Bond Development Between Carbon Fiber Reinforced Polymers and Concrete

Submitted as a final report for the 1999 Research Experience for Undergraduates in Civil Engineering
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Abstract

Carbon fiber reinforced polymer (CFRP) sheets can be externally bonded for retrofit of concrete structures, improving flexure and sheer strength in the concrete. The key to CFRP sheets is the bond to the concrete, as bond is the means to transfer stress between the tow sheet and the concrete. Experimentation has been conducted to test a current market fiber-resin system, and to develop a resin system for the Zoltek Corporation, in conjunction with the Chemical Engineering department at Washington University. Materials include the Master Builder Technologies Mbrace fiber-resin system, Zoltek Corporation carbon fiber (tow) sheets, and experimental resins developed by Washington University. The ultimate goal is the development of a marketable resin system for Zoltek Corporation that can compete with the Master Builder’s Mbrace fiber-resin system.

Introduction

The experimental goal is to be able to test the bond of as many combinations of fiber-resin systems as efficiently as possible, while giving adequate time for the materials to cure. To achieve this, a hinged concrete beam setup was chosen that has the capability of being rotated to maximize testing surfaces. Measurement of a fiber-resin system’s resistance to loading is done by placing strain gauges on CFRP sheets. Strain gauges collect data that can graphically represent the strain distribution throughout the CFRP sheet, where the strain curve represents the CFRP sheet’s effective bond to the concrete. Current experimental results show that the Mbrace system is the better fiber-resin, however development of a resin system by Washington University is under way.
Experimental Setup

To test the bond of a given fiber-resin system, a hinged concrete beam was poured and erected (Appendix A). The following schematic shows the testing and fiber layout:

1 The test setup is a modification of experimentation done by Brian Miller, M.S. student, and Antonio Nanni, Jones Professor of Civil Engineering, of the University of Missouri-Rolla, pg.240 ASCE.
A hand-pumped hydraulic jack is placed symmetrically about the hinge so that the load is distributed uniformly throughout the CFRP sheet. A CFRP strip, two inches wide, is then bonded symmetrically to the tension face of the beam. One side of the beam is unmonitored, so a CFRP patch of five by five inches is bonded to the concrete so failure on that side will not occur. On the monitored side, the CFRP sheet is debonded from the beam in a two by two-inch section. In this section, tension on the fibers will remain constant and a zippering effect will be induced on the CFRP sheet. Strain gauges are then placed at intervals of zero, one-half, one, one and one-half, two and one-half, and three and one-half inches from the furthest edge of delamination to measure the strain, and thus bond effectiveness, of the CFRP sheet at a given load.

**Resin Systems**

Currently, CFRP sheets are marketed by Master Builders, Sika and Exceed. And I do not know why we chose the master builders system.

The resin systems tested at Washington University are applied in three steps: primer, putty and saturant. Before primer application, the hinged-beam is prepared by sanding and air blasting any dust or loose aggregate from the concrete’s surface. The primer (Mbrace primer pictured above) is then rolled onto the concrete using a hard rubber roller. This is done so that the primer saturates the concrete’s surface.
to improve adhesion. After the primer cures, a putty is applied. When the beam is poured and then prepared, the surface of the concrete can have air holes or rough sections. The purpose of the putty is to fill any voids in the concrete and smooth the bonding surface (Mbrace putty pictured left, Mbrace saturant and fibers right). The final step in the resin system application is to roll on the saturant. In this process, a layer of saturant is rolled onto the putty, then the fiber tow sheet is placed and re-rolled in saturant. The saturant contains a bonding agent that glues the fibers to the putty, and a hardening agent that stiffens the tow sheet. After the saturant and tow sheet cure, the CFRP sheet is complete.

**Results**

Data has been collected on the Mbrace fiber-resin specimen and the Zoltek fiber-Mbrace resin specimen. Appendix B shows the force-strain and strain-distance graphs for each test. Current testing results show that the Mbrace system is the better fiber-resin system. In the Mbrace test, the CFRP sheet failed by zippered from the tension face of the concrete at a load of 3,000 pounds, and in the Zoltek fiber-Mbrace sheet failed, by snapping, at just over 2,516 pounds. The snapping failure was a surprising result, as the experimental setup should cause a zippering failure so the bond is being tested, not the fibers.
Analysis of the results and the CFRP specimens give two reasons why the Mbrace specimen performed better during testing: fiber integrity and different tow sheet mesh systems. The following graph is a comparison of strain and distance for a load of 2,516 pounds for the two test specimens (red squares indicate strain gauge locations):

The graph shows the strain curve is between four to five thousand microstrains lower for the Mbrace fibers than the Zoltek fibers. This indicates that the Zoltek fibers are softer than the Mbrace fibers because in both tests, the resin system has been controlled. The graph also shows that bond failure has started in the Zoltek fiber specimen. A strain curve that follows a hyperbolic path, like that of the Mbrace specimen, implies that a CFRP sheet is effectively resisting the load on the beam. However, the strain curve for the Zoltek-fiber specimen, severely deviates from a hyperbolic strain curve pattern, indicating that the specimen has started to debond from the concrete.
Another reason why the Zoltek fiber specimen failed is because of the mesh system used in the tow sheet. A mesh system is a group of nylon threading holding together a carbon fiber tow sheet. Pictured are the Zoltek (left) and Mbrace CFRP specimens after the bond test. The yellow lines point out the mesh system used to hold each fiber sheet together. The Mbrace mesh (not fully developed in yellow) is much more intricate than that of the Zoltek, giving the Mbrace tow sheet an advantage because the mesh holds the fibers straight. Carbon fibers are extremely strong, however this occurs only in tension, therefore, to create a strong CFRP sheet the fibers must be parallel before the hardening agent is applied. If this does not occur, fibers that are not straight in the CFRP sheet will not be in tension and cannot help resist the load placed on the beam.

**Experimental Resins**

Washington University is developing a resin system, based on the Mbrace system. Primers, putties and saturants have been developed using the Dow Chemical family of epoxies and hardeners. Primers and saturants have been developed from different mixing ratios of epoxies to hardening agents of different viscosities. The goal is to creating a primer and saturant that cures hard in room temperature, but is ductile upon loading.
Putties have also been developed in raising the viscosity of the primers by adding fillers. Silica sand and calcium carbonate have been mixed in different ratios to the primers for the experimental putties. An ideal putty would be one that yields at lower loads, but is still highly deformable. This is advantageous because the putty is the material in a resin system that absorbs the energy put into the concrete-CFRP sheet member by a given load.

The following table shows the experimental resin systems that have been developed and tested in adhesion experiments done by Deborah Bohot\(^2\) (primers and saturants are the same):

<table>
<thead>
<tr>
<th>Primer (hardener:epoxy)</th>
<th>Putty (filler:resin)</th>
<th>Max Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>I Mbrace Resin System</td>
<td>1.5:1 Silica Sand:</td>
<td>2,100 lbs</td>
</tr>
<tr>
<td>II 5:1 Amine HH curing agent: Epoxy Resin 324</td>
<td>1.5:1 Silica Sand: Primer</td>
<td>1,942 lbs</td>
</tr>
<tr>
<td>III 1:1 Ancamine 2390 curing agent: Epoxy Resin 325</td>
<td>1.5:1 (5 Silica: 1 Calcium Carbonate): Primer</td>
<td>1,880 lbs</td>
</tr>
<tr>
<td>IV 1:1 Ancamine 2390 curing agent: Epoxy Resin 325</td>
<td>1.5:1 Silica Sand: Primer</td>
<td>1,690 lbs</td>
</tr>
<tr>
<td>V 1:1 Ancamine 2390 curing agent: Epoxy Resin 325</td>
<td>1:1 (1 Silica: 1 Calcium Carbonate): Primer</td>
<td>1,428 lbs</td>
</tr>
</tbody>
</table>

The Mbrace system was tested as a benchmark for the experimental resin system, and from the adhesion tests, experimental resin system III has been chosen for the next specimen of hinged beam tests. Experimental resin system II does rate higher in
maximum adhesion load than resin system III, however Dr. Harmon’s beam tests, have shown that resin system II is very brittle after curing, and not very effective. Future experimental resin systems will be created from epoxies and curing agents made by the Shell Chemical company. These resins exhibit the low yielding, high deformability that a CFRP resin system is thought to have.

**Conclusion**

Current research has resulted in showing that the Mater Builder Technologies Mbrace fiber-resin system is the better fiber-resin system, in bond testing at Washington University. The mesh system used to hold the tow sheet together, and fiber integrity are the two identifiable reasons for this. If the Zoltek Corporation was to improve their mesh system, their tow sheet strength would increase, however this will be limited by the strength of the Zoltek fibers. As resin development continues, future hinged-beam bond experiments will take place. Then information will be learned about the relationship between primers, putties and saturants, so that a strong, effective resin can be developed for the Zoltek Corporation.

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2 Deborah Bohot is participating in Washington Universities REU program under the supervision of Dr. Thomas Harmon.