RECLAMATION

Managing Water in the West

Ultra-High Performance Concrete Used as a Coating

Research and Development Office
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Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Executive Summary

The primary objective of this scoping study was to develop a laboratory research plan utilizing ultra-high performance concrete as a coating. The report also contains findings from a literature review and developments in a research partnership.

Contents

Introduction

Concrete is coated regularly, especially for quick repairs. Sometimes these coatings would need a 50+ year service life to keep up with the surrounding structure. Other times the coating requires specific properties that must match the parent concrete it is on. Currently no modern coatings have been able to achieve these traits.

Ultra-high performance concrete (UHPC) may solve this problem. UHPC is not only very high strength, 21.7 ksi minimum, but is also impermeable. Being impermeable puts this concrete in a low to zero risk for any deterioration mechanisms to exist. To name a few: UHPC would prevent freeze/thaw, sulfate attack, alkali silica reaction, corrosion, and possibly hairline cracking. Although considered expensive when compared to typical concrete, UHPC could be significantly cheaper than coating systems.

Specific mixture designs allow the material to be applied similar to any other coating, but do not contain toxic chemicals or materials. This could be applied just like shotcrete in most instances. Since concrete is the second most used material in the world, most contractors are very familiar with it and would require nearly zero training to use UHPC in a standard concrete or shotcrete application.

The cheaper alternative, durability opportunities, and compatibility to concrete make UHPC a great candidate versus our current coating systems.

Conclusions

This scoping study has identified a laboratory research plan which includes mechanical and durability testing for UHPC coatings applied with varying application methods and substrate surface treatment. Results from the laboratory study will be compared with current coating technology to assess the effectiveness of UHPC as a coating. There is limited literature on UHPC as a thin overlay or coating, however the existing research shows the potential for UHPC to be used to protect Reclamation's existing and future structures.

Discussion

Literature Review

Ultra-high performance concrete (UHPC) is defined as concrete with a compressive strength greater than 21.7 ksi (150 MPa), an optimized gradation of granular constituents (including silica fume and other fine particles), a water to binder ratio of less than 0.25, and a high percentage of fiber reinforcement [1]. UHPC typically does not contain large aggregates and therefore can be applied in

a thin layer. UHPC possesses many improved mechanical and durability properties compared to conventional concrete. Typical compressive and tensile strength is approximately 21.7 ksi and 0.9 ksi, respectively [2]. There is significant post-peak behavior in UHPC in tension due to the high volume of fibers that allow the concrete to behave in a ductile manner [3]. The bond strength (as evaluated using an indirect splitting tension test) is highest when the substrate was saturated prior to application of a UHPC overlay [4]. The bond strength between UHPC and a conventional concrete substrate has not been published using ASTM procedures. Reported values of shrinkage (free shrinkage according to ASTM C157 tests) are between 620 and 766 millionths. ASTM C157 does not capture the volume change in the first 24 hours, which can be very high in UHPC [5]. Mechanical properties are highly dependent on curing conditions and can be greatly improved with heat treatment [6].

As a result of the optimized gradation of fine materials, UHPC has a very refined pore network which improves its durability. The permeability, as tested by ASTM C1202, was extremely low and almost negligible when the concrete was steam cured [6]. Despite not containing entrained air, UHPC performed well in ASTM C666 freeze-thaw testing. In 690 cycles, UHPC samples showed little deterioration. A variety of deterioration mechanisms (sulfate, abrasion, carbonation) were not seen in UHPC [6]. The extremely dense matrix prevents deleterious solutions from penetrating and causing deterioration.

UHPC has not been applied as a thin coating, however, it has been applied as a thin-bonded overlay (1.5" thick) for concrete bridge decks and pavements [5]. The bond strength was significantly improved if the substrate was wet (saturated) until the application of UHPC, regardless of surface roughness. When the substrate was dry, the overlay failed before testing [4]. Delamination, spalling and cracking occur when stresses at the interface exceed the overlay's bond strength. The stresses that develop are caused by shrinkage of the UHPC, differing thermal properties and differing stiffness between the deck substrate and overlay material [5]. The coefficient of thermal expansion is similar between UHPC and conventional concrete (~7 x 10^{-6}/°F) [6]. However, UHPC is stiffer than conventional concrete and the shrinkage can be higher due to the low water to cement ratios and large quantities of cementitious materials [7].

Research Partnership

A partnership has been developed with Mr. Gaston Doiron of Lafarge, North America. Mr. Doiron can provide consulting on UHPC products to Reclamation. He can also be available to collaborate in meetings to discuss materials, mixing, and applications of Lafarge products.

Laboratory Research Plan

There are several variables that contribute to the success of a coating system. The application method and surface preparation are among the most important. In this research plan, two application methods (shotcrete and hand application) and several surface treatments (wet versus dry; varying roughness) will be investigated.

Mechanical Testing

A suite of basic mechanical tests will be performed on UHPC mixtures. Tests include compression with elastic properties (ASTM C39, ASTM C469), direct tension, under-water abrasion (ASTM C1138) and shrinkage (ASTM C1581). Once applied to the conventional concrete substrate, pull-off bond strength with be measured (ASTM C1583). The acquired properties will aid in the final design of the coating system (i.e. surface preparation, applied thickness, etc.).

Durability Testing

The purpose of a coating is to protect the parent concrete from deleterious ions, such as sulfates, and excess moisture. After the UHPC coating has been applied, common coating testing will include immersion, cyclic testing prohesion (ASTM D5894), impact (ASTM D2794), adhesion, polarization, abrasion, and erosion testing.

At varying time intervals, the parent concrete will be examined for sulfates and alkali-silica gel (ASTM C1012 and ASTM C856) and tested for freeze-thaw durability (ASTM C666). If the impermeable coating works, it should keep water and sulfate ions out and the concrete should perform well in freezing and thawing cycles and should also not exhibit signs of expansive ASR gel.

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