INNOVATIVE CEMENT BASED THIN SHEET COMPOSITES FOR RETROFIT

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In this paper, a new type of cement-based thin sheet composite will be presented. This innovative technology can be applied to retrofit deficient concrete structures with a superior performance as compared to current Fiber Reinforced Polymer resin (FRP) thin sheets. The greatest potential of FRPs in the near future will be in the areas of repair, strengthening, and rehabilitation of existing structures, such as externally bonded composite fabrics or jackets on beams, columns, and bridge decks. Significant improvements in compressive, shear, and flexural behavior of bonded concrete elements are obtained. In an effective retrofit with external FRP sheets, a layer of dry fiber sheet (usually unidirectional tape) is placed on the top of a coat of polymer resin that will harden to bond the fiber sheet to the concrete structure. The high ratios of strength and stiffness to weight of FRP are primarily responsible for effective retrofit. The strength/stiffness of FRPs is almost entirely attributed to the fibers, since the polymeric matrix has negligible strength/stiffness in comparison to the fibers. Instead of using polymeric resins we develop innovative cement-based matrix materials for making the composites. Cement-based materials have many advantages in comparison to polymeric resins. For instance, much less or no preparation of a concrete surface is required for good bonding. Additional benefits include much higher fire and vandalism resistance, and user friendly to the construction industry.

INTRODUCTION

The U.S. has an estimated $20 trillion investment in civil infrastructure systems. Because of aging, overuse, exposure, misuse, and neglect, many of these systems are deteriorating and becoming more vulnerable to catastrophic failure when earthquake or other natural hazards strike. It would be prohibitively costly and disruptive to replace these vast networks. They must instead be renewed in an *intelligent* manner. It is generally recognized that fiber reinforced polymer (FRP) sheets are one of the most vital materials for repair, strengthening, and rehabilitation of existing structures. Applications involve such as externally bonded composite fabrics or jackets on beams, columns, and bridge decks.

FRPs (or advanced fiber composites) have long been successfully used by the aerospace and defense industries. These materials are rapidly gaining momentum in civil engineering structural applications. The thrust is twofold: (1) an urgent call for new material to fix our nation's fast deteriorating facilities where the challenge is too great using conventional materials, and (2) properties (high strength-to-weight ratio and corrosion resistance) and easy construction (fast curing process and lightweight) that are superior to conventional concrete and steel.

The greatest potential of FRPs in the near future will be in the areas of repair, strengthening, and rehabilitation of existing structures, such as externally bonded composite fabrics or jackets on beams, columns, and bridge decks. Significant improvements in compressive, shear, and flexural behavior of bonded concrete elements are obtained. Typically, increases in strength and failure strain of several times are obtained with external FRP reinforcement [1-6].

RETROFITTING/STRENGTHENING EXISTING STRUCTURES

Several important considerations regarding reinforcing or retrofitting existing structures including buildings and bridges are (1) cost efficiency, (2) convenience to the occupants with minimum interference to their operations, and (3) environmentally sound for fabrication and disposal. FRPs are found to be the favored solution due to their superior properties, light weight, and easy handling. In contrast, the use of conventional materials typically requires complete shutdown of the structure for repair, or is difficult if not impossible for internal strengthening due to weight and dimensional limitation (e.g. steel truss). These constraints are particularly significant for building repair. Hence, construction costs using conventional materials are substantially increased, although the materials could be relatively inexpensive. It is typically estimated that material costs are less than 20% of the total cost of a repair project. Therefore, even from a cost viewpoint, FRPs are very competitive. In many of the repair projects, the total cost when using FRP were reported to be less than that of using conventional materials for the same project.

In an effective retrofit with external FRP sheets, a layer of dry fiber sheet (usually unidirectional tape) is placed on the top of a coat of polymer resin that will harden to bond the fiber sheet to the concrete structure. Prior to applying resin coating, the concrete surface must be thoroughly cleaned and smoothed, including grinding and patching that are labor intensive and sometimes require complete shutdown of the operation of the structure. When needed, multiple layers of fiber sheets can be sequentially added by repeating the same procedure.

Functions of Fiber and Matrix in Composites

A typical fiber composite is primarily made of continuous fibers and matrix. The advantages of fiber reinforced polymer composites (FRP) as compared to more conventional materials are often related to the high ratios of stiffness and strength to weight. A typical FRP is about 4 times lighter than steel with an equal strength. The strength/stiffness of FRPs is almost entirely attributed to the fibers [7,8], since the polymeric matrix has negligible strength/stiffness in comparison to the fiber. The matrix serves three important functions: (1) it holds the fiber in place, (2) it transfers loads to the high-stiffness fiber, and (3) it protects the fiber. The typical density of common engineering fiber is 1.7 – 2.0 g/cm^3 for carbon, 2.5 – 2.7 g/cm^3 for glass, whereas on the matrices side, epoxy and polyester have a density between 1.2 and 1.4 g/cm^3, giving a lightweight composite density between 1.5 and 2.2 g/cm^3 [9]. It is clear from the above discussion that polymer matrix provides a negligible contribution to composite strength/stiffness that is needed for effective retrofit of concrete structures, yet polymers have many other problems such as lack of fire resistance and degradation under UV light.

We propose to replace polymer matrix by cement. Typical density of cementitious materials may range from 0.8 to 2.2 g/cm^3 depending on their compositions, hence maintaining a lightweight of the cement composites. The in-situ applicability of cement matrix is only possible when we can control the rheological properties of cement materials that can range from water-like to dough-like.

Advantages of Cement-Based Matrix

The following comparisons are made between conventional FRP sheets and the new cement-based sheets being developed at Wayne State University.

1. Concrete Surface Preparation for Better Bonding

It is generally required to apply a labor-intensive sequence of concrete surface preparation for good bonding between FRP and concrete. General procedure includes 1). Concrete grinding, 2). Priming, 3). Putty application, 4). Resin application, 5). Fiber sheet application, 6). For multiple plies repeat 4) and 5), 7). Resin application (cover and protective coating), 8). Finishing. These procedures generate noise and dust, and sometimes odors are generated from the chemical reactions of the resins. These problems are particularly acute in a closed environment. Therefore, continuous operation of the structures may not be possible during the installation of FRP retrofit, especially for buildings. Much less or no concrete surface preparation will be needed when the polymer resin is replaced by ordinary cement due to its natural affinity to concrete. No unpleasant odors will be generated.

2. Direct Bonding to Steel Structures

Steel stringer bridges are very common in the US and make up almost a third of all bridges with spans exceeding 6.1 m [10]. Since many were constructed just prior to World War II, they are nearing the end of the average service life of 65-70 years. Significant stiffness and strength increases can be achieved through the application of FRP sheets to the tension flange of steel beams [10,11]. However, in order to achieve good bonding with the FRP sheets, the steel surface needs to be thoroughly cleaned just like the concrete surface, to remove corrosion rust and other contaminants (see e.g. [12]). This cleaning process can be time consuming and expensive. In contrast, a cement-based matrix is much more tolerant of the steel surface conditions. In fact, corrosion of steel may even enhance the bonding between cement and steel due to mechanical interlocking.

3. Cost Benefit

The typical cost of polymer matrix (e.g. epoxy or polyester) is about $1.0 to $2.0 per pound, whereas cement costs about $0.03 per pound. Additional significant cost savings particularly the savings associated with the stringent surface preparation procedure of concrete and inconvenience to continuous operation of the structures when a polymer matrix is used, can be attained when the above advantages of using a cement matrix are realized.

4. Improved Stiffness

The typical stiffness of polymer matrix (e.g. epoxy or polyester) is less than 5 GPa, whereas cement/mortar is about 20 GPa. For applications involving low fiber contents, say less than 10% by volume, the composites made of 90 plus percent of cement matrix can possess much higher stiffness. The improved composite stiffness can further enhance retrofit efficiency.

Fiber Reinforced Cement Composite

In this case, we use the same kind of fiber reinforcement (unidirectional tapes) as in a regular FRP sheet, and we use cement materials to replace polymer resin. The preparation procedure is analogous to regular FRP.

Some preliminary work has been carried out to make thin plates. As shown in Figure 1, a plate as thin as 2 mm can be made with two layers of unidirectional fiber tapes.

Figure 1:Thin cement plate reinforced with unidirectional fiber tapes (thickness=2, 3, 4 mm, from bottom to top).

COMPRESSIVE BAHAVIOR OF CONFINED CONCRETE

A preliminary study on the compressive behavior of concrete confined by fiber reinforced cement (FRC) composite jackets has been carried out at Wayne State University. The purpose of these tests is to develop an innovative thin FRC composite that can be employed in retrofitting structural members. The ideal FRC composites under development are expected to provide similar or improved retrofit efficiencies with a lower cost and easier construction in comparison to Fiber Reinforced Polymer (FRP) composites.

Unidirectional carbon fiber tapes were used in this study. Cement based matrix developed at Wayne State University and epoxy resin were used separately to make thin CFRC sheets and CFRP sheets. Both CFRC and CFRP composites contain two layers of unidirectional fiber tapes. The average thickness of the CFRC jackets is 3.0 mm, whereas the CFRP between 2-3 mm. These thin composite sheets were then employed to wrap 4 inch by 8 inch concrete cylinders. The bond length of the CFRC samples is 3 inches and 2 inches for the CFRP. A 1.5 inches gap exists between the top of the cylinder and the top of the composite sheets at both ends (see Figure 2 and 3).

Figure 2: Concrete confined with CFRP composite jacket.

These concrete cylinders, unconfined and confined with CFRC or CFRP composites are tested using a high-stiffness, high-capacity MTS testing machine following ASTM C39-96, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. This equipment has sufficient capacity and stiffness, which is required for conducting such tests. The machine is also equipped with a sophisticated computer control and data acquisition system. The acquired data including the applied axial load and axial deformation of concrete are recorded automatically. Per ASTM Practice C1231-93, steel retaining rings and rubber pads were used without other capping during the tests.

Figure 3: Concrete confined with CFRC composite jacket.

Test Results

The axial stresses versus axial strains relationships of unconfined and confined concrete are shown in Figure 4. As shown in Figure 4, the initial portions of the stress-strain responses of the confined specimens essentially followed the curves of the unconfined concrete. The compressive strength of the unconfined concrete is 54 MPa. The CFRC group shows a compressive strength two times higher than that of the control from 54 to 100 MPa. In addition, the ductility is increased by 3 times from 2 mm to 6 mm. The CFRP sample has the highest compressive strength (105 MPa) and ductility. Nevertheless, the differences between CFRC and CFRP are insignificant.

The CFRP jacket samples showed explosive failure that was triggered by the complete rupture of the CFRP jacket. The remnants of the CFRP sample after failure are shown in Figure 5. The CFRC samples also show fiber rupture failure similar to the CFRP sample. The CFRC samples have a much less violent global failure than the CFRP (see Figure 6). Concrete inside the jacket was crashed completely (Figure 7).

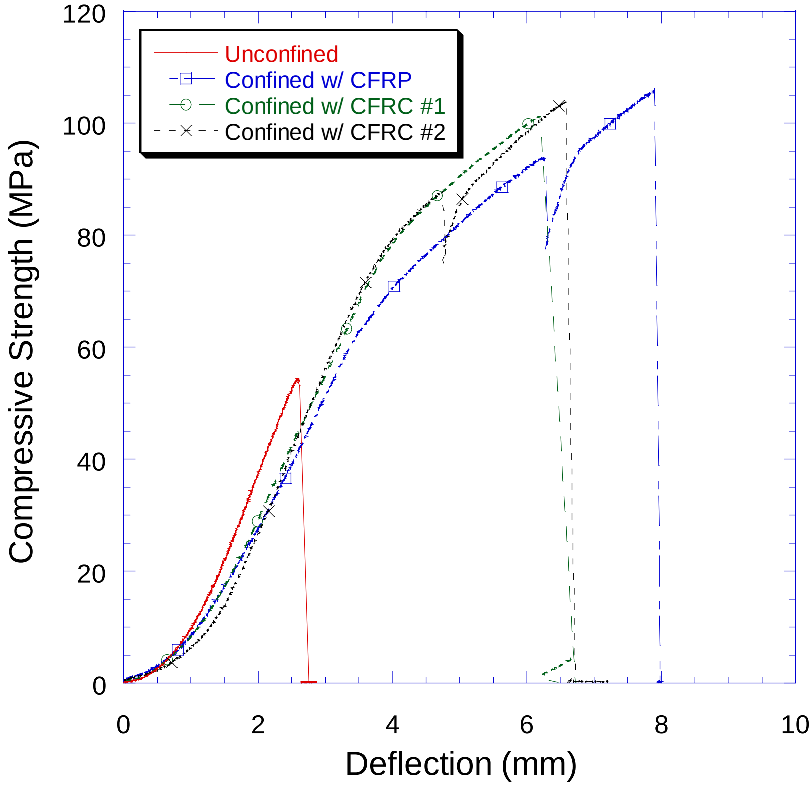

Figure 4: Compressive behavior of unconfined and confined concrete.

Figure 5: Remnants of CFRP sample after violent failure.

Figure 6: Global failure of the CFRC sample due to rupture of the CFRC jacket.

Figure 7: Concrete inside the CFRC jacket was crashed completely after global failure.

CONCLUSION

It is confirmed that the compressive strength of concrete can be significantly improved using external CFRP wraps. In addition, the ductility of the confined concrete is significantly increased. The final failure of the confined concrete is provoked at the onset of the CFRP rupture. The CFRC confined concrete show similar improvements of both ultimate compressive strength and ductility with the CFRP concrete. Because of the use of high strength concrete in this study, the final failure of the plain concrete is explosive. The final failure of the confined concrete shows even more violent.

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