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SSPC The Society for Protective Coatings

FEATURES

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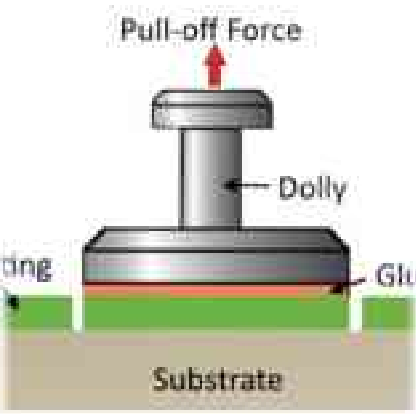
DETERMINING WHEN TO COAT CONCRETE

By Manuel Najar, V&A Consulting Engineers, Inc.

Several water and wastewater treatment owners have been confronted with the effects of biogenic corrosion and chemical deterioration of concrete in their concrete structures. Several assessment methods can be used to determine the existing condition of a coated or uncoated concrete structure and identify the type and extent of deterioration. This paper will identify some of the most important indicators of biogenic corrosion and chemical deterioration of concrete, with a few examples from different areas of the water and wastewater treatment process.



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COMPREHENDING PULL-OFF ADHESION TESTING

By Rob Francis, R A Francis Consulting Services Pty Ltd

Pull-off adhesion testing is increasingly being specified and used by coating inspectors. Manufacturers have produced new equipment models and more papers are being published on the subject, but is this increased interest based on the testing's ability to provide useful information on coating system performance, or is this a case of a test method being more attractive because it can produce a number—even if that number has little meaning? This article will look closely at pull-off testing—specifically, what is measured and what the results mean.

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2020 PAINTSQUARE CONNECT VIRTUAL EVENT RECAP

While the ongoing COVID-19 pandemic has kept coatings professionals from meeting up in person this year, JPCL publisher Technology Publishing Company hosted PaintSquare Connect, an inaugural virtual event bringing together experts throughout the industrial and commercial coatings communities, last month. The event took place Nov. 10–12 and featured a full curriculum of webinars, keynote sessions, product pavilions, award ceremonies and more. This article will provide a recap of PaintSquare Connect, as well as a guide to the archived offerings that are have been made available for registrants at paintsquare.com/psc.

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SSPC Inspection Standards Update

BY MICHAEL DAMIANO, SENIOR TECHNICAL ADVISOR, SSPC

This article takes a brief look at five industry standards and test methods that have either recently been revised or are in the final stages of revision. These standards deal with key inspection issues that will have an impact on inspection practices down the road when updated coating specifications reference these revised versions.

SSPC-PA 2, Procedure for Determining Conformance to Dry Coating Thickness Requirements, is being revised to provide inspectors, specifiers and contractors with procedures for accurately measuring dry film thickness using scanning probe technology and for measuring critical intumescent fireproofing applications.

The proposed 2020-21 revision doesn't change any of the PA 2 core (mandatory) requirements such as taking spot measurements with Type 1 or Type 2 gauges, calibration, verification and adjustment per ASTM 7091, defining the size of areas to measure, defining various restriction levels and having a procedure for isolating non-conforming areas.

The 2020-21 revision deals with four non-mandatory appendices. Certain PA 2 non-mandatory appendices provide specifiers with optional alternatives for defining area size as well as the number and frequency of spot measurements to include in project specifications for the size and shape of members or components that are not as easy to map out 100-square-foot areas for measurement as flat plate is.

Three new methods using scanning technology are being proposed. Scanning technology involves movement of a probe over the measured area to obtain more gauge readings than the single, "place and remove" gauge readings commonly used by inspectors that are required by PA 2. The proposed appendices describe procedures for obtaining a "greater population of thickness measurements" of steel girders, coated steel pipe exteriors and large flat plate.

Recent SSPC standard revisions include a new SSPC-PA 2 appendix for measuring intumescent coating thickness (left), as well as updated guidelines for stripe coating irregular surfaces under SSPC-Guide 11. FIGURES COURTESY OF SSPC

The fourth "new" appendix involves a "Method for Measuring the Thickness of Intumescent (Fireproofing) Coatings Applied to Load Bearing Structural Steel Members." This is a much-needed procedure to help specifiers obtain credible thickness readings, especially of thick film intumescent coatings that often have to be applied as high as 1,000 mils (25.4 mm) to meet fireproofing design requirements, using specially designed probes.

The frequency and acceptability of measurements under the intumescent appendix is very different than what's required in PA 2. In this appendix, a gage reading is a single instrument reading which must be taken on each steel member. The distance between gauge readings is based on the shape of the member. The parameters are described in the appendix. Very helpful illustrations are provided which show where readings are to be taken on the different member shapes typically encountered. Each gauge reading shall be no less than the specified DFT and gage readings cannot exceed 20% of the maximum thickness certified by UL for the specific intumescent coating being applied.

SSPC revised **SSPC PA Guide 11, Protecting Corners, Edges, Crevices, and Irregular Steel Geometries by Stripe Coating**, this past April. The 2020 revision added definitions for terms not previously defined such as "bolted connection," "corner," "crevice," and "edge," which are prime areas for stripe coating for additional corrosion protection. This version of Guide 11 also provides specifiers more detailed information on when a stripe coat should be applied (before or after a full coat application), on preparation of outside corners and edges for stripe coating and treatment of flame cut edges prior to application of a stripe coat.

PA Guide 11 is not a standard such as PA 2, which can be invoked in a project specification, but it can help the specifier decide where and when to apply a stripe coat and what generic material to use for a specific condition such as a sharp edge or corner. It can also help the inspector and contractor sort out clarification in cases where there is some ambiguity regarding stripe coating in the specification.

The revised Guide 11 provides a series of sample specification language options for specifying stripe coating and actual photographs of areas where stripe coating can be beneficial.

The 2020 revision of **SSPC-SP 16, Brush-Off Blast Cleaning of Coated and Uncoated Galvanized Steel, Stainless Steels, and Non-Ferrous Metals**, is nearing completion and is expected to be issued within the next few months. SP 16 has begun to show up more in specifications in recent years as coating of nonferrous substrates such as aluminum, stainless steel and galvanized steel appears to be on the rise to extend corrosion protection and also in some cases to also add color for identification.

The definition of an SP 16 sweep-blasted non-ferrous or galvanized surface has remained the same since the initial publication of SP 16 in 2010. What has however changed in the 2020 revision is the addition of more details about the types of substrates that can be cleaned using SP 16, and significantly more information about blasting abrasives and the blasting process (blast pressure and more in-depth discussion on when and when not to use certain abrasive types due to dissimilar metal and aggressive blasting of soft metal concerns).

Sample specification language to do a job mock-up before actual production work begins has been added. This can be helpful as there are no consensus industry photographic references available such as SSPC-VIS 1 to help the contractor and inspector have an idea of what the final SP 16 cleaned surface should look like based on the type of metal being cleaned and its initial condition.

The revised, non-mandatory, Appendix A provides more information on preparation of alloys such as aluminum and copper, and more guidance on roughening intact coating, as well as additional discussion of non-visible contamination.

ASTM D4417-20, Field Measurement of Surface Profile of Blast Cleaned Steel, was re-issued again this year after being updated in late 2019. Two changes of significance were made in recent 4417 Updates: the addition of Method D, which addresses measuring surface roughness by a portable stylus instrument; and modifying Method B, which describes a method for measuring surface profile using a fine pointed probe (digital surface profile gage) at a number of locations.

Concerning the addition of Method D, D4417-20 refers to ASTM D7127, which is the original test method for measuring surface roughness of abrasive blast cleaned steel using a portable stylus instrument. What would be interesting to know is whether the new Method D of 4417 is an acceptable alternative to D7127 when measuring surface profile and other surface roughness characteristics such as peak count on vertical blast cleaned steel surfaces. We will, however, leave answers to that question for a later time.

Of immediate interest to inspectors and contractors is the alternative methods Method B now allows. One method is to take 10 readings per location, record the maximum value for each location, and then determine the profile height based on the average of all the maximum location values.

An alternative method, which is what D4417 used to allow, is to take 10 readings per location and determine the average of the 10 locations. The average of the location averages then determines the profile height.

When specifications being written in the future invoke the 2020 version of D4417, which method should the contractor and inspector use for compliance if the specification refers to Method B? In some cases, the facility owner may specify the alternative it deems acceptable, but this author suspects that D4417 will often be referenced without any mention of which alternative to use—leaving it up to the inspector and contractor to get clarification.

Specification writers who wish to specify one of the alternatives, should take a close look at the note 5—The "average of the location maximums" procedure in 10.3.2.1 has been shown to produce results that correlate well with methods A, C, and D in this standard, based on theory and experimental data. The alternate "average of the averages" procedure in 10.3.2.2 has been shown to provide lower results than the other methods in this standard but reduces the impact of outliers that the operator (inspector) may fail to discard.

This issue also comes into play when power tool cleaning. SSPC-SP 15 and SP 11 power tool cleaning standards require measuring of profile using Method B unless another method such as replica tape (Method C) is allowed by the specification. D 4417-20 makes the "softer" statement in 1.2 that Method B may also be appropriate to the measurement of profile produced by using power tools. So, when power tool cleaning to create a profile, which method B alternative should be used?

Speaking of power tool cleaning, SSPC is nearing completion on a 2020 revision of **SSPC-SP 11, Power Tool Cleaning to Bare Metal**. The revised SP 11, when approved, will introduce three levels of cleanliness. Right now, SP11 defines one level of cleanliness. The three levels (paraphrased) are:

Level 1: The cleaned surface, including the bottom of pits on pitted surfaces, shall be free of oil, grease, dust, dirt, rust, mill scale, coating, corrosion products, stains and other foreign matter, when viewed without magnification. A surface profile minimum of 1 mil (25 micrometers) is required in non-pitted areas unless a higher profile is specified.

Level 2: This is the current SP-11 requirement which is same as the proposed A Level 1 with the exception that trace amounts of coating and corrosion products can remain in the lower portion of a pitted surface.

Level 3: Is the same as Level 2 with the exception that random staining consisting of light shadows, slight streaks and minor discoloration caused stains of rust, mill scale or previously applied coatings shall be limited to no more than 5% of the unit area.

Note that a Level 2 is the default if no specific level of SP-11 is specified.

These new levels, when specified, should help reduce disagreements when the extra effort to obtain Level 1 or even a Level 2 cleanliness is not justified from a cost or technical vantage point, or both. One more note in the revised draft states that in practice, SP 11 cleanliness, since its inception, has been closer to Level 3. Specifiers, it says, may consider requiring Level 3 when specifying a level. JPCL

Paint Chips from the Vending Machine

Paint Delamination from a Vending Machine Exterior

BY ROBERT LEGGAT AND VALERIE SHERBONDY, KTA-TATOR, INC.

A vending machine manufacturer experienced delamination of the paint applied to the exterior panels of its machines. The panels were made of cold-rolled steel that was pretreated in a process that included caustic cleaning followed by several rinse stages, fluorozirconate surface treatment and a silane adhesion promoter. The panels were subsequently coated with a polyester coating.

The manufacturer produces thousands of vending machines annually and observed the delamination and associated corrosion from a range of production dates. Because the appearance of the vending machines was a primary concern, the delamination was unacceptable.

There are several factors that are typically considered in an investigation of a delamination failure. The surface preparation processes include cleaning to remove any organic contaminants and making the surface receptive to the surface treatment, which converts the oxide to a surface that provides better adhesion and corrosion resistance. The surface must remain free of contaminants prior to application of the organic coating. Excessive coating thickness can cause internal coating stresses that exceed the adhesive bond strength. Conversely, insufficient coating thickness can allow for rapid moisture penetration and premature failure. Off-ratio mixing of multicomponent coatings or insufficient curing of baked coatings can contribute to failures in systems with multiple coatings, but are less likely in single-coat systems.

The laboratory investigation was designed to examine the likely failure mechanisms. The analyses included visual and microscopic examination, infrared spectroscopy, ion chromatography and scanning electron microscopy coupled with energy dispersive X-ray spectroscopy (SEM-EDS).

LABORATORY INVESTIGATION

Sections of the coated metal panels were sent by the vending machine manufacturer to the laboratory. Investigators removed small sections (roughly ½-square-inch) of the delaminating paint chips for examination.

The surfaces and cross-sections of coating samples that had delaminated from the panels were examined by optical microscopy

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along with the underlying substrate. The samples had one visible coating layer, which ranged from 1.6–6.0 mils in thickness. Although the investigators did not know what the manufacturer's recommended thickness was, the variability was concerning nonetheless.

The top surface of the coating was blue with a semi-gloss finish and an orange peel texture. A few craters were observed, but none went through the coating thickness. The backsides of the coating chips were slightly textured and contained embedded black particles. In cases where corrosion was present on the underlying substrate, an orange corrosion product was adherent on the backsides of the coating chips and occasionally produced a replicate of the corrosion pattern.

The surface of the underlying substrate was found to have both shiny and corroded areas, both of which appeared to have a

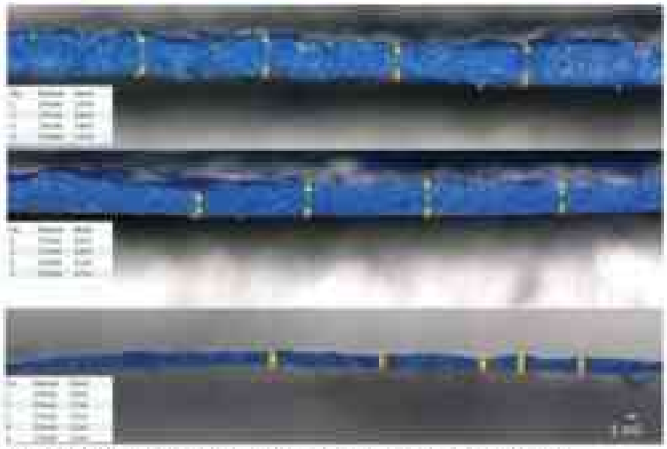

Fig. 1: Cross-sections of delaminated coating chips, showing a range of coating thicknesses. FIGURES COURTESY OF THE AUTHORS UNLESS OTHERWISE NOTED.

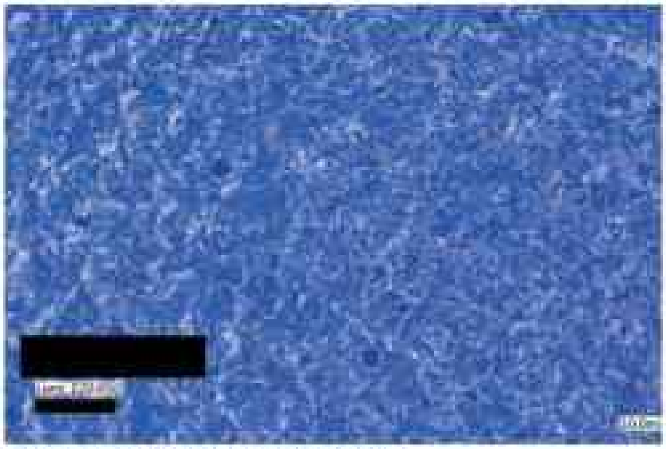

Fig. 2: Delaminated coating chip top surface

Fig. 3: Backside of delaminated coating chip, showing replica of underlying corrosion

Fig. 4: Substrate with coating removed, showing filiform corrosion

roughened appearance. Some of the corrosion spots had thin lines radiating from the center, which resembled filiform corrosion.

Ion chromatography and infrared spectroscopy were used to determine if surface contaminants that could contribute to delamination and corrosion were present. Ion chromatography was performed on a surface extraction from a panel to determine if residual surface salts were present. The extraction liquid was obtained by repeated rinsing of an uncoated panel with boiling water. The cooled extract was injected into an anion column with a conductivity detector. Three-point calibration standards for six anions commonly associated with corrosion (bromide, chloride, nitrate, nitrite, phosphate and sulfate) were used for calibration and quantification in the range of 25–100 ppm. Chloride and nitrate ions were detected but were below the reportable limits and were equivalent to less than 4.1 µg/cm^2 for the extracted area.

Surface extractions of the substrate in areas of the coating delamination were analyzed by infrared spectroscopy to determine if organic contaminants were present. Hexane was used to rinse the surface, which was then allowed to evaporate under a heat lamp. The residue was mixed with potassium bromide and pressed into a pellet for analysis. The resulting spectrum did contain a peak associated with carbon-hydrogen stretching, which is typically correlated with an organic contaminant, but it was too small for quantification or a more definitive identification. The ion chromatography and infrared spectroscopy results indicated that the presence of residual surface salts or organic contaminants were not the likely cause of the delamination.

SEM-EDS was used to image and perform elemental analysis of the substrate surface where the coating had delaminated to determine if the surface treatment was present. Briefly, the analysis revealed that the areas with corrosion (either light or heavy) did not contain fluorine, which was present in all of the scanned areas that did not display the corrosion. The levels of fluorine were low and not consistent over these surfaces.

The elements identified on the metal surfaces are presented in Table 1. The scan of the coating material confirmed

Table 1: Elements Identified on Metal Surfaces

Sample	Area	Elements
1	Not Corroded	Oxygen, Fluorine, Iron
	Corroded	Oxygen, Iron
2	Not Corroded	Oxygen, Fluorine, Iron, Occasional Chromium
	Corroded	Oxygen, Iron, Occasional Chromium, Silica, Sodium, Magnesium
3	Not Corroded	Oxygen, Fluorine, Iron
4	Corroded	Oxygen, Iron

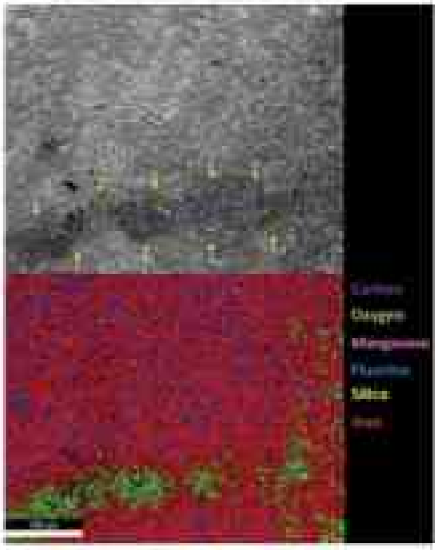

Fig. 5: Elemental map of corroded area on substrate after coating was removed

that the fluorine was not present in the coating material.

The delineation of fluoride being present on the non-corroded area and absent in the corroded areas is best demonstrated with an elemental map, which shows the location where each element was identified on the sample surface. The elemental analysis indicated that the surface treatment was not uniformly present across the panels prior to application of the polyester coating.

CONCLUSION

The laboratory investigation indicated that a flaw in the pretreatment process of the metal panels was likely the cause of the corrosion and subsequent delamination of the coating. The visual and microscopic examination indicated that none of the panels submitted would be considered in good condition due to the amount of corrosion on the metal surface. The examination also revealed the possibility of filiform corrosion, which normally indicates an environment of high humidity. Humid environments require even more specific and a higher level of surface preparation and coating requirements than standard environments.

The coating material was present as a single layer that ranged from 1.6–6.0 mils. This thickness range was not expected and may have contributed to the coating delamination. The recommended thickness was not provided for this coating; however, if the coating is too thin, the water may be more likely to penetrate the coating and lead to corrosion in humid environments. Additionally, if the coating is too thick, increased stress and lack of flexibility can lead to cracking. A consistent coating application within the manufacturer's recommendations will provide the most successful application.

Aside from the coating thickness, the other item of interest was the cleaning and pretreatment process. The cleaning process outlined appeared thorough and within the parameters of the recommendations of the data sheets provided. The two detergent cleaning steps with three rinses should have cleaned the metal if all of the baths were maintained as required. The rinsing of the metal surface with hexane did not reveal any grease or oil contamination on the surface and indicated that this step may have worked to remove that type of contamination. The analysis of the surface by ion chromatography also revealed that there was little to no salt contamination on the surface that would lead to the corrosion. Even with the lack of contamination, however, the embedded material noted on the bottom surface of the removed coating indicated that there may have been debris on the surface prior to paint application.

The application of the fluorozirconate surface treatment should have theoretically provided a surface that would decrease the occurrence of corrosion and increase the adhesion between the coating and the metal. This step in the pretreatment process appears to be in question, since the corrosion was widespread and the coating adhesion was poor. The metal surface in areas where there was not corrosion revealed the presence of fluorine. The elemental scans of the areas with corrosion revealed that there was no fluorine present. This presence or absence of fluorine was consistent between all of the corroded and non-corroded areas on each of the four samples examined.

Since there was a consistent pattern to the treated areas, the process was called into question. A more random occurrence could indicate that environmental or handling issues should be examined. There was not enough consistency in any of the other elements identified to conclude that another contaminant was a persistent contributing factor to the corrosion. It was recommended that the cleaning and surface treatment processes be inspected to ensure that the surface was properly cleaned, rinsed and treated prior to coating application. JPCL

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DETERMINING WHEN TO COAT CONCRETE

BY MANUEL NAJAR, V&A CONSULTING ENGINEERS, INC.

Several water and wastewater treatment owners have been confronted with the effects of biogenic corrosion and chemical deterioration of concrete in their structures. Assessments of these affected structures can assist in identifying the type and the extent of the deterioration. There are several methods of assessment that can be used to determine the existing condition of a coated or uncoated concrete structure. This article will identify some important indicators of biogenic corrosion and chemical deterioration of concrete, with a few examples from different areas of the water and wastewater treatment process.

REVIEW OF SERVICE ENVIRONMENTS

Most water and wastewater service environments can be broken up into four service environments: interior atmospheric, exterior atmospheric, exterior buried and immersed. The type of protection required for the concrete will depend on the liquid, solid or gas that the concrete will be exposed to during normal operation of the structure. After classifying the substrate to be coated under one or more of the service environments, the appropriate coating material, surface preparation and coating application requirements to protect the surfaces can be determined.

High Chloride Environments

Concrete can be exposed to high chloride environments, such as in waterways with high salinity and in marine environments. In addition, concrete can also be exposed to high concentrations of chlorides in the disinfection stage of the water and wastewater treatment process. Disinfection chemicals such as sodium hypochlorite, calcium hypochlorite and chlorine dioxide are commonly used to disinfect water and wastewater after it has been processed through primary and secondary treatment. In large water and wastewater treatment plants, the dosing of these chemicals is performed before it enters into a long winding channel that is typically constructed from concrete. The water must travel through the channel to allow ample time for proper mixing and disinfection. As the disinfected water travels through the channel, the chlorides begin to migrate through the uncoated concrete. The migration of chlorides through the concrete will occur and could potentially begin to corrode the reinforcing steel if there is an insufficient concrete cover, the water-to-cement ratio is high and the concrete matrix is not dense enough to prevent the migration of chlorides.

When moisture and chlorides reach the reinforcing steel, the steel begins to corrode and may lose its structural integrity. Corrosion of the reinforcing steel caused by chlorides is exacerbated by cracking, spalling or shallow depth of concrete cover over the steel. The staining on the concrete surface is caused by the corrosion cell created by the cathode and anode within the steel and water (electrolyte). The orange material forming on the surface is ferrous oxide deposits. Chlorides break down the protective oxide layer over the reinforcing steel embedded in the concrete, resulting in corrosion of the metal.

When there is damage observed in a concrete structure, owners want to know the extent of the damage and how much it will cost to repair it.

Figure 1 shows several areas of corrosion staining on the lower wall of a chlorine contact channel after 30 years of service. It is unclear if the corroding reinforcing steel shown in the photo is vertical reinforcement or an overlap length that was bent upwards from the floor slab reinforcement. In either reinforcement placement options, the reinforcing steel should be protected from further corrosion. Figure 2 is a detailed view of a corrosion nodule that formed over the reinforcing steel. The size of a corrosion nodule can vary depending on the length and depth of the reinforcing steel that is exposed or close to the surface.

Biogenic Corrosion Environments

The term "biogenic wastewater corrosion" is used here to define the corrosion process caused by the biological conversion of hydrogen sulfide gas to sulfuric acid in sewers and wastewater facilities. Biogenic wastewater corrosion is not to be confused with other biological corrosion processes, commonly called "microbiologically induced corrosion," which can often be associated with crevice corrosion in water supply and other environmental systems not associated with hydrogen sulfide gas or wastewater. Concrete is the wastewater construction material that is most susceptible to biogenic corrosion. The acid produced by the acid-ithiobacillus bacteria does more destruction in interior atmospheric environments, such as the headspace of enclosed structures or in areas where the flow of wastewater is turbulent, and contains high levels of dissolved sulfides. Some species of Acidithiobacillus found in sewers are active at a pH of 1 and can completely destroy reinforced concrete structures if high concentrations of hydrogen sulfide gas are present.

Figure 3 shows an example of biogenic corrosion in the influent channel of a primary sedimentation basin at a wastewater treatment plant. As can be seen, the concrete surfaces above the wastewater surface have deteriorated significantly due to biogenic corrosion. The deterioration of the concrete has exposed the reinforcing steel and has completely corroded it in some areas where only orange stains remain, as shown in Figure 4.

Another form of biogenic corrosion can be caused by fats, oil and grease in the form of food waste, which is being collected by private haulers and disposed of at wastewater treatment plants. The food waste is processed and sent to an anerobic digester to be mixed in with the solids and biosolids of the wastewater treatment process.

The fats, oil and fatty acids react with the alkalies in the cement paste and causes the cement paste to become soft and slippery.[1] Figure 5 (p. 16) shows the rough surfaces of a concrete pedestal after it had been water cleaned with 4,000 psi pressure. The existing coating had failed on the floor surfaces but was still well-adhered and intact on the walls.

Secondary Containment Area Damage

Bulk chemicals are widely used at various stages of the treatment processes in water and wastewater treatment plants. In water treatment plants on the west coast, chemicals

Fig. 1: Evidence of reinforcing steel corrosion on the lower wall of a concrete channel
FIGURES COURTESY OF THE AUTHOR UNLESS OTHERWISE NOTED

Fig. 2: Detail of corrosion nodule forming on the surface of a concrete wall

Fig. 3: Biogenic corrosion of concrete above the wastewater surface

Fig. 4: Deterioration of concrete has exposed and completely corroded the reinforcing steel

Fig. 5: Example of small exposed aggregate in immersed concrete exposed to FOG

Fig. 6: Severe cracking on the floor of a secondary containment structure

such as aluminum sulfate, ammonia, caustic soda, sodium hypochlorite and sulfuric acid are used in the coagulation and flocculation to remove solid particles and organic matter out of the water. They are also used to adjust the pH and alkalinity of the water.

Chemicals such as ferric chloride and sodium hypochlorite are a few examples of acids that are used in wastewater treatment plants. Ferric chloride is used to control foul odors and biogenic corrosion, and sodium hypochlorite is used to disinfect treated water.

These chemicals are stored in bulk tanks of 5,000 to 20,000 gallons depending on the demand of the treatment process. The tanks can be made of fiberglass reinforced plastic, rubber lined-steel or HDPE and have several pumps, piping, valves, pipe supports and grating over drains. Occasionally, the tanks or piping begin to fail and leak, or there is spillage of the chemicals during the filling of the tanks.

Figure 6 shows severe cracking on the floor slab of a secondary containment area, built in 1982, that stores sodium hypochlorite. When one of the valves or piping failed, it flooded all of the containment areas and the chlorides seeped into the concrete and to the depth of the reinforcing steel as much as 3 inches deep. The chloride concentrations were between 500 and 3,200 ppm—at or just above the reinforcing steel depth. As a result, several delaminations in the concrete were observed after performing sounding of the concrete with a hammer. The delaminations were created by the corrosion of the reinforcing steel that creates bursting stresses that induce radial cracking along the bars once the concrete's tensile strength has been exceeded.

INDUSTRY STANDARDS

When there is damage observed in a concrete structure, owners want to know the extent of the damage and how much it will cost to repair it. An assessment of the concrete structure can be done visually, as well as by collecting some data from the structure if safe conditions exist or a shutdown of the structure will allow for an evaluation. The following items will provide information on the cause of the deterioration so that it can help owners determine the prioritization and schedule for repairs. Due to budget and time constraints, it may not be possible for owners to request the following information during an assessment, but it is being summarized in this article for informational purposes.

Chlorides in Concrete

The chloride concentrations in concrete can vary depending on the type of aggregate used, water-to-cement ratio, admixtures (fly ash, slag cement, natural pozzolans, silica fume) and the presence of other concrete mix ingredients. The concentration will also vary with the frequency of wet-dry cycles and the concentration of the liquid, gas or vapor in contact with the concrete. Concrete core samples are collected and analyzed in a laboratory. Chloride concentrations can be measured in accordance with ASTM C1218.[2] Table 1 lists the maximum allowable chloride concentration in concrete for new construction from various sources. The thresholds should be considered in order to monitor and mitigate chloride induced corrosion. Typically, between six and seven sacks of cement are used for concrete mix design, and the chloride concentration for 7-sack concrete is shown below. The chloride concentration thresholds in percent by weight of cement were converted to percent by weight of concrete for a 7-sack mix.

Depth of Cover Over Reinforcing Steel

Concrete cover depth is an important element in corrosion protection of reinforced concrete structures. The greater the thickness of the concrete cover, the less likely that corrosive constituents have reached the embedded reinforcing steel. Per ACI 350-06, the minimum concrete cover depth for corrosion protection of reinforcing steel in formed concrete surfaces exposed to earth, water, sewage, weather or in contact with the ground should be at least 2 inches for #6 bar or larger and 1.5 inches for #5 bar or smaller. Also, per ACI 350-06, spacing between reinforcing bars for rectangular members should not exceed 12 inches to mitigate cracking.[3]

One method to determine the depth of cover over the reinforcing steel is to use surface penetrating radar. SPR is a nondestructive testing technique that uses electromagnetic waves to investigate the composition of non-conducting materials like concrete, either when searching for embedded objects such as reinforcing steel and conduits, or when searching for voids. It is best suited for concrete surfaces that are relatively smooth and would be difficult on shotcrete surfaces.

Figure 7 (p. 18) shows an example of a SPR scan on a concrete surface. The x-axis is the total distance that was scanned and the y-axis is the depth of the object that was scanned. The depth of the reinforcing steel can be measured from the top of the dark

Table 1: Summary of Chloride Concentration Thresholds for Initiation of Corrosion

SOURCE	WATER SOLUBLE CHLORIDE CONCENTRATION (% by Weight of Cement)	WATER-SOLUBLE CHLORIDE CONCENTRATION (% by Weight of 7-Sack Concrete)
ACI 318-11 (C2 Exposure)	0.15 (1,500 ppm)	0.025 (250 ppm)
FHWA-RD-76-70	0.16 (1,600 ppm)	0.027 (270 ppm)
ACI 222R-01 (Dry Conditions)	0.15 (1,500 ppm)	0.025 (250 ppm)
ACI 222R-01 (Wet Conditions)	0.08 (800 ppm)	0.013 (130 ppm)

hyperbola to the top of the slab. In Figure 7, the distance is approximately 3.1 inches. In water and wastewater structures, it is very common to see corrosion staining in areas with less than 1 inch of cover.

Overcoating

One of the toughest decisions to make for owners is whether or not to remove and replace or overcoat an existing coating system. A review of industry standards from SSPC and this author's experience with concrete coating projects over the last 20 years will help guide how the rest of the industry determines whether or not a surface is suitable to overcoating.

SSPC Technical Update No. 3 refers to steel structures; however, it was reviewed for information on the evaluation of existing coatings for overcoating.[4] It states the following.

3.2.2.9 Coating Adhesion: The adhesion of the existing coating to itself and to the substrate is a critical factor. However, it is difficult to precisely define a satisfactory adhesion value. At present, adhesion is generally evaluated by either ASTM D3359 or ASTM D4541 (on steel).[5,6] Systems exhibiting low adhesion values in these tests are more likely to delaminate when overcoated than are aged coatings with higher adhesion values. Generally, the aged coating system will fail at its weakest point. Coating type, age, thickness, and surface preparation all affect the adhesion of the aged coating system.

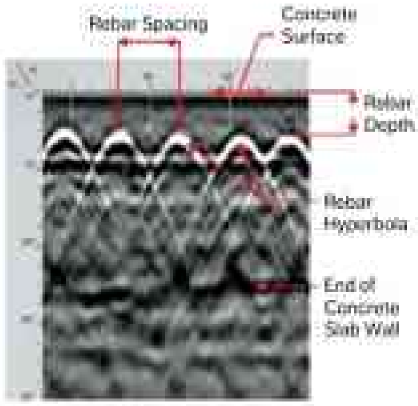

Fig. 7: Example of a surface penetrating radar scan

Table 2 is taken from SSPC TU No. 3, Appendix A, Table 1: Risk of Salvaging Existing Coating Based on Adhesion/Thickness Characteristics, which provides a guideline for overcoating. Please note that ASTM D3359, Method A is generally used for coatings on steel substrates; however, ASTM D6677 knife tests can be used for adhesion tests and applies to all surfaces.[7]

The general recommendation from Table 2 is to not overcoat if there are poor adhesion results and coating thicknesses are greater than 20 mils.

Another resource for determining overcoating requirements is SSPC-PA 14, which applies to water and wastewater

Table 2: Risk of Salvaging Existing Coating Based on Adhesion /Thickness Characteristics

ADHESION CLASSIFICATION			COATING THICKNESS		
ASTM D 3359 Method B* (using 5 mm guide)	Percentage Removed	ASTM D 3359 Method A	<10 mils (<254 µm)	10–20 mils (254–508 µm)	>20 mils (>508 µm)
5B	0%	5A	OK	OK	OK
4B	1% to 5%	4A	OK	OK	OK
3B	6% to 15%	3A	OK	OK	OK
2B	16% to 35%	2A	LR	LR	MR
1B	36% to 65%	1A	MR	HR	HR
0B	>65%	0A	NO	NO	NO

OK = essentially no risk
LR = low risk
MR = moderate risk
HR = high risk
NO = integrity too poor to salvage

*Method B is not recommended for use on films above 5 mils in thickness unless otherwise agreed upon between the contracting parties.

environments as plural-component coatings are commonly applied in these environments.[8] It states the following regarding repair of previously coated surfaces:

13. Repair of Coated Surfaces (Steel or Concrete)

13.1 Unless otherwise specified, all loose, cracked, brittle, or non-adherent coating or lining shall be removed.

Figure 8 shows an existing 30-year-old lining in a potable water sedimentation tank that showed clear evidence of failures. Further evaluation revealed that more than 30% of the surfaces were delaminated and had to be removed.

Fig. 8: Existing 30-year-old coating with delaminations had to be evaluated

pH of Concrete

Cementitious mortars are generally made from a combination of aggregate, sand and Portland cement. The Portland cement in mortar has a pH between 12.5 and 13.5 after 28 days of curing. This elevated pH level provides corrosion control for the reinforcing steel. Steel will transform from a state of active corrosion to a state of passivity, which is characterized by an oxide film that protects the steel from corrosion when the steel surface is exposed to a pH greater than 10. At a pH of less than 10, corrosion can occur if there is less than 1 inch of cover in immersed concrete or the service environment is susceptible to biogenic corrosion.

Generally, most coating manufacturers recommend that the concrete have a pH of 7 or greater before their mortar or lining products are applied. The pH scale shown in Table 3 correlates the effect of the environment on concrete corrosion, and is derived from past experience and review of literature.[9]

PROTECTING CONCRETE STRUCTURES

Concrete Mix Design

Before water and wastewater concrete structures are constructed, owners and design engineers should consider the following design criteria for water retaining structures in the environmental engineering industry.

1. Concrete mix designs should have a water-to-cement ratio in accordance with ACI 318 recommendations.[10]
2. A minimum of 1.5 inches of concrete cover is required for all reinforcing steel in accordance with ACI 350. A minimum of 3 inches of concrete cover in secondary containment areas is required when chlorides are stored.[3]
3. Determine the required design life for the structure and service environment and consider adding Pozzolans such as fly ash or silica fume to extend the life of the structure. Corrosion inhibitors can also be added to the concrete mix in order to extend the life of the concrete.

Repair Material Selection

There are several coating products on the market that are chemically resistant to the service environments in water and wastewater environments. However, there are several differences in the flexibility, moisture tolerance during application, and resistance to chemicals among the

Table 3: pH-Corrosion Correlation for Reinforcing Steel in Concrete

pH	DEGREE OF CORROSIVITY
<7	Severe
7 to 10	Moderate
10 to 12	Mild
>12	Negligible

DETERMINING WHEN TO COAT CONCRETE

different products. The coating products have to be selected for the conditions during application in addition to the normal operation of the structure.

The length of time allowed for the application and curing of a new coating system is also critical to the success of a project. In the rehabilitation of water and wastewater treatment plants or in the associated pipelines, there is limited or no shutdown time allowed to conduct surface preparation and coating application because there is flow 24 hours a day, seven days a week, all year. The coating work in wastewater treatment plants or pump stations has to be completed because there may be wet weather in the forecast, and the structures need to be put back into service as soon as possible to allow for more treatment capacity.

The surface preparation of the concrete will also have to be selected based on the age of the concrete and the condition of the surface. International Concrete Repair Institute Technical Guideline 310.2 provides standards for surface preparation in paper form and also with physical mold samples which can be used in the field as well.[11] New concrete generally does not require a deep surface profile as existing concrete that has been abrasive blasted. The goal of abrasive blasting new concrete is to remove any laitance, efflorescence and slick surfaces prior to coating. The goal of abrasive blasting existing concrete is to remove all loose deteriorated concrete. If the cement paste is deteriorated and the aggregate is protruding out of the surface, there are at least two methods to repair it.

In rehabilitation projects, the exposed aggregate can be repaired with resurfacing mortars or with special high build coatings. Resurfacing of the concrete is performed at thicknesses of ⅛-inch up to 2 inches based on the level of degradation. Certain coating products will allow for an application up to 250 mils (6.35 mm) to cover some minor exposed aggregate in some cases, but most manufacturers recommend a resurfacer.

Surface defects in concrete such as bugholes, honeycomb, exposed aggregate, fins and laitance must be filled in or removed before a new coating system is applied. Coating over these surface defects can lead to discontinuities or poor adhesion.

The coating systems will have to be selected carefully by considering the factors mentioned in this section before the coating specification is finalized and sent out for bids. It is best to discuss the project needs with a coating manufacturer representative.

Construction Documents

Before writing a coating specification, the specifier must gather as much information as possible to determine which products are best suited for the service environment and the conditions in which the coating will be applied. A good specification will contain the following:

1. Clearly defined limits of work of a concrete structure including areas around pipe penetrations, slide gate structures and connecting structures;
2. Clear definition of what is considered deteriorated concrete;
3. Depth of deteriorated concrete to be removed for immersed, interior atmospheric and other areas;
4. A description of the level of surface preparation required such as ICRI 310.2 Concrete Surface Profile 1 through 10 and SSPC SP13[11-12];
5. Minimum pH value for the concrete after surface preparation is complete; and
6. Repair methods for water infiltration, transitions from uncoated to coated surfaces, expansion joints, exposed reinforcing steel and cracks.

Onsite Inspection During Coating Operations

After coating application has commenced, the owner and specifier must ensure that the coating is applied per the specifications. Owners should invest in a third-party coating inspector that has been trained per SSPC's Protective Coatings Inspector program or the NACE Coating Inspector program. For large water and wastewater projects, the cost of having a coatings inspector is a small fraction of total project cost. For such a big investment in protective coatings, it is highly recommended that a coatings inspector be retained to ensure that the coatings are applied per the specification requirements. If a coatings inspector cannot be retained to monitor the field coating operations, the owner should require that the coating manufacturer be present during the start of surface preparation, the start of coating application and on the day of final testing.

CONCLUSIONS

When water and wastewater treatment owners see damage to their assets, it is important to gather as much information as possible before making a decision about how to rehabilitate the structure. The service environment examples presented in this article will hopefully provide some insight of some common indicators of concrete deterioration. By using some of the industry standards for chloride migration, depth of reinforcing steel and overcoating standards, these assessments can provide valuable information to owners to justify costly repairs.

This article provided examples of protecting concrete before and after a treatment structure is constructed. It is important to consider the concrete mix design and the selection of the repair materials before the coating specification is written and sent out for bids.

In addition to having a good specification, it is also important to have onsite inspection. In order to have successful coating projects, owners should consider investing in a third-party inspector that can provide quality control during the coating operations. **JPCL**

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COMPREHENDING PULL-OFF ADHESION TESTING

BY ROB FRANCIS, R A FRANCIS CONSULTING SERVICES PTY LTD

Pull-off adhesion testing of coatings is increasingly being specified and used by coating inspectors. Manufacturers have produced new models of testing equipment, more papers are being published on the subject and pull-off requirements are often required in coating specifications. Is this increased interest based on the testing's ability to provide useful information on the performance of coating systems, or is this a case of a test method being more attractive because it can produce a number—even if that number has little meaning? This article will look closely at pull-off testing—specifically, what is measured and what the results mean.

WHAT IS PULL-OFF TESTING?

Pull-off testing is a means for quantitatively determining the adhesion strength of a coating to a substrate. A loading fixture (commonly called a dolly) is secured to the coating surface with an adhesive, as shown in Figure 1. The testing apparatus is then affixed to the dolly and aligned to pull the loading fixture perpendicular to the coating surface. The force is gradually increased until the loading fixture detaches, which will be at the weakest interface within the coating system. Knowing the diameter of the test dolly, the failure force is converted to a failure stress (strength) reported in megapascals (MPa) or pounds per square inch (psi). One MPa is equal to 14 psi. A portable adhesion tester, commonly called a pull-off tester, is typically used for such tests, usually to standards such as ASTM D4541.[1] The user reports the pull-off strength as well as the location of the break in the coating system (for example, an adhesion failure between the primer and substrate or between coats, cohesive within a certain coating layer, glue failure and so on). The 2017 version of ASTM D4541 included an alternative pass/fail protocol where the force is increased only to some predetermined limit and the test terminated, minimizing, if not preventing, damage to the coating.

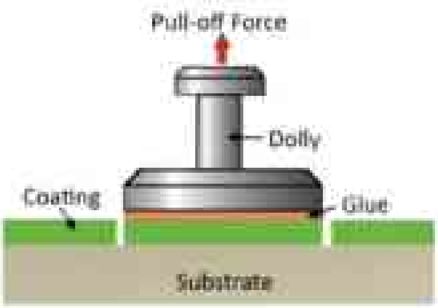

Fig. 1: Diagram of typical pull-off adhesion test.
FIGURES COURTESY OF THE AUTHOR UNLESS OTHERWISE NOTED.

Table 1: Pull-off Adhesion Testing Devices According to ASTM D4541

ASTM D4541 Type	Test Method	Load Mechanism	Dolly Alignment	Repeatability Limit (%)	Reproducibility Limit (%)
Type I	A	Mechanical	Fixed		
Type II	B	Mechanical	Fixed	64.7	76.0
Type III	C	Hydraulic	Self-aligning	33.8	65.9
Type IV	D	Pneumatic	Self-aligning	14.8	28.4
Type V	E	Hydraulic	Self-aligning	27.8	34.1
Type VI	F	Hydraulic	Self-aligning	17.5	23.0

CAN YOU TRUST THE FIGURES?

There are a number of devices on the market that use this principle for carrying out such tests, but there are differences between them that can significantly affect results obtained. In some models, the load is applied by compressing a spring (mechanical), while in others the load is applied pneumatically or hydraulically. In older models, the grip for holding the dolly is fixed, while in later models it can move, ensuring alignment is more perpendicular to the load. Because of these differences, the various pull-off gauges may not give comparable results. ASTM D4541 recognizes this and divides devices into different types, each with its own test method, as shown in Table 1. Type I gauges are generally used for concrete and were dropped from the standard in 2004, although the device is still available.

In the 2009 version of ASTM D4541, the pull-off strength of four painted panels was determined using five devices in a round-robin survey. Average readings for the pull-off strength as determined with each type are shown in Figure 2. The repeatability and reproducibility limits in Table 1 give the maximum acceptable percentage difference between results before they should be considered significant; repeatability for a single operator with a single device and reproducibility between different operators. These are also plotted as error bars on Figure 2, with the repeatability limits the lesser values. These limits are significant and indicate that test results obtained by these devices are subject to considerable uncertainty, an issue also discussed by Schilling.[2] For example, if one operator gets a result of 7 MPa (1,000 psi) with a Type II gauge under given conditions, then a second result under different conditions needs to be less than (7- [7 x .65]) = 2.5 MPa (360 psi) or more than (7+ [7 x .65]) = 11.6 MPa (1,680 psi) for the change to be considered significant. Even with the most repeatable gauge, the Type IV, a result would need to be outside the range of 6–8 MPa (870–1,160 psi) to be considered significant. When comparing results to those obtained by other operators, the expected spread of results will be even greater. Clearly, small differences in pull-off values within or between investigations, especially higher values, should not be considered as significant.

The Type II, fixed alignment gauge gives greater percentage variability than the self-aligning gauges, so the scatter is most likely due to higher probability of shear forces operating on the test fixture with such a gauge. Although self-aligning, the variability obtained with the Type III gauge is also quite high and is probably due to the different loading mechanism through the center of the testing dolly, which would introduce shear stresses. Figure 3 shows the dollies used for three of the methods, which may explain some of the scatter. The flat head on the Type II fixture means the dolly is likely to be pulled at an angle to the perpendicular, whereas the rounded head on the Type V device allows a more uniform force to be applied. As noted, an uneven load is more likely with the Type III fixture as the load is applied through a central hole, although the greater length of the fixture would also add to the likelihood of an off-center pulling force. Cunningham and Steele[3] also found variable results with more scatter around the mean with fixed alignment gauges compared to self-aligning gauges. Other reasons for the scatter include misalignment of the apparatus or loading fixture so that it is not perpendicular to the surface, voids or inclusions in the glue, improperly prepared or curved surfaces and sliding or twisting of the test fixture during the initial glue curing. Even with care, it is very difficult to apply a perfectly axially-centric load, and mistakes will give lower, not higher results. Experienced field users find that 5–10% of pulls end up being invalid. Therefore, applying at least three test fixtures per location in the field is essential when performing this test. The uncertainty and scatter in results can make discerning any trend difficult when investigating the effect of some variable on coating adhesion—often called, "distinguishing the signal from the noise," to use an analogy from electronics.

As well as differences in repeatability and reproducibility, Figure 2 shows that different gauges give different values of pull-off strength for the same test coating and panel. The Type II instruments give pull-off strengths of about half that of the other instruments, which all give similar results within the errors discussed above. It is clearly critical to identify the instrument that is used in any investigation. A separate investigation of a number of pull-off test methods[4] confirmed that the Type II instrument gave considerably lower figures than pneumatic or hydraulic methods. Cunningham and Steele[3] also noted that instruments based on hydraulics appear to achieve higher results than mechanical (spring) devices, which they believed was because the application of force was smoother in the case of hydraulic instruments. They described an experiment where a mechanical tester was modified by removing the spring and replacing it with hydraulics operated by an electric pump. The average results were twice those previously obtained. The significant factor for the lower figures with the Type II device appears to be the smoothness of force application rather than the absence of self-alignment. These findings suggest that values obtained from a Type II unit need to be doubled when compared to results from one of the other types of gauges.

Fig. 3: Dollies for Type II (fixed alignment), Type III and Type V (self aligning) pull-off testers

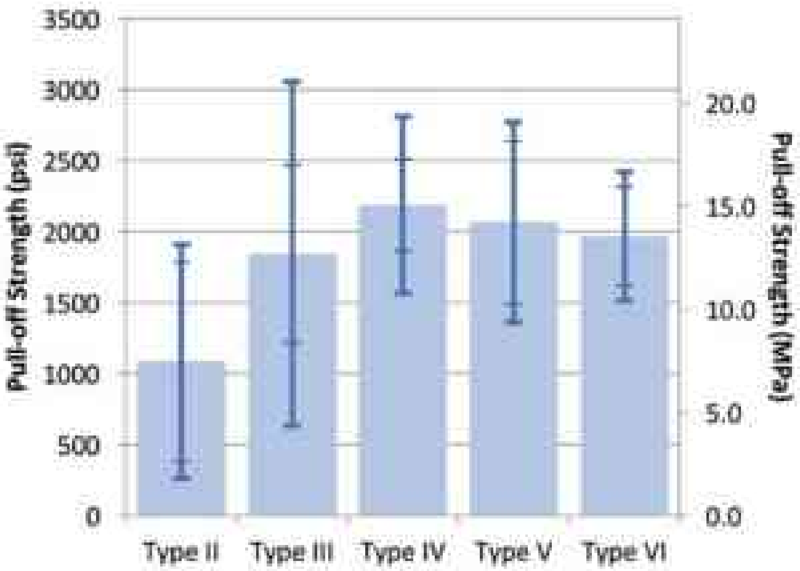

Fig. 2: Pull-off results for test panels and repeatability and reproducibility limits for five pull-off testing methods from Tables 1 to 5 in ASTM D4541-2009

WHAT DO THE RESULTS MEAN?

The pull-off test measures the fracture strength of the weakest bond in the substrate-coating-glue-dolly system. If the fracture is between layers, the strength determined will be a measure of adhesion, but if fracture is within a coating (a cohesion failure), then the result will be a measure of the coating's tensile strength. The pull-off value for a cohesion failure will not give any clue to the adhesion properties of the coating (other than indicating pull-off adhesive strength must be greater than the cohesive strength). Even the results of work that look at comparisons—say, before and after weathering—indicate nothing about adhesion strength if the failure is not an adhesion failure.

Even if the failure is adhesive between two surfaces, the adhesion figure obtained is unlikely to relate to coating performance for a number of reasons. For a start, the load is applied over a much smaller area and the loading rate during testing is likely to be much greater than that applied in service. More importantly, the test applies a tensile load to the coating while in practice, shear stresses applied to the coating are likely to be of most significance (there is no evidence that tensile adhesion of a coating has any relationship to shear adhesion). A further issue in analyzing results from pull-off testing is that it is unlikely to correlate to the long-term corrosion protection offered by a coating. There is no doubt that coatings must adhere well in order to resist the advance of water and other aggressive species across the coating surface, but it does not follow that high pull-off values will have any effect on these.[5] A slow-curing coating may show poor initial adhesion or cohesion, but these properties may rapidly improve. Alternatively, a coating may show good initial adhesion, but moisture penetration may cause corrosion at the interface leading to a rapid reduction in adhesion. Pull-off strength measured soon after coating application will rarely provide an indication of longer term performance.

Despite these concerns, there are a large number of reports and papers presenting the results of pull-off testing, but useful conclusions can really only be obtained from work that clearly identifies the testing unit used and the location of the fracture. Furthermore, triplicate or better testing should have been carried out for useful results. Results without such information are of little value.

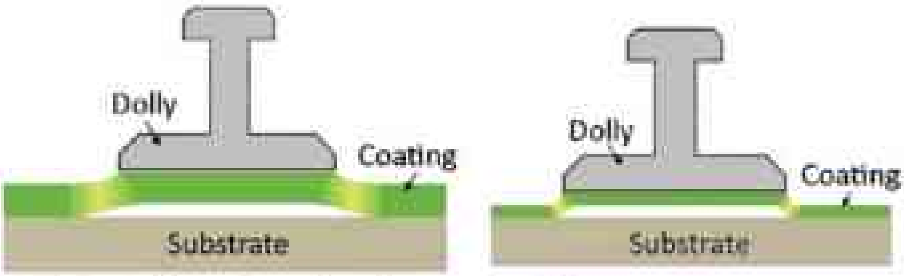

Fig. 4: The pull-off force will spread over a larger area for a thicker coating than a thin coating

Cutting around the dolly can influence pull-off testing results. Earlier versions of ASTM D4541 contained the oft-quoted sentence (Clause 6.7) that "Scoring around the fixture violates the fundamental in-situ test criterion that an unaltered coating be tested," but this was dropped in the 2017 update. The standard now notes that scoring must be agreed between purchaser and seller and clearly reported with the results, and extreme care must be taken to prevent micro-cracking. It is only recommended for thicker films (a note defines this as greater than 20 mils or 500 microns), reinforced coatings and elastomeric coatings. The effect of scoring is most likely absorbed by the uncertainty noted above in most situations, but probably becomes important for thicker coatings (Fig. 4).

WHAT ARE TYPICAL VALUES FOR ADHESION STRENGTH?

Very few pull-off investigations actually report the true adhesion strength between a coating and its substrate, or between coating layers. Most failures reported in the literature are, in fact, cohesive. One useful investigation that did show adhesion failure was that of Islam, et al.[6] who looked at the effect of different methods of surface preparation on the pull-off strength of chopped strand mat impregnated epoxy resin applied to steel. Pull-off tests were carried out to ASTM D4541 and, although the type of tester is not mentioned, from photographs it appears to be a Type V model. The authors found a direct relationship between the percentage adhesion failure and the pull-off strength (Fig. 5). For a purely adhesive failure between the resin and a smooth substrate, the pull-off strength was just over 1 MPa. The pull-off strength increased and failure became more cohesive as the substrate roughness increased. For a purely cohesive (resin) failure with a rough substrate, the pull-off strength was around 14 MPa. From this work, it would appear that poor adhesion results in very low pull-off values of the order of 1 MPa but, if the failure is more than a few

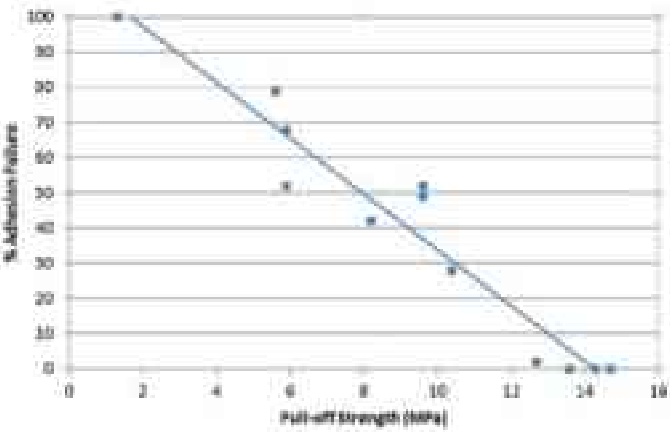

Fig. 5: Relationship between pull-off strength and percent adhesion failure for one investigation

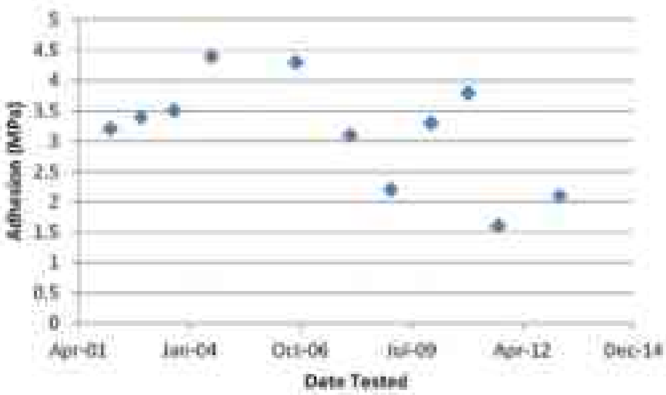

Fig. 6: Pull-off strength values at one site on Auckland Harbour Bridge

per cent cohesive, the pull-off strength for sound coatings will noticeably increase.

Pull-off testing is often mandatory for coatings where mechanical adhesion is critical, such as thermal metal-spray coatings. A minimum spot average of 3.45 MPa is required for zinc coatings in one thermal spray standard[7], with higher values for aluminium and Zn/Al coatings. This standard does not allow the use of the Type II tester, apparently recognizing that it gives different figures from the other testers.

A coating over a rusted surface that failed within the rust layer would normally be considered an adhesion failure, although strictly speaking it is a cohesion failure within the rust. White[8] used a Type V tester to investigate the adhesion of surface-tolerant epoxies compared to conventional epoxies to rusted steel surfaces prepared to various standards of cleanliness. The surface-tolerant epoxies gave high pull-off values (15–18 MPa) for both hand- and power-tool-cleaned surfaces and abrasive blast-cleaned surfaces, with either glue or cohesion failures within the epoxy. The conventional epoxies gave similar results over blast-cleaned surfaces. However, over hand- or power-tool-cleaned surfaces, these coatings—which are not, of course, designed for application to poorly prepared surfaces—failed within the rust layer, although the pull-off value was still relatively high at 10–12 MPa. It would appear that even adhesion failures can give relatively high pull-off values.

HOW DOES WEATHERING AFFECT COATING STRENGTH?

Pull-off testing has limited value in determining adhesion properties of freshly applied coatings, but is more successful when monitoring coating breakdown. As a coating ages, it normally becomes brittle, so its strength reduces. Furthermore, rust will grow under the coating as it breaks down, further reducing pull-off strength. Pull-off testing may be used to keep track of overall coating condition as a coating weathers.

El Sarraf, et al.[9] described how pull-off adhesion values are used to determine maintenance schedules for New Zealand's Auckland Harbour Bridge. Inspection of the coating condition is carried out at regular intervals and includes pull-off testing at various locations. Initial testing was carried out with a Type III unit, later changed to a Type V—which, as discussed above, should give comparable results. A minimum figure of 2.5 MPa had been determined through experience as an acceptable pull-off level to allow overcoating without risking delamination of the existing coating. Although the average pull-off value at most sites was found to be an acceptable 5 MPa, Figure 6 shows results from one site from which low figures were obtained. Although the scatter is large, the downward trend would suggest

that the coating is losing strength and the region needs further investigation before overcoating. In fact, the region withstood 4,000-psi water washing and was successfully overcoated. The authors of the study indicated to this author that recent pull-off testing at this site has given figures well above the 2.5 MPa limit.

Generally, pull-off strength of coatings would be expected to decrease with time as they age, but this is not the case with inorganic zinc coatings. Biddle[10] found that the Type II pull-off strength of uncured or partially cured inorganic zinc primer under an epoxy gave cohesion failure values of 1.5–2 MPa with failure in the primer, but this increased to 3.2 MPa or higher for cured inorganic zinc primer, with the break then occurring in the epoxy film. Curran[11] investigated pull-off strength when looking at polysiloxane alternatives to polyurethane systems used at NASA Kennedy Space Center. Testing was carried out to ASTM D4541, but the test unit type was not given, although it appears to be hydraulic. As part of the investigation, adhesion of the inorganic zinc primer was investigated, with pull-off values of 2.8–6.2 MPa for a range of commercial solvent-borne inorganic zinc primers, failing cohesively. Interestingly, adhesion was tested after heating to 400 C (752 F) for 24 hours, for coatings used in regions of rocket exhaust. Post-heat adhesion increased significantly to 11.6 to 17.9 MPa as a result of continued curing of this type of coating. Adhesion testing of the candidate topcoats showed a range of pull-off strengths and failure modes, but where failure occurred cohesively in the zinc primer, values of 12.4–14.5 MPa were observed, indicating the primer was thoroughly cured before topcoating.

These and other results show a marked reduction in cohesive strength on weathering for most coatings. However, uncured inorganic zinc will show low cohesive strength (usually less than 5 MPa) but will increase upon curing and weathering.

CONCLUSIONS

Pull-off testing is commonly specified or used to quantify the adhesion of coatings to substrates, or adhesion between coats. However, close investigation of the methods used, and published results, show that it does have a number of weaknesses, which limit its value, including the following.

- There are a number of commercial devices available, but results can differ significantly between them. For example, the mechanical, spring-operated device will give pull-off values about half that of pneumatic or hydraulic types.
- The relatively poor repeatability and reproducibility of the test methods makes obtaining and interpreting meaningful results difficult.
- There is no convincing evidence that such results provide any indication of long-term coating performance.
- Most failures will be cohesion within the coating, which is a measure of coating tensile strength, but does not relate to coating adhesion.
- Cohesive strength will normally decrease as a coating undergoes weathering and pull-off strength may be used to monitor such breakdown. However, inorganic zinc coatings may show increasing cohesive strength as they harden and weather. JPCL

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Rob Francis has over 40 years of academic, industrial and consulting experience in corrosion and protective coatings. He holds a BSc in metallurgy and a PhD in corrosion science. He has authored or co-authored more than 40 technical papers or presentations on corrosion and coatings. He edited the publication "Inorganic Zinc Coatings," for the Australasian Corrosion Association (ACA) in 2013. He has been awarded the JPCL Editor's Award twice and was named a JPCL Top Thinker in 2012. He was also awarded the Victor Nightingall award for outstanding contributions to the protective coating industry by the ACA in 2014 and made an ACA Life Member in 2016.

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MAKKARANOV / GETTY IMAGES

VIRTUAL ACCESS

How PaintSquare Connect Brought Coatings Businesses Together During a Worldwide Pandemic

Last month, PaintSquare Connect, the inaugural virtual event from JPCL publisher, Technology Publishing Company, welcomed professionals throughout the industrial and commercial coatings communities. The three-day conference took place Nov. 10–12 and was co-sponsored by **The Sherwin-Williams Company, Carboline Company, Finishing First (Powered by LMCI)** and **McBrayer & Associates**.

While the COVID-19 pandemic prevented large in-person gatherings throughout 2020, the new online site and event plan developed by TPC allowed members of the industry to interact in live educational sessions, virtual booths and private meetings from the safety of their homes or offices. Archived recordings have been made available to registrants through May 31, 2021.

"We had close to a thousand industry professionals register leading up to the event," said TPC CEO Brion Palmer. "I anticipate registration and engagement during the archive access period will be equal in numbers."

"We learned a lot while developing and producing this event, and I think the industry will continue to take advantage of the PaintSquare Connect platform to offer education and create engagement and meaningful connections with peers," he added.

> "I think the industry will continue to take advantage of the PaintSquare Connect platform to offer education and create engagement and meaningful connections with peers."
>
> *— Brion Palmer, CEO, TPC*

The following pages present a recap of PaintSquare Connect, as well as a guide to the archived offerings available at paintsquare.com/psc. Those who did not register for the live event are invited to complete a free registration on the event website and explore the session recordings in the Program section and the exhibits in the Product Pavilions. Registration, sponsored by **Harsco (Black Beauty)** and **HoldTight Solutions,** will remain open through May 31, 2021. New registrants* will receive a special event backpack, courtesy of **Tnemec Company, Inc.**, while the supply lasts.

*ELIGIBLE U.S. REGISTRANTS ONLY
IMAGES ARE STILLS FROM THE EVENT RECORDINGS, COURTESY OF THE PRESENTERS, UNLESS OTHERWISE CREDITED.

2020 EVENT RECAP

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Curriculum

Aiming to serve a broader audience than TPC's in-person Contractor Connect events, the producers of PaintSquare Connect offered three days of live educational sessions and other presentations in the following tracks: **Protective & Marine Coatings, Commercial Coatings & Solutions** and **Surface Preparation**. Co-sponsored by **10X Engineered Materials** and **PPG**, the curriculum was recorded and uploaded to the event website and will remain accessible until May 31, 2021. The following sessions (in the order they were presented) are available to registrants under the Program tab at **paintsquare.com/psc**. According to Palmer, new sessions will be announced periodically, and the recordings will be added to the event archive.

TRACK 1 PROTECTIVE & MARINE COATINGS

100%-Solids Linings for the Water/Wastewater Market, by Brian Cheshire, Market Manager – Water/Wastewater, Carboline Company

Feed Your Business Growth: Meeting the Demands of the Food & Beverage Industry with New Technologies, by Casey Ball, Global Market Director for High Performance Flooring, and Mike Marietta, Global Market Director for Food and Beverage, Sherwin-Williams

Introducing Mortarchem: The Next Generation of Cementitious Epoxy Mortar, by Andy Odorzynski, National Sales Manager, Induron Coatings, Inc.

Preparing for Changes in Tank Linings, by Mark Thomas, Vice President of Marketing, and Cory Brown, Executive Vice President, Tnemec Company, Inc.

How to Understand Polysiloxane Technology, by Tom Higginbotham, Training Manager, Americas, and Herman Rodriguez, Director of Engineering and Specifications USCA, PPG Protective and Marine Coatings; and Tom Bekemeier, Research Scientist, Dow

New Fluoropolymer Topcoat Standard for Protective and Restoration Coatings, by Kurt Wood, Senior Principal Scientist, Arkema, Inc.

Advanced IUPAT Training and Certifications that Make a Difference on a Project, by Rick Matthews, Industry Liaison Industrial Coatings Finishing First, International Union of Painters and Allied Trades

Experts discuss fire protection in one of the many videos in Sherwin-Williams' booths.

Maximize Your Investment with Paint BidTracker: Exploring Best Practices for Finding Success, by Julie Birch, General Manager, Paint BidTracker, and Jim McBrayer, CEO, McBrayer & Associates

TRACK 2 COMMERCIAL COATINGS & SOLUTIONS

Support for Sustainable Projects, by Mark Thomas, Vice President of Marketing, and Cory Brown, Executive Vice President, Tnemec Company Inc.

Coatings That Work: Providing Long-Term Solutions That Set You Apart from Your Competition and Help Your Customers Get the Most Out of Their Projects, by Hank Meinking, Area Account Executive – Architectural Services, Sherwin-Williams

Great Communication to Close More Deals, by Michael Gogan, Business Development – Education, CompanyCam

Get to Know The Industry's Newest Trade Association: The Commercial Painting Industry Association, by Aaron Moore, President, PPD Painting; and Steve Hester, President, Hester Decorating

How to Secure Meetings with Decision Makers and Keep Them Captivated, by Jim McBrayer, CEO, McBrayer & Associates

Engineering Sustainable Coating Systems, by Simon Reynolds, Vice President of Commercial Sales, Tex•Cote

Application Tools for Properly Applying Coatings, by Larry Schwartz, Assistant Vice President Business Development; and Jack Franks, National Manager Contractor Development, The Wooster Brush Company

How One CPIA Founding Member Realized Over $250k in Tax Savings and Lived to Tell About It, by Ryan Foley, Partner, Cunningham & Associates

TRACK 3 SURFACE PREPARATION

A Little Less Salt, Please! by Robert Richter and Norman Petticrew, CRW USA, LLC

Choosing Abrasive Media for Blasting Applications, by Clay Miller, Director of Business Development, SurfacePrep

Achieving a More Productive Blast Cleaning Operation, by Joe McGreal, Vice President of Sales and Marketing, Ervin Industries

A New Category of Blast Abrasives, by Stephen Ricci, PhD, Chief Technology Officer; and Jacob Vaillancourt, Partner, 10X Engineered Materials

Corr-Ze: Improving Coating Adhesion While Preventing Flash Rust, by Robert Richter and Norman Petticrew, CRW USA, LLC

Soluble Salts: Today's Solution to an Old Problem, by Ken Rossy, Vice President of Sales and Marketing, HoldTight Solutions

Harsco Environmental: A Refined Vision, by Dominic DeAngelo, Director of Sales and Marketing, Harsco Environmental

Identifying and Managing Inhalation Hazards Associated with Abrasive Blasting, by Thomas E. Enger, MS CSP Chmm, Director of Engineering Support Services, Clemco Industries Corp.

Surface Preparation Standards – Updates for Concrete, by Jim Kunkle, PCS – Manager, Development & Membership Engagement, SSPC: The Society for Protective Coatings

A video in the Clemco virtual booth demonstrates the company's all-in-one wetblast system.

Keynotes

Like the curriculum sessions, the following keynote addresses were presented in all subject-matter tracks and will be available to registrants until May 31, 2021, unless otherwise noted.

EVENT KEYNOTE | SPONSORED BY SHERWIN-WILLIAMS

The Growth Mindset for Construction Leaders, by Mark Breslin, CEO, United Contractors; President, Breslin Strategies Inc.

Opening up the virtual conference, Breslin, spoke about how to perform more effectively in a professional role as a construction leader by elevating thoughts, education and actions. He touched on topics such as creating a culture that cultivates a growth mindset for the organization, understanding the relationship between mindset and success, and discovering ways to expand emotional intelligence and improve abilities. *(No longer available online.)*

PROTECTIVE & MARINE | SPONSORED BY SHERWIN-WILLIAMS

Procurement: The Secret Ingredient to a Successful Paint Job, by Warren Brand, Principal, Chicago Corrosion Group

Brand reviewed a case study in which his team served as lead consultant in the matter of a 96-foot-diameter by 31-foot-tall anaerobic digester tank. The interior coating had been in place, unobserved, for a little over 20 years. Audience members learned what it took to access the tank for inspection and why the group advised the client to leave the coating in place. He also discussed a second the substantial coating failure of a concrete tank.

COMMERCIAL | SPONSORED BY SHERWIN-WILLIAMS AND CPIA

Laws of Success: World-Class Service to the National Facilities and Utilities Industry, by Gary Rabine, Chairman and Founder, Rabine Group

Rabine offered guidance and inspiration for making a current business situation more enjoyable, profitable and "wildly successful."

SURFACE PREP | SPONSORED BY CRW

Innovation or Insight? by Ric Beard, CEO, Otinga Group

There is no single fix-all solution for the efficiency gains that industry professionals—and clients—are searching for, said Beard. Solutions will vary in scale and must sometimes be combined to achieve the expected improvement.

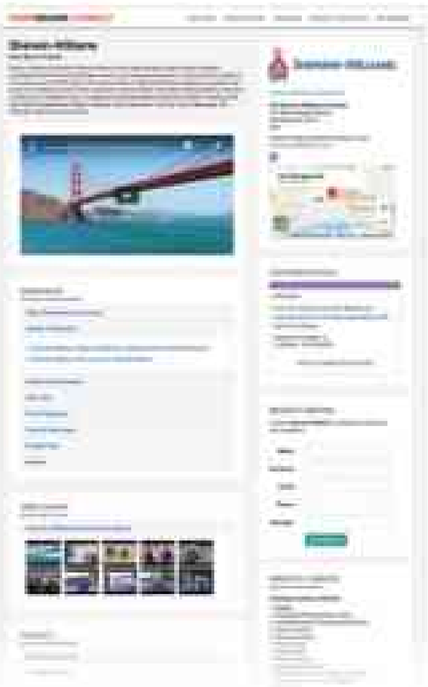
Product Pavilions

In between curriculum sessions and keynotes, PaintSquare Connect attendees were invited to visit the virtual Product Pavilions, where they could browse the latest offerings and innovations from leading companies and interact with representatives via online chat.

From now through May 31, 2021, registrants continue to have access to all Product Pavilions—**Protective & Marine Coatings, Commercial Coatings & Solutions, Surface Preparation (sponsored by Clemco Industries Corp.)** and **Equipment**—where they can continue to view the product and service offerings from event exhibitors. Some of the online booths feature tools to request a callback or schedule a meeting.

In a recent letter posted on the PaintSquare Connect website, Palmer thanked the sponsors and exhibitors, as well as the staff and presenters, for making the virtual event successful.

"PaintSquare Connect wouldn't have been possible without the support of the supplier community," he said. "It is a credit to the industry as a whole to embrace a platform like PaintSquare Connect when our ability to get together in person is greatly reduced."



Videos, galleries, downloads and more are displayed in the virtual booths.

Product Category Sponsors

ACCESS
Brand Safway

ABRASIVES
US Minerals (Black Diamond)

CONCRETE COATINGS, COMMERCIAL
Coatings Pro

EDUCATION & ONLINE TOOLS
Paint BidTracker

ENVIRONMENTAL PROTECTION EQUIPMENT; VACUUM BLAST EQUIPMENT
Industrial Vacuum

OFFICIAL PAINTBRUSH OF PAINTSQUARE CONNECT
The Wooster Brush Company

Awards & Rewards

The winners of the **2020 Contractor Community Champion (C3) Awards**, selected by **HoldTight Solutions, Inc.** (Houston) in partnership with **PaintSquare**, were announced in a virtual ceremony during the event.

According to HoldTight, the objective of the campaign was to highlight companies that have continuously sought out opportunities to do better for their communities, and have demonstrated kindness and selflessness—all without requesting recognition. For its inaugural year, the awards focused on what companies did to combat the negative effects of the COVID-19 pandemic.

This year's award winners were granted a donation in their name to the charity or organization of their choice as well as recognition on the C3 Awards website and through PaintSquare Connect. While this year's awards centered on efforts to counter the destructive effects of the pandemic, each following year's awards will vary in focus. Additionally, the campaign encouraged these types of companies to create and share their own original content inspired by the stories of how they supported local businesses, employees and essential workers during the health crisis.

"We are thrilled to present these awards to all of these great companies," said Alex Petkas, Director of Technical Sales for HoldTight Solutions. "Giving back and leaning into communities during this difficult economic time is a huge part of how we operate here at HoldTight."

Following are the C3 Award winners:

Alpine Painting & Sandblasting partnered with a local community outreach center to identify community needs, collect items, raise funds and feed families struggling during this time. The company committed to feeding more than 150 families this Thanksgiving.

To support those affected by the impact of COVID-19, the team at Alpine Painting & Sandblasting vowed to feed more than 150 families for Thanksgiving. C3 AWARDS PHOTOS COURTESY OF HOLDTIGHT

Headquartered in Paterson, New Jersey, Alpine is family owned and operated. The company reports that it provides in-house painting and sandblasting services for its customers' portable equipment, while its corporate offices employ a full complement of support staff, including administration, operations, estimating, project management, engineering, sales and customer service.

Strand's Industrial Coatings took over all communication efforts for Jonathan's House—which helps orphaned children in the Central African Republic—to spread awareness about the needs of the people there and the severe impact the pandemic has had on them. The Strand team also helped raise and donate funds.

In operation since 1955, the company has been independently owned by the Strand family for more than 60 years. Strand's provides industrial coatings and corrosion prevention recommendations (without corporate restriction) to clients around the U.S.

Strand's is getting out the word about helping these and other orphaned children in the CAR.

Hester Painting & Decorating partnered with Gino's East Pizza, Sherwin-Williams and Benjamin Moore to create a fundraising effort, bringing in more than $14,500 and providing 1,225 meals to local front line workers.

In operation since 1968, Hester provides homes and select commercial establishments with high-end decorating and coatings services. The company employs more than 60 skilled painters and craftsmen and conducts projects year-round.

Thanks to the Hester staff and partners, front line workers felt some love during a tough time.

An honorable mention was given to **The Warehouse Rentals & Supplies**.

Hearing about the shortage of PPE in their community, the company donated its entire supply of N95 masks to local police stations, fire departments, hospitals and first responders.

The Warehouse team also produced and distributed cloth masks.

"All four winners stood out as generous, passionate companies who saw the impact of the pandemic and, rather than sitting still, took action and did what they could to help," said Ken Rossy, Vice President of Sales and Marketing for HoldTight Solutions. "Not only does this award recognize the amazing work being done, it also provides an opportunity for us to donate to a charity or organization that we may not have known about without these award submissions."

— *JPCL Staff*

PAINTSQUARE ANNUAL AWARD WINNERS ANNOUNCED

The **PaintSquare Prestige Awards,** which honor the top products, projects and people in industrial coatings, and the **Elevation Awards,** PaintSquare's commercial coatings honors program, were presented in a live virtual ceremony (available to watch in the PaintSquare Connect archive). Winners will be highlighted in the winter issue of *PaintSquare Press*, which will be posted to paintsquare.com later this month.

Connect Rewards Program

Attendees automatically earn points—not unlike frequent flyer miles—each time they explore a pavilion, visit a virtual booth, request a meeting or watch a recorded session. Registrants can see their accumulated points on the "My Agenda" page. Each month, TPC will award a prize to the eligible attendee who has earned the most points.

For full details, go to paintsquare.com/psc and select the "Connect Rewards Program" link. Choose "Eligibility & Legal Info" for rules and contest dates.

SSPC's Concrete Coating Application Specialist Program

BY KATE WHITE, TRAINING FULFILLMENT COORDINATOR, SSPC

BANKSPHOTOS / GETTY IMAGES

Concrete is the most popular building material worldwide, with over 20 billion tons used yearly. Utilized in building foundations to parking structures to the bridges that ultimately connect us—concrete is all around us. As such, it is imperative for craft workers in the construction industry to protect and preserve it from deterioration. SSPC's Concrete Coating Application Specialist course is designed to enrich coating applicators' proverbial toolbox with the most up-to-date skills needed to master concrete coating projects through a comprehensive overview and instruction, as well as hands-on training. CCAS prepares applicators to maintain this vital infrastructure that is critical for sustaining our daily lives.

CCAS consists of a training level (Level 1) and a certification level (Level 2). Level 1 is a full four-day, 32-hour course that provides a detailed overview as well as practical hands-on training that focuses on repair of deteriorated concrete, surface preparation and coating application of concrete. There are no prerequisites required for Level 1, and 3.0 CEUs are earned upon successful completion of the course. The hands-on exercises in Level 1 are crucial in honing skills needed for successful completions of concrete coating projects. Robert Murphy, an SSPC Instructor and industry expert, says his favorite part of the CCAS course are the interactions that occur between him and students during the hands-on training portions of the course.

CCAS Level 1 training consists of seven carefully chosen modules:

1. The general health and safety for coating concrete;
2. The role of quality personnel in concrete coating applications/quality control;
3. Concrete composition and durability;
4. Concrete assessment prior to coating application;
5. Repairing concrete prior to coating application;
6. Surface preparation of concrete prior to coating application; and
7. Application of coatings on concrete.

These core modules, workshops, hands-on exercises and quizzes, in collaboration with industry-expert-led instruction, create a well-rounded course for any concrete craft worker. Level 1 culminates with a 50-question, multiple-choice exam in which a 70% of higher is required as a passing score.

Another CCAS instructor, Jamie Laird, further explains the importance of CCAS for today's applicators: "Concrete is one of the main substrates that industrial painters prepare and coat every day. It presents unique issues that applicators don't experience with steel. This class focuses on the three major markets where concrete is mainly encountered: tanks, infrastructure and floors. I think that this class benefits the hard-working people who need to ensure that they are preparing and applying concrete coatings. It gives them the tools to succeed and have a much deeper understanding of how to avoid failures and problems."

After successful completion of Level 1, craft workers will be able to demonstrate proper preparation and coating application methods; describe common hazards involved in coating concrete; explain the role quality control, quality assurance and coating inspection personnel play; identify the different components of concrete; describe moisture vapor transmission and its effect on coating application; identify common concrete defects and recognize why they occur; repair minor surface irregularities, deteriorated concrete, cracks and joints; discuss the importance of concrete surface profile; prepare a concrete surface for coating application; identify materials commonly used to coat concrete; and demonstrate commonly used methods for applying concrete coatings.

The soon-to-be-released CCAS Level 2 is currently being designed for contractor personnel who want to obtain certification, or those wanting to learn about surface preparation and coating application for specific projects. Students will have three concrete coating applicator certification tracks to choose from: Structural Concrete, Manhole/Wastewater or Flooring Projects.

SSPC certainly had concrete coatings courses prior to CCAS, but nothing quite like this offering. According to instructor Dudley J. Primeaux, II, CCAS "raises the bar for that professionalism in coating application for our industries' largest construction material used. This is the first complete course that covers all the steps in successful application of coatings to concrete substrates. It's not about the coating, but the process of evaluation, recognition, preparation, repair and application—the process."

Frank Slezak, another instructor, complements Primeaux's statement: "I agree that it's not about the coating, but the process. The course is challenging and hands-on and provides interaction with each other during the class and provides contacts for future discussions in the successful coating of concrete."

Just as concrete increases in strength over time, so do SSPC courses due to our outstanding instructors and students. For more information on specific CCAS training locations and dates, please see sspc.org/concrete-coating-application-specialist-ccas. JPCL