Thin-Patch Repair of Concrete in Wastewater Environments Using Commercially Available Cementitious Resurfacers

By Vaughn O'Dea

Materials commonly employed to address the surface defects and irregularities found in new or rehabilitated wastewater concrete construction include commercially available, thin-patch cementitious resurfacers. An investigation to quantitatively assess bond strength of various cementitious mortars when topcoated with high-performance protective coatings was presented at the ICRI 2007 Fall Convention. The following report is based on that presentation and related technical paper, which is available in its entirety at ***www.tnemec.com****.*

Concrete used in municipal wastewater construction is subject to deterioration and reduced service life when exposed to conditions found within these environments, including abrasion (erosion corrosion), corrosion of steel reinforcement, and biogenic sulfide corrosion (chemical attack).

The rehabilitation and protection of concrete within these aggressive exposure conditions has consistently been a challenge given that no hydraulic cement, regardless of its composition, can withstand water of high acid concentration (pH of 3 or lower). Of particular concern is the increasing concentration of hydrogen sulfide (H_2S) rising beyond the levels protected by traditional protective barrier systems, ultimately negating the protection of the concrete offered by protective coatings.

It is not uncommon to observe upward of 1/8 in. (0.3 cm) of concrete loss per year within collection systems averaging 20 to 50 ppm H_2S; extreme cases found concrete loss approaching 2 in. (5 cm) in a single year. These observations prompted the development of laboratory testing programs to evaluate the resistance of various commercially available, high-performance protective coatings to various wastewater components.

One notable program, conducted by John Redner with the Sanitation District of Los Angeles County, attributed the predominant mode of coating failure to pinholes within the barrier systems. These pinholes, which are a typical condition of vertically cast-in-place and precast concrete surfaces, are caused by the release of entrapped air (also known as bughole-induced outgassing) within the substrate during application of the protective coating system. These pinholes allow gasses or fluids to penetrate an otherwise impervious material.

Thin Overlay Material

The use of a thin overlay of a cementitious resurfacing material to repair the surface defects of new or existing concrete improves the film quality of protective coatings by eliminating possible pinholes, thereby ensuring long-term barrier protection of concrete in severe wastewater environments. To be effective, however, both the cementitious repair mortar and the protective coating must develop and maintain adhesive bond strength greater than the tensile strength of the concrete (350 to 500 psi [2.4 to 3.4 MPa]). Bond strength is the resistance of the repair material to separation from the concrete substrate or other materials with which it comes in contact.

In a concrete repair study (presented at the ICRI 2007 Fall Convention), researchers examined several factors that influence and effect the general tensile behavior of repair materials most commonly used as thin-patch overlays in wastewater construction. Cementitious composites used in the study were based on hydraulic binders including:

- Portland or blended cementitious mortars;
- Calcium aluminate-based cementitious mortars;
- Acrylic-modified cementitious mortars (two-component); and
- Epoxy-modified cementitious mortars (three-component).

Research findings confirmed the effects of external curing and surface preparation in determining the bond strength characteristics of these cementitious thin-patch resurfacers when topcoated with high-performance protective coatings. "The lack of proper curing and surface preparation has resulted in many unsubstantiated claims for product suitability and successes within wastewater applications when topcoated with high-performance protective coatings," according to the study.

Research Findings

Industry research has found that bond strength development of cementitious resurfacers proceeds at a slower rate than compressive strength development, causing workers to mistakenly abandon curing procedures prematurely when the traditional cementitious mortar seems strong. Once the mortar dries, however, strength development stops and bond failure of the mortar patch can result.

Thin-patch cementitious resurfacers are susceptible to plastic shrinkage cracking because their high surface-to-volume ratio promotes rapid evaporation under drying conditions. Failure to preserve the necessary water required for proper cement hydration results in a cure-affected zone, which lacks the integrity required to withstand the internal stresses created by protective coatings. In one published report, cement material exposed to a dry environment in its early stages resulted in the outer layer (0.2 to 0.4 in. [5 to 10 mm]) being considerably weaker by 38 to 43%.

The concrete repair study emphasized the importance of proper curing in providing cementitious resurfacing materials with the physical properties required. Proper curing also prevents unhydrated or poorly hydrated cement in the mortar due to evaporative loss of water from the surface.

According to the study, "Conventional cementitious mortars used for repairs of concrete must be externally cured according to the recommendations of ACI 308 (American Concrete Institute Guide to Curing Concrete) or other industry guidelines. Commonly used cementitious thin-patch repair mortars, with the exception of the epoxy-modified compositions, require external curing to maximize their tensile properties. This is critical when topcoating with high-performance coating systems."

The study demonstrated the use of liquid membrane-curing compounds as the most practical method of curing vertically placed mortars where job conditions are not favorable for wet curing. The membrane-curing compound prevents the loss of moisture from the mortar, thereby allowing the development of strength; however, it must be removed before the protective coating application. This criterion is echoed by surface preparation standards set forth by the protective coatings industry.

The concrete repair study also demonstrated the need for proper surface preparation of the cementitious thin-patch resurfacers before topcoating with high-performance protective coatings. These cementitious materials may form a weak surface layer resulting from the use of a too-high water-cement ratio, overworking during finishing, the exudation of fines with bleed water, or due to the improper curing of the mortar.

"The unhydrated/poorly hydrated mortar forms a plane of weakness near the surface that causes significant reduction in tensile strength properties, potentially leading to a cohesive failure of the mortar when topcoated with a high-performance protective coating," the study reported.

The removal of this weak surface material to sound mortar before the application of a protective barrier system is paramount to attaining maximum bond strength, the study concluded.

Bond Strength Testing

The concrete repair study tested 12 commercially available cementitious resurfacing materials (three from each composite type) in the bond strength evaluation. The tested materials varied in their respective surface preparation requirements, minimum application thicknesses, curing requirements and duration, and subsequent surface preparation required to receive a high-performance coating.

The bond strength properties of the selected repair materials were assessed in accordance with ASTM D7234, which delineates a procedure for evaluating the direct tensile strength of a coating on concrete. The test determines the greatest perpendicular force (normal stress σ) that a surface area can bear before a plug of material is detached. The maximum measurable force for this instrument using 2.0 in. (50 mm) diameter loading fixtures (dollies) after conversion is 560 psi (3.9 MPa).

The selected repair materials were tested on 24 x 24 x 2 in. (61 x 61 x 5 cm) concrete panels to provide a common substrate for testing. The concrete was a high-strength 5500 psi (37.9 MPa) portland Type I design mixture conforming to ASTM C387. The exposed side of each panel was finished and membrane cured per ACI 308. Two coats of an acrylic membrane-

Typical prepared CIP concrete exhibiting bugholes (upper half) and an epoxy modified cementitious overlay applied to create a contiguous surface for lining (lower half) curing compound meeting the requirements of ASTM C309 were applied.

The panels were both cast and cured in a controlled laboratory environment monitored at an average 72 °F (22 °C) and 48% relative humidity conditions. The panels remained in the forms for 7 days. After 28 days, the concrete panels, less one control panel, were mechanically prepared by dry-abrasive blasting the top face of the panels to an SSPC-SP13/NACE No. 6 surface condition and achieving an ICRI-CSP 5 surface profile.

A high-build, 100% solids, two-component, high-functionality amine epoxy was used as a representative high-performance protective coating used over cementitious mortars in aggressive environments. The epoxy was applied in a single coat to a dry film thickness of 30 mils. This commercially available high-performance coating is recommended for use as a liner over concrete and steel in highly corrosive wastewater and other chemically aggressive environments.

Concrete panel section	System	Acrylic membrane cured (ACI 308)	Subsequent surface preparation
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-CSP 3
H	Concrete/ Mortar X/ 100% solids EP	Yes	ICRI-CSP 3
I	Concrete/ Mortar X	No	ICRI-CSP 3
J	Concrete/ Mortar X	Yes	ICRI-CSP 3

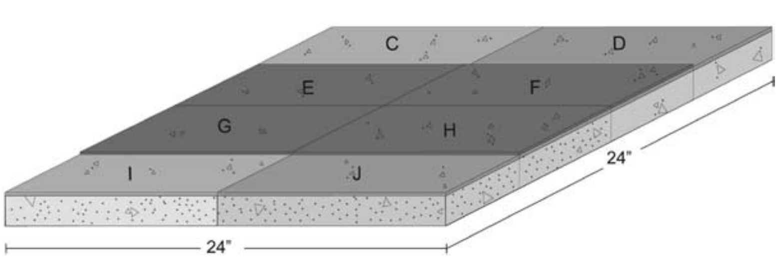


Fig. 1: Bond strength matrix—trowel finish

A randomly selected control panel was withheld in accordance with the procedures outlined in ASTM D3665, finished, membrane-cured for a period of 28 days, and mechanically prepared by dry-abrasive blasting to an SSPC-SP13/NACE No. 6, ICRI-CSP 5 profile. The upper-half of the concrete control panel (designated Section A) remained unchanged from the surface preparation condition (SSPC-SP13/NACE No. 6, ICRI-CSP 5). The lower half of the concrete control panel (designated Section B) was topcoated with 30 mils dry film thickness (DFT) of the epoxy coating and allowed to cure for 7 days. Upon the 7-day cure, Concrete Control Panel (CCP) Sections A and B were evaluated for bond strength using methods outlined in ASTM D7234 using the adhesion tester with 2 in. (50 mm) diameter dollies.

Each of the 12 selected cementitious mortars was applied to the concrete 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 using a rubber float, followed by an immediate steel trowel application of the respective mortars.

The mortars were finished using a steel trowel to obtain a smooth, uniform finish. To test the effect of mortar hydration with and without external curing, the acrylic membrane-curing compound was applied to half of the mortar (refer to Fig. 1). The left half of the concrete panel—Sections C, E, G, and I—received no external curing; the right half of the panel—Sections D, F, H, and J—were cured using two coats of an acrylic curing compound in accordance with ACI 308.

Upon the proper curing (hydration) period for each respective cementitious mortar, the lower Sections G, H, I, and J were dry-abrasive blasted to an SSPC-SP13/NACE 6, ICRI-CSP 3 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, and H of the panel and allowed to cure for an additional 7 days. Following the 7-day cure of the epoxy coating, each panel section was tested for bond strength using ASTM D7234 adhesion tester using 2 in. (50 mm) diameter dollies. Each section was tested in triplicate and an average value reported for the respective mortars.

Analysis of Testing

Results from the bond strength testing for each of the 12 cementitious mortars are highlighted in Fig. 2 through 5, which are based on tensile strength

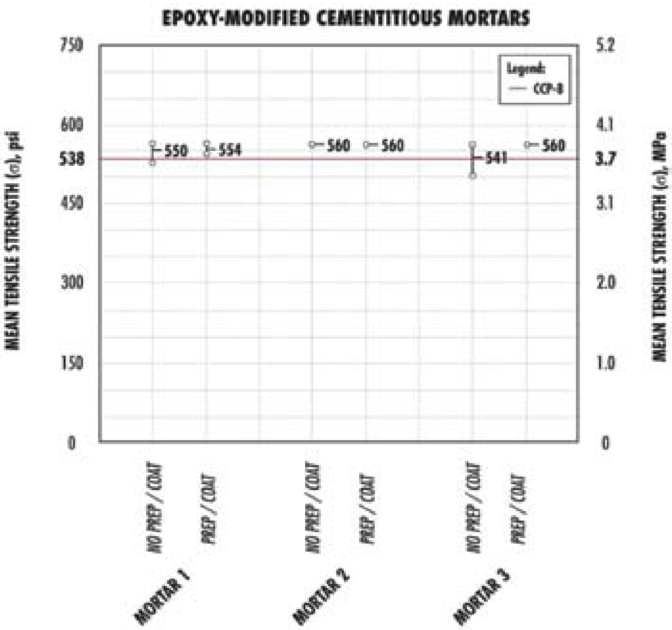


Fig. 2: The epoxy modification to Mortars 1, 2, and 3 increased the tensile properties of the mortar at the surface to eliminate the formation of a weak upper surface (laitance) layer usually present in cementitious materials. Each of these mortars demonstrated tensile strengths greater than the Concrete Control Panel B with negligible improvements of bond strengths when cured and prepared before topcoating with a high-performance topcoat

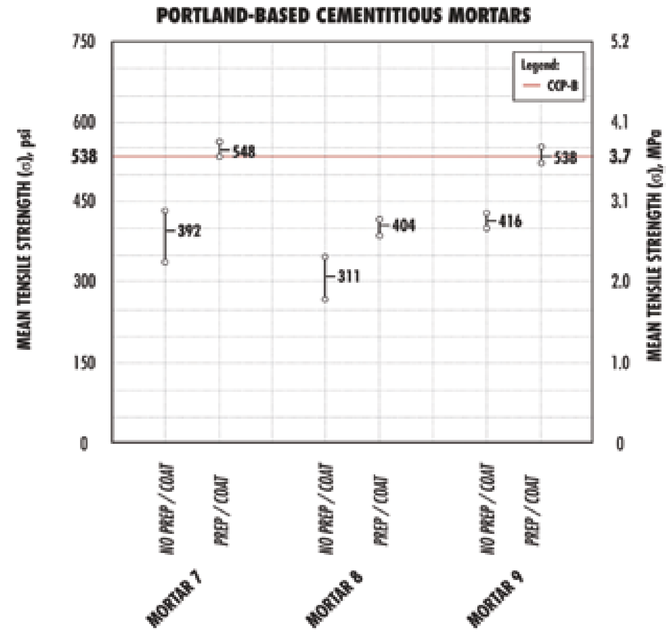


Fig. 4: Mortars 7, 8, and 9—portland-based cementitious mortars—demonstrated improvements in bond strength when properly cured and prepared before topcoating. Special consideration, however, should be given when selecting these materials for use in thin-patch repairs due to the limited tensile strength development versus Concrete Control Panel B. Evidence indicated that Mortar 8 would be the weakest component of the system, even if proper curing and surface precautions were followed

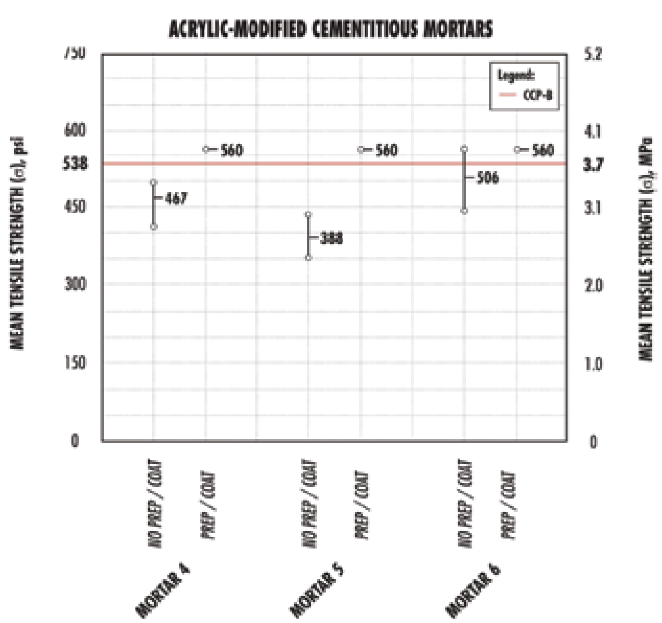


Fig. 3: The acrylic modification to Mortars 4, 5, and 6 appeared to improve the tensile strength properties, but did not allow the topcoating of a high-performance coating without first mechanically blasting the surface to remove the laitance layer. These mortars all had tensile strengths greater than Concrete Control Panel B when properly cured and prepared before topcoating. Test results concluded that the acrylic fortification does not allow the topcoating of a high-performance protective coating without first removing the weak laitance layer present on the mortar surface

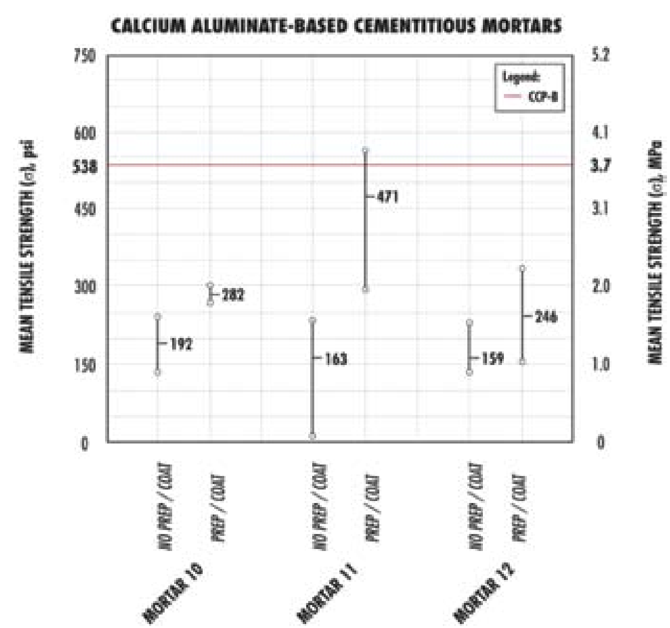


Fig. 5: Mortars 10, 11, and 12—calcium aluminate-based cementitious mortars—clearly demonstrate improvements in bond strength when properly cured and prepared before topcoating. Even when proper curing and surface precautions were followed, the data suggest extreme care should be exercised in evaluating this material under 100% solids epoxies due to limited tensile strength development versus Concrete Control Panel B

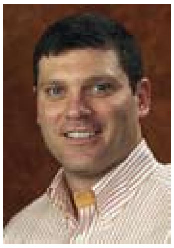
comparisons of panel sections with no preparation or coating (designated E) versus panel sections that were cured using two coats of an acrylic curing compound and dry-abrasive blasted to remove the curing compound (designated H).

In-depth descriptions of test results for each panel section in the study are presented in a series of 12 tables, which can be found in the technical paper "Bond Strength Testing of Commercially Available Cementitious Resurfacers Used for Thin-Patch Repairs of Concrete in Wastewater Environments," available on **www.tnemec.com**.

Meeting the Challenge

New cementitious resurfacing materials and methods are being introduced for use under high-performance coatings at an increasing rate, creating new challenges for manufacturers and those who use their products. As cementitious repair materials become thinner, differential behavior with the concrete substrate becomes accentuated and enhanced repair material properties, such as tensile strength, become more important. Particular attention should therefore be paid to the parameters recommended by the thin-patch manufacturers and that of industry standards governing the curing and preparation of these materials before topcoating.

Manufacturers of cementitious thin-patch composites should provide laboratory testing to substantiate claims when applying these materials as thin-patch resurfacers used under high-performance protective coatings. Because adequate curing of repairs can be difficult and are sometimes neglected within the wastewater market, warnings and clear instructions for curing are needed in application instructions and on component labels of cementitious repair materials.



Vaughn O'Dea *is the Director of Sales, Water & Wastewater Treatment, Tnemec Company, Inc., Kansas City, MO. He is a SSPC-certified Protective Coatings Specialist, a NACE-certified Coatings Inspector, and a NACE-certified Corrosion Technician. O'Dea is active in both NACE and SSPC technical committees and is a member of the American Concrete Institute, the American Water Works Association, NACE International, SSPC: The Society for Protective Coatings, ICRI, and the Water Environment Federation.*

Product Profiles

To avoid bias, the manufacturer's names of materials used in the concrete repair study were withheld. Basic descriptions of the 12 cementitious mortars tested in the study are provided in the following.

Epoxy-modified cementitious Mortars 1, 2, and 3 are commercially available, three-component, thin overlay/resurfacers that can be topcoated with high-performance coatings without subsequent preparation of the mortar. Recommended DFT for these mortars range from 1/32 to 2 in. (0.079 to 5.1 cm) depending on the manufacturer. At 75 °F (23.9 °C), Mortar 1 requires 15 hours of hydration to achieve proper cure, Mortar 2 requires 24 hours, and Mortar 3 requires only 12 hours of hydration (at less than 1 in. [2.5 cm] DFT).

Acrylic-modified cementitious Mortars 4, 5, and 6 are commercially available, two-component, shallow overlay/resurfacers. These mortars require a primer or scrub coat before placement of the coating, which varies by manufacturer between 1/8 and 3/4 in. (0.32 and 1.9 cm) DFT. Manufacturers for these products require proper curing of their acrylic-modified mortars immediately after placement in accordance with ACI 308. Recommended curing times vary between 48 and 72 hours. Mortar 4 uses a water-based membrane-curing compound, while the manufacturer of Mortar 5 explicitly states no feather edging of this material and that 1/4 in. (0.64 cm) sawcuts should be used.

Portland-based cementitious Mortars 7, 8, and 9 are commercially available shallow concrete overlay/resurfacers that can be applied by trowel or low pressure spray equipment. Recommended DFTs range from 1/8 to 3/8 in. (0.32 to 0.95 cm). The manufacturer of Mortar 7 recommends topcoating within 8 hours after placement, or else the mortar must be cured by means of fog spray, wet burlap, or an appropriate curing compound. The manufacturer of Mortar 8 recommends constant wet curing for 7 days in accordance with ACI 308 or the application of a membrane-curing compound compliant with ASTM C309. The manufacturer of Mortar 9 recommends curing per ACI 308 with two coats of a curing compound, conforming to ASTM C309 for a minimum of 3 days.

Calcium aluminate-based cementitious Mortars 10, 11, and 12 are commercially available resurfacers that can be applied by trowel or with low-pressure spray equipment to a minimum thickness of 1/2 in. (1.3 cm). The manufacturer for Mortar 10 recommends a trowel finish, followed by curing per ACI with two coats of an approved curing compound. No specific curing duration is listed on the product data sheet for Mortar 10. The manufacturer for Mortar 11 recommends a broom finish following the trowel application to optimize epoxy adhesion. Relative humidity must be above 70% for the first 24 hours; otherwise, the surface must be moisture-cured for 72 hours. The product data sheet for Mortar 12 does not provide curing recommendations.