Use of Vitreous-Ceramic Coatings on Reinforcing Steel for Pavements

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Presentation

• The Corrosion Problem in Pavements
• Nature of the Vitreous-Ceramic Coating
• Ease of Application to Reinforcement Steel
• Bond Strength and Corrosion-Resistance
• Field Demonstration Program
• Testing in Reinforced Concrete Pavement
• Summary of Current Status
Corrosion Problem

Corrosion gets most attention in bridge decks— but pavement has the same problem.

Conversion of iron to iron oxide involves an increase in volume of 600%

Concrete cracks and delaminates
Framing the Problem

- The predicted service life of continuously reinforced concrete pavement can be shortened if the rebar in the pavement corrodes prematurely and delaminates the pavement.
- Moisture and chlorides can move through the natural porosity of concrete and the cracks in the pavement.
- Application of chlorides from natural sources and from deicing compounds can greatly speed up the corrosion process.
- The concrete in the transition zone at the surface of the reinforcement steel is often the most permeable part of the concrete.
Schematic of Ceramic-Vitreous Enamel Coating

- Enamel protects and steel from corrosion; the cement grains hydrate and bond to surrounding concrete.
Properties of Coating

- Covers the reinforcement with an insulator
- Does not delaminate from the steel
- Does not allow the permeable layer at the interfacial zone to form
- Maintains the alkalinity at the surface of the steel reinforcement if the enamel is broken
- Embedded cement grains hydrate if enamel is cracked to self-heal with the formation of calcium silicate hydrate

Goal is to prevent spalling!
Vitreous-Ceramic Coatings

- Formed by fusing glass to steel at temperatures between 750° C and 850° C forming a true interlayer of iron-rich glass on the surface of steel.
- Considered to be the most durable coating that can be put on steel.
- Vitreous enameling is used primarily to prevent corrosion of underlying steel.
- Addition of ceramic to the glass provides a reactive component that can form a bond to hydrating Portland cement in fresh concrete.
- New bonding enamel can both strengthen the bond of the steel surface to surrounding concrete and prevent corrosion of the steel reinforcement.
Vitreous Enamel is Glass Fused to a Metal Substrate

Cobalt and nickel-rich glasses will fuse tightly to steel forming an iron-rich interface.

Composition of the glass can be altered to change chemical resistance, bonding properties, coefficient of expansion.
Specialized Frits Used to Developed Needed Properties

Steel-to-concrete bonding frit contains zirconium to make it alkali-resistant and a reactive Ca-silicate ceramic to make it bond.

The slip must flow, stick and the final glass must have proper thermal expansion properties to form a durable, strong, continuous coating.
Firing of a Vitreous Enamel is a Versatile Process

Firing is typically done in minutes at the 750°C to 850°C range.

Fusing the glass can also be done by torch, plasma or induction heating.

Multiple coating and multiple firing can be used to build coating thicknesses as needed. Commercial enameling is a continuous process.

One Corps, One Regiment, One Team . . . Serving Soldiers, the Army, the Nation
Vitreous-Ceramic Coating On Rebar

Portland cement is manufactured by firing the clinker at 1400°C.

Enamel application produces no changes.

After firing cement grains are embedded in glass enamel.

Mild steels used in reinforcement enamel well.
Enameled un-deformed (smooth) test rods

Uncoated rod can be dislodged by 600-800 lbf

3.5-in. long 0.25-in diameter broke during pull-out test. Rod broke at 2250 lbf. Cylinder was split after pull-test. No failure at mortar-to-enamel bond

Push-out test took 1940-2020 lbf to move the rod and broke the mortar not the bond
# Improved Bond Strength

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Average Peak Force lbf (N)</th>
<th>Std. Deviation lbf (N)</th>
<th>Average Bond Strength psi (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel fiber embedded in mortar (various published sources)</td>
<td>---</td>
<td>---</td>
<td>295.4 - 394.5 (2.0 - 2.7)</td>
</tr>
<tr>
<td>Steel rods, uncoated embedded in mortar</td>
<td>588.7 (2,618.2)</td>
<td>104.8 (466.2)</td>
<td>298.8 (2.1)</td>
</tr>
<tr>
<td>Enameled rods without portland cement embedded in mortar</td>
<td>786.4 (3,497.9)</td>
<td>121.6 (540.8)</td>
<td>391.6 (2.7)</td>
</tr>
<tr>
<td>Steel rods, uncoated, surface roughened by grit blasting (reported by PPEC)</td>
<td>--</td>
<td>--</td>
<td>595 (4.1)</td>
</tr>
<tr>
<td>Enameled rods with portland cement (acid surface preparation reported by PPEC)</td>
<td>--</td>
<td>--</td>
<td>797 (5.5)</td>
</tr>
<tr>
<td>Rods with enamel containing portland cement embedded in mortar</td>
<td>2,500.9 (11,124.6)</td>
<td>52.9 (235.3)</td>
<td>1,274.9 (8.8)</td>
</tr>
</tbody>
</table>

~4X change
Hydration of Embedded Cement

Moistened surface of rod with bonding enamel show the pH change indicating embedded cement is hydrating.

Photomicrograph showing embedded cement grains.
Enameling Provides Excellent Corrosion Resistance

Results of 40-day exposure of mild steel test rods with and without enamel in 3.5% NaCl solution at 20 °C

Bare Steel

Bonding enamel

Quartz sand saturated with 3.5% NaCl solution was test bed

Coated rods would only corrode if the enamel was intentionally removed.
Vitreous-Ceramic Coating On Rebar

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Mild steels used in reinforcement enamel well.
Field Test at Corpus Christi Army Depot

Proximity to Gulf of Mexico makes location prime test site.

Corrosion of stirrup rebar in support beam caused end of the beam to fall off.

Project will also replace beams and 14,400 feet of CRCP.
CCAD Cooling Tower Support Beams

Replacement beams with enameled rebar will be cast on site.

A conventional linear polarization resistance (LPR) corrosion detection program will be undertaken and test samples modeled after the ASTM G109 test specimen will be monitored and periodically removed for lab testing and examination.
CCAD Continuously Reinforced Concrete Pavement Section

- 14,400 sq ft
- 600 linear ft of concrete
- 300 linear ft of curb and gutter
- Pavement 6-in thick
- Design to follow AASHTO GHDS-5-M (5000 VPD)
- Post-fabrication enameled #3 and #4 rebar throughout
- Corrosion rate will be measured using Linear Polarization Resistance (LPR) corrosion monitoring.
- Crack width surveys will be conducted
- Test samples modeled after G109 test specimen will be monitored and periodically removed for lab testing and examination
Summary

- Enameled rebar with a reactive ceramic component can potentially be used to increase the concrete-to-steel bond strength
- The enameled rebar can be manufactured using the conventional enamel application methods and modification of standard alkali-resistant porcelain enamel
- Laboratory tests suggest the reactive vitreous enamel can produce significant improvements in the performance and service life of reinforced concrete
- Field demonstrations are scheduled to begin this year to evaluate the usefulness and economic benefits of a bonding enamel coating on reinforcement steel in reinforced concrete beams and in continuously reinforced concrete pavement
QUESTIONS?