INVESTIGATION ON ALTERNATIVE BONDING AGENTS FOR CFRP CONCRETE COMPOSITES

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Abstract

Carbon Fibre Reinforced Polymer (CFRP) strengthening is popular in strengthening and rehabilitation infrastructures. The most common adhesive used to create the bond between CFRP and concrete is two part epoxy resin. However, the epoxy adhesive used in Civil Engineering constructions is very sensitive to elevated temperature. In general the bond properties deteriorate rapidly around the glass transition temperature of polymeric resin (Gamage et at, 2006). Provision of adequate fire endurance to strengthened members is an important issue in the applications of buildings. Investigation of alternative bonding agent with improved thermal and mechanical properties is a key issue to expand this technology in the construction field.

An extensive experimental programme was conducted using cement grout as bonding agent. Performance in flexure was investigated using three point bonding test. Parametric study was carried out on bond line thickness. This study shows improved flexural performances of composites with 3 mm thick cements grout bond. This paper presents the preliminary test results, conclusions and recommendations on future research needs.

Keywords: CFRP/concrete composites, Epoxy bond, cement based adhesive, flexure

1. Introduction

Strengthening with externally bonded Carbon Fibre Reinforced Polymer (CFRP) has become an effective technique to strengthened concrete structures. CFRP is a layer of carbon fibre embedded in a polymer which is often epoxy. CFRP materials show superior properties; low self weight, high strength, corrosion resistance, low thermal expansion and ease of application. CFRP has been used in many structural engineering applications to improve flexure and shear strength. Mainly it is used to increase the load bearing capacity of old structures that were designed to tolerate lower service loads than they are experiencing today and to repairing damaged structures.

The greatest obstacle to applications of CFRP concrete elements using epoxy resin is the degradation of mechanical and bond properties when it exposed to high temperature. The fire behaviour of CFRP concrete composites depends mainly on behaviour of the polymer resin matrix/ adhesive. Polymer resins soften at their glass transition temperature (T_g) thus limiting the transfer of stresses between the fibres and the substrate. CFRP itself has very good thermal performance even though the bond line is very sensitive to the temperature. The exposure to elevated temperatures will lead to rapid and severe deterioration of CFRP/ concrete bond, resulting in delamination of the CFRP sheet and loss of its effectiveness. Gamage et al (2005) has noticed a rapid strength loss in epoxy bond when it exposes to temperatures above 60^0C which is the glass transition temperature of epoxy adhesive. Peeling off of CFRP sheet was the observed failure pattern at elevated temperatures.

Limited research has been carried out to explore alternative bonding systems for CFRP/ concrete composites. Cement-based materials may provide improved performance of CFRP strengthened concrete members because of very good compatibility with substrate properties. By replacing the epoxy resin with cement-based material, all the epoxies resins problems would be resolved, their poor behaviour above the glass transition temperature (is the transition in material from a relatively brittle state into molten state) and high cost (Blanksvärd, T. Täljsten, B.). The experimental study done by Siavash and Al-Mahaidhi (2009) was focused on investigation for flexural behaviour of CFRP strengthened beams using different type of mortars as bonding agents. Three different mixes have been used including silica fume, latex modified adhesive containing SBR latex and Micro-cement. They found that higher level of load carrying capacity can be achieved by OC mortar without any substantial additives compared to latex modified mortar. The best flexural performance was obtained from the micro-cement added mortar. Author has concluded that it is not economical to added SBR latex to the mix.

2. Experimental Investigation

The objective of this experimental programme was to investigate the flexural behaviour of CFRP strengthened beams using cement grout as bonding agent. This investigation has done by undergraduates in the Department of civil engineering, University of Moratuwa for final year research project. A total of eight CFRP strengthened concrete specimens were tested in flexure using one point loading test method.

2.1 Materials

The concrete material used was a machine mix concrete with 28 day compressive strength of 30 N/mm^2. Mild steel bars (6 mm diameter) with tensile strength of 250 N/mm^2 were used as tension and compression reinforcement. Galvanized steel bars (4 mm diameter) with tensile strength of 363 N/mm^2 were used as shear reinforcement. The latter material properties were measured before use in test specimens. Ordinary Portland cement with 1:3 water cement ratio was used as alternative bonding material for CFRP composites. Normal modulus of CFRP was used. The mechanical properties of CFRP samples and epoxy adhesive are shown Table 1.

Table 1: Mechanical Properties of CFRP and Adhesive

Property	***CFRP***	***Epoxy Adhesive***
Modulus (GPa)	*230*	*>3*
Tensile Strength (MPa)	*3800*	*>50*
Density (g/cm^3)	*1.7*	-

2.2 Specimen Preparation and test procedure

Eight reinforced concrete beams (150 mm x 100 mm x 750 mm) of grade 30 were constructed and kept to cure for 28 days. Each beam was reinforced with two tension reinforcement bars of 6 mm in diameter and two compression reinforcement bars of 6 mm in diameter of mild steel. Galvanized steel bars of 4 mm diameter at 50 mm spacing were used as the stirrups. Interfacial contact between concrete and CFRP is one of the most important process on strengthening process.

In order to achieve successful bonding under any environmental condition, the surface that is to be attached must be strong, sound, dry and clean. The concrete surfaces were sandblasted to remove the laitance and brush to remove dust particles and finally cleaned with acetone. The surface of CFRP kept clean by keeping the peeling ply on CFRP until just before applying adhesive. The execution of bonding work had great importance in order to achieve a composite action between adherents. A thin primer layer was applied on the prepared substrate as shown in Figure 1(a). Then, the specimens were kept to cure for about 45 minutes before applying the epoxy adhesive. A layer of saturant was spread uniformly using a spatula over the bond area required for bonding. The CFRP sheet was saturated with epoxy adhesive and pressed onto the surface using a ribbed roller into one direction in control specimens. Air trapped within the epoxy was expelled before curing. For specimens used to find the suitability of concrete grout as the bonding agent, support boards of 3 mm and 6 mm thick from concrete surfaces were provided to ensure uniform bond thickness.

Figure1: (a) Sandblasted surface before applying CFRP sheets, **(b) Cement grout layer as adhesive, (c) Applying CFRP layer to the beam**

The test span of all beams was 600 mm. The beams were tested simply supported, subjected to one point load placed at the centreline of the beam. The beams were tested using Amsler Testing Machine. Load was increased by 0.1 metric tons and the mid - span deflection was recorded using two dial gauges. Readings were recorded until the vicinity of 3 mm crack. Load relevant to 3 mm crack was considered as the failure load. After removing the gauges, further loading was done to better observation of failure. A schematic diagram of test set – up is shown in Fig.1.

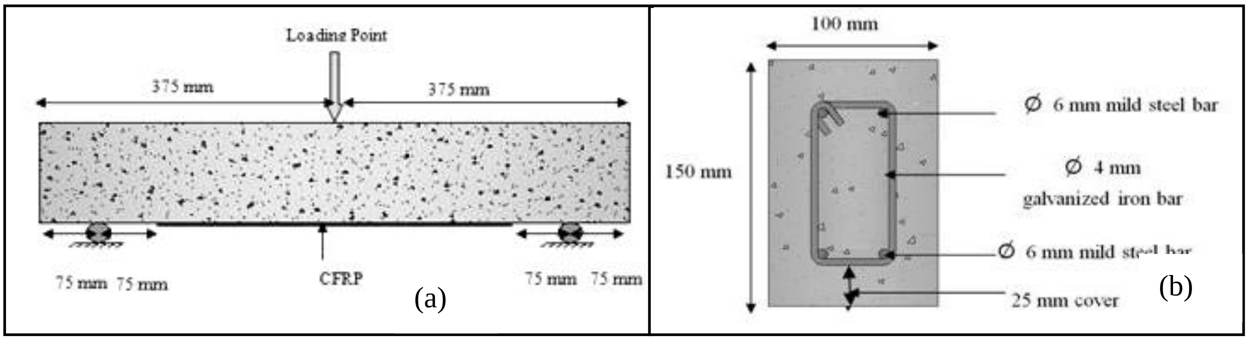


Figure 1: (a) Load setup configuration, (b) Details of the Beam

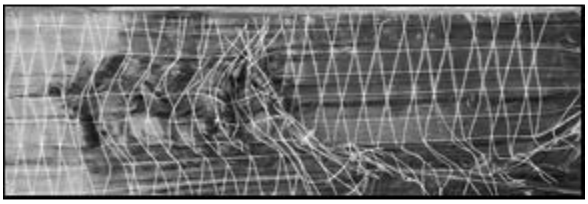
2.3 Test Results

The main outcomes of this experiment were the failure load at flexure and deflection of beams with incremental loading. The summary of test results is shown in Table 2.

Table 2: Test Results

Type	***Failure Load (KN)***	***Deflection at the middle (mm)***	***Increment Load Carrying Capacity***	***Failure Mechanism***
Control Beam (without CFRP)	*11.77*	*2.7*	-	*Flexural Failure*
	12.95	*0.65*	-	
CFRP bonded using epoxy	*15.89*	*0.86*	*26*	*De bonding Failure due to initiation of mid span flexural crack*
CFRP bonded using 3 mm cement grout bond	*16.68*	*2.05*	*35*	*CFRP material Failure*
	17.17	*1.84*	*39*	
CFRP bonded using 6 mm cement grout bond	*15.70*	*0.85*	*27*	*CFRP material Failure*
	16.67	*2.0*	*35*	

CFRP material Failure could be observed in specimens with both 3mm and 6 mm thick cement bond layer. This is mainly due to low viscosity of cement based adhesive. However, improvement in flexural strength with cement grout bond was observed. CFRP bonded with epoxy adhesives showed de bonding failure of CFRP sheet and an increment of strength in the CFRP could be observed due to saturation CFRP with epoxy adhesive.



(c) **(d)**

***Figure 3: (a) Flexure failure of control beam*, (b) De bonding Failure of specimen (CFRP with Epoxy adhesive), (c) CFRP material failure of specimens with cement grout (6 mm thick bond), (d) CFRP material Failure (3 mm thick bond)**

There was an increase in load carrying capacity for the CFRP composite beam where cement grout was used as the bonding agent than epoxy bonded composites. The specimens with 3 mm thick cement grout bond showed better performance compared to 6 mm thick bond. On average, 37% increment of load carrying capacity was achieved by 3 mm grout bonding while 31% by 6 mm grout bonding. The latter for CFRP strengthened specimens with epoxy adhesive was 26%. All these figures based on average strength of control specimens (concrete beams without CFRP).

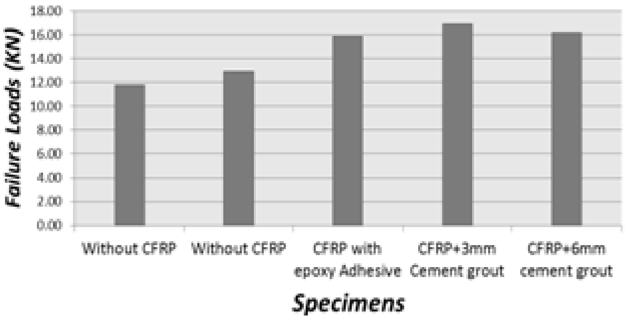
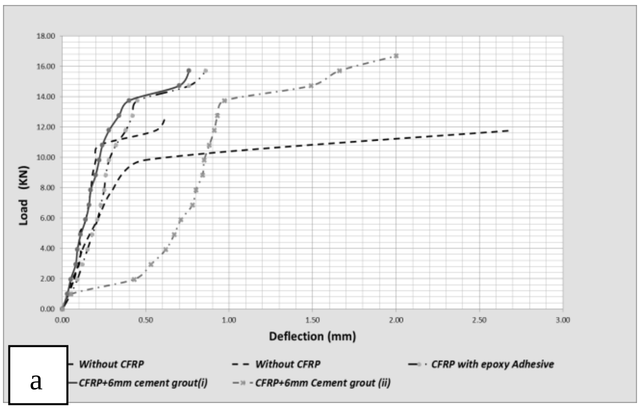


Figure 2: The bond strength variation of CFRP/epoxy and CFRP/ Cement grout



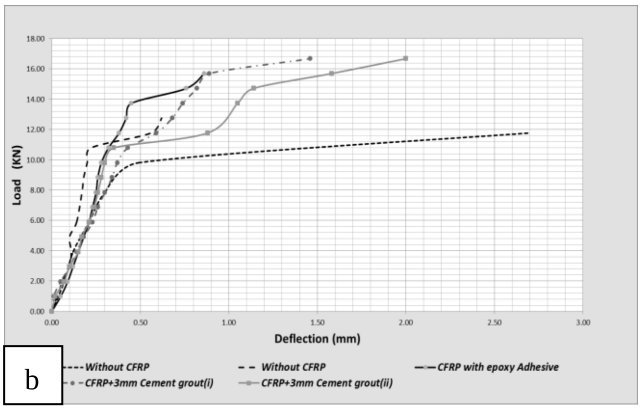


Figure 3: Comparison of deflection Vs load of control specimens with specimens of gout bond d

3. Conclusions

This investigation was based on the flexural behaviour of CFRP strengthened concrete beams. Cement grout and epoxy adhesive were used as bonding agents. Following conclusions were made on cement grout bond:

- The cement grout can be used effectively as bonding material to replace epoxy adhesive bond in CFRP/concrete composites
- Health hazards will be minimised with application of non-toxic cement grout for bonding to replace toxic adhesive bond
- Increased flexural performances were noted in the specimens with 3 mm thick cement grout bond
- Improved thermal properties of composites can be expected
- Further investigations are required to ensure short term performance such as shear and confinement, durability and fire

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References

Blanksvärd, T. Täljsten, B Strenthening of concrete structures with cement based bonded composites, (available online pure.ltu.se/portal/files/3422691/Article.pdf) [accessed on 2/11/2012]

Chowdhury E.U., Green, M.F., Bisby, L.A, 2007. Thermal and Mechanical Characterization of Fibre Reinforced Polymers, Concrete, Steel and Insulation Materials for Use in Numerical Fire Endurance Modelling, Structures under Extreme Loading, Proceedings of Protect 2007, Whistler, B.C., Aug. 20-22, 200&, pp. 1-10

Gamage, J.C.P.H., Al-Mahaidi, R. and Wong, M.B (2006) “Bond Characteristics of CFRP Plated Concrete Members under Elevated Temperatures” Journal of Composite Structures, Volume 75 Nos. 1-4, September. Pages: 199-205

Gamage, J.C.P.H., Al-Mahaidi, R. And Wong, M.B. (2009) “Durability of CFRP Strengthened Concrete Members under Extreme Temperature and Humidity”, Austrailian Journal of Structural Engineeering (AJSE), Vol.9, No.2

Hashemi, S., Al-Mahaidi, R. (2008) “Cement Based Bonding Material for FRP”, Proceedings of the eleventh Int. Inorganic-Based Fiber Composites Conference, 5-7 November 2008, Madrid - Span

Thomas Blanksvärd and Björn Täljsten by “Strengthening of concrete structures with cement based bonded composites” Luleå University of Technology,Sweden and Technical University of Denmark.

Experimental research on strengthening of concrete beams by the use of epoxy adhesive and cement-based bonding material by Sólrún Lovísa Sveinsdóttir, Thesis in Civil Engineering with Specilization in Structural Design and Concrete Technology (June 2012)