International Journal on Applications in Civil and Enviornmental Engineering
Volume 1: Issue 3: March 2015, pp 13-17. www.aetsjournal.com ISSN (Online) : 2395 - 3837

Analytical And Experimental Investigation On Shear Strengthened Rc Beams By Using Frp - A Review

A.Karthi , P.Easwaran

***Abstract*—** The present day world is witnessing the construction of very challenging and difficult civil engineering structures. To meet up the needs of advance infrastructure, new innovative materials and technologies are invented and used to overcome the earlier drawbacks. Efforts are being made in the field of concrete technology to prepare and develop concrete with composites. In last few decades extensive research has been carried out with the use of Fiber Reinforced Polymer (FRP) composites in the strengthening and retrofitting of reinforced concrete structures in the field of civil engineering around the world. This paper provides a brief review on flexural and shear strengthening of rectangular beams using CFRP/GFRP laminate of different thickness and scheme. Different applications of FRP laminate for external strengthening of RC beams are reviewed in this paper. Finally, a discussion on system of strengthening and conclusions are made along with prospective outlook approach of research.

Keywords: Fibre Reinforced polymer, Strengthening, Retrofitting, Flexure, Shear.

I. INTRODUCTION

In recent years, a number of emerging economies have begun to play a growing role in the development of infrastructure. Many infrastructures are constructed annually around the globe. Much of the concrete infrastructure in the world is aging beyond fifty years, and many of these structures are showing significant deterioration and distress. There is currently a range of techniques available for extending the useful life of structurally deficient and functionally obsolete structures. One such technique is adding fibre reinforced polymer composites (FRPCs) as external reinforcement. FRPCs have been used to strengthen / retrofit concrete members like columns, slabs beams and girders in structures such as bridges, parking decks and buildings.

Comprehensive experimental investigations conducted in the past have shown that this strengthening method has several advantages over the traditional ones, especially due to its corrosion resistance, high stiffness-to-weight ratio, improved durability and flexibility in its use over surface of the structures. Moreover, these materials are less affected by corrosive environmental conditions, known to provide longer life and require less maintenance. Apart from that FRP has more reliable bond line strength as compared to steel where corrosion at the interface is unavoidable in the presence of moisture.

The adhesives are used to bond the FRP composites to the surface of the concrete structure. Most commonly epoxy adhesive bonded FRP laminates can provide satisfactory solutions to several problems related to conventional steel plates, including the corrosion of the steel plates which brings about the bond deterioration.

In general, the flexural and shear strength of a reinforced concrete beam can be extensively increased by application of carbon (CFRP), glass (GFRP) and Aramid (AFRP) FRP laminate adhesively bonded to the soffit and side face of the beam respectively. However, for successful and cost-effective applications, engineers must improve their knowledge with respect to the actual behaviour of strengthened structures. Therefore, glass fiber reinforced polymers, because they are more ductile and cheaper than carbon fibers, can be considered as an alternative solution to repair and strengthen concrete elements.

A substantial research on CFRP/GFRP strengthening of RC beams under different thickness and scheme was briefly reviewed in this paper.

II. PERIVIOUS RESEARCH PAPERS

Varastehpour et al (1997) examined the application of composite materials in civil engineering by strengthening of a reinforced concrete beam in situ by externally-bonded fiber reinforced polymer (FRP). The study of the mechanical properties of the interface and the rheological behaviour of composite materials are very important to design. For the experimental determination of the mechanical properties of the concrete/glue/plate interface, a new test was suggested. An iterative analytical model capable of simulating the bond slip and the material non-linearity, based on the compatibility of deformation and the equilibrium of forces was developed in order to predict the ultimate forces and deflections. Finally, a series of large-scale beams strengthened with fiber reinforced plastic was tested up to failure. Load deflection curves were measured and compared with the predicted values to study the efficiency of the externally bonded plate and to verify the test results.

Chaallal et al (1998) investigated a comprehensive design approach for reinforced concrete flexural beams and unidirectional slabs strengthened with externally bonded fiber reinforced plastic (FRP) plates. The approach complied with the Canadian Concrete Standard. This was divided into two parts, namely flexural strengthening and shear strengthening. In the first part, analytical models were presented for two

A.Karthi, PG Scholar, Department of Civil Engineering,K.S. Rangasamy College of Technology, Namakkal, Tamil Nadu.(Email: sivakarthi8@gmail.com,)
P.Easwaran, Assistant Professor, Department of Civil Engineering, K.S. Rangasamy College of Technology, Namakkal, Tamil Nadu.(Email: easwaran@gmail.com)

families of failure modes: classical modes such as crushing of concrete in compression and tensile failure of the laminate, and premature modes such as debonding of the plate and ripping off of the concrete cover. These models were based on the common principles of compatibility of deformations and equilibrium of forces. They can be used to predict the ultimate strength in flexure which can be achieved by such elements, given the FRP cross-sectional area, or conversely, the required FRP cross- sectional area to achieve a targeted resisting moment for rehabilitated flexural elements. In the second part, design equations were derived to enable calculation of the required cross- sectional area of shear lateral FRP plates or strips for four number of plating patterns: vertical strips, inclined strips, wings, and U-sheet jackets.

Duthinhet al (2001) tested seven concrete beams reinforced internally with steel and externally with carbon FRP laminate applied after the concrete had cracked under four-point loading. Results showed that FRP was very effective for flexural strengthening. As the amount of steel increases, additional strength provided by the carbon decreases. Compared to a beam reinforced heavily with steel only, the beams reinforced with both steel and carbon have adequate deformation capacity in spite of their brittle mode of failure. Clamping or wrapping of the ends of the FRP laminate combined with adhesive bonding was effective in anchoring the laminate.

Alex et al (2001) studied experimentally the effect of shear strengthening of RC beams on the stress distribution, initial cracks, crack propagation, and ultimate strength. Five types of beams with different strengthening carbon-fiber–reinforced plastic sheets are often strengthened in flexure. The experimental results show that it is not necessary to strengthen the entire concrete beam surface. The general and regional behaviours of concrete beams with bonded carbon-fiber–reinforced plastic sheets are studied with the help of strain gauges. The appearance of the first cracks and the crack propagation in the structure up to the failure is monitored and discussed for five different strengthened beams. In particular, for one of the strengthened RC beams, the failure mode and the failure mechanism are fully analysed.

Khalifaet al (2002) examined experimentally the shear performance and modes of failure of the rectangular simply supported reinforced concrete (RC) beams designed with shear deficiencies. These members were strengthened with externally bonded carbon fiber reinforced polymer (CFRP) sheets and evaluated in the laboratory. The experimental program consisted of twelve full-scale RC beams tested to fail in shear. The variables investigated within this program included steel stirrups, and the shear span-to-effective depth ratio as well as amount and distribution of CFRP. The experimental results indicated that the contribution of externally bonded CFRP to the shear capacity was significant. They concluded that, the beams tested in this program, increases in shear strength upto 40 to 138%. The contribution of externally CFRP reinforcement to the shear capacity is influenced by the a/d ratio. The test results indicated that contribution of CFRP benefits the shear capacity at a greater degree for beams without shear reinforcement than for beams with adequate shear reinforcement.

Sheikh et al (2002) studied on retrofitting with fiber reinforced polymers (FRP) to strengthen and repair damaged structures, which was a relatively new technique. In an extensive research programme at the University of Toronto, application of FRP in concrete structures was 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. Research on columns had particularly focused on improving their seismic resistance by confining them with FRP. All the specimens tested were considered as full-scale to two-third scale models of the structural components generally used in practice. Results indicated that retrofitting with FRP offers an attractive alternative to the traditional techniques.

Hadi et al (2003) examined the strength and load carrying capacity enhancement of reinforced concrete (RC) beams, those had been tested and failed in shear. A total of sixteen sheared beam specimens with a length of 1.2m and cross-sectional area of 100 x 150 mm were retrofitted by using various types of fiber reinforced polymer (FRP) and then retested. The retrofitted beam specimens wrapped with different amounts and types of FRP were subjected to four-point static loading. Load, deflection and strain data were collected during testing the beam specimens to failure. Results of the experimental program indicate that there were several parameters that affect the strength of the beams. The results also show that the use of FRP composites for shear strengthening provides significant static capacity increase.

Chen et al (2003) carried out an investigation on the shear capacity of FRP-strengthened RC beams. These studies have established clearly that such strengthened beams fail in shear mainly in one of the two modes, i.e., FRP rupture and FRP debonding, and have led to preliminary design proposals. This study was concerned with the development of a simple, accurate and rational design proposal for the shear capacity of FRP-strengthened beams which fail by FRP debonding. Existing strength proposals were reviewed and their deficiencies highlighted. Based on a rational bond strength model between FRP and concrete, a new shear strength model was then developed for debonding failures in FRP shear strengthened RC beams. This new model explicitly recognises the non-uniform stress distribution in the FRP along a shear crack as determined by the bond strength between the FRP strips and the concrete.

Taljsten et al (2003) studied the method of strengthening concrete structures with CFRP composite sheets. First traditional strengthening methods are studied briefly, then the use of CFRP composites for shear strengthening. Tests on beams strengthened in shear with CFRP sheets and how to design for shear strengthening with CFRP is given. Furthermore, a field application of a parking slab strengthened for shear with CFRP unidirectional fabric is investigated. The laboratory tests show the importance of considering the principal directions of the shear crack in relation to the unidirectional fiber and the field application shows that it is easy to strengthen existing structures for shear with CFRP fabrics.

Santhakumar et al (2004) investigated the numerical study to simulate the behaviour 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 fiber reinforced plastic (CFRP) composites with ±45º and 90º fiber orientations. The effect of retrofitting on uncracked and precracked beams was studied too. In this study the finite elements are adopted by using ANSYS. A quarter of the beam was used for modelling 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 Norris et al. (1997). At ultimate stage there is a difference in behaviour between the uncracked and precracked retrofitted beams though not significant. The crack patterns in the beams are also presented. The numerical results show good agreement with the experimental values reported by Norris et al. This numerical modelling helps to track the crack formation and propagation especially in case of retrofitted beams in which the crack patterns cannot be seen by the experimental study due to wrapping of CFRP composites.

Teng et al (2004) have studied the shear strengthening of reinforced concrete (RC) beams with FRP composites. A recent technique for the shear strengthening of RC beams is to provide additional FRP web reinforcement, commonly in the form of bonded external FRP strips/sheets. Over the last few years, a large amount of research has been conducted on this new strengthening technique, which has established its effectiveness and has led to a good understanding of the behaviour and strength of such shear-strengthened beams. Here, the methods of strengthening were described first, followed by a summary of experimental observations of failure processes and modes. The accuracy of existing design provisions was examined next through comparisons with test results. Limitations of existing experimental and theoretical studies were also highlighted.

Islam et al (2005) investigated shear strengthening of RC deep beams using externally bonded FRP systems. In this study, six identical beams were fabricated and tested to failure for this purpose. One of these beams was tested in its virgin condition to serve as reference, while the remaining five beams were tested after being strengthened using carbon fiber wrap, strip or grids. The test results have shown that the use of a bonded FRP system leads to a much slower growth of the critical diagonal cracks and enhances the load-carrying capacity of the beam to a level quite sufficient to meet most of the practical upgrading requirements. Although FRP grids placed in normal orientation demonstrated to be the most effective system as far as the amount of material used in strengthening is concerned, other systems were found to be almost equally effective. An enhancement of shear strength in the order of about 40%, was achieved in this study.

Saafan et al (2006) studied the shear strengthening of reinforced concrete (RC) beams using GFRP wraps. The objective of the experimental work was to investigate the efficiency of GFRP composites in strengthening simply supported reinforced concrete beams designed with insufficient shear capacity. Using the hand lay-up technique, successive layers of a woven fiber glass fabric were bonded along the shear span to increase the shear capacity and to avoid catastrophic premature failure modes. The strengthened beams were fabricated with no web reinforcement to explore the efficiency of the proposed strengthening technique using the results of control beams with closed stirrups as web reinforcement. The test results of 18 number of beams were reported, addressing the influence of different shear strengthening schemes and variable longitudinal reinforcement ratios on the structural behaviour. The results indicated that significant increase in the shear strength and improvements in the overall structural behaviour of beams with insufficient shear capacity could be achieved by proper application of GFRP wraps. It was observed that the layers can easily slip down under self-weight.

Al-Amery et al (2006) experimentally investigated the coupling of shear-flexural strengthening of RC beams. The presence of shear straps to enhance shear strength has the dual benefit of delaying de-bonding of CFRP sheets used for flexural strengthening. Six number of RC beams were tested; having various combinations of CFRP sheets and straps in addition to a strengthened beam as control test. The instrumentation used in these tests cover the strain measurements in different CFRP layers and located along the span, in addition to the slip occurring between the concrete and CFRP sheets. Test results and observations showed that a significant improvement in the beam strength was gained due to the coupling of CFRP straps and sheets. Further, a more ductile behaviour was obtained as the debonding failure prevented.

Kim et al (2008) studied the shear strength of RC beams strengthened by fiber material. It consists of a plasticity model for web crushing, a truss model for diagonal tension, and a simple flexural theory based on the ultimate strength method. To analyse the shear strengthening effect of the fiber, the model considers the interfacial shear-bonding stress between base concrete and the fiber. This reflects that the primary cause of shear failure in strengthened RC beams is rapid loss of load capacity due to separation of the strengthening fibers from the base material. The predictive model can estimate load capacities of each failure mode, and is compared to tested specimen data including extreme load failure. The analysis matches well with the experiments concerning load capacity and failure mode. Also, the experimental results of other published data are compared to the predictive model to evaluate its application. The results show that the predictive model has good adaptability and high accuracy.

Pannirselvam et al (2009) have studied the strength behaviour of fiber reinforced polymer (FRP) of strengthened beam, the objective of this work was to evaluate the structural behaviour of reinforced concrete (RC) beams with externally bonded FRP reinforcement. Beams bonded with four different types of glass fiber reinforced polymer (GFRP) having 3.50 mm thickness were used. Totally five rectangular beams of 3 m length were cast. One beam was used as reference beam and the remaining beams were provided with GFRP laminates on their soffit. The variable considered for the study was the type of GFRP laminate. The study parameters of this investigation included first crack load, yield load, ultimate load, first crack deflection, yield deflection, ultimate deflection, crack width, deflection ductility, energy ductility, deflection ductility ratios and energy ductility ratios of the test beams. The performance of FRP plated beams was compared with that of unplated beam. The test results showed that the beams strengthened with GFRP laminates exhibited better performance.

Bukhari et al (2010) investigated on the shear strengthening of reinforced concrete (RC) beams with carbon fiber reinforced polymer (CFRP). The paper reviews existing design guidelines for strengthening beams in shear with CFRP sheets and proposes a modification to Concrete Society Technical Report TR55. It goes on to present the results of an experimental programme which evaluated the contribution of CFRP sheets towards the shear strength of continuous reinforced concrete (RC) beams. A total of seven, two-span concrete continuous beams with rectangular cross-sections were tested. The control beam was not strengthened, and the remaining six were strengthened with different arrangements of CFRP sheets. The experimental results showed that the shear strength of the beams was significantly increased by the CFRP sheet and that it was beneficial to orient the FRP at 45º to the axis of the beam. The shear strength of FRP strengthened beams is usually calculated by adding the shear resistance of individual components from the concrete, steel stirrups and FRP.

Martinola et al (2010) examined the use of a jacket made of fiber reinforced concrete (FRP) with tensile hardening behaviour for strengthening RC beams by means of full-scale tests on 4.55 m long beams. A 40 mm jacket of this material was directly applied to the beam surface. Both the strengthening and the repair of RC beams were studied. In particular, in the latter case the beam was initially damaged and eventually repaired. A numerical analysis was also performed in order to better understand the reinforcement behaviour. The experimental and numerical results show the effectiveness of the proposed technique both at ultimate and serviceability limit states.

Ceroni et al (2010) experimentally studied on RC beams externally strengthened with carbon fiber reinforced plastic (FRP) laminates and Near Surface Mounted (NSM) bars under monotonic and cyclic loads, the latter ones characterized by a low number of cycles in the elastic and post-elastic range. Comparisons between experimental and theoretical failure loads were discussed in detail.

Obaidat et al (2011) investigated experimentally, the behaviour of the structurally damaged full-scale reinforced concrete beams retrofitted with CFRP laminates in shear or in flexure. The main variables considered were the internal reinforcement ratio, position of retrofitting and the length of CFRP. The experimental results, generally, indicate that beams retrofitted in shear and flexure by using CFRP laminates are structurally efficient and are restored to stiffness and strength values nearly equal to or greater than those of the control beams. Employing externally bonded CFRP plates resulted in an increase in maximum load. The increase in maximum load of the retrofitted specimens reached values of about 23% for retrofitting in shear and between 7% and 33% for retrofitting in flexure. Moreover, retrofitting shifts the mode of failure to be brittle. It was found that the efficiency of the strengthening technique by CFRP in flexure varied depending on the length. The main failure mode in the experimental work was plate debonding which reduces the efficiency of retrofitting. Based on the conclusion deeper studies should be performed to investigate the behaviour of the interface layer between the CFRP and concrete. Also numerical work should be done to predict the behaviour of retrofitted beams and to evaluate the influence of different parameters on the overall behaviour of the beams.

III. EXPECTED SYSTEM OF STRENGTHENING

From the above review of literature, there is a need to understand the parameters such as effective length, width, thickness and suitable anchorage system of CFRP/GFRP laminate for strengthening reinforced concrete beams. Future research is necessary to prepare a design guideline for selecting the thickness and different schemes for strengthening of RC beams.

IV. CONCLUSION

In this paper, previous research programs conducted by other researchers in the areas of the flexural and shear strengthening of reinforced concrete beams using CFRP/GFRP laminate has been reviewed. Following general concluding remarks are made:

Externally bonded FRP laminate reinforcement is a viable solution towards enhancing strength, stiffness and energy dissipation characteristics of reinforced concrete beams subjected to various loading. It is clear that existing research has established the effectiveness of various methods of strengthening and identified many possible failure modes. Use of FRP laminate improves load carrying capacity; delays crack formation and energy absorption capability of beams reinforced with FRP laminates. Studies have demonstrated improvement in ultimate capacity and stiffness leading to reduction in the overall maximum deflection and strains. It also enhances flexural and shear capacity and improves overall damage control. Extent of benefit, however, depends upon many factors such as type, amount, and direction of confining material, size, shape and loading condition of the beam. To utilize the full capacity of the FRP laminate, the bond strength between FRP laminate and concrete as it is the key factor affecting the overall integrity of beams. CFRP laminates carries more loads as compared to GFRP laminates with same thickness/scheme, but in practice GFRP laminates are recommended in terms of economy.

REFERENCES

[1] Alex L., Assih J., and Delmas Y. (2001), 'Shear Strengthening of RC Beams with externally bonded CFRP sheets', Journal of Structural Engineering, 127(4), pp. 20516.

[2] Khalifa A, Gold WJ, Nanni A and Aziz A. (1998), 'Contribution of externally bonded FRP to shear capacity of RC flexural members', Journal of Composites for Construction, 2, pp.195–201.

[3] Mansur M. A. (1998), 'Effect of openings on the Behaviour and Strength of RC Beams in Shear', Cement and Concrete Composites, 20, pp 477-486.

[4] Balamuralikrishnan R., and Jeyasehar C. A. (2009), 'Flexural behaviour of RC beams strengthened with Carbon Fiber Reinforced Polymer (CFRP) fabrics', The Open Civil Engineering Journal, 3, pp 102-109.

[5] Chen J. F., and Teng J. G. (2003), 'Shear capacity of FRP-strengthened RC beams: FRP debonding', Construction and Building Materials, 17, pp 27-41.

[6] Deifalla A., and Ghobarah A. (2010), 'Strengthening RC T beams subjected combined torsion and shear using FRP fabrics: Experimental Study', Journal of Composites for Construction, ASCE, pp. 301-311.

[7] Pannirselvam N., Nagaradjane V., and Chandramouli K. (2009), 'Strength behaviour of fiber reinforced polymer strengthened beam', ARPN Journal of Engineering and Applied Sciences, 4(9), pp. 1-12.

[8] Rabinovitch O. and Frostig Y. (2003), 'Experimental and analytical comparison of RC beams strengthened with CFRP composites', Composites: Part B, 34, pp.663-677.

[9] Santhakumar R., Chandrasekaran E., and Dhanaraj R. (2004), 'Analysis of Retrofitted concrete shear beams using Carbon fiber composites', Electronic Journal of Structural Engineering, 4, pp.66-74.

[10] Teng J.G., Chen J.F., (2007) 'Debonding Failures of RC Beams Strengthened with Externally Bonded FRP Reinforcement: Behaviour and Modelling', International Institute for FRP in Construction pp.33-42.

[11] Pannirselvam N., Raghunath P.N., Suguna K., (2008) 'Strength Modeling of Reinforced Concrete Beam with Externally Bonded Fibre Reinforcement Polymer Reinforcement', American J. of Engineering and Applied Sciences 1 (3) pp.192-199.

[12] Khan A.R., Ayub T., (2009) 'Performance of RC beams strengthened in shear by externally bonded U-shaped Wraps', ACI Structural Journal pp.151-158.

[13] Balamuralikrishnan R., Antony C J, (2009) 'Flexural Behaviour of RC Beams Strengthened with Carbon Fibre Reinforced Polymer (CFRP) Fabrics', The Open Civil Engineering Journal 3 pp.102-109.

[14] Oguzgunes, Oral buyukozturk, Erdemkaraca, (2009) 'A Fracture – based model for FRP Deponding in Strengthened Beams', Engineering Fracture Mchanics 76 pp 18971909.

[15] Sayed-Ahmed E.Y., Bakay R., Shrive N.G., (2009) 'Bond Strength of FRP Laminates to Concrete: State-of-the-Art Review', Electronic Journal of Structural Engineering 9 pp 45-61.

[16] Chen G. M., Teng J. G., Chen J. F., (2010) 'RC Beams Shear-Strengthened with FRP: Shear Resistance Contributed by FRP', Magazine of Concrete Research 62 pp 301311.

[17] Bukhari I. A., Vollum R. L., Ahmad, Sagaseta, (2010) 'Shear strengthening of reinforced concrete beams with CFRP', Magazine of Concrete Research 62 pp 65-77.

[18] Habibur Rahman Sobuz, Ehsan Ahmed, Md. Alhaz Uddin (2011) 'Structural strengthening of RC beams externally bonded with different CFRP laminates configurations', Journal of Civil Engineering (IEB) 39 (1) pp 33-47.

[19] Kishor C P, Sriman K B, (2011) 'Strengthening of RC T-beams with Shear Deficiencies Using GFRP Strips', Journal of Civil Engineering and Architecture 5 (1) pp 56-67.

[20] Kheyroddin A., Naderpour H., Ghodrati A G., (2011) 'Influence of Carbon Fiber Reinforced Polymers on upgrading Shear Behaviour of RC Coupling Beams', Transactions of Civil Engineering 35(C2) pp 155-169.