ALTERNATIVES TO DELAY PREMATURE FAILURE OF CFRP STRENGTHENED REINFORCED CONCRETE MEMBERS

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Abstract

This Study was focused on identifying and proposing alternatives such that premature debonding failure of CFRP strengthened reinforced concrete members in flexure is delayed. Two of our proposed alternatives were investigated in relation to three control beams of two standard configurations. A unidirectional CFRP fabric was applied onto the concrete surface using two part epoxy resin as a binder inclusive of an inexpensive polymer mesh of polyester in specific arrangements. Three point bending tests were conducted.

This study shows that the polymer mesh of polyester laid in the bond line has effectively delayed premature failure of composites. A range of 60% to 80% strength gains with respect to control beams was noted. Failure was observed with the formation of a mid-span flexure crack causing mid span debonding and subsequently debonding at the ends.

Keywords: CFRP, Epoxy, Polyester mesh, Concrete, premature failure

1. Introduction

1.1 Problem Statement, Scope & Significance

The retrofitting of Concrete structures, with externally bonded Fibre Reinforced Polymers, (FRP) has been a preferred practice for the past few decades to overcome structural deficiencies caused by aggressive environments and to address strength inadequacies for the sustenance of current loading trends. Such FRP systems are applied in a variety of ways to enhance the load carrying capacity in flexure, shear, and torsion or in combinations. As per comparisons made by U. Meier (1995: 341-351) and parameters listed in the *fib* bulletin 14 (2001) shown in Table 1, these systems are of many different materials of which the carbon based FRPs are the most common material has been used for strengthening of Civil engineering infrastructures. Hence CFRP fabric was considered for this experiment.

Table 1: Summary of Mechanical Properties of FRP Materials

Criterion	***Carbon***	***Aramid***	***E-Glass***
Tensile Strength [N mm^{-2}]	*Very Good [2860]*	*Very Good [1280]*	*Very Good [1080]*
Compressive Strength [N mm^{-2}]	*Very Good [1875]*	*Inadequate [335]*	*Good [620]*
Modulus of Elasticity [GPa]	*Very Good [177]*	*Good - 87*	*Adequate [39]*
Long Term Behaviour	*Very Good*	*Good*	*Adequate*
Fatigue Behaviour	*Excellent*	*Good*	*Adequate*
Bulk Density [kg m^{-3}]	*Good [1600]*	*Excellent [1380]*	*Adequate [2100]*
Alkaline Resistance	*Good*	*Good*	*Inadequate*
Price	*Adequate*	*Adequate*	*Very Good*

Though these systems have impressive material properties and are capable of achieving huge strength gains, they barely perform at or beyond an accepted level of structural applicability and financial viability as premature failure by debonding would restrict its inherent potential. The occurrence of debonding relies heavily on the achievable bond between the FRP system and the concrete substrate. Therefore limitations can be imposed by the bonding material, contact surfaces, application practices and/or construction practices. Hence a perfect bond is impossible to achieve and unless debonding is delayed for the development of a different mode of failure which is inevitable. Thus our approach to this problem was to devise an alternative arrangement that would delay debonding by enhancing the mechanical properties of the binding agent and the bond characteristics between the composite and the concrete surface. Hence the proposed use of a deformable polymer mesh that is thin and fine such that it bonds well with the concrete and the CFRP fabric. Its compatibility, deformability and fineness are expected to ensure its functionality as a reinforcing medium that enhances the percentage of contact by effectively countering lapses within the bond caused by surface irregularities.

2. Experimental Programme

A total of eight beams were casted of the same geometry [100 mm x 150 mm x 750mm]. Tension reinforcement was provided by mild steel bars [6mm diameter] to ensure that flexural failure dominated over shear failure, and links were provided by galvanized steel bars [4mm diameter]. The use of galvanized steel bars was proposed to ease the process of creating links as the least diameter in available mild steel bars was not applicable for our beam geometry. Samples of the galvanized steel bar were tested to obtain its limiting tensile capacity. Steel formwork was used and was removed after the first day of casting, whereby the beams were left to cure. Nearing the 28th day from casting, the beams expected to be retrofitted with CFRP fabric. Required surfaces of beams were sand blasted such that the surface cement paste was rid and sufficient aggregate exposure was attained with a relatively smooth finish.

The blasted surface was cleaned by Acetone prior to the application of a primer coat on the concrete element. On application of a thin layer of primer, the concrete element was left to dry for an approximate 30 to 45 minutes prior to the application of the Saturant. During this period of time, the CFRP fabric was cut to meet our required dimensions [90 mm x 600 mm]. A thin saturant layer was applied onto the primed surface as well as onto the CFRP fabric. The polymer mesh was placed at specific locations on application of the Saturant onto the primer and the composite was firmly pressed from one end of the element to other. A ribbed roller was used to remove air entrapped in the bond line. On completion, the beams were left to set for another 28 days before testing. The descriptions of experimental beams are shown in Table 2 and Figures 1(a) to (f) depict various stages of the experimental process.

Table 2: Experimental Beam Descriptions

Beam	***Description***	***Mesh Placement***
w/o CFRP-01& 02	*Without CFRP - Control 01& 02*	-
w CFRP	*With CFRP Std. Arrangement - Control*	*No Polymer Mesh placement*
CFRP A01-01& 02	*Alternative 01- Beam 01& 02*	*Polymer Mesh at ends*
CFRP A02-01& 02	*Alternative 02 - Beam 01& 02*	*Polymer Mesh for full CFRP length*

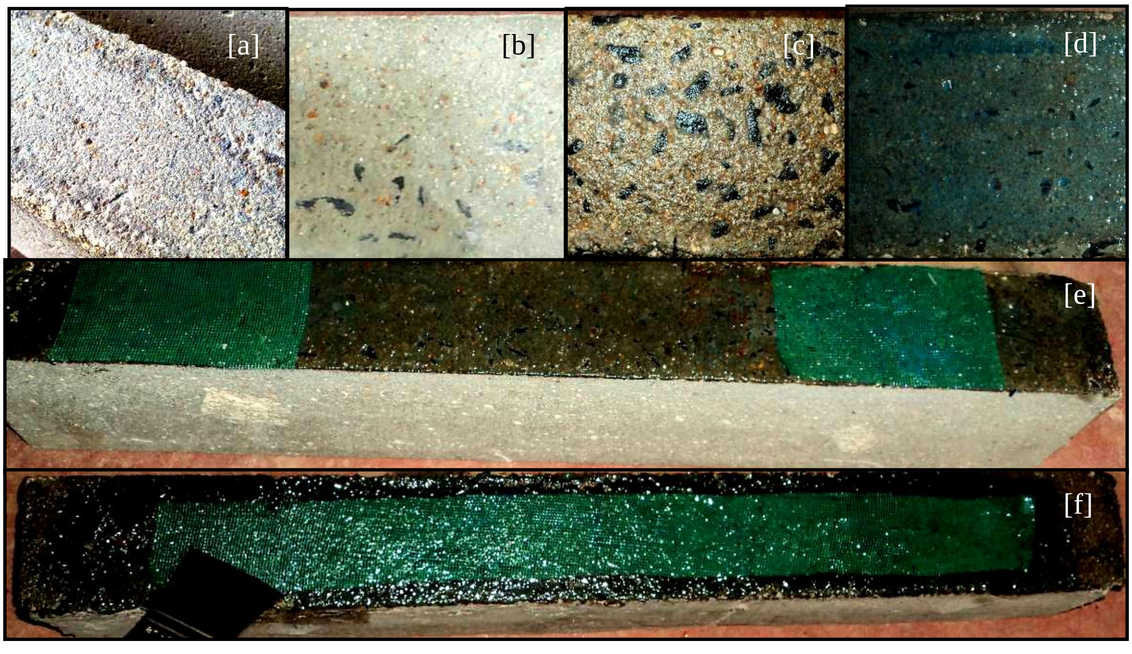

Figure 1: (a) Sand Blasted Beam Surface, (b) Application of Acetone, (c) Applied Primer; (d) Applied Saturant; (e) Alternative 01 - Polymer Mesh at Ends, (f) Alternative 02 - Polymer Mesh for Full length

2.1 Material Properties

Structural properties of the materials used are given in Table 3. A mix design was done for a characteristic concrete strength of 30N mm^{-2} with a target mean strength of 43.12N mm^{-2} having considered a percentage of defectiveness at 5% and a water cement ratio of 0.5. Samples of the proposed galvanized steel were tested via the tensometer apparatus. CFRP strengths are those provided by the manufacturer.

Table 3: Measured Material Properties

Beam	***Parameters***
Concrete Cube Strength [Compressive]	*7day = 29 N mm^{-2}* *28day = 43.6 N mm^{-2}*
Mild Steel	*250 N mm^{-2}*
Galvanized Steel	*363.01 N mm^{-2}*
CFRP Fabric	*4600 N mm^{-2}*

2.2 Testing Arrangement & Data Collection

Three point bending tests were conducted on the retrofitted beams having an effective span of approximately 0.6m. Careful inspections were conducted and adjustments were made to ensure that anchorage of composites at the supports was avoided since flexural strengthening was done to the full extent of the clear span. The loads were applied at mid-span at a constant rate of increase and dial gauges were placed to measure deflections at mid-span as well as those at the supports. A crack width gauge was used to identify the 0.3mm crack width and aid in determining its corresponding load. Failure patterns and the modes of failure were noted for each specimen.

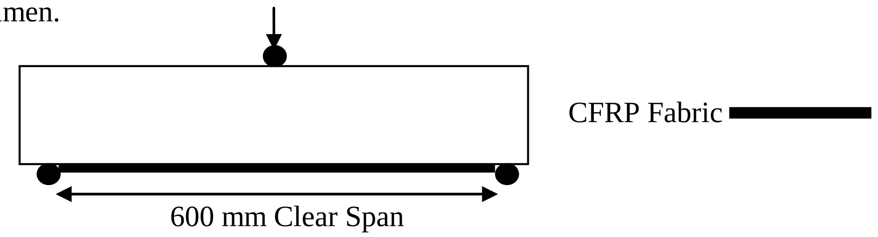

Figure 7: The Three Point Bending Test Arrangement Considered for the loading of test elements

3. Experimental Results

The two control beams without CFRP underwent flexural failure, where one had two flexure cracks on either side of its mid-span vertical plane and the other had a single flexure crack at its mid-span. All CFRP strengthened beams and proposed alternatives have failed due to mid-span debonding caused by the formation of a mid-span flexure crack which soon caused the propagation of debonding to the ends. Figures 2 (a) to (f) are samples of observed failure patterns.

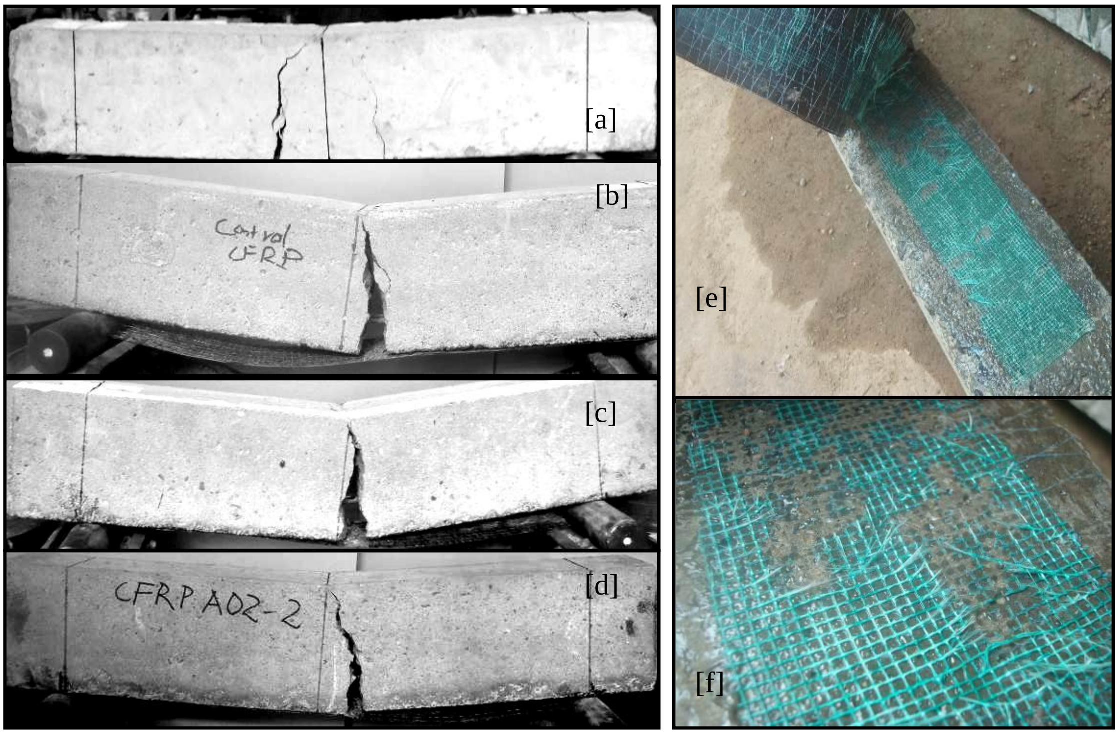

Figure 2: (a) Double flexure crack observed in "w/o CFRP" control beam with one dominant; (b) Single flexure crack observed in "w CFRP" control beam and CFRP fabric debond; (c) Single flexure crack observed in "A01-01"and CFRP fabric debond; (d) Single flexure crack observed in "A02-02" and CFRP fabric debond; (e) and (f) State of the Polymer Mesh After Failure

Table 4: Obtained Results & Estimated Strength Gains Based on Load Carrying Capacity

	Beam	**Load at 0.3mm crack width [kN]**	**Relative gain over 01[%]**	**Relative gain over 02[%]**	**Relative gain over 03[%]**
01	*w/o CFRP-01*	*11.77*	-	-	-
02	*w/o CFRP-02*	*12.95*	-	-	-
03	*w CFRP*	*15.89*	*35*	*23*	-
04	*CFRP A01-01*	*19.62*	*67*	*52*	*23*
05	*CFRP A01-02*	*20.11*	*71*	*55*	*27*
06	*CFRP A02-01*	*22.56*	*92*	*74*	*42*
07	*CFRP A02-02*	*22.56*	*92*	*74*	*42*

The obtained load-deflection data were used for graphical representation of results as shown in Figure 3 & 4. Structural importance/relevance was given to the set of data obtained up to the formation of the 0.3mm crack width where the proposed alternatives, as shown in Table 4, have considerable strength gains over the without CFRP and with CFRP control beams. Alternative two shows the highest gains.

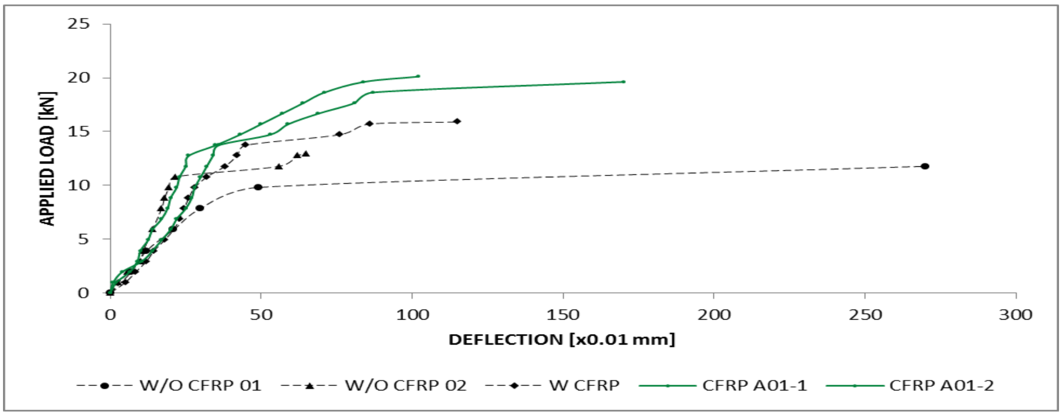

Figure 3: Load Deflection curve for Alternatives 01-01& 01-02

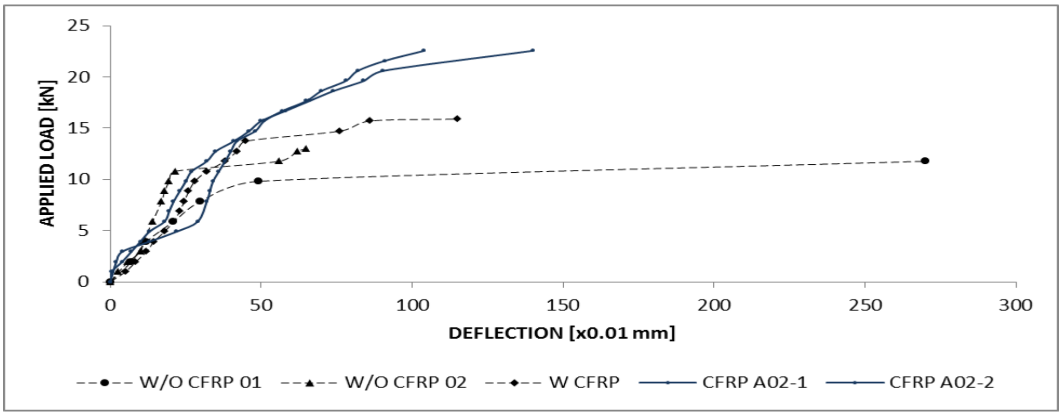

Figure 4: Load Deflection Curve for Alternatives 02-01& 02-02

There are observations with adequate and consistent evidence suggesting that the following considerations are conclusive.

1. The Polymer mesh, of polyester, has resulted to enhanced load carrying capacities under flexure and has achieved strength gains of upto an average of 63%, over the "without CFRP" control beam, when placed at the ends.

2. The Polymer mesh had further enhanced the load carrying capacity under flexure by a factor of 1.32 over the arrangement proposed in "alternative 01" and with an average overall gain of 83% over the "without CFRP" control beam when placed full length below the CFRP fabric.

5. Discussion & Recommendations

As shown via experimentation, it is evident that the Polymer mesh, of polyester, seems to have worked and has effectively delayed end debonding which is the most common failure mode of CFRP/concrete composites. The Polyester mesh, as assumed, seems to have functioned as a reinforcing medium for the epoxy as well, and has ensured an enhanced percentage of contact by countering minor surface irregularities to promote better adhesion.

Since our primary mode of failure was mid-span debonding, “Alternative 02” proved to be the most effective since the composite-concrete face had been externally reinforced at that location by the full length mesh. Alternative 01 was at a lapse of external reinforcement so that critical location and had succumbed to the primary mode of failure earlier than “Alternative 02”.

The cost of Polymer Mesh of polyester is negligible when compared to the CFRP fabric and its installation cost. However, more than double strength increment was observed from the specimens made using this alternative bonding technique. The cost of strengthening project will be reduced considerably with the use of this bonding technique and improved performance can be expected.

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