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IMPROVING PERFORMANCE OF CFRP RETROFITTED RC MEMBERS USING RUBBER MODIFIED EPOXY (ON GOING RESEARCH)

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ABSTRACT

Although the method of external attachment of CFRP to the concrete members is the most effective and economical solution for strengthening and repairing concrete structure in the century, the bonding issue between CFRP and the hosting surface still a challenge for the structural engineers. Many solutions are proposed to overcome the early de-bonding failure in the strengthened members. This paper reports an ongoing experimental program for testing CFRP retrofitted RC beams and slabs. Fifteen RC beams of dimensions 150x250x2300mm and twelve two- way RC slabs of size 85x1670x1670mm will be strengthened using different types of epoxies, different configurations and variable number of layers of CFRP strips (MBrace-230). Rubber modified epoxy will be used for carbon fibre external attachment using wet lay-up method. Loading frame of 500 kN capacity will be used for beams testing. While for applying uniformly distributed load on the slabs a purpose built attachment will be used. The experimental results will report on the ultimate load, failure mode, mid-span deflection, strains readings in different locations and the ductility for both groups of strengthened beams and slabs. A mathematical model will be developed to predict the behavior of RC beams and two-way slabs.

KEYWORDS:

Rubber modified Epoxy, CFRP sheet, RC beams, RC slabs, Retrofitted Structures.

INTRODUCTION

The integrity of the bond between the composite and concrete is the key to a successful external reinforcement of members. Quality of the epoxy, laminate application and the surface preparation are the main parameters affecting a successful bond. Moreover, the quality of the work and the reliability of the material also have a significant effect on bond integrity. The weak layers and/or non-compact particles should be removed from the hosting surface (Triantafillou, Deskovic & Deuring 1992). Mechanical grinding, sandblasting and grit blasting, water jet or vacuuming are used to remove the scattered fragments. There is no particular method specified for surface preparation, however, a high-pressure water jet is a common method. Changes in concrete strength and the geometry of a test specimen help in selecting the surface preparation method. It is difficult to obtain a uniform epoxy thickness as suggested by the producer due to surface roughness. The use of a hand roller is a common method among many to achieve uniform epoxy thickness (Al-Ameri, R & Al-Mahaidi 2006; Rahimi & Hutchinson 2001). In spite of the difficulty in achieving a precise uniform thickness, the complete coverage of the laminates can be guaranteed by forcing excess epoxy out of the joint region.

One of the drawbacks of strengthening with composite is the brittle failure mode, which has a strong relationship with the extent of composite behavior. The loss of bond integrity between the FRP composites and concrete substrate lead to premature failure of the structural member. The member fails either by FRP delamination or by cover delamination. The strain compatibility can be developed by the sufficient bond between the concrete and the external composites, and it is the main concern of design codes and mathematical modelling. The performance of any composite member can be evaluated by the amount of forces transferred between the concrete and the composites. Hence, the amount of interface slip increases when the retrofitted member has strain incompatibility.

The main objective of externally retrofitted concrete members is to develop the interaction with the composite component and maintain the overall composite behavior up to failure (Al-Ameri, R. 2011; Swamy & Mukhopadhyaya 1995). Furthermore, Al-Ameri and Al-Mahaidi (2006) reported that the full composite state is achieved by increasing the composite action through improving the anchorage of CFRP layers. The relationship between the degree of composite interaction and failure modes still unclear (Nguyen, Chan & Cheong 2001). Many researchers have noted that strain compatibility is not achieved, especially in the stage prior to failure (Brena et al. 2003;Esfahani, Kianoush & Tajari 2007;Riad 1999;Sayed-Ahmed, Riad & Shrive 2004). However, strain compatibility is achievable through the depth of the section (Lee et al. 1999; Spadea, Bencardino & Swamy 1998; Triantafillou & Plevris 1992).

The composite behaviour is greatly affected by the external anchorage system (Al-Ameri, R & Al-Mahaidi 2006;Spadea, Bencardino & Swamy 1998). Bakay (2003) concluded that the composite action of the RC beams externally strengthened using CFRP strips, is aborted at 85% of maximum beam load. On the other hand, composite action sustained 99% of the maximum beam load when an additional anchorage system was used. Triantafillou & Plevris (1992) asserted that one of the important factors for increasing the composite action is the characteristics of the adhesive. The critical factor for efficient stress transfer is adherent stiffness (Buyukozturk & Hearing 1998). The adhesive physical properties such as stiffness, viscosity and flexibility, in addition to the bond between concrete/composite and interfacial stress, are significant factors in the ability of the adhesive to transfer stress (Swamy & Mukhopadhyaya 1995). The composite behavior adversely affected by a lack of any one of these properties (Sayed-Ahmed, Bakay & Shrive 2009).

Stiff adhesive is now to be associated with de-bonding failure in concrete member retrofitted with FRP composites. Maeda et al. (2002) concluded that, the use of a flexible adhesive (in terms of modulus of elasticity) assisted to increase the overall bending moment by reducing the stress concentration along the FRP/concrete interface. The de-bonding failure has less chance to occur when a flexible adhesive layer is used compared to the stiff adhesion (Kotynia & Harries 2006). Sebastian (2001) stated that the use of a flexible adhesive layer allows shear deformation to occur, which consequently allows the plate to slip partially and give more stress/strain gradient, thus resulting in improved FRP efficiency. In the same manner Al-Ameri (2011) reported the overall behavior of the composite was greatly affected by the type of shear connection between the two components. Therefore, the shear connection (adhesive layer) should be soft to exhibit large deformation. On the other hand, to avoid the vertical separation, the adherent must have sufficient anchoring properties. The shear stiffness of the bonding agent (K_s) can be defined as the membrane force required to produce a unit length of deformation. (Al-Ameri, R. 2011). Therefore, we need to look for an adhesion agent with a softer binder compared to what is now used to allow more flexibility (deformation) at the interface during loading. In this research, the rubber-modified resin is used by mixing the Hypro reactive polymer CTBN1300x13 with MBrace saturant in order to get a soft-bonding agent.

RESEARCH SIGNIFICANCE

The Aim of this research is to improve the performance of CFRP retrofitting system when modifying the bonding agent using rubber liquid. The resulted epoxy is expected to improve the overall ductility of the composite section, minimizing the interface stress concentration, and hence prevent the premature failure in the composite members.

MATERIAL PROPERTIES

Concrete of grade 32 MPa was used to cast the RC beams and slabs specimens. Unidirectional carbon fibre type MBrace-230 will be used to strengthen the test specimens with physical properties as given in Table 1.
The bonding agent used in this research is MBrace resin system. It is one of the commonly used resins in the retrofitting applications. The features and benefits of MBrace system are increasing flexural strength, increasing shear strength, increasing impact resistance, confinement, blast resistance, fatigue enhancement, lightweight, durable, control of crack propagation, and have excellent strength to thickness ratio. The MBrace bonding system consisted of two components: primer and saturant. In order to improve the performance and ductility of the bonding agent, MBrace resin is modified by adding liquid rubber (type Hypro 1300x13 CBN) which enhances the toughness and flexibility of most Thermoset Resins. Hypro 1300X13 CTBN is a carboxyl terminated butadiene acrylonitrile

copolymer used predominately as a reactant with the base thermoset resin to gain product performance improvements. Alternatively, introduce a rubber film (Kynar 740 PVDF) as a damper at the interface between CFRP and hosting surface. The mechanical properties of the bonding materials are given in Table 2.

Table 1: Properties of CFRP, (BASF company).

Fibre Type	MBrace CF-230/4900
Fibre Density	1.76 g/cm^3
Fibre Modulus of Elasticity	230 GPa
Thickness	0.17 mm
Ultimate Strain	2.1%
Ultimate Tensile Strength	4900 MPa

Table 2: The mechanical properties of the bonding materials (BASF company).

Material	Density (Kg/m^3)	YS (MPa)	UTS (MPa)	E (MPa)	% Elongation
MBrace Primer	1102	14.5	17.2	717	40
MBrace Saturant	983	40.0	14.0	1138	5.3
Hypro 1300X13 CTBN					
Kynar 740 PVDF	1780	50		1700	50

EXPERIMENTAL PROGRAME

Preparation of Test Specimens

Fifteen RC beams of 150x250x2300 and twelve RC two-way slabs of size 85x1670x1670 mm were casted according the mix proportions designed for the required concrete grade. Beams reinforced with mild steel of 3Ø12 and stirrup hanger of 2Ø12 and stirrups of Ø8 with max spacing 125mm. The slabs were reinforced with 8@163 mm steel bars as main reinforcement, upper reinforcement were achieved with steel mesh of <u>8.55 @ 200mm</u> (SL92), to carry the tensile action when the slab is overturned. Figure 1 & Figure 2 show the cross section details for beams and slabs respectively. Four inside threaded bolts were fixed at the slab corners as lifting points; at location of 200x200 mm from the slab corners, see Figure 3.

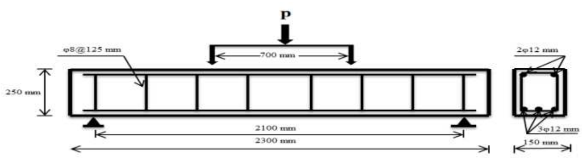


Figure 1: Beam cross- section.

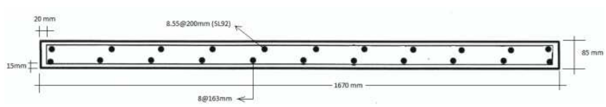


Figure 2: Slab cross- section.

CFRP Configurations

CFRP will be attached as 100mm strips to the concrete beams bottom, with different number of layers. For the slab specimens, different carbon fibre configurations are selected in an attempt to observe the best distribution of the carbon fibre among the tested specimens. CFRP patterns will be selected in terms of coverage area ratio and effective cross sectional area ratio in x & y directions. The strips will be attached to the soffits of the slabs. The first configuration is performed by attaching CFRP strips in x & y directions and in the central region of the two-way slabs, in order to confirm the ductility improvement when using the epoxy with the rubber liquid, and to compare the results with the neat epoxy case. Second CFRP configuration will be applied on the slabs, similar to the first arrangement, in addition to inclined strips crossing the path of the yield lines that were firstly appeared during the control slab test.

Test Program

The first series of the test program consisted of 15 RC beams including a control beam. The second beam will be strengthened by three layers of CFRP sheet using neat epoxy. The third one will be strengthened by three layers of CFRP sheets using rubber modified resin. The other 12 beams will be with variable strengthening parameters. The second series of the test program consisted of 12 RC slabs. One slab was tested as a control slab, as will be explained in the next section. Two slabs will be strengthened by three layers of CFRP strips in x & y directions, one of them using neat epoxy, the second will be strengthened using rubber modified epoxy. Three more slabs will be strengthened with different CFRP configurations as explained in the previous section. The CFRP will be applied using rubber modified epoxy. The remainder slabs will be tested with different parameters.

Test Setup and Instrumentations

All beams will be tested up to failure under point loading arrangements as in Figure 4. The 500 kN testing frame will be used for all the tests.The slabs were simply supported on its four edges using a special steel frame suited the slab dimensions, as shown in Figure 5. The slabs were tested under uniformly distributed load provided by UDL attachment, and consists of 16 hydraulic pistons arranged in square grid pattern, every piston have 50 mm travel except the centred 4 pistons that have 75 mm travel. The supply of each piston hydraulic can be either closed or open; all 16 pistons are linked hydraulically; they are manually operated (pumped) to reach to a desired initial pressure. Once it is achieved, the hydraulic actuator is placed in closed position, then it creates a self-levelling ‘cushion’ or UDL. Figure 5 showed the UDL apparatus when attached to the loading frame of 500 kN capacity. Laser LVDT of 100mm deflection capacity will be used to measure the mid-span deflection for beams and slabs.


Figure 3: Slab specimens.


Figure 4: Beam testing.


Figure 5: UDL attachment.


Figure 6: Slab lifting.

Lifting & Handling the Slab specimens

The slab specimen is too heavy to be carried and overturned by conventional methods noting that a single slab mass is 569 kg. An efficient procedure is used through fixing threaded steel sleeves prior to concrete casting at the four corners of the slab (200x200mm distance from the corner). These sleeves are used as lifting points for the slab together with a steel frame to be bolt connected to the four points. The slab and the frame together enable the turnover of the slab as much times as required with minimum effort, as shown in Figure 6.

Testing of the control slab


Figure 7: cracking pattern for control slab.

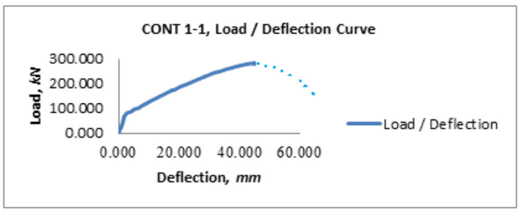
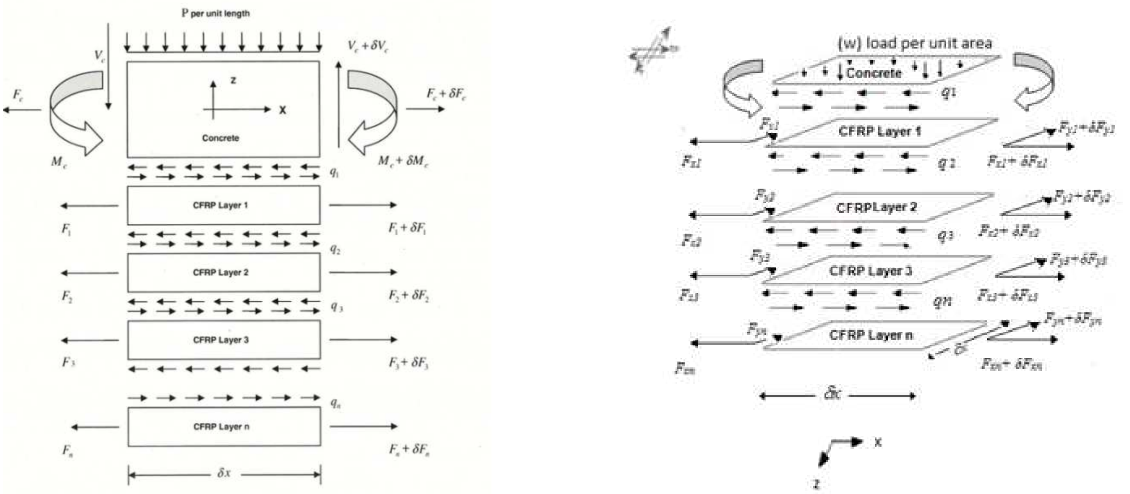


Figure 8: Load deflection Curve of the Control slab.

The slab was tested under load control procedure and at rate of 5 kN/ min. At the time 15 min after loading, the first crack was observed at a load of 74.5 kN, initiated at the mid span region and propagated towards one edge of the slab. The first crack was followed gradually by diagonal cracks towards the slab corners and at a load of 100kN. At 150 kN, the cracks propagated in different directions over the slab surface. At 160 kN the cracks propagated through the depth of the slab and could be observed easily. At load of 260 kN, the cracks covered a large area of the slab bottom surface, and then the cracks formed a diagonal pattern. Through most of the slab thickness the cracks width continued to widen until failure at a load of 280 kN Figure 7, shows the cracks patterns at the bottom of the tested control slabs while Figure 8 shows the load deflection curve of the control slab. The trend of the curve presents the conventional behaviour of a two way RC slab supported on four edges.

MATHMATICAL MODELING

A mathematical model will be developed in order to predict the correct failure mode of the composite section and to simulate the behaviour of RC beams, see Figure 9(a). The RC beams will be strengthened with a multi-layered CFRP matrix, which allow for inter-layer slip and partial interaction. This model will consider non-linear material properties and the results will be verified with test results and a finite element analysis using ABAQUS software. While a two dimensional plate element will be used to model the composite two-way slab members, see Figure 9(b).



(a) Composite beam element. (b) Composite plate element.

Figure 9: System of composite element.

CONCLUSION

External attachment of CFRP is sufficient for improving the capacity of the retrofitted section. De-bonding is one of the most common problems related to this retrofitting technique, hence; improving the mechanical properties of the used epoxy is a successful measure to overcome the premature failure. This paper reports an ongoing experimental program for testing CFRP retrofitted RC beams and slabs. Fifteen RC beams and twelve two- way RC slabs will be strengthened using different types of epoxies, different configurations and variable number of layers of CFRP strips (MBrace-230). Rubber modified epoxy will be used for carbon fibre external attachment using wet lay-up method. Loading frame of 500 kN capacity with a purpose built attachment will be used for testing. The experimental results will report on the ultimate load, failure mode, mid-span deflection, strains values and ductility of the strengthened beams and slabs. A mathematical model will be developed to predict the behaviour of RC beams and two-way slabs.

REFERENCES

Al-Ameri, R 2011, 'Interface Slip Control for CFRP-Concrete Composite Beams', paper presented to Concrete Conference 2011, Perth, Australia.

Al-Ameri, R & Al-Mahaidi, R 2006, 'Coupled flexural-shear retrofitting of RC beams using CFRP straps', *Composite Structures*, vol. 75, no. 1-4, pp. 457-64.

Bakay, RCP 2003, 'Midspan shear debonding of CFRP-laminated reinforced concrete beams', M.Sc. thesis, University of Calgary (Canada).

Bizindavyi, L & Neale, K 1999, 'Transfer lengths and bond strengths for composites bonded to concrete', *Journal of Composites for Construction*, vol. 3, no. 4, pp. 153-60.

Brena, SF, Bramblett, RM, Wood, SL & Kreger, ME 2003, 'Increasing flexural capacity of reinforced concrete beams using carbon fiber-reinforced polymer composites', *ACI structural journal*, vol. 100, no. 1.

Buyukozturk, O & Hearing, B 1998, 'Failure behavior of precracked concrete beams retrofitted with FRP', *Journal of Composites for Construction*, vol. 2, no. 3, pp. 138-44.

Chajes, MJ, Finch Jr, WW, Januszka, TF & Thomson Jr, TA 1996, 'Bond and force transfer of composite-material plates bonded to concrete', *ACI structural journal*, vol. 93, no. 2, pp. 208-17.

Esfahani, MR, Kianoush, M & Tajari, A 2007, 'Flexural behaviour of reinforced concrete beams strengthened by CFRP sheets', *Engineering Structures*, vol. 29, no. 10, pp. 2428-44.

Kotynia, R & Harries, KA 2006, 'Strain Efficiency and Limit States of Externally Bonded and Near-Surface Mounted CFRP-Strengthened RC Members', *Composites B.*

Lee, Y, Boothby, T, Bakis, C & Nanni, A 1999, 'Slip modulus of FRP sheets bonded to concrete', *Journal of Composites for Construction*, vol. 3, p. 161.

Maeda, T, Komaki, H, Tsubouchi, K & Murakami, K 2002, 'Strengthening Effect of Carbon Fiber Sheet Adhesion Method Using Flexible Layer', *Transactions of the Japan Concrete Institute*, vol. 23, pp. 185-92.

Nguyen, DM, Chan, TK & Cheong, HK 2001, 'Brittle failure and bond development length of CFRP-concrete beams', *Journal of Composites for Construction*, vol. 5, no. 1, pp. 12-7.

Rahimi, H & Hutchinson, A 2001, 'Concrete beams strengthened with externally bonded FRP plates', *Journal of Composites for Construction*, vol. 5, no. 1, pp. 44-56.

Riad, AH 1999, 'Rehabilitation of HC-type bridge girders using CFRP-sheets/strips or external post-tensioning', M.Sc. thesis, University of Calgary (Canada).

Sayed-Ahmed, E, Bakay, R & Shrive, N 2009, 'Bond Strength of FRP Laminates to Concrete: State-of-the-Art Review', *Electronic Journal of Structural Engineering*, vol. 9.

Sayed-Ahmed, E, Riad, A & Shrive, N 2004, 'Flexural strengthening of precast reinforced concrete bridge girders using bonded CFRP strips or external posttensioning', *Canadian Journal of Civil Engineering*, vol. 31, no. 3, pp. 499-512.

Sebastian, WM 2001, 'Significance of midspan debonding failure in FRP-plated concrete beams', *Journal of structural engineering*, vol. 127, p. 792.

Spadea, G, Bencardino, F & Swamy, R 1998, 'Structural behavior of composite RC beams with externally bonded CFRP', *Journal of Composites for Construction*, vol. 2, p. 132.

Swamy, R & Mukhopadhyaya, P 1995, 'Role and effectiveness of non-metallic plates in strengthening and upgrading concrete structures', in *the Second International RILEM Symposium (FRPRCS-2)*, Ghent, vol. 29, p. 473.

Triantafillou, TC, Deskovic, N & Deuring, M 1992, 'Strengthening of concrete structures with prestressed fiber reinforced plastic sheets', *ACI structural journal*, vol. 89, no. 3, pp. 235-44.

Triantafillou, TC & Plevris, N 1992, 'Strengthening of RC beams with epoxy-bonded fibre-composite materials', *Materials and Structures*, vol. 25, no. 4, pp. 201-11.