR, INC.

When a large-scale bridge is in need of significant reconstruction, many factors should be considered prior to initiation of the project.

Part of this particular reconstruction involved repainting of the structural steel on a 40-foot-wide lift bridge that had a total length (including approaches) of 2,877 feet, with a main span of 418 feet. The coating system selected consisted of four coats: a zinc primer coat, a tie-coat, one coat of epoxy and an acrylic polysiloxane topcoat with high gloss.

The coating system was applied during the winter, spring and summer of 2008. Sometime after the topcoat was applied to the bridge, staining was noticed in numerous areas. These stains appeared as spots and streaks and were observed on various locations of the bridge, but the most concentrated areas were on the north side. The owner, through a recommendation of the prime engineer, contracted an independent, third-party consultant to investigate the staining problem and determine the cause in order to prepare for further rehabilitation.

FIELD INVESTIGATION

The consultant, accompanied by a representative of the engineer and various other project personnel, visited the lift bridge in July of 2010. Access to the deck support steel was gained from existing staging. The truss steel was accessed from the sidewalk. The results of the investigation are summarized as follows.

The structural steel on the bridge was painted a burgundy-red color. In general, the coating was in good condition with minimal corrosion, paint peeling or other objectionable properties.

There was noticeable staining on the bridge finish coat in many areas. The first area examined was on the truss steel on the west side of the bridge. There were noticeable spots in many areas, and these spots had an iridescent appearance. Upon close examination, it was found that most of the spots had a visible piece of contamination at the center of the spot (Fig. 1). In some cases, the contamination was embedded in the paint, with the very top of the contamination exposed. In other cases, the contamination was embedded in the top layer of the paint and could be removed with a fingernail.

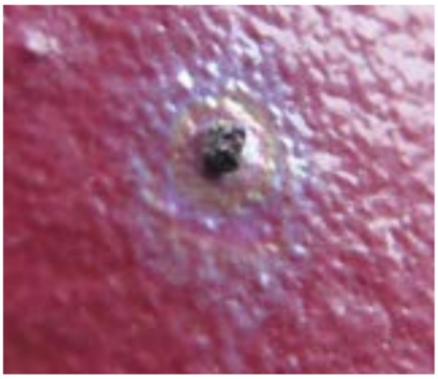

Fig. 1: Close-up of stain around particle embedded in the topcoat. Figures courtesy of KTA-Tator, Inc.

In some areas, staining appeared in a streaky pattern. The streaks were consistently aligned in a vertical pattern and had the same iridescent sheen as the spots. In some cases, the streaks originated on the top of box chords and other structural steel members close to the edge of riveted lattice pieces. Typical of lattice bridge members, the edges had a gap in the coating between the chord and the riveted lattice piece. The stains also consistently appeared on or directly below rivets. In many areas on the north side, staining was visible on virtually every rivet, although the degree of staining varied considerably from rivet to rivet.

On the lift towers, several squares of coating were missing where metal pieces were reported to have been mechanically removed. Long iridescent stains and streaks were clearly visible starting at the bare steel area and extending vertically downward (Fig. 2). The bare steel areas were rusted.

In one area near the middle of the bridge, a piece of rust scale that had been overcoated was visible on the bottom of a beam flange. The coating was cracked on the upper left side of the piece of scale. Iridescent staining started at the crack in the paint and continued vertically downward.

The staining was clearly more concentrated on the north side of the bridge (Figs. 3 and 4, p. 14). The most severe area was on a section of

Fig. 2: Streaks of staining on one of the bridge lift towers.

Fig. 3: Staining on north box chord.

Fig. 4: Severe staining on north fascia.

fascia directly beneath and bordering the road deck, where the staining covered up to 50 percent of the surface. In other areas, staining was less severe but clearly visible. In the middle and on the south side of the bridge, staining was visible, but only as small spots or vertical streaks.

On several areas on the north side of the bridge, the topcoat appeared to have been touched up. Reportedly, the touch-up work had been performed during the week prior to the site visit. The touch-up paint was in good condition, free of visible staining and appeared to adhere well to the previously applied topcoat. No delamination was visible.

LABORATORY ANALYSIS AND DISCUSSION

The field investigation and the laboratory analysis indicated that the staining on the surface of the acrylic polysiloxane topcoat on the bridge was the result of rust bleeding from various areas. Water runoff that results during periods of

Fig. 5: Close-up of stain streak in sample area.

Fig. 6: Close-up of stain underneath rivet.

rain carried iron oxide from small areas of the bridge where the steel was exposed and deposited the iron oxide on the surface of the topcoat. The iron oxide thus created the iridescent-like staining that had been observed visually.

During the laboratory analysis, samples of the topcoat that were discolored with the iridescent stain were analyzed using scanning electron microscopy-energy dispersive spectroscopy (SEM-EDS). The stained samples were then compared to a sample that was removed from an area where no staining was evident. The examination of the stained samples revealed that the composition of the staining was primarily iron (likely as an iron oxide). The analysis did not identify any other elements on the unstained coating. The results of the analysis indicate that the stain was primarily composed of iron compounds.

The visual examination of the bridge also pointed to rust bleed as the main cause of the staining. Streaking typically occurred in areas where rust bleed emanated from crevices. Some of the most concentrated areas were apparent on the north face beneath the deck, where rust streaking originated from the gap between the steel and the concrete deck. Other areas of severe staining occurred directly below locations where lattice work was connected to the beams with rivets. This configuration creates several areas where steel surfaces could mate and form a back-to-back connection. These areas are difficult to seal with paint, and ultimately water enters. When water enters these areas, the steel corrodes and the corrosion products are carried away with the water (i.e., rust bleed), eventually depositing on the surface of the coating.

Further evidence that rust was the primary cause of the staining was found on the lift towers. As noted previously, there were several areas of uncoated and rusted bare steel. In these areas, long streaks of the iridescent staining were visible below the bare rusted area. Additionally, on an area on the top of the floor beam, similar staining was coming from a crack in the coating around a piece of rust scale that had not been removed.

The iridescent appearance of rust staining is not uncommon following accelerated testing of coatings on steel panels. Often, when rust spots appear on steel panels during the testing, iridescent staining is visible around and below the rust spots.

The stains on this lift bridge may have been more visible than usual because of the finish color and the gloss of the applied topcoat. The iron oxide deposits on the surface scattered light and made the surface appear to be lighter in color and lower in gloss. This sharply contrasted with the glossy burgundy-colored topcoat and made the stains more visible.

It was the consultant's opinion that the staining was merely an aesthetic problem that would not affect the performance of the coating. There was no indication that the deposit was degrading the topcoat or any other coat. Unfortunately, it appeared that the stains were very difficult to remove. Attempts to remove the stains with a wet cloth were made during the field visit, but this proved unsuccessful. Because the materials were well-adhered and could not be easily removed, the easiest way to hide the staining was to apply an additional coat of the burgundy-colored topcoat.

To avoid similar issues on future projects, attempts should also be made to apply additional coatings around rivets in order to reduce the amount of rust bleeding. Also, it may be advisable to apply a penetrating sealer (i.e., an epoxy penetrating sealer) around the back-to-back connections where rust bleed originates from crevices. The penetrating sealer will wick into and seal the crevice, helping to reduce rust bleed from those areas.

Regardless of the repair attempt procedure, it was unlikely that the staining on this particular lift bridge could be completely prevented because of the presence of ongoing corrosion in the crevice areas between lattice bars and around rivets. Crevice corrosion is a design issue common to virtually all bridge structures, particularly older structures with lattice bar construction. Industry experience has shown that even the best methods of remediation, such as penetrating sealers and caulking, are temporary, bandage-like measures that only minimize rust bleed.

ABOUT THE AUTHOR

Cynthia O'Malley is the vice president and group manager of the professional services business unit at KTA-Tator, Inc., and co-chair of SSPC's Women in Coatings Program. During her more than 20 years with KTA, she has been active in several industry organizations. O'Malley is an SSPC-certified Protective Coatings Specialist, a member of ASTM International and past-president of the Pittsburgh Society for Coatings Technology (PSCT). Her industry honors include the SSPC's 2013 Presidents' Lecture Series Award and the 2015 Women in Coatings Impact Award.

ROOT CAUSE ANALYSIS AND CORRECTIVE ACTION: TURNING PROBLEMS INTO SOLUTIONS

BY ALISON B. KAELIN, CQA, ABKAELIN, LLC

The coatings industry at all levels is becoming increasingly subject to auditing by a variety of entities. The American Society for Quality (ASQ) defines an audit as a "systematic, independent and documented process for obtaining audit evidence (records, statements of fact or other information which are relevant and verifiable) and evaluating it objectively to determine the extent to which the audit criteria (set of policies, procedures or requirements) are fulfilled."

Audits are performed by certification organizations such as SSPC Qualification Procedures (QP), the NACE International Institute Contractor Accreditation Program (NIICAP), ASIC Sophisticated Endorsement for Fabrication or Painting (AISC SPE 420) or against various International Standards Organization (ISO) programs for laboratory analysis, calibration and quality. Work related to nuclear work generally involves auditing against 40 CFR 50, Appendix B or ASME NQA-l standard, "Quality Assurance Requirements for Nuclear Facility Applications." Many large manufacturing or construction projects also perform supplier audits on current and potential vendors or contractors.

Audits should also be internal and ongoing. These internal audits are generally performed on processes, employees, procedures and other functions used to control quality. SSPC's QP programs require an annual internal audit.

So, you got audited, or performed an internal audit of your own company. Obviously, there were some findings. Now what?

Requests for correcting nonconformities or findings commonly result from any type of audit. Corrective action is action taken to eliminate the causes of the nonconformity, defect or other situation in order to prevent recurrence. Corrective action is reactive and is about eliminating the cause of a current problem. Preventive action is action taken to eliminate the causes of future issues— a proactive approach.

Most corrective actions fail because they treat the symptoms or perceived symptoms, but never address the cause. Addressing the symptoms instead of the cause leads to a temporary or partial fix. For example, if you have high dry-film thickness (DFT) readings and only correct it by reducing the applied DFT to resolve that single problem, you may not learn why the DFT readings were high in the first place. Maybe the gauges weren't calibrated properly, leading to inaccurate readings, or perhaps the applicators did not receive adequate training in the equipment and methods they were using. This is where root cause analysis comes in handy.

ROOT CAUSE ANALYSIS

A root cause is a factor that caused a nonconformance and should be permanently eliminated through process improvement. Root cause analysis (RCA) is a term that describes the variety of approaches, tools and techniques used to uncover causes of problems.

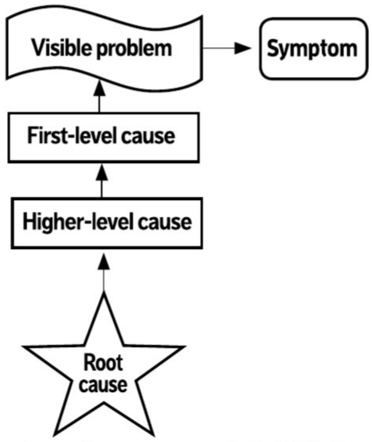

Fig. 1: A sample root cause analysis (RCA) diagram. Figures courtesy of the author.

RCA is best done as a team involving all stakeholders. People on the team should be familiar with the details of the nonconformance or findings and with the process, service or product being fixed. If it's a process issue, such as painting contracts not being reviewed and key information not making its way to the field, it might include the estimators, office personnel, quality control, safety and production teams. A moderator is often helpful to avoid finger-pointing and keep the discussion centered on producing solutions instead of simply scapegoating.

There are many ways to do an RCA, but a couple of the simplest approaches that this author prefers, without statistical analysis, are the Five "Why?"s and the Fishbone Diagram.

Five "Why?"s

The Five "Why?"s technique is used in the Analyze phase of the Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) methodology to increase process efficiency. The Five "Why?"s concept simply brainstorms by asking why the problem is occurring. Asking "why?" sounds simple, but answering it requires thought and intelligent application. By repeatedly asking the question "why?" (five is the rule of thumb, but some cases call for fewer or more "why?"s to be asked), you can peel away the layers of symptoms that can lead to the root cause of a problem. Search for answers that are grounded in fact; they must be accounts of things that have actually happened, not guesses as to what might have happened.

1. Start by writing down the specific problem or finding. Writing the issue down helps you to formalize the problem and describe it completely. It also helps a team focus on the same problem.

2. Then, ask why the problem happens and write the answer down below the problem.
3. If the answer you just provided doesn't identify the root cause of the problem that you wrote down in Step I, ask "why?" again and write that answer down.
4. Loop back to Step 3 until the team is in agreement that the problem's root cause has been identified. Again, this may take fewer or more than five "why?"s.

The Five "Why?"s method is not without limitations, though. It may not lead to a root cause identification if the cause is ultimately unknown, or if the problem may have more than one cause. The Five "Why?"s method is also highly dependent on the objective insights of those conducting it. In some cases, it can lead to settling on an easy target as the cause, rather than the real root of the problem.

Fishbone Diagram

The Fishbone Diagram (also known as the Cause and Effect Diagram) is a technique generated by Japanese professor Kaoru Ishikawa to graphically identify and organize many possible causes of a problem (the effect, in this case). The fishbone incorporates the Five "Why?"s way of analysis, but allows a team to identify, explore and graphically display all of the possible causes related to a problem or finding in increasing detail. For most businesses, there are several predictable "bones" to evaluate.

- Environmental issues: causal factors found in the environment where the event took place such as temperature, noise and clutter.
- Equipment issues: errors or problems with all types of equipment being used.
- Materials: incorrect, or problems with type, application, storage, use.
- Methods and processes: issues pertaining to the different processes and procedures being run in the organization.
- Measurements: inaccurate, erroneous or misinterpreted readings.
- Human factors: training, qualifications, attitude, fatigue or abilities.
- Leadership issues: causes resulting from the climate and culture created by the organization's management.
- Information issues: causes linked to a lack of information or erroneous information.

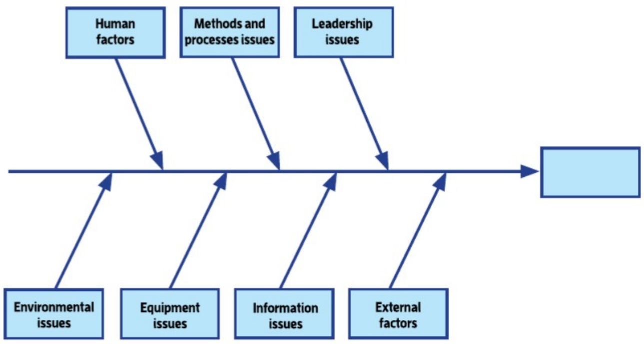

Fig. 2: A fishbone diagram displays the possible causes of a problem.

Within each group, some specific questions might need to be asked.

- Human factors: Was the document properly interpreted? Was the information properly disseminated? Did the recipient understand the information? Was the proper training to perform the task administered to the person? Did the environment influence the actions of the individual? Are there distractions in the workplace? Is fatigue a mitigating factor? How much experience does the individual have in performing this task?
- Equipment: Was the correct tool used? Is the equipment affected by the environment? Is the equipment being properly maintained (i.e., a daily/weekly/monthly preventative maintenance schedule)?
- Measurement: Does the gauge have a valid calibration date? Was the proper gauge used to measure the part, process, chemical or compound? Do measurements vary significantly from operator to operator? Do operators have a tough time using the prescribed gauge?
- Materials: Was the material properly tested? Was the material substituted? Was the material handled properly (stored, dispensed, used and disposed of)?
- Environment: Is the process affected by temperature changes over the course of a day? Is the process affected by humidity, vibration, noise or lighting? Does the process run in a controlled environment?
- Methods: Were the workers trained properly in the procedure? Are the work instructions clearly written? Are the work instructions complete? Is handling/packaging adequately specified? Was adequate sampling done? Are features of the process critical to safety clearly spelled out to the operator?

Let's look at the high DFTs issue using the fishbone diagram. Some potential answers identified during an RCA appear in red.

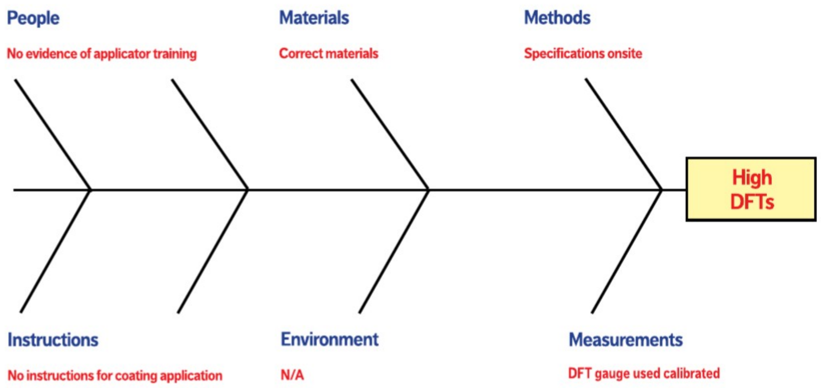

Fig. 3: This completed fishbone diagram shows some of the root causes for high DFT readings.

IMPLEMENTING CORRECTIVE ACTIONS

Our RCA identified two causes: lack of training and lack of written instructions. Now what?

We need to plan and implement how to eliminate the root causes through a corrective action plan (CAP). The CAP should provide specific procedures to be implemented.

- What is the corrective action(s), including supporting documentation?
- Who is responsible for the corrective action?
- Who is conducting the training?
- When (date) is the corrective action completed or projected to be completed?

The CAP for this example may state something like the following.

– Coating application instructions to be developed by Production by 4/1/18.

– Training in coating application instruction provided by the Production Manager by 5/1/18.

– Audit coatings application by QA around 6/1/18 to see if DFT results are in range.

Sometimes, you have to provide evidence that the CAP was implemented to outside auditors by providing objective evidence of the actions, such as providing a copy of the new coating application procedures or training list.

Once implemented, the CAP should be verified as resolving the root cause. Using our high DFT example, we should see more accurate application with specified DFT ranges. If not, we should investigate again and implement new corrective actions until the problem is corrected.

Both the office and field should understand RCAs and CAPs and how to go about them. When used properly, RCAs and CAPs can improve quality, reduce costs and change how a company functions for the better.

ABOUT THE AUTHOR

Alison B. Kaelin, CQA, has more than 30 years of public health, environmental, transportation and construction management experience in the coatings industry. She is the owner of ABKaelin, LLC, a provider of EHS, coatings quality assurance, consulting and related services to the protective coatings, construction, fabrication and nuclear industries. Kaelin is a certified quality auditor and a NACE-certified Coating Inspector. She was a co-recipient of the 2016 Coatings Education Award, a co-recipient of the inaugural SSPC 2014 Women in Coatings Award, a 2012 *JPCL* Top Thinker, a 2012 *JPCL* Editor's Award Winner and an SSPC Technical Achievement Award winner in 2005. Kaelin is also a *JPCL* contributing editor.

Evaluating Material Loss of Steel Under Protective Coatings in Marine Environments

BY PATRICK CASSIDY AND JAMES A. ELLOR, P.E.,ELZLY TECHNOLOGY CORPORATION; AND JOHN WEGAND, JAMES MARTIN, PAUL SLEBODNICK AND JAMES TAGERT, U.S. NAVAL RESEARCH LABORATORY

Over the past 20 years, the U.S. Navy has widely implemented the use of advanced ultra-high-solids (UHS) coatings for the protection of ship tanks and voids to extend the life of tank coatings[1,2,3]. The Navy intends these coatings to provide 20 years of service. Experience to date has been largely positive concerning these coatings, although they are not immune to breakdown prior to the end of their intended service lives. In areas of breakdown, the maintenance community needs a suitable touch-up and repair coating and as part of this ongoing effort, the Navy sought methods to improve basic coating test methods to better assess repair coating performance. The program intended to conduct testing that would determine greater than 10 years of service life.

The technical community identified repair coatings applied to hull cuts and stringers as particularly problematic. Particular challenges include application of coatings over inadequate surface profile adjacent to weld-beads and the effectiveness of hand-tool cleaning in promoting long coating life in a repair scenario (Fig. 1). The Navy implemented an expansive study of coatings applied over pre-rusted and hand-tool-cleaned steel intending to rate the performance of coatings using traditional visual inspection methods. The objective of this article is to report on observations of corrosion and material loss under coatings included in this test and suggest the criticality of making such observations in the ranking of coating effectiveness to augment traditional visual ranking methods.

EXPERIMENTAL PROCEDURE

To evaluate repair coatings applied directly to corroded, uneven steel such as a tank access cut, the program included flat plate panels with a weld bead on each. The base plate consisted of a nominal 4-inch-by-6-inch-by-⅛-inch-thick carbon steel panel. A ¼-inch-high and ¼-inch-wide weld bead was placed roughly 1 inch in from the panel's long-edge, extending 4 inches along the center length of the panel.

Fig. 1: Initial coating deterioration at weld beads and edges. Figures courtesy of the authors.

After the weld bead was applied, the panels were abrasive blasted to an SSPC-SP 5/NACE No. 1, "White Metal Blast Cleaning" finish creating a 2-to-3-mil surface profile[4]. Twenty-seven panels were prepared. The backs and edges of the panels were coated with a high-solids epoxy per the manufacturer's instructions, leaving only the front face with the weld bead exposed. The panels were subjected to 30 days of alternate natural seawater immersion (12 hours wet/dry) in Key West, Florida to artificially age or "pre-rust" the steel.

Upon removal, the weld bead panel front face was cleaned to SSPC-SP 11, "Bare Metal Power Tool Cleaning" using a needle gun[5]. Surface profile and conductivity were measured and recorded for each panel. For a set of nine panels, one of three specific repair coatings was applied by brush and roller to achieve specific dry-film-thickness (DFT) target levels of 5, 10 and 15 mils. Table 1 summarizes the coating test matrix.

The three repair coatings applied were a rapid curing, edge-retentive epoxy (98-percent solids), a surface-tolerant epoxy (90-percent solids) and a polyamide epoxy (67-percent solids). Manufacturers' recommendations were followed for all environmental conditions and curing time. Coating thickness, surface profile and surface conductivity QA data were obtained using standard Navy practices as documented in NAVSEA Standard Item 009-32[6]. Five DFT measurements were taken on the face of each coated panel. A single profile and surface contamination reading was taken on the face of each panel.

After curing of the coating and prior to immersion testing, the panel had an intentional scribe made in the coating. This was a ⅛-inch wide scribe made with a ⅛-inch wide spiral mill bit using a milling machine. This scribe in the coating was placed parallel to the weld bead, 1 inch from the opposite edge of the coated panel.

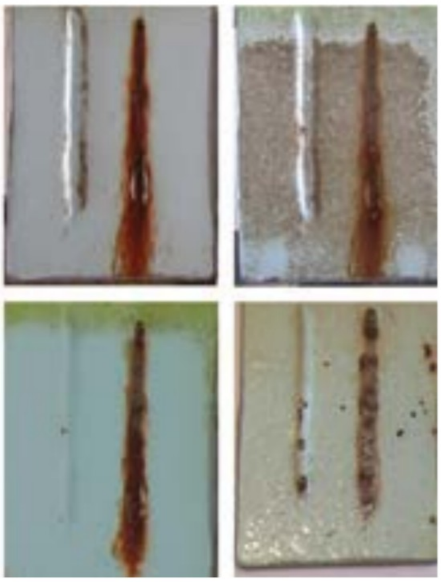

Fig. 2: System 1 at three (top, left), six (top, right), 12 (bottom left) and 40 months (bottom right) of exposure.

Table 1: Coating Test Matrix for Test Panels.

		DFT			
		5 mils	10 mils	15 mils	
System No.	Coating Description	# of Panels	# of Panels	# of Panels	Total
1	Rapid curing, edge retentive epoxy (98% Volume Solids)	3	3	3	9
2	Surface tolerant high build epoxy (90% Volume Solids)	3	3	3	9
3	Polyamide epoxy (67% Volume Solids)	3	3	3	9
	Total Panels:	9	9	9	27

Table 2: Summary of Depth of Attack Data (in inches).

System	Pit Depth(s) Adjacent to Scribe (inches)			Pit Depth(s) On the Panel Face (inches)		
Edge Retentive, 5 mils (1 year)	0.013	0.011	0.012	0.001	0.000	0.000
Edge Retentive, 10 mils (1 year)	0.003	0.002	0.003	0.000	0.000	0.001
Edge Retentive, 15 mils (1 year)	0.004	0.004	0.005	0.000	0.001	0.000
Edge Retentive, 5 mils (3.3 year)	0.009	0.010	0.009	0.001	0.002	0.001
Edge Retentive, 5 mils (3.3 year)	Not inspected; retained for future evaluation.					
Edge Retentive, 10 mils (3.3 year)	0.014	0.019	0.017	0.006	0.006	0.005
Edge Retentive, 10 mils (3.3 year)	Not inspected; retained for future evaluation.					
Edge Retentive, 15 mils (3.3 year)	0.017	0.014	0.015	0.000	0.000	0.001
Edge Retentive, 15 mils (3.3 year)	0.012	0.009	0.010	0.010	0.010	0.008
Surface Tolerant, 5 mils (1 year)	0.002	0.001	0.005	0.001	0.002	0.001
Surface Tolerant, 10 mils (1 year)	0.003	0.002	0.003	0.002	0.002	0.002
Surface Tolerant, 15 mils (1 year)	0.005	0.006	0.005	0.002	0.003	0.002
Surface Tolerant, 5 mils (3.3 year)	0.018	0.016	0.014	0.018	0.019	0.014
Surface Tolerant, 5 mils (3.3 year)	0.014	0.016	0.012	0.009	0.006	0.005
Surface Tolerant, 10 mils (3.3 year)	0.023	0.027	0.025	0.006	0.004	0.005
Surface Tolerant, 10 mils (3.3 year)	0.019	0.020	0.018	0.004	0.005	0.002
Surface Tolerant, 15 mils (3.3 year)	0.010	0.009	0.010	0.004	0.005	0.003
Surface Tolerant, 15 mils (3.3 year)	0.017	0.018	0.015	0.005	0.004	0.002
Polyamide Epoxy, 5 mils (1 year)	0.010	0.015	0.014	0.009	0.010	0.011
Polyamide Epoxy, 10 mils (1 year)	0.004	0.003	0.004	0.001	0.002	0.001
Polyamide Epoxy, 15 mils (1 year)	0.008	0.006	0.006	0.001	0.001	0.001
Polyamide Epoxy, 5 mils (3.3 year)	0.012	0.013	0.016	0.002	0.001	0.001
Polyamide Epoxy, 5 mils (3.3 year)	Not inspected; retained for future evaluation.					
Polyamide Epoxy, 10 mils (3.3 year)	0.007	0.005	0.010	0.004	0.006	0.012
Polyamide Epoxy, 10 mils (3.3 year)	0.008	0.006	0.008	0.001	0.002	0.001
Polyamide Epoxy, 15 mils (3.3 year)	0.004	0.005	0.004	0.000	0.001	0.000
Polyamide Epoxy, 15 mils (3.3 year)	0.010	0.007	0.017	0.015	0.011	0.013

The panels were exposed in natural seawater alternate immersion (12 hours wet/dry) in Key West, Florida and were periodically inspected for coating blistering and rust-through on the faces of the panels using the procedures of ASTM D714 and ASTM D610 respectively[7,8]. Cutback at the scribe was measured by ASTM D 1654[9]. Cutback data were reported as actual

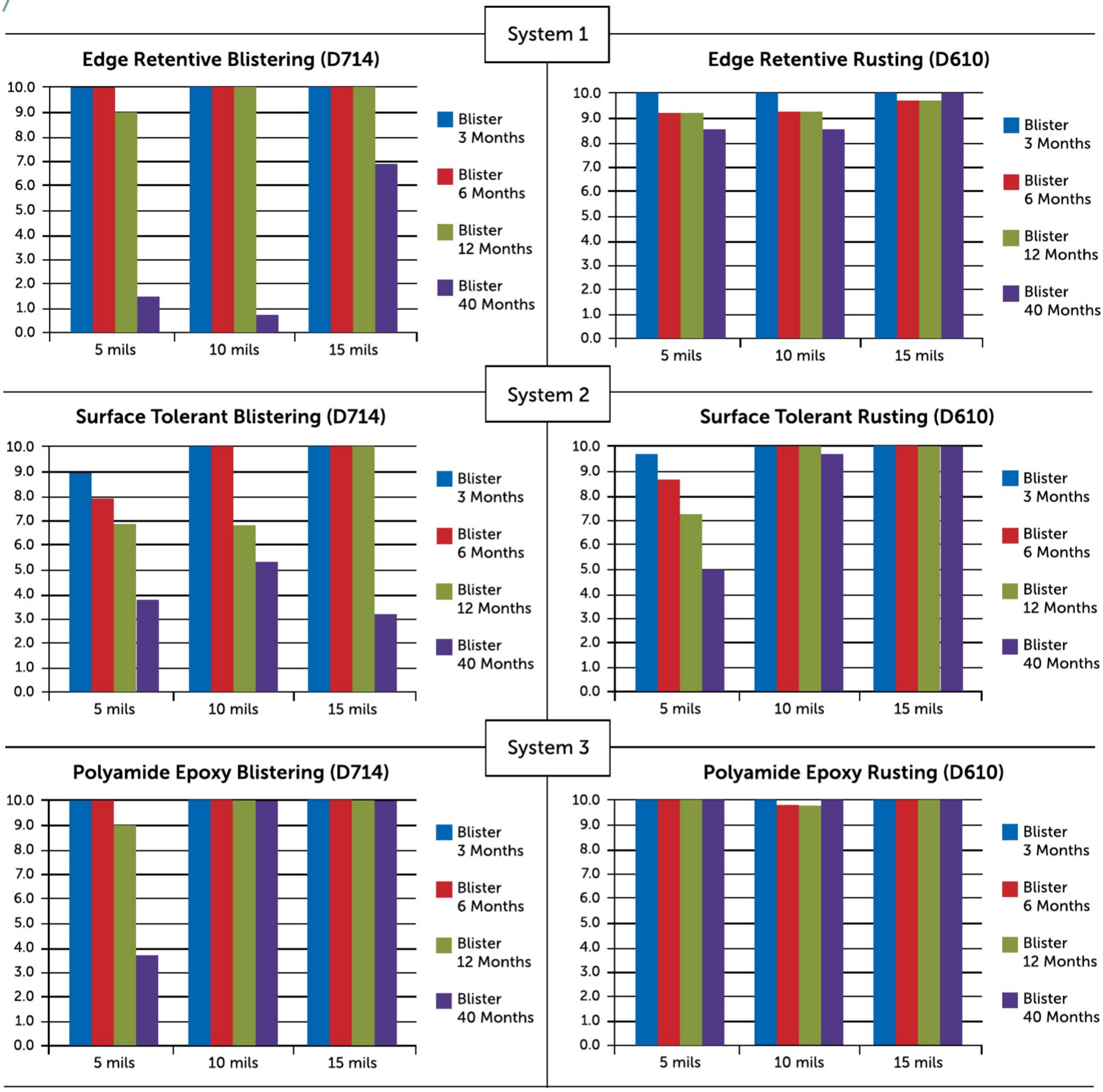

Fig. 3: Summary of blistering and rust-through data via visual inspection: System 1 (top), System 2 (center) and System 3 (bottom).

measurements in mils (0.001 inch), not the standard rating scale. A single panel from each set of three from Table 1 was destructively inspected after 12 months of exposure. The remaining two of three panels from each set were destructively inspected after 40 months of exposure.

At the conclusion of the exposure, all panels were soaked in a methylene chloride paint stripper and subsequently glass-bead blasted with 80-to-120 grit glass at 80 psi to remove all coating and corrosion products without altering or removing the underlying steel.

To evaluate material loss of the steel substrate under and adjacent to the scribe, the depths of corrosion attack (pits) were measured to the nearest 0.001 inch using a needle micrometer. Pits were identified and categorized as either adjacent to/contiguous with corrosion activity around the intentional scribe or on the general panel surface away from the scribe/around the weld bead. The pitting corrosion depth data that follows is presented as being either on the "panel face" or "adjacent to the scribe." Note that the pitting measured adjacent to the scribe and on the panel face was found only after removing visually intact coating. A minimum of the three deepest pits were recorded in each area on each panel.

RESULTS

Visual Data

The weld bead panel preparation at the target thicknesses of 5, 10 and 15 mils resulted in panels with average DFTs of 5.7, 10.2 and

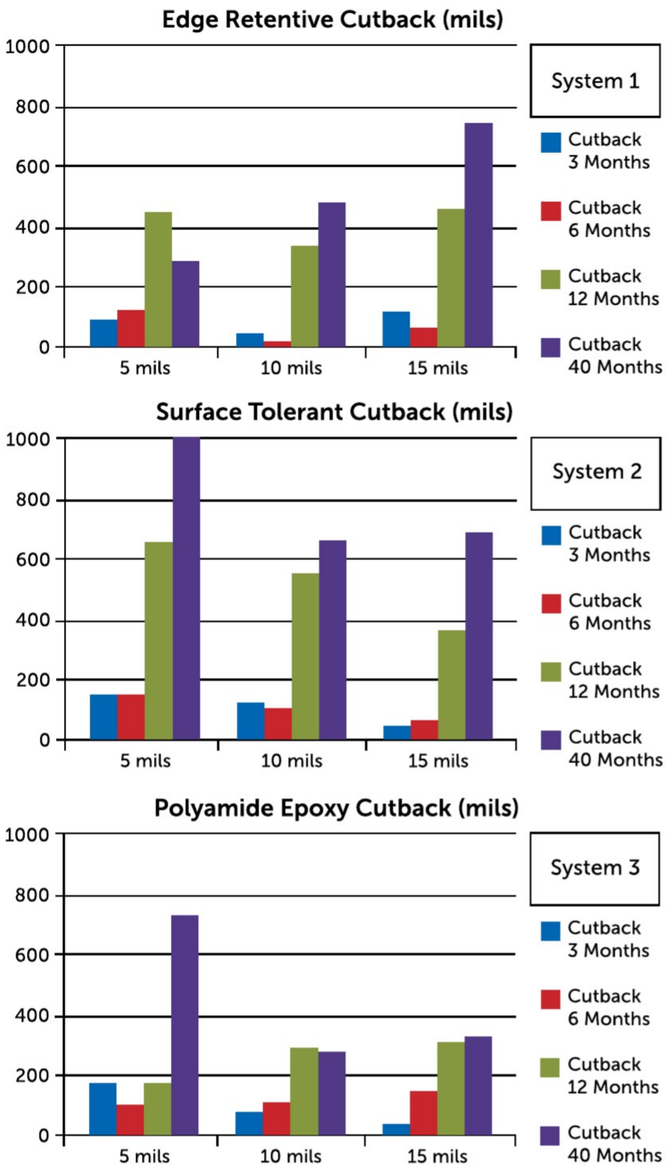

Fig. 4 (left): Summary of cutback measurements via destructive inspection: System 1 (top), System 2 (center) and System 3 (bottom).

15.7 mils with a coefficient of variation of less than 7 percent. The target thicknesses were carefully controlled and met. Before application of the repair materials, the surface profile was between 2.2 and 3.0 mils, essentially retaining much of the original blast profile simply with the removal of visible corrosion products (leaving rust staining as permitted in SSPC SP-11)[5], although the profile did become more visibly rounded from the needle gun. The surface salt readings before application of the repair material ranged from 140-to-218 µS/in, with an average of 185 µS/in.

Fig. 5: System 3 polyamide epoxy 15-mil-thick coating at the end of exposure (left) and after coating removal at 40 months alternate seawater immersion (right).

Fig. 6: System 1 edge-retentive epoxy 15-mil-thick coating at the end of exposure (left) and after coating removal after 40 months of alternate seawater immersion (right).

Over the course of the exposure period, coating rust-through and blistering was observed, inspected for and recorded for each test panel. Figure 2 (p. 25) shows the typical progression of deterioration observed visually on System 1 at a 5 mil thickness.

Over time, there is obvious corrosion developing at the scribe, leading to coating undercutting. There is also the onset of deterioration at the weld bead and on the general panel surface. Figure 3 provides the summary of the visual inspection data via ASTM D714 and D610 for all three coating systems at the three different film thicknesses over the exposure period[8,9].

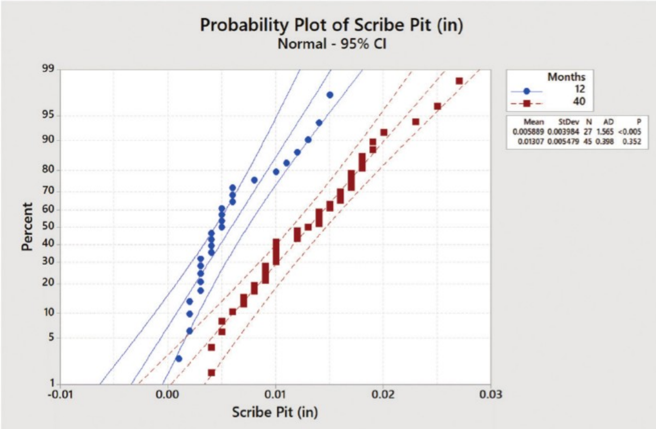

Fig. 7: Pitting corrosion depth adjacent to the scribe over time at 12 and 40 months of exposure.

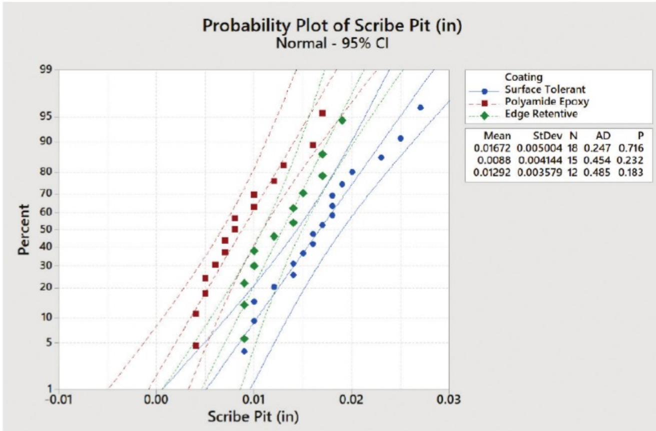

Fig. 8: Pitting corrosion depth adjacent to the scribe by coating type at 40 months of exposure, System 1 (green), System 2 (blue) and System 3 (red).

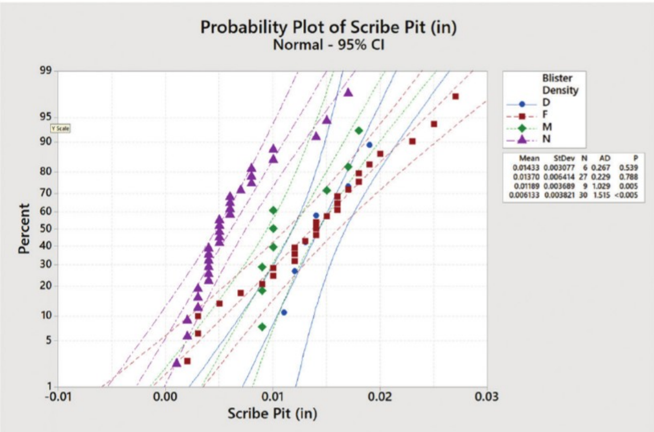

Fig. 9: Pitting corrosion depth adjacent to the scribe as a function of blister density, 40 months of exposure.

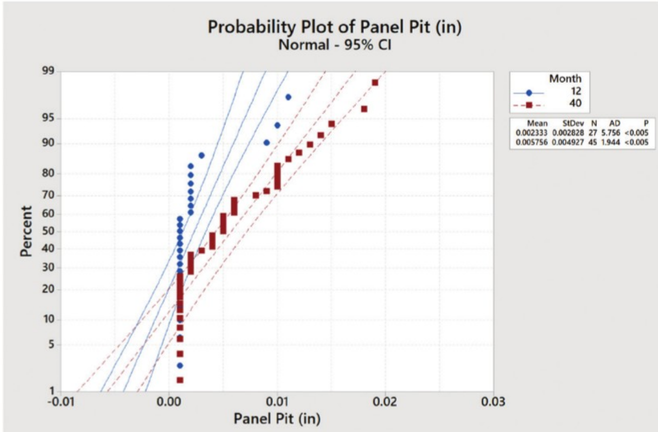

Fig. 10: Pitting corrosion depth on the panel face over time, at 12 and 40 months of exposure.

Figure 4 (p. 28) provides a summary of the cutback data for these same systems and thicknesses over the exposure period.

These standard inspection and evaluation criterion data suggest the following conclusions concerning the performance of each coating.

For coatings with blistering, those with a lower film build tended to blister first and to the greatest extent. Over time, selected blisters would break and become active rusting sites. Blisters tended to form initially adjacent to scribes; over time, more blisters were observed remote from the scribes.

Coating cutback increased over time. There did not appear to be a strong correlation with film thickness for the range of coatings and thicknesses tested.

The coating with the least visually apparent damage is the polyamide epoxy system, System 3. This coating system had substantially less blistering and rusting than any of the other coatings.

Material Loss/Corrosion Data

Table 2 (p. 25) summarizes data on the raw depth of attack after coating removal and measurement of the deepest pits. These data are from defects in the repair coatings. No significant pits were noted in the obverse side of the test panel protected with a high-solids coating applied over the original abrasive-blasted surface preparation.

Figure 5 (p. 28) shows the physical appearance of corrosion attack under a 15-mil-thick polyamide epoxy coating after 40 months of exposure.

Both Figures 5 and 6 (p. 28) show the presence of pitting corrosion under the previously intact coating systems. The deepest pits were observed adjacent to the scribe, though still not visible before coating removal. Figure 7 (p. 30) shows the distribution of the extent of pitting corrosion around the scribe over time. These data, and the subsequent similar plots, are presented as normal distributions of the data. This distribution was selected as a convenience, as some of the data do not fit well to a normal distribution.

From month 12 to month 40, the mean pit depth doubles from 6 to 13 mils. The deepest pits approach 30 mils after 40 months of alternate immersion exposure, suggesting a corrosion rate of 9 mils per year under the coating. Figure 8 shows the 40-month pit data adjacent to the scribe as a function of coating type.

The surface-tolerant coating, System 2, performs quite differently than the polyamide epoxy System 3, and does so consistently. These

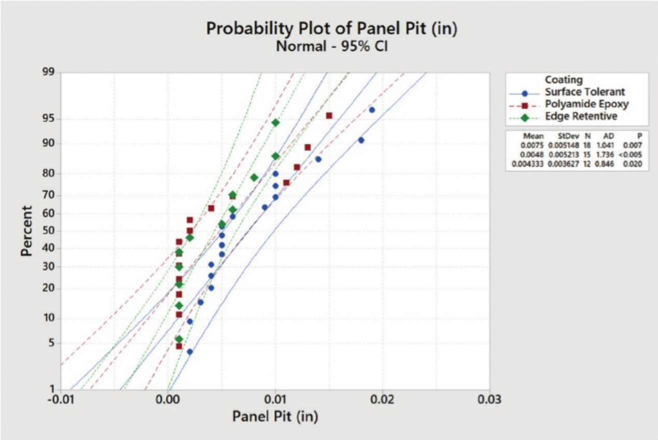

Fig. 11: Pitting corrosion depth on the panel face by coating type at 40 months of exposure, System 1 (green), System 2 (blue) and System 3 (red).

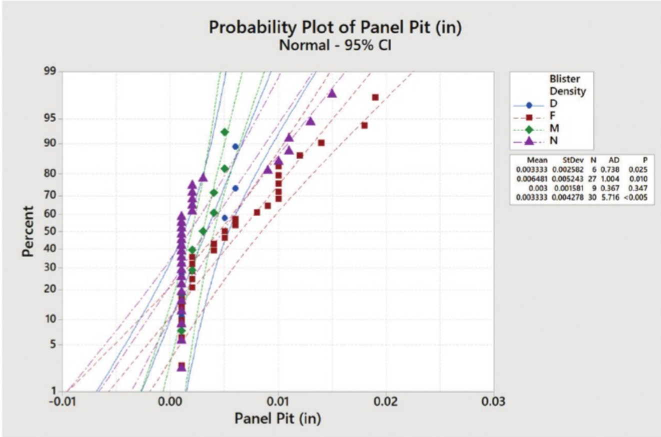

Fig. 12: Pitting corrosion depth on the panel face as a function of blister density at 40 months of exposure.

data show a real difference in barrier coating performance when compared to the visual inspection data in Figures 4 and 5.

Figure 9 shows the pit depths adjacent to the scribe for all coatings as a function of the ASTM D714 blister density rating[9]. The panels exhibited visual ratings of dense, medium and few (D, M and F) blistering. The code "N" indicates none or no blistering.

Figure 9 also suggests that pitting corrosion is associated with blistering, although the deepest pits are on those panels with few blisters as opposed to medium or dense blistering. This increase may be associated with the blisters serving as anodic sites to other areas of the panel. A limited number of blisters would tend to concentrate the anodic current.

Figure 10 shows the distribution of pits found outside of the scribe on the face of the panel as a function of exposure time.

The figure exhibits at least two distributions: those panels without any sensible pitting and those with pitting. For the panels with pitting on the face, the depth approaches the depth of those at the scribe but appears to be of a slightly lower magnitude.

Figure 11 (p. 31) shows the panel face pit data as a function of coating type. In this condition, there is not a consistent impact of coating type.

Figure 12 (p. 31) shows the impact of the blister density rating on panel pit depths outside the scribe area on the face of the panel.

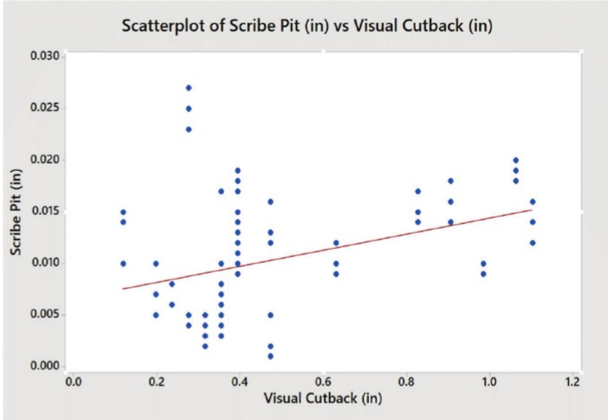

Fig. 13: Maximum pit depth adjacent to the scribe vs. measured coating cutback at the scribe.

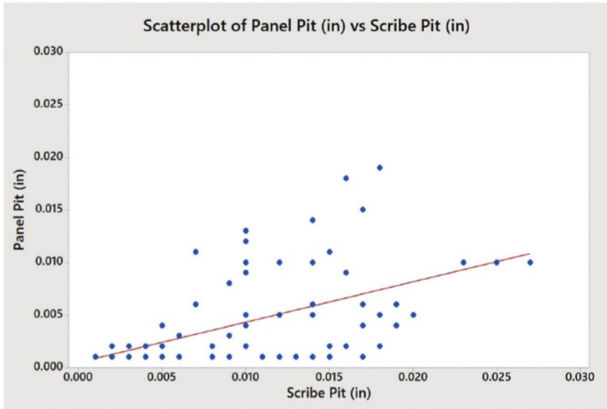

Fig. 14: Pit depth on panel face vs. pit depth adjacent to the scribe.

Figure 13 shows the relationship between the pit depth adjacent to the scribe and the maximum measured cutback (undercutting) of the coating adjacent to the scribe. There is no apparent correlation between these two coating-performance parameters; that is, panels with minimal undercutting of the coating did not necessarily have less pitting.

Figure 14 shows the relationship between pitting corrosion depth on the panel face versus pitting corrosion depth adjacent to the scribe area. Again, the correlation is weak.

CONCLUSIONS

1. Pit depths under repair coatings approach 30 mils adjacent to scribes and 20 mils under seemingly visually intact paint on the panel face. No pitting corrosion was observed on abrasive-blasted steel protected with high-solids coatings.
2. This magnitude of attack in 40 months of exposure is significant. Thirty mils of corrosion in 40 months represents about half of the Navy criteria for potential structural repair for a ¼-inch-thick steel bulkhead. Unchecked, this corrosion rate can lead to necessary structural repair.
3. The depths of corrosion attack do not correlate with the visual inspections. Especially, they do not correlate with general rankings of rust-through in accordance with ASTM D610[8]. The depth of attack has some correlation to blistering; however, less depth of attack is observed with more extensive blistering.
4. This work, and similar effort to quantify corrosion under coatings, represents an initial investigation of improved methods for ranking coatings to support long-term structural integrity. Measuring actual corrosion and material loss under the coating seems to be a better method for evaluating coating materials than the standard visual methods. At a minimum, destructive evaluation methods for corrosion and material loss should be used to augment visual rankings.

ABOUT THE AUTHORS

Patrick Cassidy has been working in the corrosion and coatings industry for over 10 years and is currently a senior engineer with Elzly

Technology Corporation. He has been involved in a diverse number of programs including coatings research, field investigation and application of corrosion control products. He holds a Bachelor of Science degree in mechanical engineering from the University of Virginia. Cassidy is an SSPC-certified NAVSEA Coatings Inspector and has completed additional training in Navy Ship Corrosion Assessment and Cathodic Protection Design. In 2015, he was profiled in the *JPCL* annual bonus issue, "Coatings Professionals: The Next Generation."

James A. Ellor has over 35 years of experience in the corrosion industry. He is currently a senior consultant with Elzly Technology Corporation. Throughout his career, Ellor has been involved in myriad programs including contract research, field investigations and application of corrosion control products. He holds a Bachelor of Science degree in chemical engineering from the University of California, Berkeley and is also a registered Professional Engineer, a NACE-certified Corrosion Specialist and Cathodic Protection Specialist.

John Wegand is a senior engineer at the U.S. Naval Research Laboratory within the Center of Corrosion Science and Engineering. Wegand has a Bachelor of Science degree in mechanical engineering from the University of Maryland and has over 30 years of experience working with the U.S. Navy executing and managing various research, development, test and evaluation technical programs. His experience ranges from development in the laboratory to implementation in the fleet, including policy and requirements development for the Naval Sea Systems Command.

James Martin has been with the NRL for over 18 years. He is the head of the Marine Coatings Technology and Systems section Code 6138. Martin is responsible for introducing coatings technology to the Fleet through applied research and development, testing and demonstrations. He has been active in addressing Fleet concerns from both maintenance and new construction with respect to coatings. Martin continues to introduce new technology that will help to reduce the life-cycle and ownership costs of today's Fleet.

Paul Slebodnick is employed by the NRL in the Washington, D.C., Center for Corrosion Science & Engineering, under the Marine Engineering Section. He currently leads research programs in developing technologies for the United States Navy that produce maintenance reductions and reduce Ships Force workload. Slebodnick is responsible

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James Tagert is a materials research engineer at the Naval Research

Laboratory and has over 12 years of experience working in the coatings industry. He graduated from the University of Maryland in 2004 earning a Bachelor of Science degree in mechanical engineering and is a member of both the American Society of Naval Engineers and NACE International. Tagert has worked at NRL since 2008 supporting U.S. Navy research and engineering programs related to materials science with an emphasis on the development and transition of advanced coating systems.

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FUNDAMENTALS OF FUSION-BONDED EPOXY APPLICATION

BY DAVID A. HUNTER AND SEAN M. BROWNING, POND & COMPANY

Protective coatings for carbon steel are well known as an economical method of controlling corrosion versus the use of alternative materials such as stainless steel. At first glance, buried piping seems to have a stable environment. One might assume that coatings would not necessarily be required, as they might be for atmospheric environments, which are bombarded with rain, snow (depending on location), fog, ultraviolet light and significant temperature differentials. Buried environments, however, even in semi-arid climates, contain enough moisture in the soil to conduct ionic current, which completes the circuit for corrosion of most metals.

One way to control buried corrosion is to employ cathodic protection (CP), and indeed, buried pipe corrosion can be controlled with CP alone. The limitation of using solely CP, however, is the amount of CP required to protect the exposed surface area. The greater the current requirements, the larger and more expansive the CP required, meaning greater installation, maintenance and monitoring costs which drives up the cost of operating a pipeline. And for pipelines carrying hazardous materials, the requirements for maintaining the lines are prescribed by federal law. Therefore, a cost-effective design approach is to use coatings in conjunction with cathodic protection to protect the line.

COATING SYSTEM SELECTION

There are many types of appropriate coating systems, such as two-component liquid epoxies and urethanes, but single- or two-layer fusion-bonded epoxy (FBE) is most often used for buried steel pipelines in the U.S. The durability of FBE in a buried environment has been well proven. An advantage of using FBE over liquid coating applications is that the materials can be applied in a highly controlled environment at fairly high speed which tends to drive down overall cost of application.

The coating process involves cleaning the steel pipe surface with abrasive grit in a centrifugal blasting cabinet to a required cleanliness level of SSPC-SP 10/NACE No. 2, "Near-White Blast Cleaning." Either induction or oven heating is used to heat the cleaned pipe to approximately 350-to-480 F before it is sent through an electrostatic sprayed epoxy powder. The powder melts, flows into a film and fuses on contact to the heated pipe. The curing of the film occurs within several minutes and is followed by a water quench. The speed at which the pipe is moving through the FBE determines the coating thickness.

FBE can be mill-applied as a one- or two-layer pipeline coating. Single-layer FBE is applied in the range of 12-to-16 mils. A dual-layer process can be used where two consecutive FBE layers are applied to the heated pipe. The inner layer, at 12-to-16 mils dry film thickness (DFT)

Fig. 1: FBE powder application. Figures courtesy of Consolidated Pipe & Supply Company, Inc..

provides corrosion protection to the steel pipe. While it is still soft, a second or outer layer at 15-to-40 mils DFT is applied as an additional barrier coat and provides abrasion resistance (Table 1, p. 38).

This article discusses the fundamental steps of FBE application, some advantages and disadvantages, and some basic inspection criteria for a quality application.

THE 1-2-3 OF FBE

As the name implies, FBE is cured by introduction to high temperature. An advantage of FBE is that the coating has no hazardous solvents; it is cured by melting dry powder until it forms a liquid which flows out and cures, creating a coating that is more consistent in thickness as compared to a liquid-spray application. Additionally, because the pipe is rotated during application, the uniformity extends around the pipe and to each pipe in a run, as long as there is consistency in the process.

It is important to monitor drifts in speed and temperature during surface prep and application. Also, as abrasive is recycled throughout the blasting process, abrasive size becomes smaller resulting in a shallower surface profile. Therefore knowing when to replace abrasive media is of utmost importance.

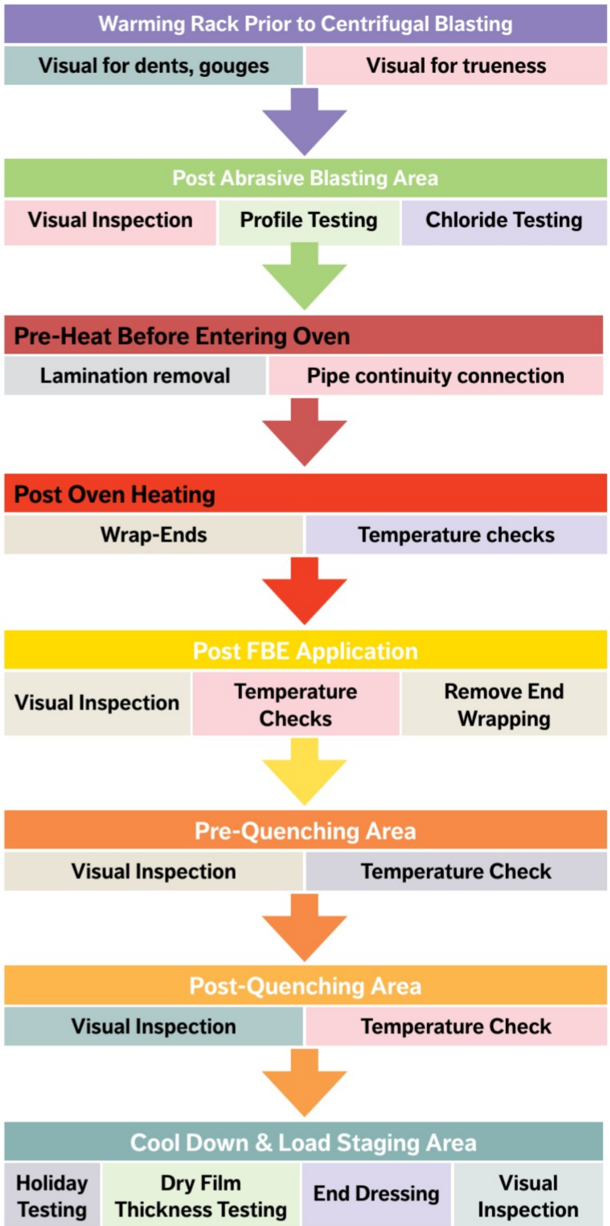

Fig. 2: Outline of the FBE process.

Fig. 3: View of pipes in the laydown yard.

Fig. 4: View of air-heating units to warm pipes.

Fig. 5: Pipe entering shot-blasting machine.

Fig. 7: Pipes after surface preparation with pipe connectors attached.

Table 1: Characteristics and Limitations of Fusion-Bonded Epoxy

Thickness Range, 1-Layer, Mils	12-18
Thickness Range, 2-Layer, Mils	20-60
Electrical Resistance Water Penetration	Excellent
Resistance	Excellent
Heat Resistance	250 F
Solvent Resistance	Excellent
Impact Resistance	Good
Bendability	Good
Abrasion Resistance	Good
Cathodic Disbondment Resistance	Excellent
Mill Application	Yes
Field Application	Yes

Table courtesy of E. Bud Senkowski, *JPCL*, November 2015.

Fig. 6: Wheel-blasting machines lined up in series.

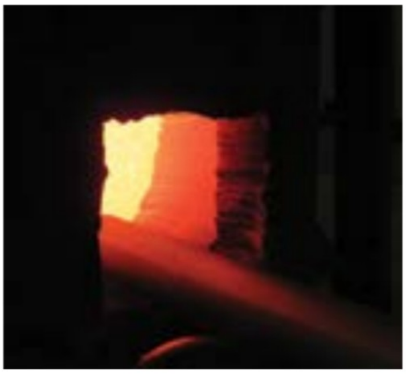

Fig. 8: Pipes entering the furnace.

The steps, with minor variation, are based on a manufacturer's individualized process, but in general are illustrated in Figure 2 (p. 37).

The process of FBE application is straightforward. The pipe is first brought indoors to impart a uniform temperature across the pipe and to prevent variation in pipe temperature once heated, as shown in Figure 3 (p. 37). The surface of the pipe is then prepared by abrasive blasting, which is a two-step process. First the pipe is blasted with steel shot to remove mill scale and then blasted with steel grit to create an angular profile, which increases the surface area of the substrate and promotes better adhesion as shown in Figures 5 through 7.

The pipe is then heated in an oven running at 2,000 F, which at the speed of throughput, heats the pipe to approximately 450 F. This is immediately followed by powder application, as shown in Figure 1 (p. 36).

The temperature of the pipe causes the powder to melt, flow out and then cure into a continuous film. After exiting the FBE application, the pipe is cooled using water in a curtain effect as shown in Figure 9. The final steps include holiday testing, inspection, repair and loading as shown in Figures 10 through 12.

SUMMARY

FBE coatings can be applied in a manufacturing process that provides a consistent, durable coating for buried application. As with any manufacturing process, diligence in identifying flaws and monitoring temperature, consistency of surface preparation and application are critical to the long-term performance of the materials.

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Fig. 9: Quenching area.

Fig. 10: Holiday testing.

Fig. 11: Taking dry-film-thickness measurements.

Fig. 12: Loading pipes.

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REFERENCE

1. Senkowski, Bud, "Meeting Demands of Gas Exploration: The Evolution of Pipeline Coatings," *JPCL*, November, 2015. ***JPCL***

15-to-40 mils

The thickness at which the outer layer of FBE is applied as an additional barrier coat to provide abrasion resistance.
See page 36.

2,877 feet

The total length of a steel lift bridge that exhibited rust staining and crevice corrosion after paint application.
See page 13.

20

The number of structure types and industrial applications showcased in the *JPCL* Annual Directory of Industrial Painting Contractors.
See page 49.

5

"Why?" questions that Alison Kaelin recommends asking when performing root cause analysis and determining corrective actions.
See page 19.

30 mils in 40 months

The rate of corrosion that represents about half of the Navy criteria for potential structural repair for a ¼-inch-thick steel bulkhead.
See page 24.