Strengthening of Concrete using Carbon fibre Reinforced Polymer Sheet: A Review

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Abstract: There is a pressing requirement to rehabilitate/repair or upgrade the buildings and civil infrastructure in many parts of the world. Day to day concrete structure need to strengthen and rehabilitate due to various factor like corrosion, lack of supervision, lace of detailing and failure of bonding etc. In strengthening and rehabilitation, Fibre Reinforced Polymer is relatively new techniques to strengthen and repair damage of the structure. The effectiveness of the fibre reinforced polymer (FRP) in strengthening/ repairing of the concrete components has been studied in the past to great details. The FRP materials has gained notable acceptance from the civil engineering community in recent years.

In this study, the application of CFRP sheet in concrete structure is being investigated for its effectiveness in enhancing structural performance in terms of strength. In this study, a concrete specimen will be wrapped by CFRP sheet in single layer and double layer configuration and compare with the control specimen on the basis of compressive strength. This is the part of strengthening and other one is repair in which fractured concrete specimen will be bonded with epoxy adhesive and wrapped by CFRP sheet. This will also test for compressive strength and to be compare with strength of control specimen.

Keywords: Strengthening, Rehabilitation, Retrofitting, Fibre Reinforced Polymer (FRP), Carbon Fibre Reinforced Polymer (CFRP), Epoxy adhesive.

I. INTRODUCTION

The requirement of strengthening and repair of the concrete structure is increase due to the modernization of buildings. The failure of civil engineering structures takes place either due to corrosion, impact due to natural forces,
Lack of detailing etc. In such circumstances there are two possible solutions replacements or retrofitting/strengthening. Replacement might have disadvantages such as high cost for material and labour, inconvenience due to interruption of the function of structure. To overcome this retrofitting/strengthening is adopted. Rehabilitation and strengthening of structures with inadequate bearing capacity has reached a level of extended design alternatives. Use of fibre-reinforced polymer (FRP) materials is growing in the upgrading of existing concrete structures. Considering the mechanism of confinement in enhancement of strength and ductility of structural members, FRP materials often turn out to be more advantageous than steel. The linear elastic behaviour of FRP reinforcement (either pre-cured tube or wet lay-up sheet) up to failure provides an ever increasing pressure on the confined concrete core.

Fiber reinforced polymer (FRP) reinforcement is increasingly becoming prominent in the strengthening and rehabilitation of reinforced concrete (RC) structures. Strengthening techniques using FRPs involve the external bonding of laminates to concrete slabs and beams, or the wrapping of concrete columns. Interest in these techniques is widespread, and continues to grow, due to the ease of installation, lower cost, negligible clearance loss, and high strength to weight ratio of FRP materials. The efficiency of FRP retrofitting in strengthening/repairing of structural beam-column joints has been confirmed in many studies worldwide. CFRP and GFRP are the main fibres composing the fibrous phase of these materials, while epoxy is generally used on the matrix phase. Wet lay-up (sheets and fabrics) and prefabricated elements (laminates and bars) are the main types of FRP strengthening systems available in the market. The increasing demand of FRP for structural repair and strengthening is due to the following main advantages of these composites: low weight, easy installation, high durability and tensile strength, large deformation capacity, electromagnetic permeability and practically unlimited availability in FRP sizes, geometry and dimensions.

II. RESEARCH AND STUDIES ON USE OF STEEL FIBERS

Relevant research work and studies are reviewed here:

Amir Mirmiran1 and Mohsen Shahawy (1997) [1] In this study, it was found that the External confinement of concrete by the high-strength fiber composites can significantly upgrade its strength and ductility as well as it result in large energy absorption capacity. The mechanism of confinement may include wrapping of fibre on existing columns as a retrofitting measure or encasement of concrete in the fiber reinforced plastic tube for new construction. The proper design of such hybrid columns, however, needs an accurate estimate of the performance enhancement. The current design methods use simple extension of the models developed for conventional reinforced concrete columns. Results from a series of uniaxial compression tests on concrete-filled FRP tubes are compared with the available confinement models in the literature. This study indicates that these models generally result in overestimating the strength and unsafe design. The study also shows a unique characteristic of confinement with fiber composites in that, unlike steel, FRP curtails the dilation tendency of concrete, as it reverses the direction of volumetric strains. This study provides a framework for the better understanding of the behaviour of fiber-wrapped or FRP-encased concrete columns.

M. Shahawy et al. (2000) [2] this study was done for an urgent need for models that can accurately predict the performance of fiber-wrapped concrete columns. In this, it was reported that, the axial compression tests on a total of 45 carbon-wrapped concrete stubs of two batches of normal and high-strength concrete and five different number of wraps were used to verify a confinement model, which was originally developed for concrete-filled glass FRP tubes. Also, a nonlinear finite element model with a non-associative Drucker±Prager plasticity was developed. Both models compared favourably with test results. It was concluded that the adhesive bond between concrete and the wrap would not significantly affect the confinement behaviour. Moreover, the same confinement model can be applied to carbon and glass fibers, as long as the model has incorporated the dilation tendency of concrete as a function of the stiffness of the jacket. However, it is of utmost importance to establish the effective hoop rupture strain of the wrap through a reliability analysis by setting proper confidence level for design purposes.

Hamid Rahimi and Allan Hutchinson (2001) [3] the structural behavior of reinforced concrete beams strengthened with adhesively bonded fiberreinforced plastics (FRP) is presented. The experimental work included flexural testing of 2.3-m-long concrete beams with bonded external reinforcements. The test variables included the amount of conventional (internal) reinforcement and also the type and amount of external reinforcement. For comparison, some of the beams were strengthened with bonded steel plates. Theoretical analyses included 2D nonlinear finite-element modeling incorporating a ''damage'' material model for concrete. In general there were reasonably good correlations between the experimental results and nonlinear finite-element models. It is suggested that the detachment of bonded external plates from the concrete, at ultimate loads, is governed by a limiting principal stress value at the concrete/external plate interface.

R.Santhakumar et al. (2004) [4] Presented the numerical study to simulate the behavior of retrofitted reinforced concrete (RC) shear beams. The study was carried out on the unretrofitted RC beam designated as control beam and RC beams retrofitted using carbon fibre reinforced plastic (CFRP) composites with ±45^o and 90^o fibre orientations. The effect of retrofitting on uncracked and precracked beams was studied too. The finite elements adopted by ANSYS were used in this study. A quarter of the full beam was used for modeling by taking advantage of the symmetry of the beam and loadings. The load deflection plots obtained from numerical study show good agreement with the experimental plots reported by Tom Norris, et al (1997). There is a difference in behavior between the uncracked and precracked retrofitted beams though not significant. The crack patterns in the beams are also presented.

V. Valdmanis et al. (2007) [5] the mechanical behaviour of concrete confined by carbon fibre-reinforced polymer (CFRP) sheets was investigated in this study. Two series of tests were conducted on standard concrete cylinders with cube compressive strength ranging from 34.2 to 104.1 MPa, confined by CFRP sheets with 234 GPa elastic modulus and volumetric ratio ranging between 0.45 and 1.35%. Split-disc tests were performed to estimate the tensile properties of the CFRP sheet in the hoop direction. The concrete cylinders were subjected to monotonic and cyclic axial compressive loading with Teflon sheets inserted between concrete and steel bearing platens to reduce friction. The confined cylinder strength, strains and tangent moduli are compared with the values predicted by the recommendations of fe´ de´ ration international du be´ ton task group 9.3, fib Bulletin 14. It is concluded that, at least for the investigated range of variables, the CFRP tensile strength has to be reduced with a factor 0.50 in the ultimate strength approach in order to obtain accurate strength predictions. For stability control the tangent modulus E2 of the confined concrete in the second pseudo-linear branch of the stress–strain curve (above the unconfined concrete strength) must be estimated and in the tests ranged from about 8 to 20% of the tangent modulus of elasticity E1 of the first branch of the curve.

Jason Fitzwilliam and Luke A. Bisby (2010) [6] In this study, it showed that the external bonding of circumferential fiber-reinforced polymer (FRP) wraps is a widely accepted technique to strengthen circular RC columns, till date, most of the tests performed on FRP strengthened columns have considered short, unreinforced, small-scale concrete cylinders, with height-to-diameter ratios of less than three, tested under concentric, monotonic, and axial load. In practice, most RC columns have height-to-diameter ratios considerably larger than three and were subjected to loads with at least minimal eccentricity. Results of an experimental program performed to study the effects of slenderness on carbon FRP (CFRP) wrapped circular RC columns under eccentric axial loads are presented. It was showed that CFRP wraps increase the strength and deformation capacity of slender columns, although the beneficial confining effects are proportionally greater for short columns, and that theoretical axial-flexural interaction diagrams developed using conventional sectional analysis (but incorporating a simple FRP confined concrete stress-strain model) provide conservative predictions for nonslender CFRP wrapped columns under eccentric loads. The use of longitudinal CFRP wraps to reduce lateral deflections and allow slender columns to achieve higher strengths, similar to otherwise identical nonslender columns, is also demonstrated.

H.R. Ronagh and A. Eslami (2013) [7] He examined that the effectiveness of fibre reinforced polymers (FRPs) in retrofitting/repairing of the reinforced concrete (RC) components has been studied in the past to great detail. However, the seismic performance of RC structures retrofitted using FRP composites is yet to be scrutinized in terms of lateral resistance, ductility, and failure mechanism. This is of high importance if the retrofitted structures are to withstand higher seismic ground motions than they were designed for and/or pulse-type ground motions. In a comparative study, this paper reports on the results of an investigation into the flexural strengthening of RC buildings using glass/carbon fibre reinforced polymers (GFRP/CFRP). An 8-storey code-compliant RC building was considered as the case study to represent the medium-rise structures. With a slight intervention in the lateral displacement ductility and provision of the weak-beam strong-column design philosophy, the strengthening design strategy is aimed at increasing the lateral resistance. For this purpose, composite sheets were designed to be applied at the two end regions of all beams and columns on a practical flange-bonded scheme. The nonlinear pushover analysis with lumped plasticity approach was implemented in order to compare the seismic response of the original structure with the GFRP/CFRP retrofitted structures. Following validation of the adopted models, the force-deformation curves of the nonlinear plastic hinges are determined in a rigorous approach considering the material inelastic behaviour, reinforcement details, and dimensions of the members. While the nonlinear results confirm a significant increase in the lateral load carrying capacity using both composite materials, the CFRP improvement was as much as twice of the GFRP. However, the latter provides higher ductility.

Katarina Gajdosova and Juraj Bilcik (2013) [8] The paper presents an investigation into the performance of slender rectangular reinforced concrete columns strengthened with carbon fiber-reinforced polymers (CFRPs) in two manners. The first approach is a well-known form of CFRP sheet jacketing with the effect demonstrated in many studies, and a second one is a relatively new retrofit method of near surface mounted (NSM) CFRP strips. A total of eight full-scale specimens with rectangular cross sections (210 × 150 mm) were tested to failure under eccentric compressive loading. The total length of the specimens was 4,100 mm. The results of this study demonstrate a significant difference in slender and short column strengthening in accordance with the predominant stress manner. It was confirmed that the effect of CFRP wraps on the increase in column strength is proportionally greater for short RC columns subjected to predominant compression. The longitudinal fibers in CFRP strips bonded into grooves in concrete cover are more effective in enhancing the flexural load-carrying capacity of slender reinforced concrete columns subjected to eccentric loading. The most effective approach to flexural capacity enhancement was demonstrated by a synergistic effect of NSM CFRP reinforcement ensured by CFRP sheet wrapping.

P.N Saira et al. (2017) [9] This study investigate the improvements in the structural behaviour of the RC beams retrofitted with various types of FRP such as glass fibres, coir fibres, banana fibres, jute fibres and cotton fibres. The experimental programme includes strengthening and flexural strength test of 18 simply supported RC beams of 500x100x100 mm. The test results showed an increase in ultimate load for the retrofitted beam when compared to normal control beam and corresponding increase in the value of modulus of rupture. The retrofitted beams with glass fibre using epoxy as binder having 47.32% more strength than the control beams. Area under load-deflection curve gives toughness. Toughness value is found to be more in RC beams retrofitted with banana fibre.

Ankit Dasgupta (2018) [10] in this paper, the application of FRP in concrete structures is being investigated for its effectiveness in enhancing structural performance both in terms of strength and ductility. The structural components tested so far include slabs, beams, columns and bridge culverts. So far indicate that retrofitting with FRP offers an attractive alternative to the traditional techniques. In many circumstances, it can provide the most economical (and superior) solution for a structural rehabilitation problem. The manufacturing process of FRP and the field application of FRP is very easy and selected results from experimental and analytical. Seismic retrofit with FRP materials has gained notable acceptance from the civil engineering community in recent years.

III. CONCLUSIONS

After going through the various research carried out by many researchers, it may be concluded that:

1: It was observed that most of the researchers focussed on the different types of FRP materials and their effects on strengthening and repair, there is only few study has been done on the configuration of wrapping.
2: Most of the researchers had considered FRP as a composite material and the influence of fibre and epoxy has not been studied separately.
3: From the above literature it is clear that most of the studies concentrate on comparison of different strengthening method with FRP, lack of study was observed on the effect of use of FRP only in strengthening and repair in different patterns.
4: From the above literature, it is seen that, repair of fractured concrete with FRP CFRP sheet is not discussed extensively.
5: After above conclusion there is a need of separate study of different types of FRP materials for strengthening and repair.

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