INVESTIGATION ON ALTERNATIVES TO AVOID DE-BONDING FAILURE OF CFRP STRENGTHENED CONCRETE MEMBERS

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ABSTRACT

This study deals with the investigation of de-bonding failures when CFRP is used for structural retrofitting to enhance the load carrying capacity of reinforced concrete members. De-bonding failures being the most dominating failure mode as limiting factor for enhancing strength hinders the full utilization of the capabilities of CFRP. Therefore the objective of this study is to come up with a proposal that would delay the premature failure of strengthened members by enhancing the strength gains by means of a specific arrangement or orientation of placement or any other fastening mechanism. This study would yield better strength gains and present a simple method that would overcome debonding failure by a significant fraction.

Keywords: Carbon Fibre Reinforced Polymer (CFRP), Epoxy, Debonding failure, Mechanical anchorage, Concrete

1. INTRODUCTION

The degradation of reinforced concrete structures is inevitable, though concrete may have properties of time dependent strength gain. The exposure to aggressive environments would destabilize any structural element, unless designed to resist. Unexpected stresses due may be to earthquakes, settlements or temperature variations may drastically hinder the expected performance of structures. Hence a compromised structure is best retrofitted than replaced to overcome inconveniences and costs for replacement. Out of many adopted techniques for structural retrofitting, the use of CFRP provides many advantageous. Use of CFRP materials has increasingly become popular in Civil Engineering constructions due to its superior properties. This composite is in general a combination of a polymer resin matrix embedded with carbon fibres. Its high durability and strength-to-weight ratio has made it a favourable choice for a wide variety of applications in many work disciplines, most notably the automotive and aerospace industries as well as small consumer goods manufacturers. .

Having identified its effectiveness and possible ease in application, it had been adopted into the realm of civil engineering. Its use as a strengthening or repair material has been a decade long practice and is still a frenzied topic for research. It also can be cut to take any shape or length and is applied simply to remain under adhesion onto a concrete surface. Though its high strength and low weight characteristics have extensive scope within structural retrofitting, its low stiffness property may remain restrictive. Its affinity to undergo deformation has hindered the possibility of significantly magnifying elemental strength, as the bonding agent or the considered element (reinforced concrete member) or the material (CFRP) itself would undergo failure. Since de-bonding is the most encountered and most critical of failure modes, binder properties and fixing mechanisms or even perhaps the orientation of the CFRP layout could nurture greater governance towards altering strength inadequacies in applied concrete members (most notably flexural members) targeted for economical long term benefits. Though the material permits higher gains, this setback allows only for gains that are feeble. Therefore a research is at hand to seek alternatives that could prevent this common yet frustrating mode of failure that is of a de-bonding nature.

1.1 Problem statement & overall objective

As mentioned within the introduction above, the CFRP material has a tendency to de-bond, due maybe of the limitations of the binder or maybe of the application and arrangement of the CFRP. Also primarily for flexural members, the reduction in long term strength gains may substantially be from bond failures occurring at the composite ends within the vicinity of supports. Therefore other than observing the behaviour of CFRP strengthened reinforced concrete members, there is a necessity to identify alternatives to minimize or substantially suppress failure due to de-bonding in such members (primarily of flexural members) in hopes of achieving intended benefits for the spent cost.
It has also come to Authors understanding that due to de-bonding, the strength gain is very low when compare with strength properties of remain short term and the percentage of gain approaches only a mere twenty. Therefore our primary objective is to fractionally enhance the load carrying capacity of members to bring about a substantial cost relief by proposing an arrangement or fixing mechanism. The results of this study will provide a significant contribution to the FRP strengthening technology

worldwide.

2. FIBRE REINFORCED POLYMER (FRP)

FRP is in general a polymer resin matrix embedded with high strength fibres, which can be of different materials. The overall properties of the material is governed by the properties of the fibre, the polymer matrix, volume fractions of constituent materials, the orientation of fibres, local defects, the strength of adhesive and the method of application or fixing whether wet lay up or mechanically fastened.

Table 1 Mechanical properties of FRP materials

MATERIAL	DENSITY [kg m^{-3}]	TENSILE STRENGTH [N mm^{-2}]	MODULUS OF ELASTICITY [GPa]
Carbon	1800 - 2200	1500 - 4000	150 - 420
Aramid	1400 - 1500	2000 - 3600	130 - 160
Glass	2200 - 2500	1500 - 3500	70 - 90
Steel	7850	415	190 - 210

The materials commonly used as fibres are carbon, aramid and glass. A comparison of their material properties to those of steel are as shown in Table 1. The matrix is typically of a polymer that is of a thermosetting type, functioning as a binder, stress distributor and a protector from abrasion or environmental degradation of fibres. Epoxy resins or polyesters are typically used as the substance for the polymeric matrix. The fibres within this matrix are oriented to be either unidirectional or multidirectional or even of a woven nature. Acting as a medium to provide a shear load path between the concrete surface and that of the composite material, the effectiveness of the FRP is greatly influenced by the adhesive used to bond onto concrete. The most widely used adhesive is epoxy and is of epoxy resins mixed with a hardener. To successfully utilize an adhesive, much requires consideration during its application. The pot life, open life, glass transition temperature, mixing temperature, application temperature, curing temperature, adequate surface preparation, technique of application, abrasion resistance, chemical resistance, provisional substances and much more significantly impact the quality of adhesion achieved. Typical properties of ambient cured epoxy adhesive are shown in Table 2.

Table 2 Properties of epoxy adhesive

PROPERTY	COLD CURING EPOXY ADHESIVE
Young's Modulus [GPa]	0.5 - 20
Tensile Strength [N mm^{-2}]	9 - 30
Coefficient of Thermal Expansion [(^{o}C)$^{-1}$]	25 - 100
Glass Transition Temperature [^{o}C]	45 - 80

The composite is therefore known as CFRP, GFRP, AFRP or a hybrid depending on the use of fibres and in each type there are many variations [low modulus CFRP, high modulus CFRP, E-Glass FRP, S-Glass FRP and so on]. The required mechanical properties of these composites can easily be found if the volume fractions and properties of constituent materials are known or by simply tensile testing the substance. The composites are in general immune to erosion, is of low weight, easy to apply, requires no support till adhesive strength gain, is of very high tensile strength and can be of any dimension or geometry. Though FRP is advantageous in many ways, the setbacks cannot simply be shunted away. Unlike steel, FRP operates within the linear elastic region and its failure is sudden without any yielding or plastic deformation. However, this brittle nature does not affect on the system because other elements such as epoxy and concrete in the composite is much weaker than FRP materials. This will cause failure in the concrete substrate or in the bond line before reaching ultimate strength of FRP. Fibres out of carbon or aramid may have incompatible coefficients of thermal expansion in comparison to concrete and at high temperatures the polymeric resin may weaken and lead to premature failures of strengthened elements. Also on a cost basis, FRP strengthening may not be a cheap solution and researches similar to this study are being undertaken to increase the gains for the spent cost.

The application of FRP can be of a variety of techniques and on a variety of elements. They can be applied as an external bonding, wrapping or a near surface mount for beams, columns, slabs, walls, bridges and much more. Though our primary focus is to study and enhance the behaviour of FRP when applied as externally bonded on to the tensile face of a reinforced concrete beam for flexural strength gain, it can also be applied onto the beam web region for enhanced shear strength or wrapped around columns to enhance confinement as well. Mounting can be of placing FRP bars or strips into groves or by mechanical fasteners.

2.1 Proposed experimental works

Many experimental works have been done and many are still in the process of being initiated to study the behaviour of simply supported CFRP retrofitted reinforced concrete beams under a single point, a two point or a uniformly distributed loading and to also identify influencing parameters. Such tests have enabled the identification of the following failure modes being either due to the rupture of CFRP after yielding of steel, the crushing of concrete in flexure though the CFRP is intact, the shear failure of strengthened element, the interfacial de-bonding due to loss of composite action, the separation of concrete cover at the tensile reinforcement region or below, the interfacial de-bonding induced by intermediate flexure cracks or the interfacial de-bonding induced by intermediate flexural-shear crack. Failures within the CFRP layer, Adhesive layer or at the CFRP adhesive interface are also possible ways of delamination and may prove problematic if unaddressed.

But nevertheless the load carrying capacity of CFRP strengthened flexural members are limited by the de-bonding failure modes due to the prevalence of high interfacial stresses at the ends of bonded elements as a result of its high strength to stiffness ratio, or due to the presence of high moment regions causing intermediate flexural and flexural-shear cracks as a result of the CFRP being relatively thin. Also, the presence of CFRP material near or away from supports would govern the formations of critical diagonal crack de-boding or the latter with concrete cover separation. The resulting increase in flexural capacity due to the use of CFRP may also result in the generation of excessive shear forces which may have to be restrained by inadequate shear reinforcement. A proper evaluation has to be done to find whether flexural strengthening would have to be accompanied by shear strengthening.

Strengthening using CFRP can be done in many ways and orientations like longitudinal bonding, transverse bonding, diagonal bonding, side bonding, wrapping (for columns), U jacketing, near surface mount techniques, overlapping layers or a mix of those mentioned (Pham, 2005). This study would aid in proposing an alternative arrangement by looking into the existing methods of application. Initially, the CFRP strengthened concrete member was designed to fail by debonding of CFRP laminate (ACI440). The beam dimensions, bonding parameters and reinforcements were selected in accordance with design calculations. A total of ten CFRP strengthened concrete members will be tested. Two of them was selected without any measure to avoid debonding failure (control specimens). Then, remedial measures will be introduced to the system with continuation of test program to increase the strength gain of strengthened system.

3. CONCLUSIONS

Though much research has been done on the use of CFRP as a strengthening material for reinforced concrete members, much is still unknown and uncertain as to how sufficient strength gains could be achieved by suppressing premature failures. Some influencing parameters and member behaviours are still at a lapse of control and understanding to enhance full utilization of CFRP capabilities for long term benefits. The understanding of the circumstances under which such parameters inflict governance is a must.

Strengthened members should also be accurately evaluated to ensure the prevention of stated failures other than that of a de-bonding nature as well as those that are of a de-bonding type. Though end peeling maybe restrained via appropriate anchors, mid span tension delamination and premature shear failure due to lack of shear reinforcement (a result of enhanced flexural capacity) remain as limitations.

The alternatives to be proposed as a result of conducting this study would hopefully enhance the load carrying capacity to add value to the use of CFRP as a strengthening material for reinforced concrete beams worldwide.

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