

## **Applicability of Decorative Concrete Overlays as a Context Sensitive Solution for Vertical Infrastructure**

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### **ABSTRACT:**

The concept of applying Decorative Concrete Overlays (DCO) in infrastructure is an innovative solution that supports the widespread implementation of green engineering through Context Sensitive Solutions (CSS). The purpose of this research was to determine the limits of durability on decorative concrete overlay in terms of bond strength. Although DCO has been used extensively in horizontal applications such as sidewalks and driveways, the parameters of feasibility and durability must be tested for its use on vertical infrastructure surfaces (bridge piers, traffic barriers, noise walls, etc.). This study looks at initial evaluation of these parameters by conducting laboratory testing to measure flexural fatigue and adhesion strength of DCO on two sets of specimens varying in age; 28 days old vs. 125 days old.

The flexural fatigue results proved that the bond between concrete and DCO was very effective. Even though the concrete finally failed under the increasing load, the DCO product remained completely bonded as evidenced by the cracked chips of specimen surface. The adhesion strength of the DCO bond to beam specimens varied and results indicated that this difference in strength is due to the thickness of the DCO coating rather than the age of the concrete.

### **INTRODUCTION**

The Federal Highway Administration (FHWA) strongly encourages state transportation agencies to more extensively implement context-sensitive solutions (CSS) into new and existing transportation facilities. Context-sensitive solutions are defined as: “A collaborative, interdisciplinary approach that involves all stakeholders to develop a transportation facility that fits its physical setting and preserve scenic, aesthetic, historic and environmental resources, while maintaining safety and mobility” [1]. A tool which has hitherto been used in landscape architecture but not in transportation is decorative concrete overlay (DCO), a microtopping of a polymer-acrylic cementitious product. Decorative concrete overlay is one potential tool for CSS and can be applied directly on top of new or existing concrete. A great benefit of using DCO as a CSS is its versatility to be color-admixed, patterned, textured and stained to resemble stone, brick, wood, tile or many other materials. Unlike other CSS tools like cast-in-place panels or stamped concrete, DCO can be quickly applied to existing concrete structures or new construction after the process of surface preparation, thus making the structure more aesthetically pleasing.

### **Preparation of Test Samples**

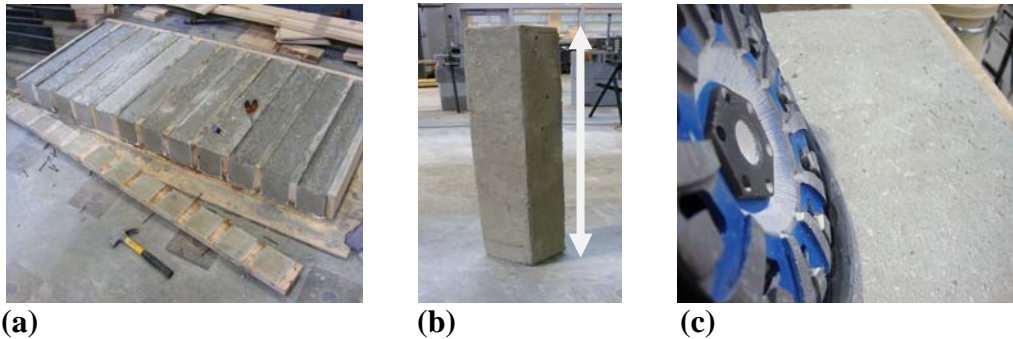
The first step in determining the durability of DCO was to identify a series of appropriate laboratory tests. It was determined that flexural fatigue tests and adhesion tests would be conducted as initial experiments. During sample specimen preparation, the beams were cast using wooden forms as shown in Figure 1. A total of 12 beams were constructed using ½-inch (1.27-cm) plywood as the base of the formwork, adding 2x6 pieces of wood as the walls. Each beam was measured precisely at 3 ft x 5.5 in. x 5.5 in. (91.44 cm x 13.97 cm x 13.97 cm) in dimension.



**FIG. 1. Beam formwork**

Since the primary purpose of the experimentation was specifically to test the durability of DCO on vertical components of infrastructure, the concrete mixture was designed in accordance with Pennsylvania Department of Transportation (PennDOT) specifications for vertical structures [2]. In order to be consistent with PennDOT Section 714 (standards for concrete barriers, median barriers, and sound barrier panels), the design used No. 57 coarse aggregate, standard Type A fine aggregate, and ordinary portland cement. The concrete was designed to have a water to cement

ratio of 0.45 and an air content of 6%. The specimens were mixed using a 7-cubic foot concrete mixer and poured into the formwork following ASTM C192 procedure [3]. Additionally, each beam was reinforced with one #5 bar placed directly in the center of the sample shown in Figure 2a. After 24 hours, the samples were removed from the forms, and moved to the moist room at a constant temperature of 22.8 °C (73 °F) with a relative humidity of 100% maintained for 7 days. Figure 2b presents an example of the cured concrete beams.



**FIG. 2. (a) Beam specimens, (b) Cured concrete beam, and (c) Grinding surface**

### **DCO Application Process**

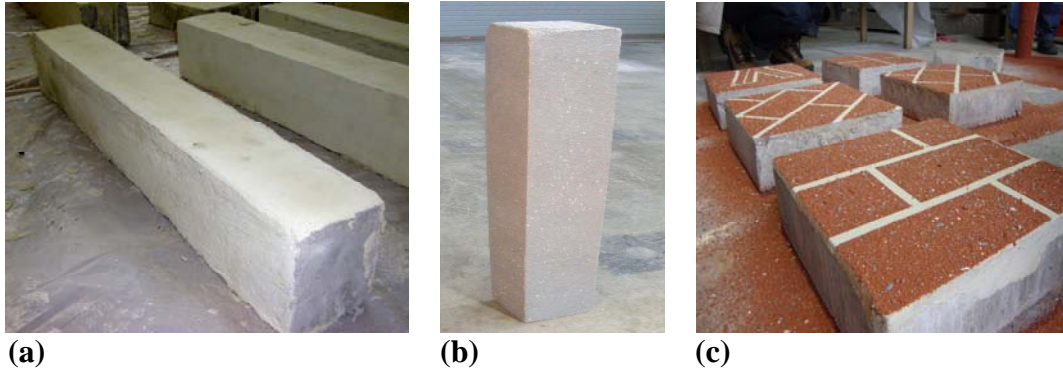
A complete surface preparation of the specimens is essential to ensure optimum bond strength between the structural concrete and the decorative overlay [4]. Therefore sufficient cleaning and profiling of the concrete was necessary to prevent any bonding failures. There are two conditions that must be met before the coating can achieve a strong bond with the concrete. The first condition is that the surface must be clean of dirt, chemicals, and other contaminants. The second condition is that the surface must be given a mechanical etch or profile. Scarifying or grinding down the surface (as shown in Figure 2c) removes any dirt, coatings, grease, or sealers. Denatured alcohol was then rubbed onto the surface of the concrete for etching. The final step of preparation was high pressure water jetting to finalize the cleaning process before any decorative concrete overlay was applied. This preparation was done prior to DCO application on both series of sample to be tested at 28-days and 125-days.

The mixture components of the decorative concrete overlay include cement (series 105 polymerized dry component), a liquid modifier (modified acrylic resin), and any desired colorant [5, 6]. The proportion of a complete mixture used was 8 ounces colorant to 4.25 gallons modifier to 50 pounds of cement. The mixing process occurs immediately prior to application of DCO to the test specimens.

After the mixture is complete, DCO can be applied using a trowel, sponge, and/or spray gun. While each technique can be used either separately or concurrently, the test beams were only treated using a trowel and spray gun. The first coat was applied using a trowel while the second coat was sprayed on. Before the first mixture of DCO is mixed and applied, a primer coat containing 3 parts water and 1 part liquid modifier was sprayed onto the concrete surface to ensure enhanced adhesion of the

decorative concrete overlay to the surface for the purpose of increasing the durability of the overlay.

Once the concrete surface is slightly moist with the primer coat, the first coat of sandstone-colored DCO was applied using a trowel and allowed to dry for approximately two hours (Figure 3a). Afterward, a second coat with gray colorant was applied using a spray gun as pictured in Figure 3b. This procedure was also applied on slab specimens to resemble a monochromatic brick pattern as pictured in Figure 3c. Grout lines were made by laying tape lines as desired prior to spraying the second coating of red colorant on the slabs.

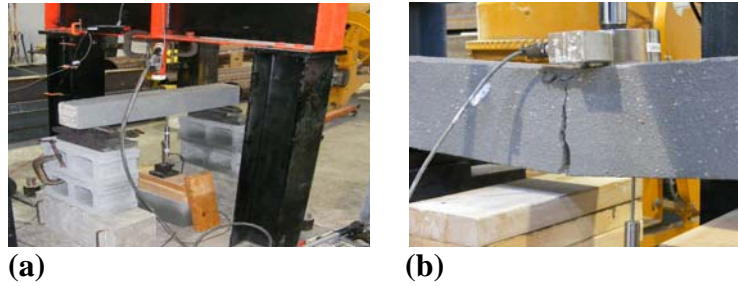


**FIG.3. (a) First coat (sandstone), (b) Second coat (gray), (c) Slab brick pattern**

The last and final step to the decorative overlay process was to apply two series 150 clear coats. A double-layered clear coat is designed to enhance the DCO's durability by providing additional protection against various environmental conditions including temperature, sunlight, and humidity, as well as preventing the penetration of dirt and chemicals. The series 150 clear coat also enhances the color of the DCO by making it more vibrant. Manufacturers recommend that the clear coat be reapplied every three years to the overlay for the purpose of preventative maintenance [7].

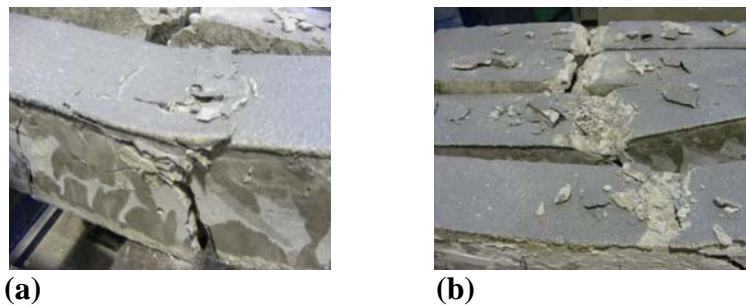
### **Flexural Fatigue Testing**

This test method covers the determination of the flexural strength of concrete by the use of a simple beam with third-point loading [8]. In relation to decorative overlay durability, the flexural fatigue test was used to investigate the effect of cyclical loading on the bond of the DCO to concrete. The simply-supported reinforced decorative concrete beam specimens were subjected to loads applied in 200-lb increments, and then qualitatively examined for cracks and other failures in the overlay. The apparatus, as pictured in Figure 4a and 4b, included a load cell, hydraulic piston, and a deflection gauge located at the center span of the beam. As the amount of force at center-span increased, the decorative concrete beam was monitored for cracking, particularly in the overlay. All 12 beams were loaded until failure.

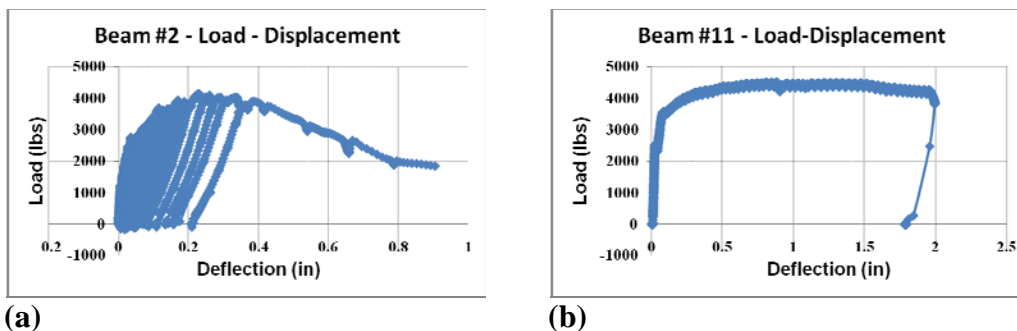


**FIG. 4. (a) Flexural fatigue test system, (b) Piston applying force to load cell**

In all twelve tests that were conducted, the concrete failed close to the center (Figure 4b), causing the decorative concrete overlay to bubble and chip off. However, an inspection of the chips that had peeled off revealed that the overlay had remained attached to the top layer of the broken concrete pieces. This implies that the force applied to the beam caused spalling to the concrete and not the decorative overlay (concrete fractured rather than the overlay) as seen in Figures 5a and 5b. Under cyclical loading, the reinforced concrete beam failed as expected with cracking and spalling primarily at center span. Directly underneath the hydraulic piston, no cracks were found in the overlay. Ultimately for both the 28 and 125 day specimens, the bond between the decorative overlay and the concrete endured the force applied from the piston. The load-deflection plots in Figures 6a and 6b demonstrate that all twelve beams behaved as typical reinforced concrete beams.



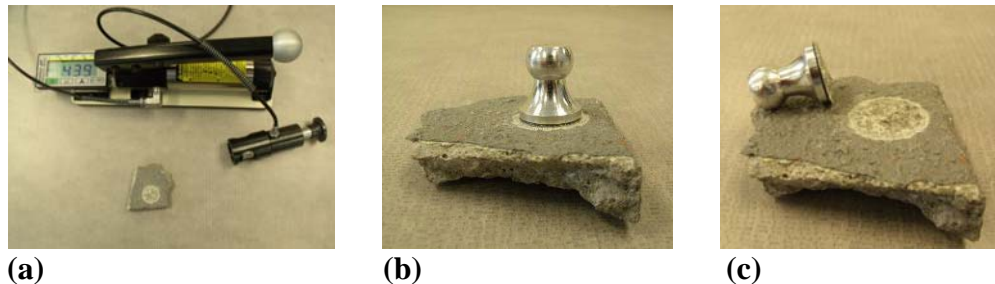
**FIG. 5. (a) Spalling on beam 2, (b) Spalling on beams 1-4**



**FIG. 6. (a) Beam 2 (28-days), (b) Beam 11 (125-days)**

## Pull-off Adhesion Strength Testing

In order to further investigate the potential of DCO as a viable CSS tool, another bond durability test was conducted. The strength of the overlay to the decorative concrete beam before and after failure was evaluated as per ASTM Standard D-7234-05. This test determines the greatest perpendicular force (in tension) that a surface area can bear before a plug of material is detached [9]. While attached to the decorative concrete overlay, the portable pull-off adhesion tester (Figure 7a) applied a uniformly-increased concentric tensile load until the localized layer of overlay (Figure 7b) was separated from the concrete piece (Figure 7c).



**FIG. 7. (a) Apparatus, (b) Before DCO removal, (c) After DCO removal**

As reported in Table 1, the force required to remove the DCO from the concrete was much greater with the 28-day old beam specimens than it was for the 125-day old beam specimens. The average adhesion strength for the 28-day old beams and the 125-day old beams was 286 psi and 131 psi, respectively. However, data implies that the difference in strength was not dependent on age of the test beams, but rather on thickness of the DCO coating on the 125-day specimens (applied twice as thick as on 28-day beams). As a result, the increase in thickness produced a weaker bond to the concrete.

**Table 1. Adhesion Strength, 28 days vs. 125 days**

	<b>Age (days)</b>	<b>Strength (psi)</b>	<b>Specimen</b>
1	28	109	Beam
2	28	312	Beam
3	28	439	Beam
4	28	285	Beam
5	125	64	Beam
6	125	45	Beam
7	125	97	Beam
8	125	310	Beam
9	125	101	Beam
10	125	166	Beam
11	120	104	Outdoor Slab
12	120	122	Outdoor Slab

In order to capture real-time weathering and temperature effects, DCO was applied to an outdoor field slab (Figure 8) in November 2009. Pull-off adhesion strength testing was conducted when the outdoor slab had already experienced four months of exposure to multiple freeze-thaw cycles, and multiple snowstorms, throughout the winter and spring seasons. The results from the portable pull-off testing on the outdoor field section are well within the range shown for other beams of the same age (Table 1).



**FIG. 8 DCO on outdoor field slab**

## CONCLUSIONS

The intent of the research was to provide initial steps in evaluating a new potential context sensitive solution for state transportation agencies to utilize on new or existing infrastructure. Thus far, the research has shown that decorative concrete overlay (DCO) appears to be a viable and easily accessible tool for today's infrastructure. In comparison to other CSS tools such as stamped concrete and cast-in-place panels, DCO demonstrated advantages such as ease and speed of application by three simplistic approaches (trowel, sponge, and/or spray). Flexural fatigue and adhesion test results, which were conducted on both 28-day and 125-day old specimens, confirmed that the bond of DCO to structural concrete can withstand extreme load conditions as well as substantial tensile forces. In all twelve flexural fatigue tests, the bond of DCO to concrete was only broken along fracture lines, implying that it was the concrete that had cracked rather than the overlay under increased loading. Average adhesion strength values indicated that the thickness of DCO can significantly influence the bond to structural concrete. The thinner DCO surfacing showed a double increase in bond strength. Extreme weathering and real-time temperature cycling of a concrete field slab treated with DCO did not appear to degrade the bond strength when compared to laboratory-controlled samples. Initial research has indicated that the durability of DCO make it an effective option for the aesthetic treatment of vertical infrastructure surfaces.

## RECOMMENDATIONS

Initial results from testing DCO indicate a deal of promise as a CSS tool; however, further research is required to test its durability in full-scale environmental conditions. For example, an investigation into sodium chloride ponding and sodium chloride tank submersion is necessary to determine the effect of salt solutions on the structure and

appearance of the overlay. This is particularly important to ascertain the use of DCO on infrastructure components that would be subjected to deicing salts (walkways) or aqueous conditions (bridge piers). Also, an extensive look into the behavior of DCO subjected to ultra-violet light testing and freeze-thaw cycling would give important insight on its ability to withstand fundamental weathering conditions. Additionally, results from the adhesion testing stressed the importance of maintaining as thin a layer of DCO as possible. This could be most reasonably achieved by the use of professional contractors who are trained in the successful application of DCO.

## ACKNOWLEDGMENTS

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