Bond performance of patching materials subjected to environmental effects

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ABSTRACT: This study investigated the bond strength between concrete patching materials and fiber reinforced polymer (FRP) laminates used in the repair of impact damaged girders. Research was performed to understand how the FRP substrate-bond is affected by using different commercially available patching materials and environmental conditioning methods under sustained load. Variables included the selected patching material, the conditioning exposure and the level of sustained loading. Using the results an effective bond length for each material was obtained and an understanding of the overall bond strength was determined.

1 INTRODUCTION

Over the last several years FRP has been increasingly used in the repair of impact damaged prestressed concrete (PC) members. These materials have been extensively researched in their ability to repair and bond with concrete members; however, very little research has been done to investigate the effectiveness of bond between FRP and the patching materials used for impact damaged members within this process. This project accessed the bond performance of patching materials while also studying the effects of environmental conditioning and sustained loading.

A typical example for the use of this patching process in the field is the retrofit of highway overpass girders. Many times large vehicles that do not meet the clearance requirements attempt to pass under the overpass and incur damage to the girder overhead. To restore the original capacity to these damaged members, engineers use FRP and patching materials. The patching material is applied to the damaged beam or girder and then it is wrapped in FRP sheets or laminates. This results in the restoration of the ultimate flexural capacity.

2 EXPERIMENTAL PROGRAM

2.1 *Material Properties*

The FRP selected for testing had a tensile strength of 35,500 kg/cm^2 (505 ksi), a design modulus of 2.35x10^6 kg/cm^2 (33,000 ksi) and a design thickness of 0.165 mm/ply (0.0065 in/ply). The patching materials tested were Verticoat Supreme (EUCO-Euclid Chemical Company), Burke V/O Patch (Edoco), and TPM723 (General Polymers) which had compressive strengths of 142 kg/cm^2 (2016 psi), 490 kg/cm^2 (6965 psi) and 364 kg/cm^2 (5185 psi) respectively. Each of these materials are specifically marketed and used for concrete repair of damaged concrete members.

2.2 *Specimen Preparation*

The specimens tested consisted of two concrete blocks, 152.4 mm x 152.4 mm x 304.8 mm (6 in. x 6 in. x 12 in.). One of which was poured with two 12.7 mm x 101.6 mm x 304.8 mm (½ in. x 4 in. x 12 in.) grooves, one on each side, to accommodate the patching material. The solid block was used as an anchor for the shear bond test setup. The patching material was applied to the grooves of the grooved block. The materials chosen were ones that are used in vertical applications for repairing damaged concrete structures.

FRP was attached to the patching material and connected to the anchor block laterally on both sides as shown in Figure 1. To avoid edge effects, a 50.8 mm (2 in.) strip was left unbonded on the inside of the specimen. The strip itself was 990.6 mm (35 in.) long with 381 mm (15 in.) of spacing between the anchored block and the specimen. To guarantee bond failure would occur on the monitored side of the specimen, an additional FRP wrap was attached to both sides of the anchor block.

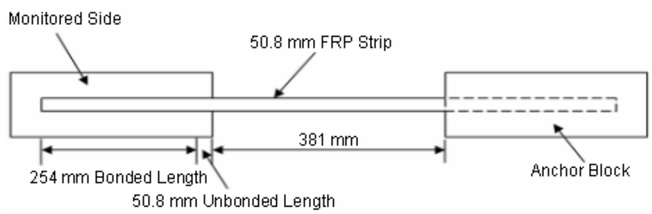


Figure 1. Specimen setup prior to any loading or environmental conditioning.

2.3 *Surface Roughening*

To ensure bonding between the concrete and patching material, the blocks were roughened with a wire brush as specified by the preparation directions of each patching material.

The surface of the patching material was also roughened prior to application of the FRP. This was performed by using a wire brush attached to a grinder. The Verticoat Supreme material roughened the best, followed by the TPM723, and then the Burke V/O Patch. The Burke V/O Patch was actually very difficult to roughen and did not yield as distinct results as the Verticoat Supreme. Higher levels in roughness resulted in higher failure loads during the testing portion of the experiment. The three blocks can be seen in Figure 2.

Figure 2. Surface preparation (left to right: Verticoat Supreme, TPM723, & Burke V/O Patch).

2.4 *Environmental Conditioning and Loading*

For each patching material, twelve (12) specimens were tested using six (6) combinations, thus producing a set of two specimens per condition. Of those twelve (12), six (6) were conditioned in an environmental chamber, four (4) were exposed to ambient winter conditions for six weeks and conditioned naturally in Rolla, Missouri, USA, and two (2) were stored under laboratory conditions to serve as control specimens.

The conditioned specimens were cycled in the environmental chamber for four weeks. During this time they underwent 112 conditioning cycles. A cycle began at 4 degrees C (40 degrees F) and then slowly decreased to -18 degrees C (-1 degrees F) in one hour. It was then soaked at that temperature for two hours, before it began an hour long increase back up to 4 degrees C (40 degrees F). Four cycles were performed each day. Figure 3 represents the environmental conditioning performed in the environmental chamber.

Along with variance of environmental effects, the specimens were also subjected to different sustained loadings. These acceptable sustained loading levels were determined by the ultimate tensile strength of a 50.8 mm (2 in.) strip of FRP and the associated bond strength of a control specimen which failed at 14.1 kN (3.17 kips). For each material, two (2) of the conditioned specimens were loaded at 10 percent and two (2) at 20 percent of the ultimate tensile capacity of the FRP strip. The two (2) specimens exposed to ambient conditions were loaded at 20 percent. These correspond to 6.36 kN (1.43 kips) and 12.72 kN (2.86 kips) for the 10 and 20 percent sustained loading levels respectively.

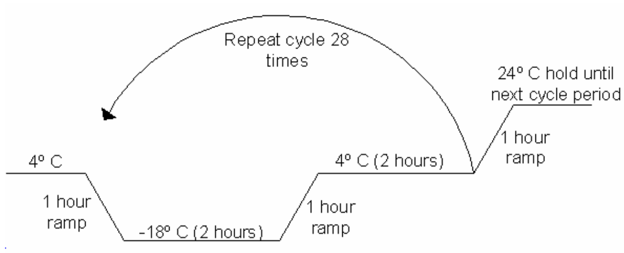


Figure 3. Environmental conditioning cycle.

Due to a malfunction at the start of the conditioning, three specimens accidentally debonded including a Burke V/O Patch loaded at 10 percent, a Burke V/O Patch loaded at 20 percent and a Verticoat Supreme loaded at 10 percent. It may be noted that there was one fewer test result for these three series of specimens at the aforementioned sustained loading level.

The sustained loading setup is illustrated in Figure 4. By tightening the bolt, the spring compressed to load the specimen. A spring compression of 12.7 mm (0.5 in.) was equivalent to 20 percent, and 6.35 mm (0.25 in.) was equivalent to a 10 percent sustained loading level. This loading level was calibrated in a compression testing machine prior to installation.

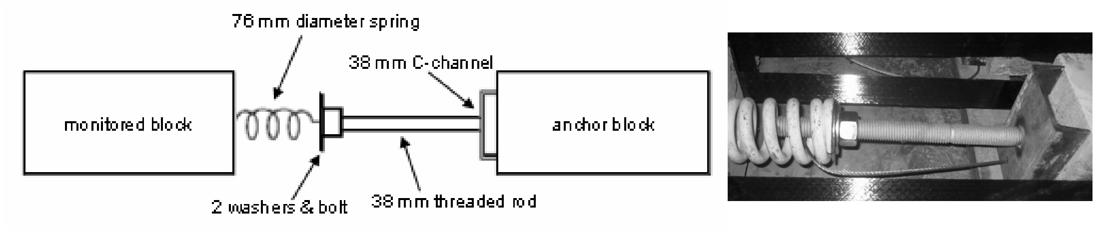


Figure 4. Schematic of loading setup (left) & actual loading setup (right).

2.5 *Test Setup*

The shear bond test setup can be seen in Figures 5-6. The specimen and attached anchor block were placed on a flat smooth surface to minimize friction, and then a hydraulic ram and load cell were placed in between the two blocks. The specimen was then slowly loaded until bond failure occurred. Four strain gauges were attached to at least one FRP strip for each condition investigated on the monitored block. The remaining blocks in the series had only one strain gauge as illustrated in Figure 6.

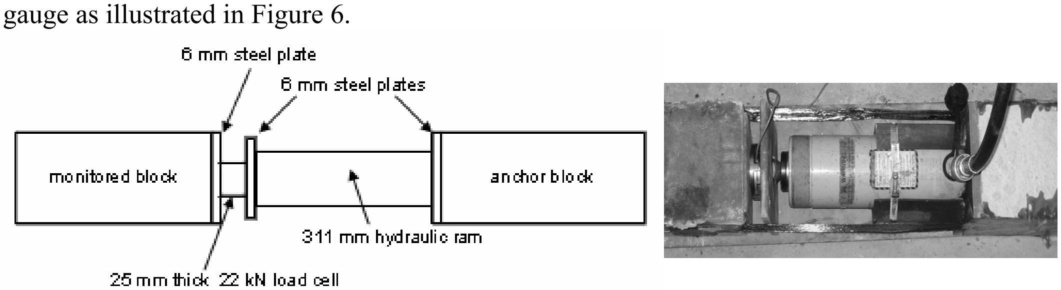


Figure 5. Schematic of test setup (left) and actual test setup (right).

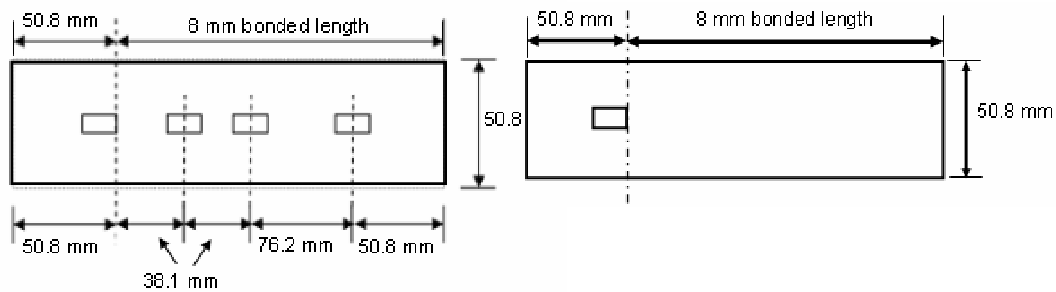


Figure 6. Strain gauge locations for specimens with four gauges (left), and one strain gauge (right).

3 RESULTS

Figures 7-9 compare the failure load and peak strain for each variable. The numbers above each bar indicate the standard deviation for the set of each variable. Bars without the notation represent sets where one of the specimens debonded due to the experimental malfunction.

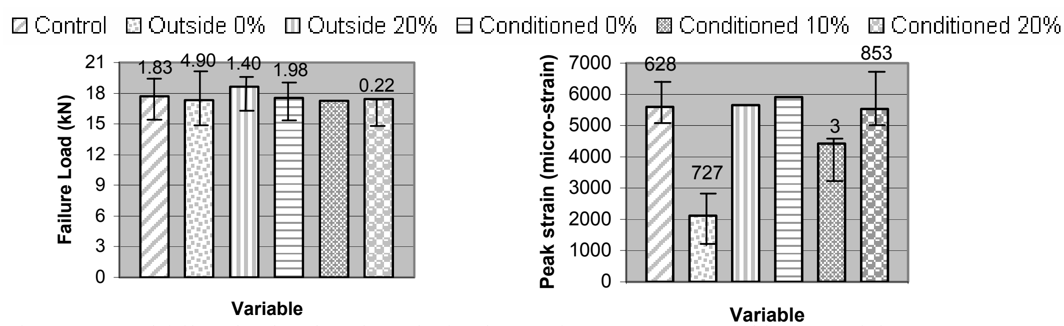


Figure 7. Bond failure load and peak strain for the Verticoat Supreme patching material.

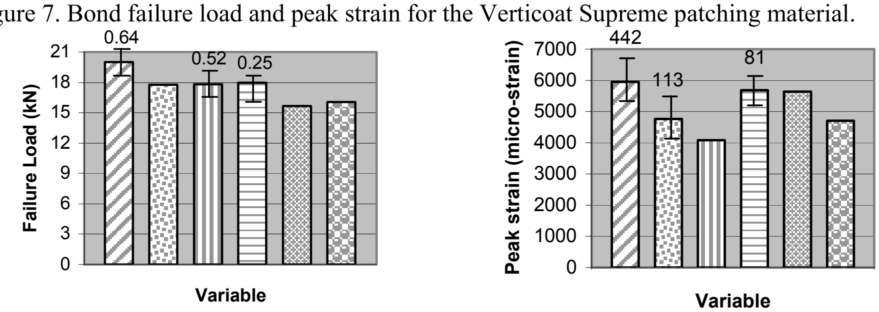


Figure 8. Bond failure load and peak strain for the Burke V/O Patch patching material.

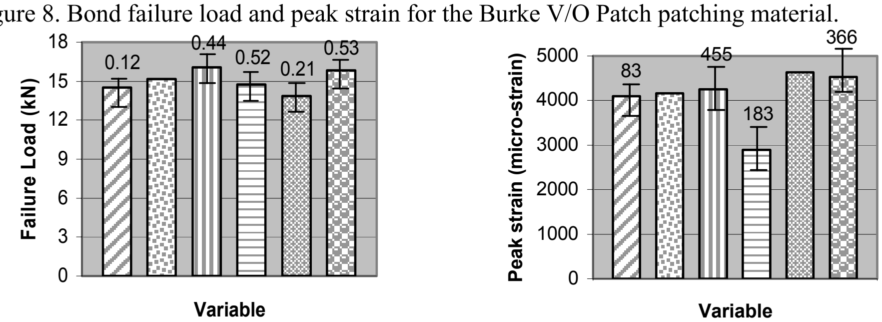
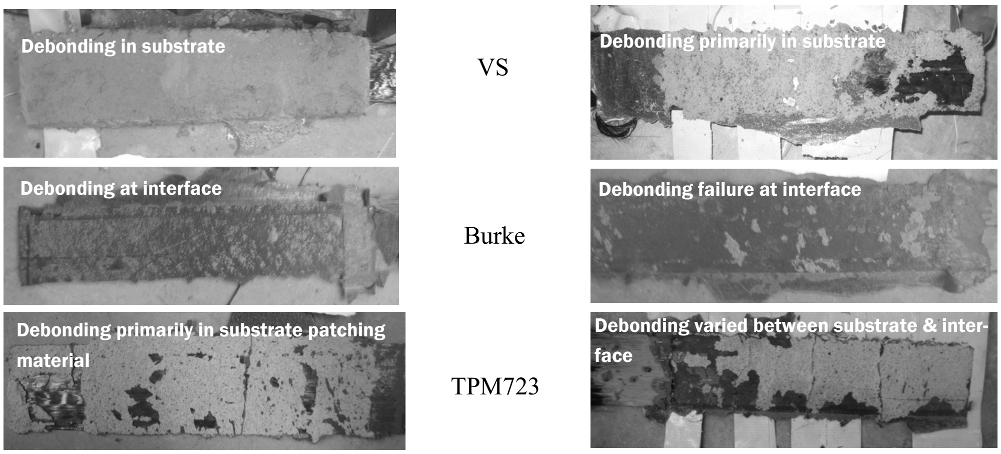


Figure 9. Bond failure load and peak strain for the TPM723 patching material.

Figures 7-9 also provide a comparative explanation of the failure of the materials. Of the three materials, Verticoat Supreme exhibited the least amount of degradation as illustrated numerically in the Failure Load plots. The largest variance from the control for Verticoat Supreme was 5.3 percent while Burke V/O Patch had a maximum variance of 21.9 percent, indicating substantial degradation. The TPM723 failure load of the control was lower than most of the specimens. This was likely due to the abnormalities within the test which are discussed later. As noted in Section 2.4, Verticoat Supreme produced the highest debonding failure loads overall, followed by TPM723 and Burke V/O Patch. Typical failure modes for each patching material are illustrated in Figure 10.



a. Control specimens b. Conditioned with 20% sustained loading

Figure 10. FRP strips after testing for control (left) and conditioned 20 percent (right).

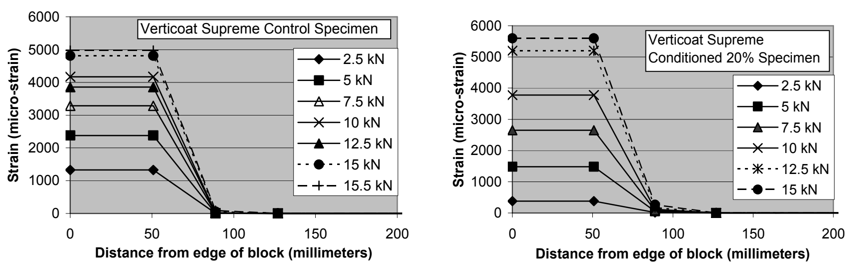


Figure 11. Strain distribution along unbonded and bonded length for Verticoat Supreme patch.

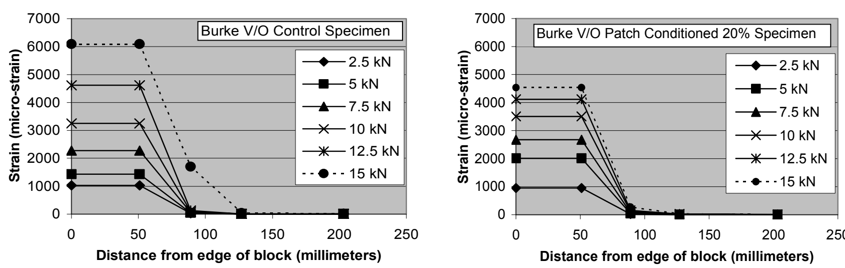


Figure 12. Strain distribution along unbonded and bonded length for Burke V/O Patch.

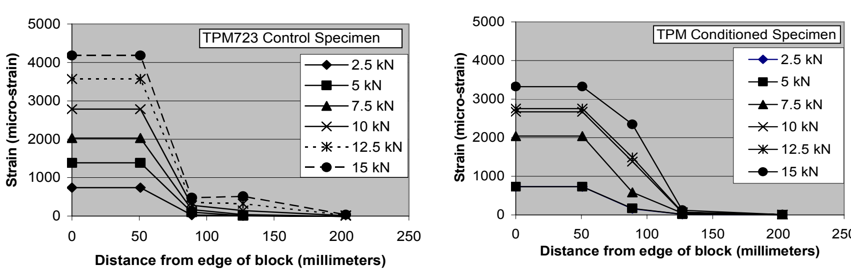


Figure 13. Strain distribution along unbonded and bonded length for TPM723.

Worthy of note is the fact that the debonding location for the Verticoat Supreme and TPM723 specimens primarily occurred within the patching material substrate; however, for the Burke V/O Patch the debonding failure occurred at the interface between the FRP laminate and the substrate patching material. Naturally, it is more desirable for the failure mode to occur in the substrate, so the full shear capacity of the bond behavior can be realized. Specimens that were conditioned under sustained loading exhibited slightly less favorable debonding surfaces visually. An analysis was also performed to investigate the effective bond length for each patching material. The strain versus distance from the edge of block was plotted for load increments of 2.5 kN (562 lbs). The analysis was performed on both the control and the 20 percent conditioned specimen for each material. The results from these plots can be seen in Figures 11-13.

Due to the limited number of strain gauges it is difficult to determine the exact effective bond length. However, the obtained results from the physical testing do allow the opportunity to gain an understanding for each material. For the Verticoat Supreme material the effective bond length appears to be no more than 80 mm (3.15 in.) for both the control and 20 percent conditioned specimen. The Burke V/O Patch and TPM723 also had effective bond lengths of around 80 mm (3.15 in.) based on the selected strain gauge layout for both the control and 20 percent conditioned specimens. However, as the load increased for both cases the bond length also increased to a value of 150 mm (5.9 in.). Overall, the effective bond length for all three patching materials at service level loads behaved similar to bonded FRP to a traditional concrete substrate parent material which has an effective bond length between 76.2 mm (3 in.) and 101.6 mm (4 in.). (Myers et al., 2007)

Within this experiment several abnormalities did exist which may have led to unexpected results. These include the load being slightly off-center, manual load may have not been consistent the entire test, and FRP may not have bonded to the patching material the same on both sides of the block. With any surface testing, errors will occur due to the inability to maintain constancy for each surface. However, with this test every precaution was taken to ensure accurate and consistent results.

4 CONCLUSION

In all cases of this investigation there was a slight decrease in overall bond strength for the specimens that were conditioned with sustained load prior to testing. Depending on the patch material this difference was minor in one case or more significant in another case. The sustained loading and conditioning appeared to affect the bond performance at the interface in the case of the Burke V/O Patch material.

The Verticoat Supreme material exhibited the most consistent and desirable debonding failure mode within the substrate under the various conditions investigated. This may be attributed to a variation in the composition of the patch material allowing improved penetration of epoxy saturant into the pore structure of the patching material.

Based on the physical testing, the effective bond length of the patching materials appeared to be between 76.2 mm (3 in.) and 101.6 mm (4 in.) which is similar to conventional concrete.

5 REFERENCES

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