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Fiber Reinforced Cementitious Matrix (FRCM) Composites for Reinforced Concrete Strengthening

by

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16. Abstract

Fiber-reinforced composite systems are widely used for strengthening, repairing, and rehabilitation of reinforced concrete structural members. A promising newly-developed type of composite, comprised of fibers and an inorganic cement-based matrix, provides several environmental, structural, and sustainability-related advantages over fiber reinforced polymer (FRP) composites traditionally used in structural applications, which potentially expands the strengthening applications beyond those currently utilized. Such advantages include: 1) high resistance to fire and high temperatures; 2) resistance to UV radiation; 3) ease of handling during the application because the inorganic binder is water-based; 4) easy cleanup and reuse of tools; 5) low odor and toxin emissions during application and curing; 6) permeability compatibility with the concrete substrate; and 7) unvarying workability time (between 40°F and 105°F). Stress-transfer mechanisms and interfacial fracture propagation of fiber-reinforced composites externally-bonded to a concrete substrate are complex phenomena that are highly dependent on the bond characteristics of the composite matrix material to the fibers. These phenomena have not yet been clearly defined and understood for FRCM composites. Experimental work will be carried out in this study to isolate the shear debonding phenomenon using single lap shear tests

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Fiber Reinforced Cementitious Matrix (FRCM) Composites for Reinforced Concrete Strengthening

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Dr. Sneed's visiting scholar, Tommaso D'Antino (a Ph.D. student at the University of Padova in Italy), was supported in part by NUTC funds from August 20, 2012 to May 31, 2013. During this period, Mr. D'Antino conducted approximately 250 experiments to understand the load transfer of FRCM composites externally bonded to a concrete substrate. Tests included single- and double-lap shear tests under monotonic or fatigue loading conditions. Experiments were conducted in the High Bay Structural Engineering Research Laboratory at Missouri S&T. The results of this work have been disseminated in two journal papers that have been accepted and three peer reviewed conference papers presented at international conferences. Additional journal papers are currently under development. This final report includes the abstracts of the papers that have been accepted or published.

Peer Reviewed Journal Publications - Accepted

1. Sneed, L.H., D'Antino, T., and Carloni, C. (*accepted to ACI Materials Journal, 07/08/13*) "Investigation of the Bond Behavior of the PBO FRCM-Concrete Interface." (MS No. M-2012-406)

   ABSTRACT: This paper presents the results of an experimental study conducted to understand the stress-transfer mechanism of fiber reinforced cementitious matrix (FRCM) composites externally bonded to a concrete substrate for strengthening applications. The FRCM composite was comprised of a polyparaphenylene benzobisoxazole (PBO) fiber net embedded within two layers of polymer-modified cement-based mortar. Single-lap shear tests were conducted on specimens with composite strips bonded to concrete prisms. Parameters varied were bonded length and width of composite. Additionally, the external coating layer of matrix was omitted on a limited number of specimens to examine the interfacial behavior between fibers and matrix and the role of the matrix in the stress transfer. Strain measurements along the composite bonded length were used to investigate the stress-transfer mechanism. Results suggest that the effective bond length of this composite is within the range of 250 to 330 mm (10 to 13 in.). Unlike with fiber reinforced polymer (FRP) composites, no width effect was observed in terms of the maximum load. Finally, the stress-transfer mechanism at the matrix-fiber interfaces on either side of the fiber net was found to be unequal.

2. Sneed, L.H., D'Antino, T., and Carloni, C. (*accepted to ACI Advanced Materials and Sensors towards Smart Concrete Bridges: Concept, Performance, Evaluation, and Repair, SP-XXX, 04/27/13*) "Experimental Investigation of FRCM/Concrete Interfacial Debonding."

   SYNOPSIS: This paper presents the results of an experimental study conducted to understand the stress-transfer mechanism of fiber reinforced concrete matrix (FRCM) composites externally bonded to a concrete substrate for strengthening applications. The FRCM composite was comprised of a polyparaphenylene benzobisoxazole (PBO) fiber net and polymer-modified cement-based mortar. Direct shear tests were conducted on specimens with composite strips bonded to concrete blocks. Parameters varied were composite bonded length and bonded width. Results were analyzed to understand the effective bonded length, which can be used to establish the load-carrying capacity of the interface to design the strengthening system. The normalized load carrying-capacity was plotted against the width of the composite strip to study the width effect. Finally, strain gage measurements along the bonded length were used to investigate the stress-transfer mechanism.

Peer Reviewed Conference Papers – Published (Underline indicates presenter)

1. D'Antino, T., Carloni, C., Sneed, L.H., and Pellegrino, C., 2013, "Fiber-Matrix Interaction in PBO FRCM Composites," *Anidis 2013 - L'ingegenria Sismica in Italia (Anidis 2013 - Earthquake Engineering in Italy),* Padova, Italy, 8 pp.

   ABSTRACT: This paper presents the results of an experimental study and discusses the applicability of a fracture mechanics based approach to understand the stress-transfer mechanism of fiber reinforced cementitious matrix (FRCM) composites externally bonded to a concrete substrate. The FRCM composite was comprised of polyparaphenylene benzobisoxazole (PBO) fibers and polymer-modified cement-based mortar. This research aims to gain insight into the fundamental behavior of the bond between concrete and FRCM composites, which is critical in structural strengthening applications because complete loss of bond (debonding) generally initiates structural member failure. Single-lap shear tests were conducted on specimens with composite strips bonded to concrete blocks. Parameters varied were composite bonded length and bonded width. Results were analyzed to understand if an effective bond length, which can be used to establish the load-carrying capacity of the interface to design the strengthening system, exists in this kind of composite.

2. D'Antino, T., Sneed, L.H., Carloni, C., and Pellegrino, C., 2013, "Bond Behavior of the FRCM-Concrete Interface," *FRPRCS11, 11th International Symposium on Fiber Reinforced Polymers for Reinforced Concrete Structures,* Guimarães, Portugal, 10 pp.

   SUMMARY: Stress-transfer mechanism and interfacial fracture propagation of fiber-reinforced composites externally-bonded to a concrete substrate are complex phenomena that are highly dependent on the bond characteristics of the composite matrix material. These phenomena have not yet been clearly defined and understood for fiber reinforced cementitious matrix (FRCM) composites. The results of single-lap shear tests, conducted on specimens with FRCM composite strips bonded to concrete blocks, are presented in this paper. The FRCM composite was comprised of polyparaphenylene benzobisoxazole (PBO)

fibers and polymer-modified cement-based mortar. The bonded length of the composite was varied to investigate whether an effective length similar to the FRP-concrete interface exists. Strain profiles along the bonded length were also analyzed to determine if a cohesive fracture approach can be employed to describe the stress-transfer mechanism of the matrix-fiber interface. The experimental data herein presented indicate that the strain profiles resemble those observed for the FRP-concrete interface.

3. Carloni, C., Sneed, L.H., and D'Antino, T., 2013, "Interfacial Bond Characteristics of Fiber Reinforced Concrete Mortar for External Strengthening of Reinforced Concrete Members," *FraMCos-8, 8th International Conference on Fracture Mechanics of Concrete and Concrete Structures*, Toledo, Spain, 9 pp. (***Keynote presentation***)

   Abstract: This paper presents the results of an experimental study and discusses the applicability of a fracture mechanics based approach to understand the stress transfer mechanism of fiber reinforced cementitious matrix (FRCM) composites externally bonded to a concrete substrate. The FRCM composite was comprised of polyparaphenylene benzobisoxazole (PBO) fibers and polymer-modified cement-based mortar. This research aims to gain insight into the fundamental behavior of the bond between concrete and FRCM composites, which is critical in structural strengthening applications because complete loss of bond (debonding) generally initiates structural member failure. Single lap shear tests were conducted on specimens with composite strips bonded to concrete blocks. Parameters varied were composite bonded length and bonded width. Results were analyzed to understand the effective bond length, which can be used to establish the load-carrying capacity of the interface to design the strengthening system. Results also shed light on the interfacial behavior between fibers and matrix and highlight the role of the matrix in the stress transfer.