Surface Preparation of Concrete Substrates
A JPCL eBook

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Introduction

This eBook consists of a compilation of articles published in *JPCL* during the last several years on the topic of preparing concrete for coating. In keeping with *JPCL's* focus, these articles, for the most part, deal with cleaning and protecting industrial concrete with coatings in aggressive exposure environments found in wastewater facilities, on bridges, and on the floors of process plants in heavy industrial settings.

Described here are surface preparation methods, tools, and standards, as well as work that is unique to concrete substrates, such as measuring moisture content and dewatering. Repair procedures and materials, which respond to the propensity of concrete to cracking and spalling, and the corrosion of rebar, are also covered.

This collection is designed as a general introduction for the layman. It should alert him to the need for special attention in preparing concrete substrates for coating.

An Overview of Preparing Concrete for Coatings: What to Ask, What to Do, and Where to Find Help

"I want you to apply a coating, sealer, topping, overlay, membrane, or some kind of protective or decorative material to this concrete." It's deer in the headlights time for contractors. Quickly you think, "I'm trapped amid the project cost (*and my profit*), the condition of the concrete substrate, the expectations of the owner, the surface preparation required, the material properties, the application conditions, and the service environment. What do I need to ask, know, do, and find out myself? Where do I go to get help?" This article intends to help with some of these questions for one of the most basic and important parts of the work: concrete surface preparation. Included in the discussion are lessons learned from industry standards and guidance documents.

By Fred Goodwin, Fellow Scientist, BASF Construction Chemicals, Beachwood, OH

The Big Picture

First, determine the project objectives. Define with the owner and other interested parties what success means on this project. Mockups can help all parties decide what can be done and can serve as a test bed for different techniques, materials, and cost vs. performance results. Decide what happens if the results are less than expected. Who pays? What are the penalties? Who can arbitrate disputes?

Agree on the project "tolerables": how to mitigate the side effects of the construction process (e.g., noise, dust, vibration, fumes); what to do with debris; whether utilities (e.g., power, ventilation, water) are available for the needed procedures; what kind of protection for the project area is possible (e.g., from weather and traffic); and what kind of protection (from the construction activity) is needed for the environment around the project.

When it comes to thinking broadly about what surface preparation method to use, follow the steps outlined in the guideline, ICRI No. 310.2 (formerly 03732) from the International Concrete Repair Institute (ICRI). The document notes, for instance, that to determine the correct surface preparation, you must analyze the project and develop a preparation strategy by answering a number of questions, including those about the substrate conditions, coating requirements, owner requirements, application conditions, project objectives, the performance criteria and their price, and methods that will meet the performance criteria.[1]

Editor's Note: This article is a condensed version of a paper the author presented at PACE 2009, the joint conference of SSPC: The Society for Protective Coatings and PDCA, the Painting and Decorating Contractors of America, held February 15–18, 2009, in New Orleans, LA. The full presentation, "Concrete Surface Preparation," appears in the conference proceedings (www.sspc.org).

It is also helpful to think in detail about what surface preparation *is* before determining how it is best achieved on a particular project. For concrete, SSPC-SP 13/ NACE No. 6, Surface Preparation of Concrete, defines surface preparation as "[t]he method or combination of methods used to clean a concrete surface, remove loose and weak materials and contaminants from the surface, repair the surface, and roughen the surface to promote adhesion of a protective coating or lining system." SP 13 further requires that an "acceptable prepared concrete surface should be free of contaminants, laitance, loosely adhering concrete, and dust, and should provide a sound, uniform substrate suitable for the application of protective coating or lining systems."[2]

Questions and issues to address on a specific project form the remainder of this article.

Learn the Substrate's Condition

What kind of concrete is involved? What can you learn about its properties, such as its orientation, its age, its exposure, its finish, and its quality? Surface preparation provides options for improving those properties of the host concrete that facilitate accepting the specified material.

What orientation is the substrate? Horizontal concrete can be on-grade or suspended slabs with different types of traffic. Slabs suspended above the ground can usually dry from two directions. Vertical concrete is not subject to traffic but can be exposed to wind-driven rain on elevated surfaces and hydrostatic pressure on below-surface walls. Overhead concrete may require water drainage through the slab and light-reflective coatings. Vertical and overhead concrete are subject to defects such as fins, bugholes, and formwork pattern transfer.

For slabs on grade, check for a vapor barrier. If one is present, is it over or under the subbase fill? If granular fill has been applied over the vapor barrier, the fill can act as a reservoir for water that can escape only through the slab. If no vapor barrier is present, the chances of success decrease as the moisture sensitivity of the material to be applied increases and the amount of moisture underneath the slab increases . Vapor barriers can also let water through—both from punctures (which create localized high vapor emission regions) and from the use of substandard material (out of sight, out of mind, until it becomes your problem). Some success has been reported with moisture vapor mitigation systems, but before considering them, you must first test the substrate to see if it is uniformly moist, where the moisture is coming from, and whether the changes in the substrate's environment will affect the moisture vapor permeability. (For example, starting an HVAC system can change the dew point; covering the slab with a moisture impermeable material changes the escape path of the moisture; and changes in drainage provide external sources of water). Testing for moisture vapor emissions and internal relative humidity only capture the situation during the time of the test; the conditions may be different after the material application. Consult ACI 302.2 R-06 if you will be using moisture-sensitive coatings.[3]

Table 1: Typical Surface Properties of Finished Concrete

Method	Profile	Porosity[A]	Strength[A]	Problems
Formed concrete	Smooth to medium	Low to medium	Medium	Voids, protrusions, release agents
Wood float	Medium	Medium	Medium	
Metal trowel	Smooth	Low	High	
Power trowel	Smooth	Very low	High	Very dense
Broom finish	Coarse to very coarse	Medium	Medium	
Sacking	Smooth	Low to medium	Low to high[B]	Weak layer if not properly cured
Stoning	Smooth to medium	Low to medium	Low to high[B]	Weak layer if not properly cured
Concrete block	Coarse to very coarse	Very high	Medium	Pinholes
Shotcrete[C]	Very coarse	Medium	Medium	Too rough for thin coatings

[A] These surface properties are based on similiar concrete mix, placement, and vibration and are prior to surface preparation.
[B] Strength depends on application and cure.
[C] Shotcrete may be refinished after placement, which would change the surface properties shown in this table.

How old is the concrete and what does its age mean? Concrete yet to be placed can be modified to reduce moisture issues, be textured for coating acceptance, or even become a decorative surface not requiring further preparation. Recently placed concrete has a relatively high rate of shrinkage (developing cracking and curling) and contains more moisture than older concrete. Applying cementitious toppings and overlays to freshly placed concrete can allow both materials to shrink at the same time.

Old concrete can be rehabilitated for change of use, restored by recoating, or repaired (thereby creating the issues of both old and new concrete on the same installation). But beware: old concrete can also be contaminated with oil, chlorides, carbonation, or other unknown materials absorbed during previous service. Coating suppliers usually recommend removing existing curing compounds, form release agents, coatings, and membranes (as well as contamination) because compatibility between different coating and concrete products is generally not known and difficult to ensure, especially when long-term service life is expected.

All concrete can be subject to contamination from carbonation—a reaction between carbon dioxide in the atmosphere and hydrated components of Portland cement paste in the concrete. Carbonation occurs in two forms: early carbonation, which forms during cement hydration and produces a dusty chalky surface; and longer-term carbonation, which lowers the pH of the exposed concrete surface. Early carbonation must be removed before applying any material to the surface. Treatment of later carbonation depends on the properties of the protective systems applied. Laitance (a weak layer on the concrete surface) from bleeding and settlement during the concrete's hardening must also be removed.

And remember: new or old concrete may have residual form release agents and curing compounds that must be removed before applying any protective material.

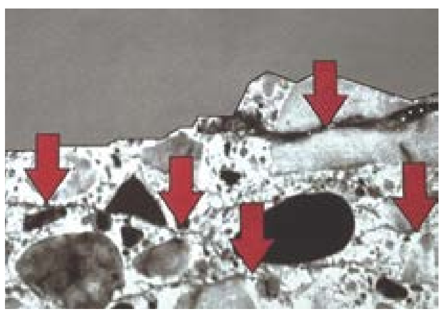

Fig. 1: Microcracking ("bruising") of concrete from impact type surface preparation

What exposure does the concrete have? Most deterioration mechanisms of concrete require moisture, whether from internal mechanisms (e.g., alkali aggregate reactions, sulfate attack, and freezing and thawing damage) or from the migration of deleterious influences, such as chlorides and carbonation, that lead to reinforcement corrosion, staining (except from oil), leaching, and efflorescence. Keeping water out of hardened concrete is a major reason for applying a protective system to concrete. Concrete exposed to differential temperatures (such as through an exterior wall or at the periphery of a cold storage unit) will develop a moisture profile, depending on the amount of moisture present and the temperature difference. When used for secondary containment, concrete will be subject to chemical exposures and will need chemical-resistant coatings. (See SSPC-TU 2/NACE 6G197.[4])

What kind of finish does the concrete have? Table 1 from SSPC-SP 13 describes typical concrete surfaces with respect to different types of concrete finishes.[2]

Is the concrete sound? SSPC-SP 13 also describes several simple qualitative tests to determine soundness of the concrete, including lightly scratching a concrete surface with a screwdriver, file, or pocket knife; lightly striking the concrete with the edge of a hammer head; and dragging a chain across horizontal concrete.[2]

ICRI No. 210.3 (formerly 03739) and ASTM C 1583 quantify the soundness of the concrete substrate using near-surface tensile strength measurements and should be used to supplement the simple tests above.[5,6] The same tensile tests can also be used to perform adhesion for coating compatibility during application mockup and quality control for the applied system. SSPC-SP 3 includes a table that provides guidance on acceptable concrete surfaces for many coating applications following surface preparation; while the tests are helpful, the recommendations of the coating manufacturer and good trade practice for the specific situation should always be followed.[2]

Surface Profile Requirements

What are the requirements of the surface profile for the applied coating? The required profile will depend on the thickness of the material to be applied. ICRI No. 310.2 (formerly 03732) describes three thicknesses of material:

- sealers (0–3 mils) [0–75 μ];
- thin film coatings (4–10 mils) [100–250 μ]; and
- high build coatings, self leveling coatings, and polymer overlays (10 mils–1/4 inch) [250 μ–6mm].[1]

ACI defines a sealer as a liquid applied to the surface of hardened concrete to either prevent or decrease the penetration of liquid or gaseous media. A sealer is absorbed by the concrete, is colorless, and leaves little or nothing visible on the surface.[7] Sealers require surface preparation mainly to promote penetration into the concrete; any visible defects or profile will be unaffected. Depending on the chemical makeup of the sealer, different amounts of breathability (moisture vapor emission), darkening, and protection are provided.

Generally, breathable sealers such as silanes and siloxanes will prevent the absorption of liquid water while allowing moisture vapor to escape without noticeably changing the appearance of the concrete. Some sealers, such as silicates and fluorosilicates, change the pH of the concrete and are reported to also densify and improve abrasion resistance of the concrete surface. Stains and dyes for concrete may also fall into the sealer category, depending on their drying film formation, unless the only purpose of the stain is to change the color of the concrete. Surface polishing has also recently gained popularity as an enhancement for concrete surfaces. Frequently, the polished concrete is stained and then sealed.

Thin-film coatings may be formulated to mask very minor defects and surface discolorations. Suitable surface preparation techniques for thin-film coatings depend on several factors. Patterns from surface preparation and any but the smallest defects will likely become visible through the coating. If the amplitude of the surface profile is greater than the dry film thickness, a smooth coating surface is not possible. Some thin-film coatings on smooth horizontal surfaces can become very slippery when wet and generally require periodic recoating if subjected to wear from traffic. Thin-film coatings that are impermeable or otherwise sensitive to moisture tend to be problematic unless the concrete substrate is very dry.

Thicker coatings, such as self leveling materials, polymer overlays, toppings, and high-build coatings, have much in common with thin-film coatings regarding the relationship between surface profile and dry film thickness, moisture sensitivity, and wear; however, thicker coating layers can fill larger defects, create surface texture to yield slip-resistant surfaces; and provide longer service life than thin-film coatings.

Characterizing Surface Preparation

One way of describing surface preparation is by comparing the substrate's surface roughness with various other surfaces, such as the ICRI CSP specimens or sandpaper, or by using semi-quantifiable methods such as ASTM E 965 (commonly called the "sand patch test").[8] More sophisticated methods are being developed, including ASTM E 2157 and laser profilimetry, which are compared with ASTM E965 in the VTRC reference.[9,10] Other techniques occasionally referenced are ASTM standard WK16987 (in development), which takes measurements from a cast replica of the roughened concrete surface (ASTM D 4417 Method C/NACE RP0287-95).[11,12,13]

The most common guidance for the required profile for each coating thickness is also found in ICRI No. 310.2 (formerly 03732), which assigns a concrete surface profile (CSP) number based on the coating to be applied; the document further defines profile with physical replica specimens prepared with different surface preparation techniques.[1] The higher the CSP number, the more aggressive the profile.

Another method of describing surface preparation techniques is by the mechanism of concrete removal or treatment. Mechanisms include cleaning, erosion, impact, pulverization, chemical reaction, and expansive pressure. Table 2, which is based on information in ICRI No. 310.2 (formerly 03732), compares different surface preparation techniques, which are also briefly described below.[1]

Table 2: Surface Preparation Methods for Concrete (Ref. 1)

Method	Equipment	Mechanism	Surface Texture Achieved	CSP Ranking
Detergent Scrubbing	Mop and Pail, Floor Scrubber	Emulsification	No change	0-1
Low Pressure Water Rinse	Pressure Washer	Emulsification (if soap in water), Erosion (of loose particles)	Removal of loose debris	0-1
Acid Etching	Acid, Mixing Container, Neutralizing Agent	Reaction	Light profile, removal of concrete paste, discoloration	1-3
Dry Grinding	Dry Grinder	Erosion	Smooth surface, dust, debris to remove, pattern	1-3
Wet Grinding	Wet Grinder	Erosion	Wet, smooth surface, slurry, debris to remove, pattern	1-3
Dry Abrasive Blasting	Dry Sand Blast	Pulverization, Erosion, Expansive Pressure	Dusty substrate, light profile (depending on media, size, pressure, time) debris to remove	2-4
Recuperative Abrasive Blasting	Vacuum Recovery Sand Blasting	Pulverization, Erosion, Expansive Pressure	Light profile (depending on media, size, pressure, time)	2-4
Wet Abrasive Blasting	Wet Sand Blast	Pulverization, Erosion, Expansive Pressure	Wet substrate, light profile (depending on media, size, pressure, time) debris and slurry to remove	2-4
Shot Blasting	Shot Blast Unit	Pulverization, Impact Erosion	Dust free substrate, some pattern, depth dependent on shot size, sustrate hardness, equipment	2-8
Scarifying	Scarifier	Impact	Dusty substrate with striated pattern, bruising likely, debris to remove	4-9
Needle Scaling	Needle Scaler	Impact	Similar to shot blasting, striated pattern, debris to remove	5-8
Scabbling	Scabbler	Impact	Dusty substrate, irregular pattern, fractured aggregate, bruising likely, debris to remove	7-9
Hydrodemolition, Hydroblasting, Water Jetting	High- and Ultra-High-Pressure Water Blast	Erosion, Expansive Pressure	Saturated substrate, debris to remove, profile dependent on substrate hardness, equipment, pressure, time	6-9
Flame Blasting	Special Oxy-acetylene Torch, Saturated Substrate Helpful	Expansive Pressure, Reaction	Irregular chipped surface, hot, charred debris to remove, bruising possible	8-9
Rotomilling	Rotomiller	Impact	Dusty substrate (unless water used to suppress dust), grooving, tool marks, fractured aggregate, bruising likely	9
Liquid Surface Etchant	Specialty Chemical, Fresh Concrete	Reaction	Exposed aggregate, green wet concrete with debris to remove using pressure wash, curing still required, no bruising, depth dependent on retarder chemistry, curing rate, length of exposure	3-9

Cleaning with low-pressure water (pressure washing <5000 psi) and scrubbing with detergent do not remove sound concrete or change the concrete surface profile. Removal of surface contaminants from scrubbing, use of surfactants, and water velocity followed by vacuum removal of the cleaning solution produces a wet substrate and removes minor amounts of dirt, oil, grease, dust, friable, materials, debris, or other water-soluble contaminants. ASTM D 4258, ASTM D 4259, and a guidance document from the Water Jet Technology Association are useful resources.[14,15,16]

Erosion methods (i.e., grinding) uniformly wear away the concrete surface with abrasive force from grinding media such as abrasive discs. This method leaves a dry dusty surface with very little profile. See ASTM D4259 for guidance on good practice of this technique.[15]

Chemical reaction methods include acid etching and the use of surface retarders for fresh concrete. Acid etching dissolves the cement paste (and limestone aggregate, if present), producing a very light profile on the concrete surface that has a relatively low pH unless neutralized. Acid etching does not work well on vertical surfaces or on concrete that has had a curing compound or sealer applied. ASTM D 4260 provides guidance for acid etching and D4262 for surface neutralization following acid etching.[17,18]

Surface retarders are used only for freshly placed concrete. The cement hydration adjacent to the layer of surface retarder is delayed, while the remaining concrete continues to harden normally. After sufficient strength has developed in the underlying concrete, the layer affected by the retarder is removed by pressure washing and scrubbing, leaving an exposed aggregate wet surface suitable for placement of cementitious overlays and toppings. Guidance on surface retarders is usually supplied by the material producer.

Some methods of surface preparation can cause "bruising" (Fig. 1, p. 42). Bruising occurs when a surface layer is weakened by interconnected microcracks in concrete substrates; the microcracks are caused by use of impact, pulverization, and other mechanical methods for surface preparation. Be careful of bruising when using bush hammers, scabblers, scarifiers, and rotomilling machines for surface preparation. Scarifiers and rotomilling (also known as surface planers or milling machines) use the chipping action of multi-tipped cutting wheels that rotate at high speeds to chip away at the concrete surface. Bush hammers and scabblers use serrated hammers with rows of pyramidal points and remove concrete by pounding the surface with piston-driven cutting heads placed at a right angle to the surface. The bruised layer typically extends to a depth of 1⁄8 to 3⁄8 in. (3 to 10 mm) and frequently results in lower bond strengths as compared to surfaces prepared with nonimpact methods.

Abrasive blasting, shotblasting, and hydrodemolition are methods not only for surface preparation, but can also be used to remediate bruised concrete. Shot blasting, used to strip, clean and profile surfaces, produces a roughened texture that is dry and relatively dust free. Depending on the size of the steel shot, its speed, and machine design, the method can selectively remove softer and more brittle portions of the substrate. Hydrodemolition uses very-high-pressure water jets to prepare the surface, producing a saturated deeply profiled substrate. ICRI No. 310.3 (formerly 03737) discusses hydrodemolition in great detail.[19] The hardness of the concrete, speed of hydrodemolition jet travel, impingement angle, and pressure of the water jet control the amount of removal.

Primers are sometimes used as a form of surface conditioning following surface preparation. Primers are used to improve the bond between the prepared surface and the subsequent coating material or to improve the surface for coating.

Conclusions

Unless the concrete surface is properly prepared, even the best sealer, coating, topping, overlay, or membrane will not perform satisfactorily. Trial applications that follow the manufacturer's instructions and good trade practices referenced in this article are the best means of achieving good system performance; they also provide acceptance criteria for proceeding with an installation. On any trial areas, bond testing, substrate cleanliness, substrate surface hardness, porosity, and moisture condition evaluation should be performed to assure integrity of the substrate preparation effectiveness, coating adhesion, and finished appearance.

Notes

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18. ASTM D4262-05, Standard Test Method for pH of Chemically Cleaned or Etched Concrete Surfaces (2005), ASTM International, West Conshohocken, PA.
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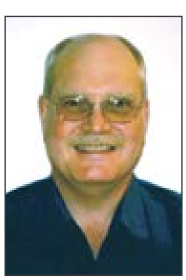

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Keys to Concrete Surface Preparation: Shot Blasting, Scarifying, and Grinding

By Amy Flanagan, Blastrac

For the painting or flooring contractor hired to apply or repair a coating on a concrete floor, the range of tools and possible techniques available for surface preparation can be extensive. Surface preparation methods may include anything from detergent scrubbing to acid etching to mechanical abrasion. Proper surface preparation is critical to a successful and long lasting coating job, and the key to preventing call backs. This article provides an overview of the most commonly specified surface preparation methods used on concrete floors: shot blasting, scarifying, and concrete grinding. Tips for how to select the most appropriate surface preparation method (or methods) for a job are offered.

Shot Blasting

Typically, closed loop or enclosed shot blasting is one of the cleanest and fastest methods of mechanical abrasion (Fig. 1). In addition to a "typical" coating job (if there truly is one), shot blasting can also be used for floors in sensitive areas that are otherwise "off limits" to other methods, including food preparation or manufacturing areas, clean rooms, areas around sensitive inventory or machinery, or simply areas where chemical-free, dustless methods are required for all candidate shot blasting equipment. The recycling wheel blast technology found in most shot blasters works by throwing steel shot or grit at a high velocity onto the surface being cleaned (such as the concrete floor). This is achieved through centrifugal force by a wheel with removable paddle- type blades that revolve at a high speed. Abrasive travels along the radial length of the blade and is thrown in a predetermined and adjustable direction. Once it hits the surface, the abrasive dislodges the coating and/or debris, thereby cleaning the surface. The abrasive and debris rebound into a reclaim

Fig. 1: Enclosed shot blasting is a clean and effective process. To help maximize productivity, vary the travel speed for areas of softer or harder concrete. Photos courtesy of Blastrac.

chamber to be recycled. The reusable abrasive is separated from the dust and debris and is transported into a storage hopper for recirculation. Air flow transports the dust and debris through a hose to a dust collector.

Tips for Successfully Shot Blasting a Floor

• Wear appropriate safety gear.

• Remove chewing gum, sticky adhesives, or other soft materials from the floor that will prevent the surface from being evenly shot blasted.

• If a floor is soaked with grease or oil, clean it first with an industrial detergent. If the floor is not cleaned first, the heat generated during the shot blasting process will bring the oil to the surface and cause adhesion problems when the floor is coated.

• Make sure the surface is dry. Shot blasting equipment will not work properly on a wet floor.

• Shot blast a small test area first to ensure that the desired result is achieved.

• Plan the travel route for your shot blaster so that you achieve a consistent pattern over the entire surface.

• Use the smallest steel shot possible that will provide the desired results. Smaller shot provides better coverage and higher production.

• Monitor the level of the shot in the hopper. Keeping the hopper full will help achieve a more consistent blast pattern.

• Vary the travel speed of the machine as needed to address areas of softer or harder concrete.

Common Shot Blasting Mistakes

• Stopping a blast machine with the control valve open can cause the machine to blast deeply into the substrate.

• Using the wrong shot size can result in the wrong profile.

• Incomplete removal of curing compounds and laitance layer due to too light a blast will affect subsequent coating adhesion.

• Attempting to remove too much material at once will clog the storage hopper and vacuum filters.

• Poor planning of travel route can result in overlapping or crooked passes.

Fig. 2: Scarifying is a versatile method of surface preparation. Be sure to inspect the drum that holds the cutters, and replace worn cutters.

Scarifiers

Scarifiers are versatile surface preparation tools used for concrete, asphalt, and even steel surfaces (Fig. 2). Scarifiers use steel- or carbide-tipped cutters (in various shapes, depending on the application) that are loaded on shafts, which are placed around the perimeter of a cylindrical drum. As the drum rotates, the cutters strike the surface at a high speed, fracturing the coating and/or contaminants and abrading the concrete surface. The tools are used to remove contaminants, coatings, adhesives, and paint. They are also very useful for preparing problem areas on concrete slabs, such as burned areas, high spots, curled joints, excessive trowel marks, trip hazards, etc. Many models can be connected to dust collection systems.

Tips for Achieving a Successfully Scarified Floor

• Wear appropriate safety gear.

• Match the cutter type to the substrate (concrete, asphalt, or steel) and the problem to be solved. Is a coating being removed?

If so, what type? What contaminant is being removed? Are high spots being fixed?
- Match the machine to the size (surface area) of the job.
- Consider the final desired result. Cutter types, cutter spacing, and the speed of the machine all affect the appearance of the surface after scarification.
- To achieve greater depth, make several passes over the same area instead of trying to take off the material in one pass.
- Vary the travel speed of the scarifier to address areas that have more or less coating, or harder/softer concrete.

Fig. 3: Used for cleaning, planing, or removing coatings, a grinder should be eased through the material to be ground, not forced.

Common Mistakes When Scarifying
- Not inspecting the drum frequently. Cutters and spacers wear out and need replacement
- Using the wrong type of cutters
- Setting the cutter depth incorrectly
- Trying to remove too much material at once

Grinding

Grinders are used for concrete cleaning, planing, or coating removal (Fig. 3). A diamond grinding disk is recommended because many other types of abrasive disks may not offer the profile required for coating application. Depending on the type of abrasive wheel used, a grinder can be used to lightly prepare the surface, which is especially useful when applying thin-film coatings. Some abrasive disks are designed to quickly remove mastics, epoxies, urethanes, and other thick coatings. Special types of multi-headed grinders can be outfitted with carbide-tipped slicers to quickly cut through heavy materials such as built-up adhesives, elastomeric coatings, and waterproof membranes. When these multi-headed grinders are fitted with diamond polishing plugs, they can smooth and flatten a floor, removing minor imperfections in the concrete slab.

Tips for Concrete Grinding
- Wear appropriate safety gear, including a dust mask and knee pads.
- Move the grinder in a random motion during operation to minimize swirl marks and uneven grinding.
- Ease the grinder through material that is being ground. Don’t try to force it.
- Check and empty the dust collector frequently so that the system operates properly.

Common Mistakes When Grinding
- Putting too much weight on the tool, particularly hand-held grinders. This can cause the motor to burn out.
- Operating the system with the improper dust collector. Standard industrial vacuums do not have the filtration capacity of specialized dust control units.
- Using diamond tools on edge. Using a grinder properly will result in longer tool life as well as a better finished, more consistent surface.

How To Pick a Surface Preparation Method

Each of the surface preparation methods discussed can be used to prepare a concrete floor. While there may be no single "right" method, most jobs do have characteristics that can point you towards a method (or in some case a combination of methods) that will provide better results than others.

Look at what coatings, if any, are on the surface now. The thickness and nature of the coating can help determine the type of equipment needed for surface preparation. Rubbery or sticky coatings, for example, call for scarification or grinding with special abrasive disks.

Consider the type of coating that will be applied to the prepared floor. Thin coatings and sealers are not appropriate on a floor that requires moderate to heavy shot blasting or scarification. Concrete grinding is typically more appropriate for situations requiring the use of thin coat or staining products.

Ask your coating manufacturer for recommendations. Many manufacturers specify the method of surface preparation that is most appropriate for their coatings.

Perform a test patch, in a variety of locations on the slab if needed, to help determine whether one surface preparation method performs better than another.

Consider a mix of tool types to address the specific needs of the floor and to address the type of coating or surface that is being removed. Scarification followed by shot blasting, or a combination of light shot blasting in open areas and hand grinding for corners and edges, are two possibilities. In restoration work, it is very common to use several types of surface preparation tools on one project.

Where To Go for Help

For more information on concrete surface preparation, consult industry organizations such as the following.

- American Society of Concrete Contractors (ASCC)—tel: 314-962-0210; website: www.ascconline.org
- International Concrete Repair Institute (ICRI)—tel: 847-827-0830; website: www.icri.org.
- SSPC: The Society for Protective Coatings—tel: 877-281-7772; website: www.sspc.org.

Efflorescence and Laitance on Concrete: Identification, Remediation, and Prevention

By Dan Savage, Tnemec Company, Inc.

"Efflorescence" and "laitance" are often used interchangeably in the coatings industry to describe certain surface defects on coated or uncoated concrete and other masonry substrates. While the defects described by the terms both include loose, friable layers on concrete or other masonry substrates, the terms reflect two different phenomena that result from different processes within the substrate.

Found on both coated and bare concrete in service, efflorescence has the physical appearance of a granular and/or powdery substance that is or can become loosely bonded to the surface (Fig. 1). Efflorescence is related to moisture vapor transmission, with the moisture source outside of the concrete.

Laitance, formed on newly poured or finished concrete, is a thin, weak layer of aggregate fines and non-reactive as well as unreacted residual concrete constituents loosely bonded to the substrate (Fig. 2). The occurrence and the appearance of laitance are associated with how much the concrete is worked during placement. If the concrete is worked too much, laitance will appear as a shiny layer. If the concrete is not worked enough, laitance will be a dull surface layer of residual concrete constituents, commonly referred to in the field as "scum."

Fig. 1: Efflorescence has a granular or powdery appearance. The effect is caused by moisture vapor transmission. Photos courtesy of the author.

Although these surface defects result from entirely different phenomena, they share one critical characteristic: if coated over, they both compromise the long-term adhesion of the coating system. But the differences between laitance and efflorescence matter because how each is formed determines how each is addressed. Recognizing and defining the causes of these two separate surface phenomena, their subsequent effects on applied coating systems, their treatment, and their prevention will help specifiers and contractors optimize the performance of coating systems over masonry substrates. For the purposes of this article, we will speak of both defects in terms of concrete, the most common masonry material of construction in industry.

Efflorescence

Efflorescence develops as moisture migrates through coated or bare concrete and extracts from the concrete elements such as alkaline calcium components, hydroxide residues, and salts. The migrating moisture dissolves the elements and carries them to the surface. As the moisture evaporates, the residues react with carbon dioxide and airborne pollutants to create a loose, granular layer that prevents proper adhesion of any coating system applied over it. Typically, the granular layer is loosely bonded to the concrete. The source of the moisture is generally external to the concrete, such as groundwater, which can wick through a concrete foundation.

To check concrete for efflorescence, apply a drop of a mineral acid, such as hydrochloric (muriatic), phosphoric, or sulfuric acid, to the surface in question. If efflorescence is present, the mineral acid interaction will produce carbon dioxide bubbles (similar to the bubbling effect you see when you pour hydrogen peroxide over a cut that is bleeding).

Note that as with any substance, these acids should be used in accordance with their respective material safety data sheets (MSDS) and handled with care, in compliance with all relevant safety and environmental regulations. Anyone on a paint project who is properly trained in the use of this field test can perform it.

Fig. 3: If the source of moisture that causes efflorescence is not eliminated, freeze/thaw cycling or other moisture-related effects can weaken the substrate.

The moisture "perm rate" of a coating can affect the formation of efflorescence. The perm rate, generally measured according to ASTM D 1653, is the rate at which water vapor passes through (permeates) a coating. The greater the moisture perm rate of a coating, the more moisture can pass through a paint film while efflorescence accumulates underneath it, eventually forcing the film off the substrate.

Other effects or side effects of efflorescence include the following:

- Accumulated alkaline salts can attack an existing coating film, degrade its structure, and break previously established adhesion bonds of the coating film to the substrate.
- It is difficult to create a smooth, uniform film when applying a coating over efflorescence, thus preventing solid, intimate contact between the substrate and the coating film. Without this contact, proper adhesion cannot occur, and the applied film becomes susceptible to pinholes and voids, which create further opportunities for the coating to fail.
- The substrate can be weakened or be destroyed over time through freeze/thaw cycling if the source of moisture is not eliminated (Fig. 3).
- The applied film can have poor aesthetic value.

Fig. 2: Laitance, a thin, weak layer of fines and cement residue, is related to unreacted concrete constituents.

Laitance

Laitance is, in essence, residual fines (unreacted material in the concrete mix) that are pulled to the surface as new concrete is being poured or finished. Factors contributing to laitance include the amount of water in the concrete mix, additional water applied over the placed concrete during the curing process, and overworking or improperly finishing the placed concrete. The type and amount of admixtures added to the concrete mixture can also contribute to laitance.

To check for laitance, use the impact or the surface scratching method. The first method involves striking the surface lightly with the edge of a hammer (Fig. 4). If the hammer lands witha dull thud and leaves powdered dust in the indentation, the surface is not sound. The second method involves scratching the concrete with a screwdriver or a stiff blade of some type (Fig. 5). If the scratching results in gouging the surface, then laitance is most likely present. (See NACE International's publication 6G191 or refer to SSPC-SP13/NACE No. 6, Appendix A, for more details on these evaluation methods.)

Laitance does not provide a stable surface for coating systems. Normal stress applied to a layer of laitance during the the service of a concrete structure can cause the laitance to disintegrate and most likely lose adhesion from the concrete substrate. In turn, the coating film loses adhesion and "fails" prematurely. As with efflorescence, laitance can have an objectionable visual appearance for the concrete's intended use.

Surface Preparation

Efflorescence and laitance must be removed completely from a masonry surface before applying a coating. But the process for removal depends on whether efflorescence or laitance is present.

If you have efflorescence on concrete, you must identify and eliminate the source of moisture—whether it is liquid or vapor—before you remove the efflorescence and coat the surface. Examples of potential sources of moisture intrusion to investigate include the following.

- The lack of, or an improperly installed, wall vapor/air barrier system
- Improper or worn flashings and degraded sealants/caulking (e.g., around a window, door, roof edge, or penetration point)
- Groundwater wicking through the foundation

After you find and eliminate the source of moisture, remove the efflorescence. Thoroghly scrub the affected surface with a stiff wire brush, and rinse the surface with water using pressure washing or other methods. For difficult areas, first dampen the surface with water, and then wash it with a diluted (5 to 10%) solution of muriatic acid or vinegar. (See note above on precautions when using acids.) Allow the solution to sit for five minutes (depending on the temperature), and then thoroughly pressure wash the surface, removing and neutralizing all residual acid from the substrate. Several applications may be necessary, depending on the buildup of efflorescence and the orientation—vertical or horizontal—of the substrate.

Fig. 4: Concrete can be tested for the presence of laitance by lightly striking the substrate with a hammer. Powdered dust in the indentation indicates unsound concrete.

If you have laitance on concrete, moisture ingress is not an issue, and you can proceed directly to removing the laitance. Suitable mechanical methods include wet or dry abrasive blasting, steel shot blasting, ultra-high-pressure waterjetting, diamond grinding, and scabbling. Where the laitance is a very thin layer and the intended service of the floor is light (such as pedestrian traffic), you can remove the laitance by etching the surface with acid (e.g., hydrochloric or citric acid) instead of using a mechanical method. You might need to etch the surface more than once to remove all of the laitance and provide the necessary surface profile for the protective coating. This method is not recommended for vertical surfaces because they cannot be etched uniformly.

An Ounce of Prevention

To prevent efflorescence, you need to try to prevent the ingress of moisture, whether as a vapor or condensate. Preventive efforts are most effective at the construction stage, but they can also be taken on structures in service.

While it is not possible to anticipate every potential source of moisture, a properly installed wall vapor or air barrier system for vertical concrete can protect against external moisture condensing on the inside of a wall. A properly installed vapor barrier for slabs on grade can help prevent groundwater from wicking through the foundation of a building. Joints or other points where moisture can penetrate should be properly sealed, and such points should be periodically checked during the life of the structure. Worn sealant or caulking should be replaced.

Avoiding the formation of laitance on new concrete is difficult, even with the use of concrete admixtures thought to be able to prevent its occurence. However, novel cementitious acrylic epoxy-modified surfacer-fillers used to resurface or repair concrete floors and walls may provide a laitance-free surface that can be coated.

Fig. 5: Scratching a concrete surface with a stiff blade can also show whether laitance is present. If the blade gouges the surface, laitance is likely present.

Summary

Laitance, found on new concrete, and efflorescence, found on existing concrete, are two different kinds of phenomena that can develop on the surfaces of masonry sustrates. For coating systems to provide long-term performance over masonry substrates, these surface defects need to be recognized, removed, or better yet, prevented from occurring.

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Preparing Concrete for Coating:

Make Sure Your Work Is Up To Industry Standards

By Vaughn O'Dea and Dan Savage, Tnemec Company, Inc.

It is widely understood that the overall performance of a coating system is directly related to the adhesion of the coating to the substrate. Concrete and other cementitious substrates can be considered the antithesis of steel substrates in terms of physical characteristics that may affect coating performance. In contrast to steel, the properties of concrete substrates vary greatly depending upon their intended use, the water/cement ratio, and construction, to name a few influencing factors. The old practice of specifying that concrete be "clean and dry" does not exclude all possible contaminants and conditions that can interfere with the adhesion of a coating system to these substrates. (For the purpose of this article, "concrete" and "cementitious substrates" are used interchangeably.)

Properly specifying the repair of deteriorated concrete, like the interior walls of this wastewater collection basin, depends on taking into account many more contaminants and conditions than the boilerplate phrase, "clean and dry," accounts for.
Photos above and on opposite page courtesy of the authors

SSPC: The Society for Protective Coatings (SSPC) and NACE International (NACE) developed a joint standard describing the practice for preparing cementitious substrates. Entitled SSPC-SP 13/NACE No. 6, Surface Preparation of Concrete, the standard is applicable to the preparation of both new and existing concrete surfaces, including cast-in-place concrete floors and walls, precast slabs, masonry walls, and shotcrete surfaces. Inspection, surface preparation, classification, and acceptance criteria are all encompassed by this joint standard to determine whether concrete surfaces have been prepared to the point at which they are suitable for coating. This article reviews key features in SSPC-SP 13/NACE No. 6 as well as relevant features in other industry standards that the joint document references.

Inspection Procedures before Surface Preparation

The joint SSPC/NACE standard outlines inspection procedures to be performed before surface preparation to determine the condition of the cementitious substrate and the appropriate method(s) for meeting the coating system requirements. Before surface preparation operations begin, all concrete surfaces should be visually inspected for signs of defects, physical and chemical damage, contamination, cure, and excess moisture.

Maintaining sufficient moisture and proper temperature of the concrete during the early stages of curing is important for optimum hydraulic-cement hydration, which con-

Resurfacing of deteriorated concrete may be needed, as shown in this partially resurfaced wall of the collection basin.

tributes to overall strength development. It also serves to reduce slab curling, maximize surface tensile strength, and minimize surface cracking. If used, membrane-curing compounds should always be removed before applying a coating system.

Traditionally, Type I concrete is coated no sooner than 28 days after placement at 75 F (24 C). This value was adopted from The American Concrete Institute (ACI) as an indicator that the concrete has gained the designed compressive strength. Twenty-eight days is an arbitrary measure, however, of the minimum time required between placing the concrete and coating it. Rather, the drying rate of concrete is a complex function of the concrete mix-design, temperature, thickness, porosity, and initial free-water content, as well as a function of the velocity and dew point of the drying air. Thus, the actual drying time of concrete can exceed 28 days, given certain conditions.

Surface Preparation

Surface cleaning and other preparation of a cementitious substrate are necessary to produce a surface that is suitable for the application and adhesion of a specified protective coating system. The SSPC/NACE joint standard outlines three types of surface preparation methods for cementitious substrates. The types of methods are identified below.

- Mechanical surface preparation, including wet or dry abrasive blasting, high-pressure water cleaning or water jetting, and impact and power tools: Such mechanical methods should be used until the surface is uniform and sound; is free of laitance, efflorescence, concrete curing compounds, or form release agents; and is suitable for the specified coating system.
- Chemical surface preparation methods, including acid etching of horizontal concrete surfaces: These methods are not recommended for vertical surfaces and areas where curing compounds or sealers have been applied to the concrete substrate. (Generally, acid etching is not used in Europe.) The joint standard also states that acid etching is not to be used where corrosion of the concrete reinforcement can occur, such as expansion joints in floor slabs with reinforcing steel carried through the joint.
- Flame (Thermal) cleaning and blasting techniques: These methods are not common. If used, care should be taken to avoid inadvertent thermal degradation of the substrate.

For the new lining to perform properly, surface preparation must meet acceptance criteria such as those described in the SSPC/ NACE joint standard on preparing concrete for coating.

Voids, gouges, bugholes, and other surface anomalies are also addressed under the surface preparation section of the joint standard and are to be repaired with the appropriate patching materials before applying a coating system.

Inspecting and Classifying Prepared Concrete Surfaces

The joint standard is intended to detail the inspection and classification of prepared concrete surfaces in a surface preparation document. During this stage, the uncoated concrete is evaluated for tensile strength in accordance with ASTM D 4541, Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers, referenced in the SSPC/NACE standard, or other methods agreed upon by all parties before applying a coating system. The results of such testing are necessary to determine the tensile strength of the concrete substrate, which is subsequently used, when required, to determine adequate adhesion of the coating system. Sometimes a predetermined tensile strength value of 9–10% of the compressive strength of the substrate is to be used instead of actually performing the tensile testing. Be careful when using these arbitrary values as the basis for tensile strength criteria due to the variability of concrete mixes and curing processes of compressive strength cylinder specimens, as well as the variability of the tensile strength instrument.

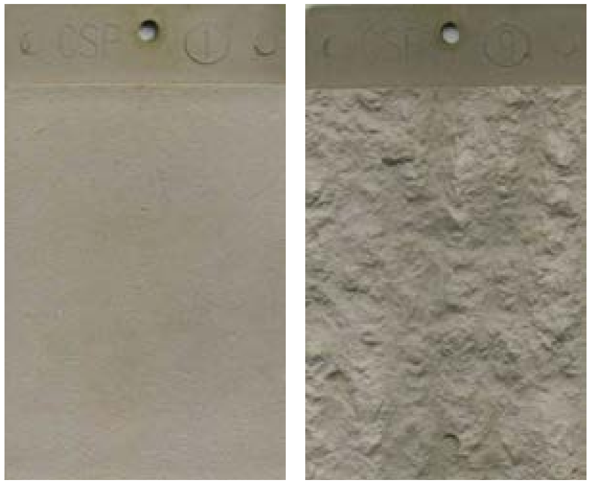

Fig. 1: (left) ICRI CSP 1 (nearly flat); (right) ICRI CSP 9 (very rough) Reprinted from ICRI Technical Guideline No. 03732 with permission of the International Concrete Repair Institute

The surface of the concrete substrate should be evaluated in accordance with the project specifications to determine if the proper surface profile has been obtained. This may be accomplished by comparing the surface profile of the prepared concrete to graded abrasive paper (sandpaper); by comparing the substrate with the Concrete Surface Profile (CSP) comparators in ICRI Technical Guideline No. 03732, "Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays"; or by comparing the prepared surface to other agreed-upon standards. The ICRI Technical Guideline No. 03732 CSP comparators provide both visual as well as tactile evaluations and are thus less subjective than other evaluation methods.

So what exactly are the ICRI Technical Guidelines No. 03732 CSP comparators? ICRI Technical Guideline No. 03732 provides nine distinct profile configurations that may be produced by one or more surface preparation methods. As a set, these profiles replicate degrees of roughness considered suitable for applying one or more of the sealer, coating, or polymer overlay systems, up to a thickness of ¼ in. (6 microns). Each profile carries a CSP number ranging from a base line CSP 1 (nearly flat) through CSP 9 (very rough), as shown in Fig. 1.

According to the SSPC/NACE joint standard, concrete surfaces are also to be inspected for cleanliness. Lightly rubbing the surface with a dark cloth or pressing a translucent adhesive tape on the surface should reveal the amount of residue on the surface and whether it is acceptable. The test method and acceptable level of residual dust should be outlined in the project specifications or agreed upon by all parties. Surface cleanliness is especially critical with the use of 100% solids products that may not have the wetting capabilities to penetrate minor surface dust particles and other dry contaminants. Chemical cleaning with acidic or alkaline products can leave residuals that may adversely affect the adhesion and other performance characteristics of the coating system. The pH of concrete can be tested to determine if these residuals are neutralized. Additionally, a simple water drop test can be used to evaluate the presence of hydrophobic materials on the surface of the concrete substrate.

Measuring the residual moisture content of the concrete is an important step in achieving proper coating adhesion and is therefore outlined within the SSPC/NACE joint standard. Such testing should always be performed at the conclusion of the surface preparation operations and before coating application.

In section A1.8 of the SSPC/NACE joint standard, the following industry standards for measuring moisture are referenced.

- ASTM D 4263, Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method, is a qualitative test method commonly used to identify the free moisture in concrete substrates. This test is conducted by taping down an 18-inch x 18-inch polyethylene plastic sheet (4 mils thick) for 16 hours. After 16 hours, the plastic is pulled back and evaluated for the presence of moisture.
- ASTM F 1869, Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride, measures the rate of moisture emission from a horizontal concrete surface. It is generally acceptable to coat concrete if

ASTM F 1869 testing indicates that less than 3 lb (1.35 kg) of moisture is transmitted from a 1,000 sq ft (10 sq m) surface over 24 hours.

- ASTM F 2170, Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using In-Situ Probes, may also be used to determine the amount of residual moisture in the concrete.

Acceptance Criteria

Finally, to fulfill the requirements of the standard, all prepared surfaces must meet defined acceptance criteria, including, but not only, those for surface tensile strength, surface profile, acceptable pH, moisture content, and residual contaminants. When possible, it is always best to customize the level of cleaning and surface preparation for the specific project. The joint standard specifically states that the acceptance criteria for prepared concrete surfaces are to be written in the project specifications. However, specifications may refer to either "Light Service" or "Severe Service" acceptance criteria as detailed in the joint standard. The Light Service category is defined as "surfaces and coatings that will have minimal exposure to traffic, chemicals, and changes in temperature" (Section 6.1). The same section of the standard defines the Severe Service category as "surfaces and coatings that will have significant exposure to traffic, chemicals, and/or changes in temperature."

Summary

Concrete and other cementitious substrates greatly vary. These variations often prompt specifiers to use a "blanket" degree of surface preparation, such as "clean and dry," to encompass all possible contaminants and adverse properties that may affect coating adhesion. However, this commonly used phrase is far too ambiguous to specify the correct level of surface preparation for concrete.

The SSPC SP13/NACE No. 6 joint standard and the standards it references help specifiers move beyond "clean and dry." The joint standard does not recommend surface preparation methods or differentiate levels of surface preparation that are specifically required for various protective system designs, types, thicknesses, and end use requirements. But it does identify the kinds of contaminants that can affect all cementitious substrates. It also discusses surface preparation methods for cementitious substrates, and it defines methods for measuring tensile strength and adhesion. Discussions of concrete evaluation methods, including surface cleanliness, pH, moisture content, and surface profile are also included within the document.

The joint document standardizes reproducible methods for inspection, surface preparation, and acceptance criteria to ensure the specifier and owner that surface preparation methods for concrete are consistent within the industry.

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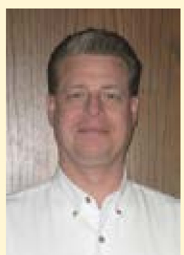

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How to Handle Exposed Rebar when Repairing Concrete

What is the best approach to cleaning and protecting exposed rebar during repair of structural concrete?

Gary Hall, Sauereisen, Inc.

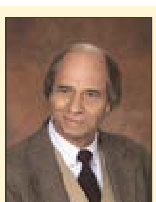
The American Concrete Institute has a proven procedure that should be followed for cleaning and protecting exposed rebar when repairing structural concrete.

The first thing to do is to make sure that all loose or cracked concrete is removed. Do not leave loose pieces behind the rebar. The rebar that is exposed needs to be thoroughly cleaned and repaired, if necessary. Corroded rebar that has lost its temper due to excessive metal loss will not have the same supporting capabilities as the original rebar and must be evaluated by a competent engineer. If a rebar is spliced, either by tie-wire or by welding, the splice must be grouted with a high-strength grout that has very little shrinkage. The grout can be epoxy or portland-based.

Cleaning and profiling the rebar and the existing concrete may well be the most difficult and the most important part of the process. Getting behind and between corroded rebar requires patience and perseverance. High pressure water jetting is a good way to remove rust contaminants and loose concrete. Abrasive blasting is difficult, as it is nearly impossible to direct the abrasive stream onto the hidden faces of the rebar. Hand grinding and chipping are almost always involved, especially behind the rebar and between overlapping rebar. If corrosion products are left in place, the entire process may well be jeopardized. An old rule of thumb is that you need at least one-inch of clearance around and behind rebar to enable placement of repair materials.

Once cleaned, the rebar needs to be protected from excessive rust bloom or flash rusting until covered by new concrete. There are commercial treatments available that work well for this and that also aid in salt removal. Care must be exercised to ensure that construction debris such as mud, grease, or oil does not accumulate on the cleaned rebar or surrounding concrete. Weld splatter and cutting torch debris must also be removed from the rebar and surrounding concrete. If the new concrete placed around the repaired rebar is not going to receive a protective coating, it is important to protect the rebar with at least four inches of concrete to prevent premature corrosion of the repaired rebar.

Coat the rebar with a high-quality, corrosion-resistant coating and bonding compound. Coat the existing concrete with the same bonding compound. There are several epoxy formulations that work well for this application. Choose the repair material carefully, ensuring that it has the correct properties of adhesion, strength, shrinkage compensation, and application characteristics. For maximum protection after the repair material has been applied, the entire concrete structure should be protected with an appropriate coating.



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It is not uncommon to encounter exposed reinforcing steel (rebar) when rehabilitating structural concrete. Most designs for industrial cast-in-place concrete structures specify the rebar to be placed 1.0–2.0 inches (25.4–50.8 mm) below the concrete surface. Frequently, rebar is damaged by corrosion, contributing to the delamination and spalling of concrete. Reinforcement corrosion has a variety of causes, including chloride or chemical ingress, misplaced reinforcing steel (too shallow), poor quality concrete, and carbonation of the concrete.

To properly repair corroded rebar, it is first necessary to expose it and evaluate its condition. In many cases, the specifier or owner may elect to further protect the exposed rebar with a high-performance protective coating before rehabilitating the concrete. When applied to rebar, a protective coating reduces future reinforcement corrosion and eliminates the halo effect (i.e., anodic ring). The halo effect occurs when the same rebar extends into two distinctly different environments (new repair vs. existing/contaminated/carbonated concrete). This leads to accelerated corrosion by setting up anodic/cathodic conditions along the surfaces of the rebar.

A protective coating is also beneficial in cases where there is lack of concrete cover over the reinforcing steel. In these instances, two-component epoxy barrier coatings are commonly used to isolate the rebar from the detrimental chemical or salt solutions and prevent future reinforcement corrosion.

According to the American Concrete Institute (ACI 546), all weak, spalled, severely cracked, damaged, and easily removable concrete should be chipped away from corroded reinforcement steel. Concrete removal should proceed to create a clear space behind the reinforcing steel of 0.25 in (6 mm), plus the dimension of the maximum size aggregate of the repair material when the rebar has loose rust or corrosion product, or is not well bonded to the surrounding concrete. If reinforcement steel is only partially exposed after all unsound concrete is removed, it may not be necessary to remove additional concrete to expose the full circumference of the reinforcement.

Similar to other applications to steel, proper surface preparation of rebar is required to achieve coating adhesion. All exposed surfaces of the reinforcement should be thoroughly cleaned of all loose mortar, rust, and other contaminants. The preferred method is abrasive blasting (SSPC-SP 10/NACE No. 2) or waterjetting (SSPC-SP 12/NACE No. 5, WJ-1, L). Any excess sand and loose debris should be blown from the surface with oil-free compressed air. If water jetting is used, cement and particulate slurry must be removed from the reinforcing steel. The high-performance protective coating should be applied at a thickness less than 12 mils (305 microns) to prevent overbuilding and to minimize loss of bond development at the rebar deformations. Likewise, reinforcing bars that have lost their original shape (deformations) as a result of corrosion and cleaning have less bond development with most repair materials.

Also, care should be taken during the coating process to avoid spillage on the parent concrete. Always consult the coating manufacturer to confirm compatibility of the product with the rebar.

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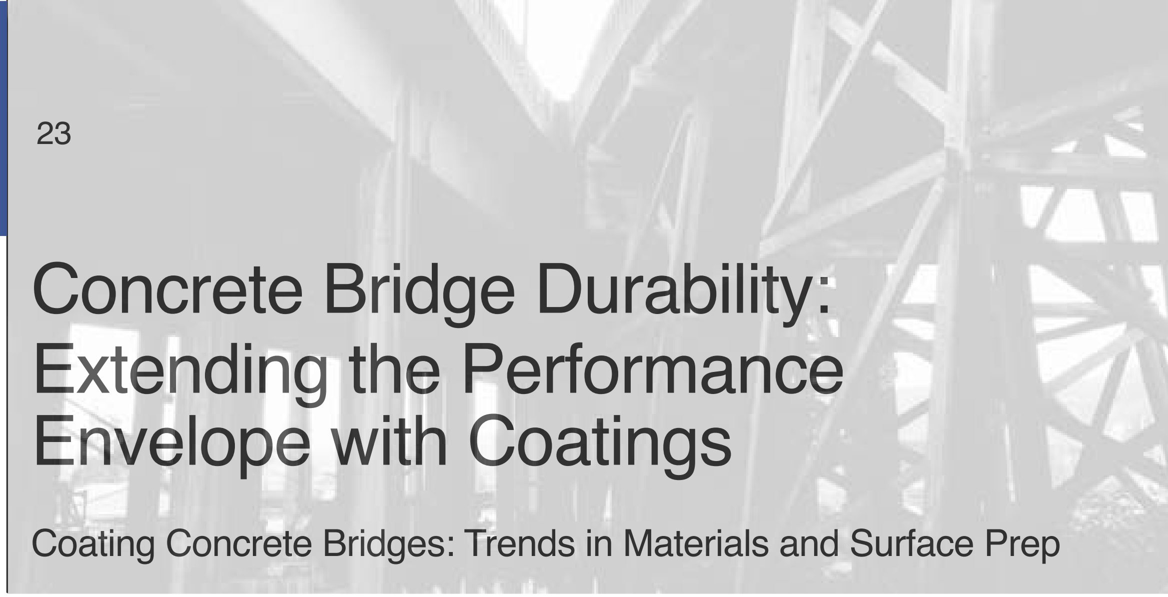


Concrete Bridge Durability: Extending the Performance Envelope with Coatings

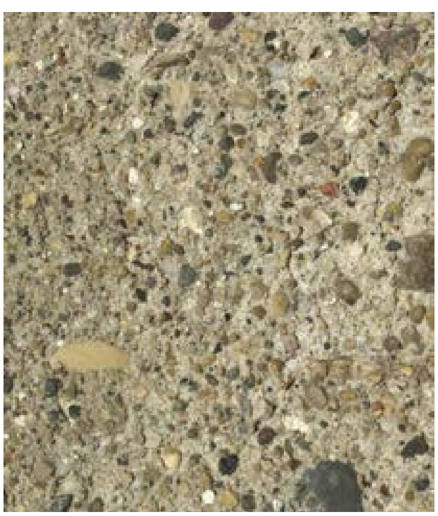
Coating Concrete Bridges: Trends in Materials and Surface Prep

By Robert Kogler, Rampart LLC

When we consider the implementation of industrial coatings to protect concrete highway bridges, an obvious question arises: why now? After all, the concrete industry has not embraced protective coatings in the past, and, in fact, the need for protective coatings on steel bridge structures has long been used as a perceived competitive advantage by the concrete industry. So now, after two decades of work developing refined, high-performance concrete mix specifications and implementing widespread use of epoxy coated rebar, why should the use of protective coatings be considered?

The answer is that at no time in the past has the protective coatings industry had so much value to offer the concrete industry and the owners of infrastructure–value in terms of engineered materials, advanced surface preparation systems, jobsite operational expertise, and the knowledge base of the coatings industry with regard to the operational particulars of repair and replacement work in the highway environment.

Concrete has also become a more "value-added" and engineered material. As with all construction materials, the price of the basic raw materials for concrete has increased, and the industry has put significant emphasis on obtaining higher strength and higher performance from its mixes across the board. Current high-performance concrete consists of mixes with lower water/cement ratios, various additives, such as pozzolanic materials, and polymer modifications.



Concrete photos courtesy of NLB
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The enhanced nature of modern concrete should provide an opportunity for coatings to now be considered as complementary materials to high-performance concrete applications where enhanced durability is required. Going forward, as the cost of concrete rises on a unit basis, the motivation to protect it will also increase, and the acceptability of value-added protective agents, like coatings, will be entertained more often by engineers and designers.[1]

After briefly discussing general industry trends in coatings for concrete, this article will illustrate how coating and surface preparation technologies have advanced to meet the durability needs of concrete bridges.

Editor's Note: *This article is the third in a series focused on the potential for protective coatings applied to protect concrete bridge infrastructure. The first article appeared in the April 2007* JPCL *and focused on defining the scope of the concrete bridge infrastructure durability issue. The April article outlined the large and growing number of concrete bridges and their increasing average age. In addition, the article presented evidence of that a continuing need exists for enhanced durability for many concrete bridges and that protective coatings offer a potential solution. The second article, appearing in the July* JPCL*, focused on the current and recent testing and field applications by several bridge owner agencies pursuing coatings-based solutions to enhance concrete bridge durability. The third article focuses on coating and surface preparation technology for concrete.*

General Industry Trends in Coatings for Concrete

For the past several years, there has been a major push within the protective coatings community for an increasing emphasis on coatings technology for concrete infrastructure. This push has manifested itself in various ways within the community, from a noticeable increase in training courses, seminars, and symposia focused on coatings for concrete to the symbolic change in the name of SSPC, broadening the moniker from its traditional focus on steel, to include industrial surfaces of all kinds. Ten to fifteen years ago, very little of the technical content of SSPC's programs focused on concrete, whereas today, SSPC offers two formal training courses solely focused on concrete applications with additional concrete- focused content added to several other core training and certification programs. In addition, at PACE 2008, the coatings seminar programs for concrete will more than double compared to previous years.

The target of the shift in focus of the protective coatings industry is the burgeoning national concrete market, which has grown rapidly in the value-added consumer and commercial sectors. As evidence, the annual World of Concrete trade show draws over 85,000 attendees and hosts a contingent of coatings and surface preparation vendors, with the vast majority focused on consumer, flooring, and commercial applications. However, traditional industrial infrastructure applications for coatings are somewhat conspicuous by their absence, yet the need for these applications is urgent.

Trends in Coatings Innovation

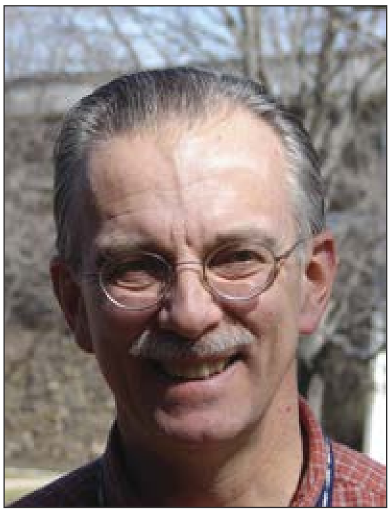
The past two decades have brought significant innovation to the protective coatings sector in general, and the innovation has been driven often by environmental, health, and safety regulations. But recently, with the bevy of regulatory drivers somewhat neutralized, much of the investment of financial and human capital that had been directed toward regulatory compliance has turned toward the primary obstacles now facing the industry: quality and productivity. The reformulation efforts of the 1990s have not only yielded compliant coating systems, but also systems at the high end of the market that show significant performance improvements over previous material generations.[2] Furthermore, qualities such as rapid cure and expanded application flexibility with regard to environmental conditions have made the task of selecting the proper coating system for a specific application more difficult and technical, but, when done properly, more rewarding.

Over the past several years, the innovations in coatings technology have also positioned coatings for concrete to provide significantly more value to infrastructure owners than in the past. Many coatings innovations have developed in the process plant, tank, flooring, and even the architectural industries. (These innovations often have found more ready acceptance in Europe and Canada than in the U.S.) Many companies also offer protective systems that promise the combined benefits of service life extension and aesthetics well beyond the previously accepted standards for concrete structures.

Although the number and type of coatings offered to the industrial community for concrete applications still lag behind the offerings for steel surfaces, the market has grown. The September JPCL's Coatings Buying Guide listed over 200 generic coating systems offered specifically for application to protect concrete bridges. The majority of the systems include some type of epoxy as their resin system, but it is the specific formulation of these various materials that allows a designer to now choose properties that meet the particular requirements of a given job.

The number of high-build and solventless systems has increased dramatically. These types of systems, whether polyurea/polyurethane hybrids or methacrylate-based materials, have gained significant traction recently as high-performance, spray-applied waterproofing membranes for bridge decks in Europe and, more recently, North America.[3] Because bridge decks are the concrete elements of bridges currently in the most desperate need of improved durability, the waterproofing of bridge decks should be viewed as the best entree to the bridge market for coatings of all kinds.

Moreover, manufacturers of various waterborne systems claim excellent performance for their systems, even when applied to "green concrete" (concrete that has been placed only a few hours before application of the coating). Successful coating of green concrete holds great potential for both shop application and field repair applications, where coatings have often been seen as an additional, time-consuming step at the end of a fabrication or rehabilitation process. Materials now available combine the function of a curing compound with a protective sealer into a single step.



Don Schmidt, Rohm & Haas

According to Don Schmidt, group leader for Rohm & Haas's Industrial and Construction Technology Department, "The cure and seal materials qualified to ASTM C1315 provide the complementary benefit of protection to the necessary function of a curing compound without adding a step to the fabrication process." He also notes that the chemistry used in these materials is employed in other available waterborne acrylic coatings so that they can be applied to green concrete shortly after placement.

Speed, combined with quality, will be the mantra of highway work from now on. Fabricators and repair contractors are more often than not working under incentives (or penalties) to complete work rapidly. The days of applying coatings after a 28-day full concrete cure are likely never going to happen in the highway sector.

Trends in Surface Preparation Innovations

Significant progress has also been made in the area of surface preparation of concrete. Now many available technologies suit the needs of specific projects. These technologies include wet methods that range from pressure washing to ultra high-pressure water blasting and closed loop systems. In the area of dry surface preparation technology, significant advances have been made for horizontal surfaces, particularly leveraging the rapid growth of the coating industry in the industrial flooring market. Much of the knowledge developed in the flooring industry is now being transferred by equipment manufacturers and some of the larger contractors to bridge decks, with resulting productivity claims of 30,000 square feet cleaned per hour.

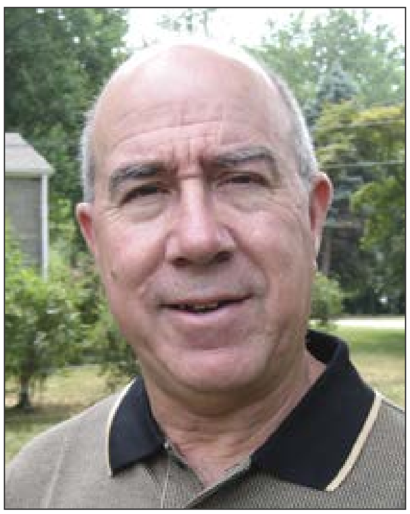
One advantage to the higher productivity equipment is that it reduces the time between surface preparation and coating application. "As long as equipment and procedures are used properly, a rapid placement job can actually bring a complementary quality benefit, as the reduced turnaround time reduces the chances for surface contamination and changing environmental conditions between the surface preparation and first coat application steps," says Greg Bowers, Blastrac's North American market manager, Highways and Airports.

According to Steve Klugherz, global vice president of Strategic Business Development for Blastrac, there are many new methods today, but, "most notable are, grinding technology, dust suppression, and the tooling options for scale." Klugherz notes that the large number of available methods is a benefit only if coupled with the knowledge of when and how to properly use each one. The knowledge base in the industry has developed among the large contractors, but the majority of the contractors doing the work are smaller operations.

To the present author, the need to build the knowedge base reflects conditions in steel bridge painting 15 years ago: in the early 1990s, massive changes in regulatory requirements for steel bridge painting operations, especially for lead paint removal, had a mobilizing effect on the protective coatings industry. Lead paint conferences and training helped build and share the industry's knowledge base.

A similar need for greater cooperation and knowledge sharing in the form of seminars, training, and consensus specifications now exists for surface preparation of concrete. The International Concrete Repair Institute (ICRI) has the most accepted and useful surface preparation standard in the industry, ICRI Technical Guideline # 03732, Selecting and Specifying Concrete Surface Preparation for Coatings, Sealers, and Polymer Overlays. However, the Guideline is not as well known as it needs to be, particularly among specifying engineers and bridge owners.

Wet methods of surface preparation have matured over the past decade as well. As ultra high-pressure water expands its niche in the marine and concrete demolition sectors, it is providing opportunities for technology transfer to surface preparation applications for coating concrete bridges. The extreme flexibility of ultra high- and high-pressure water methods will likely provide a valuable tool for concrete surfaces in the bridge area going forward. John Tanner, Surface Preparation Product Manager for NLB, observed that as a surface preparation tool, "water allows for the cleaning of the concrete surface without the generation of dust. The new, ultra high-pressure systems remove loose or weakened material without fracturing the concrete surface or forcing water into the concrete matrix. The clean, mechanically stable surface that results contributes to better adhesion of the coating system."



John Tanner, NLB

Current Needs

In spite of innovations like the ones referenced above, a crucial need remains for significant investment in the area of industrial coatings for concrete. Standards and applied research and testing are lacking. Discussions with industry experts in development of this article raised a common point–surface preparation and coating material technology are currently available, but more applied testing and research are desperately needed for concrete bridge coatings. Test applications and model specifications are needed to begin implementation of modern, engineered coating systems onto bridge structures on a larger scale.

Within the bridge engineering community, the knowledge base is very thin in this area due to the lack of past experience with coatings for protective purposes and the incremental nature of the past applications that have occurred.

However, several DOTs and toll agencies have years of experience applying coatings to concrete, primarily for aesthetic purposes. There is a common notion among these agencies that they have received an added protective benefit from these aesthetic applications, but consistent, useful documentation of these benefits does not exist.

With the established track record of success of coatings over concrete in recent years in flooring, wastewater, chemical, and secondary containment industries, a recognized, concerted technology transfer effort is possible. Such an effort could jump-start implementation of coatings for concrete bridges.

The best way to accomplish the technology transfer, standards development work, and baseline engineering (spec development, etc.) is to establish formal cooperative efforts. Such efforts could begin through the ongoing regional efforts (e.g., Northeast Protective Coatings Committee (NEPCOAT) and feed into national cooperative programs akin to the National Transportation Product Evaluation Program (NTPEP) run by the American Association of State Highway and Transportation Officials (AASHTO). These collaborative test programs have brought significant continuity to the performance requirements for bridge coatings and technical value to bridge owner organizations.

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Bob Kogler is a principal with Rampart LLC. Previously with the Federal Highway Administration, he led the agency's corrosion protection and coatings research efforts for the past decade. In his last assignment at FHWA, Mr. Kogler led the development effort of the Bridge of the Future research team aimed at making bridges that can be built faster and last longer. He is also a recent past president of SSPC. He can be reached at bob.kogler@mindspring.com.

Preparing Repair Mortars for Wastewater Service: Broom Finish or Blasted Surface?

By Vaughn O'Dea and Rick Schwab, Tnemec Company, Inc.

Concrete is inherently durable and is used extensively in municipal wastewater construction.[1] The deterioration of concrete and reduction of its service life can result, however, when exposed to conditions frequently found within these environments including abrasion, corrosion of steel reinforcement, and biogenic sulfide corrosion.[2,3] The rehabilitation and protection of concrete within these aggressive exposure conditions has consistently been a challenge given the fact that no hydraulic cement, regardless of its composition, will long withstand a pH 3 or lower.[4,5] This problem is exacerbated by increasing concentrations of hydrogen sulfide (H_2S) gas rising beyond the levels protected by traditional protective barrier systems, ultimately negating the protection of the cementitious substrate from biogenic sulfide corrosion.[6,7,8] As a result, high-performance lining systems have emerged specifically for severe wastewater environments.[9]


All photos courtesy of the authors

The protective coatings industry has also paid special attention to the repair of concrete using cementitious resurfacing mortars—both thin overlays and shallow depth replacements—before applying high-performance linings.[10] Resurfacing improves the film quality of a protective coating by providing a contiguous surface for topcoating and ensures a monolithic protective barrier film at a specified nominal thickness. Because of this expanding repair market, cementitious resurfacing materials and repair methods are being introduced at an increasing rate for use under high-performance protective coatings. Unfortunately, as the repair market expands, one result has been conflicting manufacturers' instructions and deviations from many industry standards regarding the curing, finishing and preparation (e.g., broom finish vs. blasted surface) of various cementitious materials, even those that are generically similar. In fact, commonly, manufacturers of repair mortars recommend a broom finish to create a "profiled" surface before applying the lining. Less commonly, manufacturers recommend that the cementitious mortars be blast cleaned or otherwise mechanically profiled to impart a mechanical profile before applying the lining. In the following article, the authors summarize the results of an investigation to quantitatively assess adhesion of a protective lining when applied to a broom finish surface versus a mechanically profiled concrete surface.

Editor's Note: This article is based on a paper presented at PACE 2009, the joint conference of SSPC and PDCA, held February 15-18, 2009, in New Orleans, LA.

Background on Adhesion

The Importance of Surface Profile for Lining Adhesion

When applying a high-performance protective lining directly to new concrete, it is widely accepted that profiling increases the surface area available for bonding the protective lining to the concrete substrate. Profiling also enhances the mechanical adhesion at the concrete/coating interface and helps the lining resist peeling and shear forces. (This premise excludes the effects of a chemical adhesion bond obtainable by some polymer-modified repair mortars.) It seems logical that mechanically profiling a cementitious resurfacing mortar would offer similar benefits to the lining performance. But because broom finishing is still common in wastewater repair, the question arises: does a broom finish profile provide similar adhesive properties to those of a blast cleaned (mechanically profiled) surface (a more expensive and time consuming process)?

Tensile Strength and Adhesion

To be effective in the rehabilitation and protection of concrete, a protective system, which includes both the cementitious repair mortar and protective lining, must develop and maintain adhesive and cohesive direct tensile strengths greater than the surface tensile strength of the parent concrete. This criterion ensures that the system is able to withstand the stresses imposed on, and the processes of deterioration associated with, severe wastewater environments.

A cementitious resurfacer exhibiting weaker surface tensile strength properties than the parent concrete surface potentially compromises the integrity of the protective system and is prone to cause the system to fail prematurely. The repair mortar's surface tensile strength, or bond zone strength, which refers to the surface of the mortar that will be in contact with the coating, is not as well understood as it should be. Because of the diverse finishing/preparation recommendations oftentimes encountered within the wastewater repair industry, there is a need for a more comprehensive understanding of the general surface tensile behavior of the various hydraulic resurfacing composites for use under high-performance protective linings. Specifiers and users of cementitious repair materials would clearly benefit from information that quantifies the bond zone strength of popular cementitious mortars.

Measuring Bond Strength

It is well established that the development and maintenance of a sound bond between the coating and the concrete substrate is an essential requirement for heavy-duty, high-performance protective lining systems. Tensile pull-off tests are becoming increasingly favored in laboratory and site quality control/quality assurance testing. Various industry consensus guidelines recommend that pull-off adhesion tensile testing should result in substrate (parent) concrete cohesive failure as most desirable for coatings applied to concrete. In this case, the pull-off stress (adhesion) is considered exceeding the direct tensile strength of the substrate concrete. There are two popular ASTM testing methods describing tensile pull-off testing.

ASTM D 7234 *Standard Test Method for Pull-Off Adhesion Strength of Coatings on Concrete Using Portable Pull-Off Adhesion Testers* (formerly recommended for coatings on concrete under ASTM D 4541) stipulates scoring of the coating down to the surface of the substrate. As reasonably interpreted, the substrate is considered any cementitious material (i.e., cast concrete substrate, cementitious repair mortar, etc.). This "limited" scoring, however, causes stress non-uniformity due to the concentration of tensile stress at the dolly periphery at its interface with the substrate. This leads to a corresponding increase in the substrate stress at this position, which extends into the concrete (or cementitious mortar) beyond the dolly perimeter. This may provide an explanation to the small degree of 'overbreak', whereby the tensile stress extends beyond the dolly perimeter and results in higher measured tensile strength of the cementitious repair mortars (often exceeding the actual tensile strength values of the concrete substrate).

ASTM C 1583/C 1583M *Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method)*, on the other hand, requires partial core drilling through the cementitious mortar and into the concrete substrate a minimum one-half inch. Partial coring reduces stress variation and ensures a reasonably uniform distribution of concrete stress over the full depth of the coring. Unlike ASTM D 7234, the failure plane is usually located at the end of the drilling core – reflecting actual direct tensile strength. The failure load (measured tensile strength) tends to be slightly lower when using this method compared to ASTM D 7234.

Laitance and Adhesion

New concrete—along with other cementitious substrates—commonly has a weak surface layer, called laitance, resulting from use of too high a water/cement ratio, draw-

Table 1: Cementitious Resurfacing Materials Included in Surface Bond Strength Evaluation

Product Designation	Cementitious Mortar Type	Minimum Thickness	Maximum Thickness	Mfgr's Recommended Finishing Technique(s)	Mfgr's ACI External Curing Requirements
Mortar 1	Epoxy-modified	1/16"	1/4"	Rubber float, steel trowel, masons brush	None
Mortar 2	Epoxy-modified	1/16"	1/8"	Rubber float, steel trowel, masons brush	None
Mortar 3	Epoxy-modified	1/16"	1"	Conventional concrete finishing tools	None
Mortar 4A	Acrylic-modified	1/4"	2"	Wooden or rubber float, trowel	ACI 308
Mortar 5	Acrylic-modified	1/4"	3/4"	Trowel	ACI 308
Mortar 6	Acrylic-modified	1/8"	1.5"	Wooden or rubber float, trowel	ACI 308
Mortar 7	Portland-based	1/4"	1/2"	Broom	<5-8 hrs apply coating; >8 hrs ACI
Mortar 8	Portland-based	3/8"	2"	Wooden or rubber float, trowel	ACI 308
Mortar 9	Portland-based	3/8"	1.5"	Wooden or rubber float, trowel	ACI 308
Mortar 10	Calcium Aluminate-based	1/2"	3"	Broom	ACI 308
Mortar 11	Calcium Aluminate-based	1/2"	1"	Broom	<70% R.H. Curing Required; >70% None
Mortar 12	Calcium Aluminate-based	1/2"	3"	Trowel or broom	Not listed

ing of fines to the surface during surface finishing, the exudation of fines with bleed water, or improper curing. Laitance will have a weaker tensile strength than the rest of the concrete substrate, and if not removed, will weaken the concrete's ability to provide an adequate surface for lining adhesion. It is possible that like concrete, cementitious repair materials form a laitance layer that could similarly interfere with the adhesion of the lining and the success of the complete repair system.

Unfortunately, the presence and the depth of laitance typically cannot be detected visually, but must nevertheless be removed to create a surface profile that will enhance lining adhesion.

Mechanically Profiled Surface and Laitance

The value of a mechanically profiled concrete surface before applying a lining reflects the prevailing view that the removal of the laitance is paramount to achieving maximum bond strength of the lining.[11,12] Moreover, a recent study by the author found that most cementitious repair mortars commonly used for wastewater rehabilitation increased their surface tensile properties when externally cured, that is, with a curing membrane applied in accordance with ACI 308R.[13,14] The study further concluded that the adhesion of a high-performance protective lining was maximized when the surface of these repair mortars was mechanically profiled, which removed the laitance layer and curing compound, where present. (Adhesion of the lining over a broom-finished surface was not addressed in the earlier study.)

Broom Finished Surface Profile and Laitance

Research suggests the broom finish profile for linings may have originated from the concrete repair industry practices (when no lining is involved) to improve the bond of the mortar to itself. When rehabilitating concrete using cementitious mortars in multiple lifts, it is common practice to thoroughly roughen, cross hatch, or rake the surface of the first lift of the repair mortar to promote additional mechanical bond for the subsequent lift (Fig. 1).[15-18] Despite the common use of broom finishing to profile repair mortar before lining application, the authors found no literature suggesting whether or not this finishing technique categorically alleviates the formation of laitance, the weak surface layer that may affect the bonding of a protective lining system.

Fig. 1: Typical broom-finished surface

Objectives of the Study

Because of the lack of available research on repair mortars and laitance, the study described in this article was undertaken to address the following questions. Is it possible that a broom-finished surface eliminates the formation of a laitance layer on cementitious repair mortars? And is the surface tensile strength of a broom-finished surface equal to or greater than the surface tensile strength of the parent concrete so that the mortar can properly receive a high-performance lining?

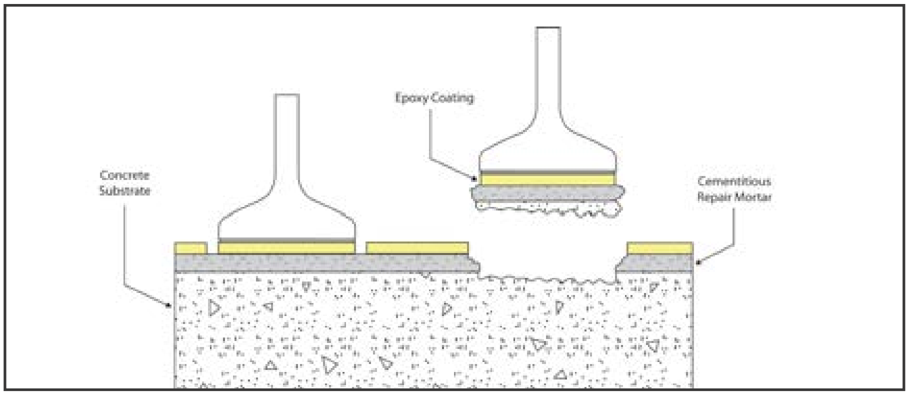


Fig. 2: Tensile strength testing, ASTM D 7234

Experimental Method

Cementitious Mortars

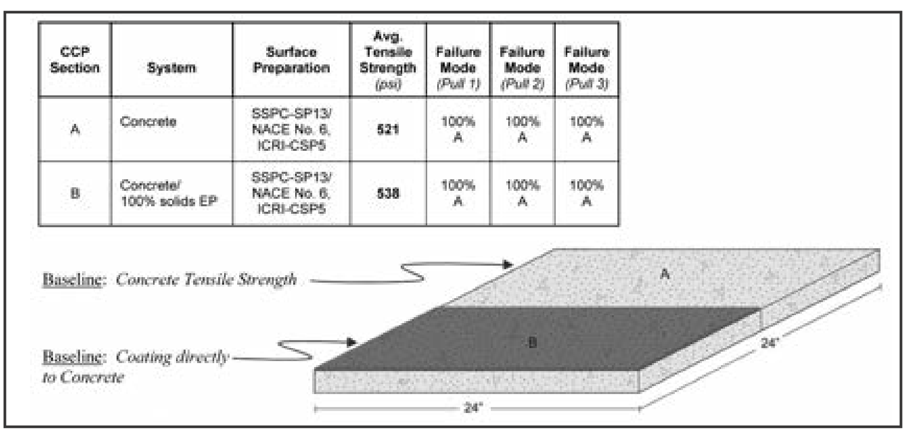
Cementitious mortars using ingredients that most closely match those of concrete are the best choices for repair materials.[17] Based upon this principle, the authors surveyed 100 wastewater projects and found the four cementitious repair composites most commonly specified for use in concrete repair under protective lining systems.[19] These cementitious composites are generically classified as:

- epoxy-modified cementitious mortars,
- acrylic-modified cementitious mortars,
- portland-based cementitious mortars, and
- calcium aluminate-based cementitious mortars

Three commercially available repair materials from each generic composite type were procured for this research study. The mortars vary in their respective surface preparation requirements, minimum application thicknesses, curing requirements (and durations), surface finishing technique(s), and subsequent surface preparation required to receive a high-performance coating (Table 1). Testing matrices were developed to compare the surface tensile properties of the twelve mortars when applied at their respective minimum recommended thickness.

Bond Strength Testing

The surface tensile strength properties of the selected repair materials–with and without a high-performance topcoat– were assessed in accordance with ASTM D 7234 (Fig. 2).[20] This test method delineates a procedure for evaluating the direct tensile strength (commonly referred to as adhesion) of a coating on concrete (or other cementitious substrate). The test determines either the greatest perpendicular force (normal stress, s) that a surface area can bear before a plug of material is detached.[21] The uniaxial testing instrument used for this tensile strength assessment was the self-aligning tensile pull-off adhesion tester using 50-mm (2-in.) diameter dollies. Tension was applied until failure was achieved, and the maximum normal stress and the location of the failure were recorded. The peak loading for this instrument using 50-mm diameter loading fixtures (dollies) after conversion is 560 psi. (See sidebar on p. 29)



CCP Section	System	Surface Preparation	Avg. Tensile Strength (psi)	Failure Mode (Pull 1)	Failure Mode (Pull 2)	Failure Mode (Pull 3)
A	Concrete	SSPC-SP13/ NACE No. 6, ICRI-CSP5	521	100% A	100% A	100% A
B	Concrete/ 100% solids EP	SSPC-SP13/ NACE No. 6, ICRI-CSP5	538	100% A	100% A	100% A

Fig. 3: Concrete control panel–tensile strength

Fig. 4a: Testing surface tensile strength properties using 50-mm-diameter dollies in accordance with ASTM D 7234

Fig. 4b: Testing surface tensile strength properties of Concrete Control Panel A (SSPC-SP 13/NACE No. 6, ICRI-CSP5 prepared concrete panel) using 50-mm-diameter dollies in accordance with ASTM D 7234.

Fig. 4c: Evaluating surface tensile strength properties of Concrete Control Panel B.

Failure occurs along the weakest plane within the system. The test results were reported as determined by observing the bottom of the dollies with the following designations:

- Concrete substrate: A
- Mortar: B
- Epoxy topcoat: C (where applied)
- Adhesive (glue): Y
- Loading Fixture (Dolly): Z

Cohesive failures and the percent of each were denoted as A, B, C, or Y. Adhesive failures by the interfaces at which they occur where denoted A/B, B/C, C/Y, etc.

- Concrete Substrate Panels: In laboratory work it is common to produce a high strength substrate to maximize the chance of obtaining adhesive bond failure as opposed to a tensile (cohesive) failure of the concrete substrate. Non-reinforced concrete panels were cast 24 in. x 24 in. x 2 in. to provide a common substrate for testing. The concrete was a high-strength 5,500 psi Portland Type I design mix conforming to ASTM C 387.[22] The top faces of the panels (exposed side) were finished and membrane cured per ACI 308R[14] using two coats of an acrylic membrane-curing compound conforming to the requirements of ASTM C 309.[23] The concrete panels were both cast and cured in a controlled laboratory environment (72 F and 48% RH) and remained in the forms for 7 days; the panels were demolded and maintained in laboratory conditions. After a period of 28-days, the concrete panels were prepared by dry-abrasive blasting the top face of the panels to an SSPC-SP 13/NACE No. 6 surface condition,[12] and achieving an ICRI-CSP5 surface profile.[24] The concrete substrate panels serve as the parent concrete for our study.
- Epoxy Coating (EP): A high-build, 100% solids, two-component, high-functionality amine epoxy was used as a representative high-performance protective lining used over cementitious mortars in aggressive environments. The epoxy was applied in a single coat to a dry film thickness (DFT) of 30 mils.

This commercially available high-performance lining is recommended for use over concrete and steel in highly corrosive wastewater and other chemically aggressive environments. The suggested thickness range for this product is 30–80 mils DFT. When applied directly to properly prepared concrete, the technical data sheet indicates that the adhesion exceeds the tensile strength of concrete (cohesive concrete failure).

- Concrete Control Panel (CCP): A single, randomly selected concrete substrate panel was withheld for use as a control in accordance with the sampling procedures outlined in ASTM D 3665.[25] The concrete panel was 24 in. x 24 in. x 2 in., finished, membrane cured, and prepared consistent with the panels and methods described above.

Concrete Panel Section	Mortar System[1]	Acrylic Membrane Cured *(ACI 308)*	Subsequent Surface Preparation[2]
C	Concrete/ Mortar X	No	None
D	Concrete/ Mortar X	Yes	None
E	Concrete/ Mortar X/ 100% solids EP	No	None
F	Concrete/ Mortar X/ 100% solids EP	Yes	None
G	Concrete/ Mortar X/ 100% solids EP	No	ICRI-CSP3
H	Concrete/ Mortar X/ 100% solids EP	Yes	ICRI-CSP3
I	Concrete/ Mortar X	No	ICRI-CSP3
J	Concrete/ Mortar X	Yes	ICRI-CSP3

[1] *Cementitious Resurfacing Mortars, Refer to Table 1.*
[2] *Mortar surface preparation to produce an ICRI-CSP3 surface profile.*

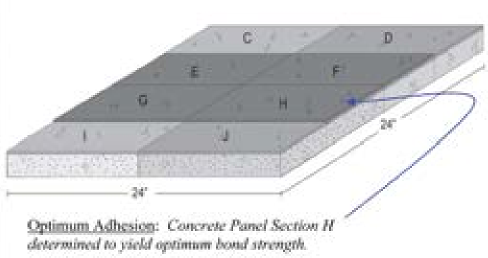


Fig. 5: Bond strength matrix—trowel finished/mechanically profiled

The upper-half of the concrete panel—Section A (Fig. 3 on p. 31)—was designated as the Concrete Control Panel-A (CCP-A) and remained unchanged from the surface preparation condition (SSPC-SP 13/NACE No. 6, ICRI-CSP5). CCP-A was used to determine the tensile strength of the concrete control panel. The lower half of the concrete panel section—denoted CCP-B—was topcoated with 30 mils' DFT of the epoxy coating and allowed to cure for 7 days. After the 7-day cure, sections A and B were evaluated for bond strength using methods outlined in

Concrete Panel Section	System¹	Acrylic Membrane Cured (ACI 308)	Subsequent Surface Preparation
K	Concrete/ Mortar X	No	None
L	Concrete/ Mortar X	Yes	None
M	Concrete/ Mortar X/ 100% solids EP	No	None
N	Concrete/ Mortar X/ 100% solids EP	Yes	None

¹Cementitious Resurfacing Mortars, Refer to Table 1.

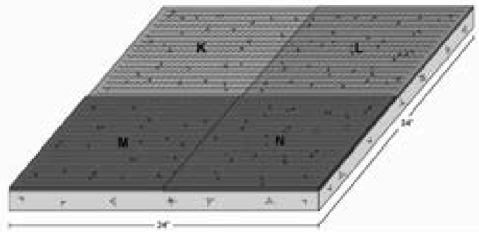


Fig. 6: Bond strength matrix—broom finished

ASTM D 7234 using the adhesion tester with 50-mm diameter dollies (Figs. 4a, 4b, and 4c). The CCP-B was used to determine the tensile strength of the representative parent concrete substrate using the uniaxial testing instrument when a 100% solids epoxy barrier system was applied directly to the prepared substrate. Both CCP-A and CCP-B serve as the control for this study. The baseline tensile adhesion values are outlined in Fig. 3. As Fig. 3 shows, in the tensile strength tests, all failures of the lined concrete were cohesive, occurring within the concrete, not within the lining or at the lining-concrete interface. Hence, as indicated in the lining manufacturer's data sheet, the lining adhesion exceeded the tensile strength of the concrete substrate. These results confirm that proper preparation and application procedures were followed.

After the tests, the bond strength of broom-finished and mechanically profiled coated mortar test panels would be compared to CCP-B to determine whether or not the coated cementitious repair mortar exhibits properties equal to the coated concrete control, and if finishing technique affects the soundness of the surface of the repair mortar and its ability to properly accept the coating.

Fig. 7a: Typical broom finish profile using mason's brush

Fig. 7b: Lining over broom-finished mortar

Fig. 7c: Surface tensile strength failure planes were determined by observing the bottom of the 50-mm dollies.

Testing Matrices

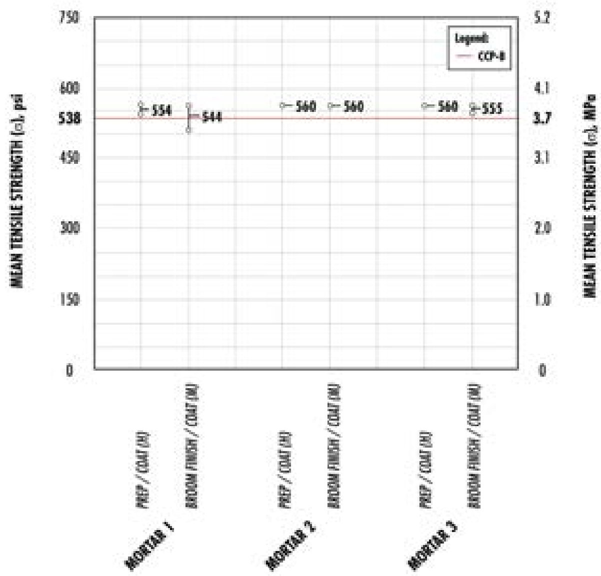
Two testing matrices were developed to determine which surface finishing technique (e.g., blasted surface or broom finish) maximizes adhesion of the protective lining applied to the twelve repair mortars. The results were then compared to the tensile strength of CCP-B, which represents a coating applied directly to properly prepared concrete.

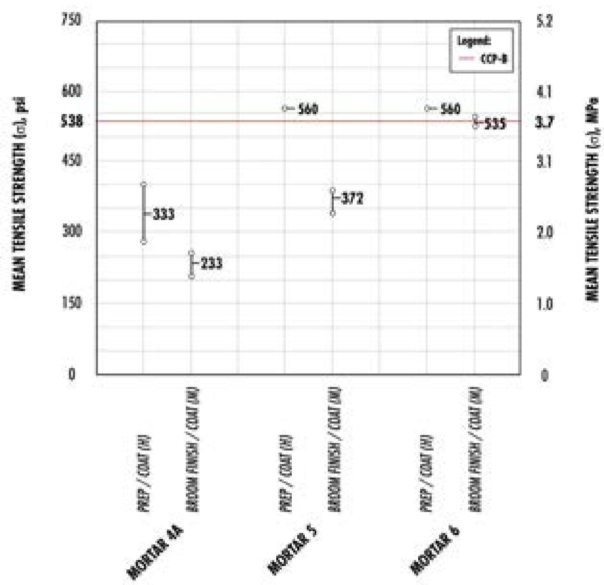
• Mechanically Profiled Surface Matrix: This testing matrix comprises eight quadrants (concrete panel sections) that compare the bond strengths of the twelve repair mortars by evaluating the influences of curing/no curing, mechanical preparation/no preparation, and topcoating/no topcoating with a high-performance lining system (Fig. 5). Excerpts from the research study on the effects of curing and mechanically profiling these cementitious repair mortars are presented below.[13]

Each of the twelve selected cementitious mortars was applied to the concrete substrate panels at their respective minimum recommended thickness. The concrete panels were first dampened with potable water to achieve a saturated surface dry (SSD) condition. A scrub coat of each mortar was then applied to the prepared concrete substrate panel followed by the immediate application using a rubber float. The mortars were finished using a steel trowel to obtain a smooth, uniform finish. In order to test the effect of mortar hydration with and without external curing, an acrylic membrane-curing compound was applied to half of the mortar (Fig. 5). The left half of the concrete panel—Sections C, E, G, I—received no external curing; the right half of the panel—Sections D, F, H, J—were cured using two coats of an acrylic curing compound in accordance with ACI 308R.

After the proper curing (hydration) period for each respective cementitious mortar, the lower sections G, H, I, J were blasted to an SSPC-SP 13/NACE 6, ICRI-CSP3 profile to remove the curing compound (where used) and weak laitance layer of the mortar (where present). The 100% solids epoxy coating was immediately applied to the middle sections E, F, G, H of the panel and allowed to cure for an additional 7 days.

Following the 7 days' cure of the epoxy coating, each panel section was tested for bond strength using ASTM D 7234 adhesion tester using 50-mm diameter dollies.





Each section was tested in triplicate, and an average value was reported for the respective mortars.

- Broom-Finished Surface Matrix: A testing matrix composed of four quadrants (concrete panel sections) was established to assess the effects of broom finishing of the 12 repair mortars with and without topcoating. Each panel section compared the surface bond strength of the mortar upon receiving a broom finish by evaluating both the influences of curing/not curing and topcoating/not topcoating with a high-performance lining on the repaired surface (Fig. 6).

Each of the twelve selected cementitious mortars was applied to the concrete substrate panels at their respective minimum recommended thickness. The concrete panels were first dampened with potable water to achieve a saturated surface dry (SSD) condition. A scrub coat of each mortar was then applied to the concrete panel followed by the immediate application using a rubber float. The mortars were finished using a mason's brush to produce a broom finish profile. In order to test the effect of mortar hydration with and without external curing, an acrylic membrane-curing compound was applied to half of the mortar (Fig. 6).

The left half of the concrete panel—Sections K, M—received no external curing; the right half of the panel—Sections L, N—were cured using two coats of an acrylic curing compound in accordance with ACI 308R. Upon the proper curing (hydration) period for each respective cementitious mortar, the 100% solids epoxy coating was applied directly to the lower sections M, N of the panel and allowed to cure for an additional 7 days. Following the 7 days' cure of the epoxy coating, each panel section was tested for bond strength using ASTM D 7234 adhesion tester using 50-mm diameter dollies (Figs. 7a, 7b, and 7c).

Analysis

Blasted (Mechanically Profiled) Surface Matrix

Of the mechanically prepared sections, Concrete Panel Section H (membrane cured and blasted profile) achieved the maximum bond strength when topcoated with a protective lining system. This is not entirely unexpected given that liquid membrane-curing compounds prevent the loss of moisture from the mortar, thereby allowing the

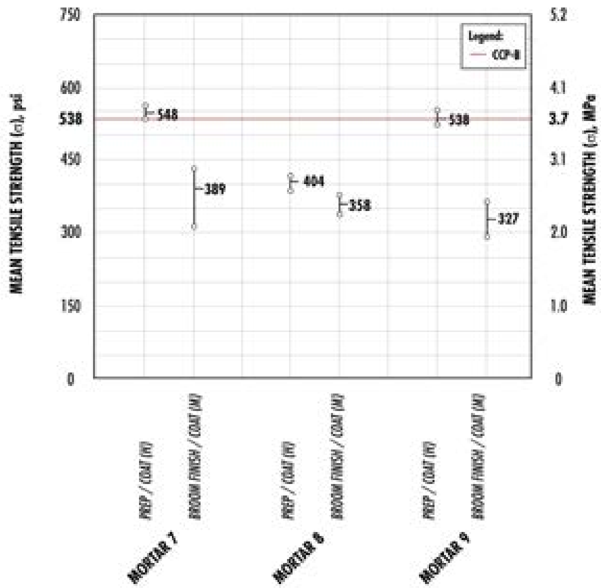


Fig. 10: Portland-based cementitious mortars

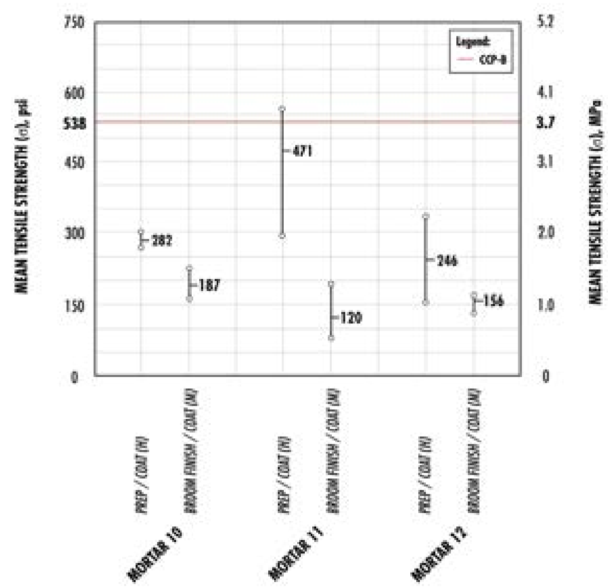


Fig. 11: Calcium aluminate-based cementitious mortars

development of surface tensile strength properties. Membrane curing is the most practical method of curing vertically- and overhead-placed repair mortars common to wastewater rehabilitation where job conditions are not favorable for wet-curing in accordance with ACI 308R. What's more, membrane curing compounds must be removed prior to the application of the lining system in accordance with guidelines of the protective coatings industry.[12]

Broom-Finished Surface Matrix

Of the broom-finished sections, the results for the twelve cementitious repair mortars suggest that Concrete Panel Section M (broom-finished profile and no membrane curing) achieved the maximum mortar surface bond strength when topcoated with a protective lining system. A few of the mortars actually yielded higher adhesion values in Concrete Panel Section N (broom finished and membrane curing compound). Upon closer examination, it is plausible that the anomalous improvement in tensile strength derived from proper curing exceeded any diminished bonding of the lining system to the mortar by the presence of the membrane "bond breaker." Nevertheless, when canvassing the candidate repair mortars used in this study, it appears that a broom-finished surface is not recommended to receive a membrane curing compound if topcoated with protective lining systems. That is, a curing membrane is supposed to be removed before coating; otherwise, the membrane may form an adhesion "bond breaker" between the mortar and the topcoat. The advantages of the broom-finished profile would be lost, however, during the required removal of the curing compound.

The results of these testing matrices can now be evaluated to determine which surface finish optimizes the adhesion of a high-performance lining to a cementitious repair mortar. The surface tensile strengths of Concrete Panel Section H (Prep/Coat) and Concrete Panel Section M (Broom Finish/Coat) have been juxtaposed in (Figs. 8–11), along with the Concrete Control Panel B (CCP-B). Recall, the optimum surface tensile strength (pull-off adhesion) value for coatings over mortar test panels in our study is greater than or equal to the adhesion of a high-performance protective lining applied directly to properly prepared concrete (CCP-B). The baseline coating pull-off adhesion for CCP-B for use in our study, is 538 psi (Fig. 3).

Tensile Strength Comparisons of Mortar Panel Sections H vs. M

For each of the four repair composite types tested, Figs. 8–11 compare the coating pull-off adhesion values of Panel H (mechanical preparation) against those of Panel M (broom finish). Figures 8–11 also show the coating adhesion values of panels H and M relative to 538 psi for CCP-B, our baseline coating adhesion value.

Conclusions

Our findings indicate that a blasted (mechanically profiled) surface offers superior adhesion to that of a broom-finished (profiled) surface when preparing cementitious repair mortars to receive high-performance lining systems. In sum, 7 of the 12 mechanically profiled panels had surface tensile strengths equal to or greater than that of properly prepared concrete, as indicated by the coating pull-off adhesion values in Figs. 8–11. In contrast, 8 of the 12 broom-finished mortars yielded near-surface tensile strengths significantly lower than that of properly prepared concrete. Adhesion of coatings over most broom-finished mortars didn't even meet the benchmark surface tensile strength 538 psi of CCP-B Control for the optimum bonding of the lining system. Based on the coating adhesion values, the epoxy cementitious composites were the only mortars that, when broom finished and mechanically profiled, exhibited tensile strengths comparable to each other and to CCP-B.

Further, it was concluded a broom-finished surface generally forms a weak upper surface (laitance) layer on the majority of the cementitious composites tested in this study. This conclusion was drawn from observing a clear pattern of preferential failure in this surface zone, which indicates that the repair material, when broom finished, was generally the weakest link in the repair system. (An exception to this finding was the epoxy cementitious composite, possibly because the epoxy polymerization prevents the formation of the laitance layer.) A laitance layer manifests as a weakened or decreased surface tensile strength compared to properly prepared cementitious mortar, and requires removal in accordance with standards set forth by the protective coatings industry.[11,12]

It should be noted that this study contrasted mortar surfaces prepared to an ICRI-CSP3 profile only to detect a weak upper surface (laitance) layer. Greater surface rugosity (amplitude) may be required by the coatings manufacturer for long-term adhesion performance within wastewater environments.

Buyers beware! Beware of exaggerated claims of experience with surface finishing of cementitious repair materials. Beware of anecdotal evidence as means of a repair mortar's capability. Beware of crotchets or other forms of unorthodox experience as evidence of success. Instead, request that manufacturers submit testing of compatibility of the entire system in accordance with industry consensus standards. Request that manufacturers provide laboratory testing to substantiate surface finishing and preparation requirements when topcoated with high-performance lining systems. Require manufacturers to provide clear instructions for curing, finishing, and preparation in application instructions and on component labels of cementitious repair materials. And lastly, be diligent and perform testing of onsite mock-ups of candidate cementitious repair mortars when topcoated with high-performance protective lining systems.

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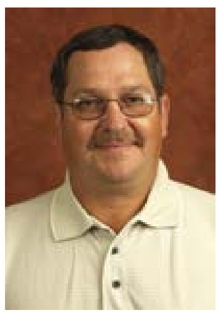

Rick Schwab has 35 years of experience with Tnemec Company. As Product Support/ Quality Control Manager, he is in charge of the company's quality control procedures and testing laboratory as well as troubleshooting on the production floor. He has been involved with ASTM for 10 years, including work with the D01.46 industrial coatings committee and the accelerated testing committee.