Shear Strengthening of Reinforced Concrete Beam Using High Density Polyethylene (HDPE) Laminate – A Review

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***Abstract*— The issue of upgrading and repair of existing civil engineering infrastructure has been one of great importance for over a decade. Deterioration of bridge decks, beams, girders and columns, buildings, parking structures and others may be attributed to several factors such as ageing, environmentally induced degradation, poor initial design and construction and lack of maintenance. In many cases, retrofit and rehabilitation by conventional means is very costly since it calls for specialized equipment and the shutdown of the structure during repair. In this report, results of an ongoing research program aimed at investigating alternative methods for strengthening and repairing concrete structures will be presented. However, structural performance is comparable and is superior to panels produced using hand lamination.**

In this sense, the aim of the present study, is to evaluate the contribution of the external reinforcement of concrete beams, reinforced by High Density Polyethylene (HDPE) laminates. An experimental program on a total of five concrete beams reinforced by various hybrid configurations of reinforcement tested up to 75% failure under a static loading in two points bending, to determine the best combination of the strengthening scheme.

This report reviews eighteen articles on RC beams strengthened with HDPE. Finally, this report attempts to address an important practical issue that is encountered in strengthening of beams with different type and different thicknesses of fibre reinforced polymer laminate.

***Index Terms*— Retrofitting, Rehabilitation, Laminate, High density polyethylene, Strengthening.**

I. INTRODUCTION

Strengthening of R.C beam using various laminates enhance the ductility in loading conditions including tension, shear, and flexure. The multiple cracks are controlled to small widths, where by the gas, moisture, chloride ingress is prevented significantly.

To achieve such ductility and crack control the surface of the beam has been prepared. By a smooth interface the mechanism of lamination is applied. The debonding of layers has been controlled by applying effective lamination over the beam surface. Here the HDPE is used for the strengthening of R.C beam for a various surface overlay configuration.

HDPE is known for its large strength-to-density ratio. The density of HDPE can range from 0.93 to 0.97 g/cm^3. Although the density of HDPE is only marginally higher than that of low-density polyethylene, HDPE has little branching, giving it stronger intermolecular forces and tensile strength than Low Density Polyethylene (LDPE). The difference in strength exceeds the difference in density, giving HDPE a higher specific strength. It is also harder and more opaque and can withstand somewhat higher temperatures (120°C for short periods, 110 °C continuously).

II. PREVIOUS RESEARCH WORK

Several researches on shear and flexural strengthening of RC beams using different fibre composites and adhesives have been studied and discussed in this paper.

Khan et al. (2013) have studied experimentally the behaviour of nine rectangular beams of section 150mm x 200mm x 1800mm. All the beams were retrofitted with Ferro mesh with Epoxy resin of which one beam was kept as controlled beam. The laminate was laid on the soffit of the beam. Two to three layers of laminate were used for strengthening. Single concentric loading system was applied to study the flexural strength of beams. Three layers of Ferro-mesh performed better in terms of load carrying capacity and stiffness.

Salvador & Joaquim, (2009) conducted an experimental investigation on RC beams shear strengthened according to the Near Surface Mounted (NSM) technique with Carbon Fiber Reinforced Polymer (CFRP) laminates. The reinforcement systems were designed in order that all beams fail in shear. The experimental program was made up of four beams with steel stirrups φ6@300mm and five beams with steel stirrups φ6@200mm. The loads where applied at one third distance of the beam length. After the pre-cracking test, the strengthening activities were executed with the beams in the unloaded state. The principal difference of the behavior of NSM CFRP beams with and without pre-cracks can be resumed to an expected loss of initial stiffness in the pre-cracked specimens.

Ekenelet al. (2005) examined the experimental investigation on flexural strengthening of five reinforced concrete (RC) beams with FRP. Two of the RC beams were strengthened with CFRP fabrics, whereas the remaining two were strengthened using FRP pre-cured laminates. All of the beams were tested under fatigue loading for 2-million cycles. All of the beams survived fatigue testing except for the un-strengthened control beam. The beams were designed to fail in flexural. All of the beams were pre-cracked before strengthening by loading the beams beyond the cracking load to simulate the condition of a typical RC beam prior to

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repair/strengthening. All beams were tested for fatigue over a simply supported span of 1829 mm. All beams were cycled under fatigue loading between a minimum 33% and maximum 63% of the ultimate moment carrying capacity of the section. The highest change in stiffness was observed in CFRP pre-cured laminate strengthening with mechanical fasteners by 22% at 2-million cycles as compared to initial cycle.

Mosallam&Swagata (2007) performed an experimental investigation on shear strength enhancement of reinforced concrete beams externally reinforced with fiber reinforced polymer (FRP) composites. A total of nine full-scale beam specimens of size 150mm x 250mm x 3460mm were cast and the load was applied using a four-point loading configuration. Four models are used to predict the shear strength capacity of the retrofitted beam specimens and compare those with experimental result. Based on the experimental results conducted on reinforced concrete beam FRP composite systems provided appreciable increase and enhancement in both ultimate strength and toughness of strengthened beams.

Sobuz1 et al. (2013) experimentally carried out tests on total of five beams having different CFRP laminates configurations were tested to failure in four-point bending over a clear span 1900mm. All the beam specimens were 150 × 200 mm in cross section and 1900 mm in span length on a simply supported span. A total of five reinforced concrete beams having different CFRP configurations were fabricated in the laboratory for the strengthening purposes. Test results showed that the addition of CFRP sheets to the tension surface of the beams demonstrated significantly improvement in stiffness and ultimate capacity of beams.

Norris et al. (1997) to examined the behaviour of damaged beams retrofitted with thin carbon fiber reinforced plastic (CFRP) sheets, epoxy bonded to the tension face and web of the concrete beams to enhance their flexural and shear strengths. The effect of CFRP sheets on strength and stiffness of the beams is considered for various orientations of the fibers with respect to the axis of the beam. The beams were fabricated, loaded beyond concrete cracking strength, and retrofitted with different CFRP systems. The beams were subsequently loaded to failure. The test results shows that there is increase in strength and stiffness of the existing concrete structures after providing CFRP sheets in the tension face and web of the concrete beam depending upon the different orientation of fiber.

Sayed et al. (1999) investigated the behavior of reinforced concrete beams strengthened with various types of fiber reinforced polymer (FRP) laminates. The ratio of absorbed energy at failure to total energy, or energy ratio, was used as a measure of beam ductility. The presence of vertical FRP sheets along the entire span length eliminates the potential for rupture of the longitudinal sheets. The combination of vertical and horizontal sheets, together with a proper epoxy, can lead to a doubling of the ultimate load carrying capacity of the beam.

Khalifa et al. (2000) has investigated the shear performance of reinforced concrete (RC) beams with T-section. The experimental program consisted of six full-scale, simply supported beams. The experimental results show that externally bonded CFRP can increase the shear capacity of the beam significantly. In addition, the results indicated that the most effective configuration was the U-wrap with end anchorage. Results showed that the proposed design approach is conservative and acceptable.

Kachlakev& McCurry (2000) studied the behaviour of full-scale reinforced concrete (RC) beams retrofitted for shear and flexure with fiber reinforced polymer (FRP) laminates. Of the four number of beams, one served as a control beam and the remaining three were implemented with varying configurations of carbon FRP (CFRP) and glass FRP (GFRP) composites to simulate the retrofit of the existing structure. The test results from this study show that the use of FRP composites for structural strengthening provides significant static capacity increase to about 150% compared to unstrengthened sections. Load at first crack and post cracking stiffness of all beams were increased primarily due to flexural CFRP. The test results suggest the static demand of 658 kN-m sustaining up to 868kN-m applied moment. This allowed ultimate deflections to be 200% higher than the pre-existing shear deficient beam.

Rabinovitch and Frostig (2003) studied strengthening, upgrading, and rehabilitation of existing reinforced concrete structures using externally bonded composite materials. Five numbers of strengthened, retrofitted, or rehabilitated reinforced concrete beams were experimentally and analytically investigated. The results revealed a significant improvement in the serviceability and strength of the tested beams and demonstrated that the method was suitable for the rehabilitation of severely damaged structural members.

Balamuralikrishnan (2009) studied the flexural behaviour of RC beams strengthened with carbon fiber reinforced polymer (CFRP) fabrics. For flexural strengthening of RC beams, total ten number of beams were cast and tested over an effective span of 3000 mm up to failure under monotonic and cyclic loads. Static and cyclic responses of all the beams were evaluated in terms of strength, stiffness, ductility ratio, energy absorption capacity factor, compositeness between CFRP fabric and concrete, and the associated failure modes. The theoretical moment-curvature relationship and the load-displacement response of the strengthened beams and control beams were predicted by using software ANSYS. Comparison has been made between the numerical (ANSYS) and the experimental results. The results show that the strengthened beams exhibit increased flexural strength, enhanced flexural stiffness, and composite action until failure.

Sundarraja&Rajamohan, (2009) studied on strengthening of reinforced concrete (RC) beams which are deficient in shear using glass fiber reinforced polymer(GFRP) inclined strips experimentally. Included in the study are effectiveness in terms of width and spacing of inclined GFRP strips, spacing of internal steel stirrups, and longitudinal steel rebar section on shear capacity of the RC beam. The study also aims to understand the shear contribution of concrete, shear strength due to steel bars and steel stirrups and the additional shear capacity due to GFRP strips in a RC beam. And also the failure modes, shear strengthening effect on ultimate force and load deflection behaviour of RC beams bonded externally with GFRP inclined strips on the shear region of the beam. The use of GFRP strips had effect in delaying the growth of crack formation, which is, evident from the load causing the initial cracks. When both the wrapping schemes were considered, it was found that the retrofitted beams with inclined U-wrap GFRP strips had a better load-deflection behaviour compared to the side strips, which is very important for shear strengthening of the RC beams. Finally, the use of inclined GFRP strips was able to avoid the brittle failure of the beams.

Grace *et al*., 2002 investigated thirteen rectangular beams. Two strengthening configuration were used such as strengthening material only on the bottom face beam and strengthening material on the bottom face and extending upto 150mm on both side face of beams.group: one beam was used as a control beam without external GFRP laminates, three beams bonded with one layer, two layers and three layers of 2.5 m long GFRP laminates. The other two beams were strengthened with one layer of GFRP laminates at length of 2.2 and 1.9 m. The nominal thickness of the laminate is 1.3 mm and the authors revealed that the bonding of the GFRP laminates; the ultimate strengths of the beams are enhanced to an extent of 18-46%. The increases of the stiffness of the beams are noticeable up to 24% of the control beam. By bonding GFRP laminates to the tension face of flexural RC beams, both strength and stiffness of the beams can be increased.

Adhikary et al (2004), carried out the tests of eight simply supported RC beams strengthened for shear with CFRP sheet using two different wrapping schemas; U-wrap and two sides of the beam. He investigated the effectiveness of cross plies one over another, vertical and horizontal; the main parameter, direction of fiber alignment (90°,0°and 90°+0°) and number of layers (1 and 2). They observed that the maximum shear strength was obtained for the beam with full U-wrapped sheets having vertically aligned fibers. Horizontally aligned fibers also showed enhanced shear strengths as compared to beam with no CFRP. On the other part, they found that the lowest concrete strain was the same load range among all beams. The beam with full U-wrapping of a single layer of CFRP with vertically aligned fibers, was observed at a maximum of 119% increase in shear strength. Also, they compared with the experimental value, using models for the prediction of shear contribution of sheet to shear capacity of CFRP bonded beams.

Table.1 Experimental results and load carrying capacity of the reference beams

Author/ size of beam (mm)	Beam ID	Material	No of layer	Fcu MPa	Anchorage (mm)	Adhesive	Ultimate load (kN)	Failure mode
Khan&Rafeeqi 150x200x1800	Group-A Group-B Group-C	Ferro mesh	2,3	72.5	75		62.4	Flexure
Khalifa et al. 24/150x405x3050mm,	BT1 BT2 BT3	CFRP	- 1 1	35 35 35	- No yes	Epoxy paste.	180 310 442	Diagonal shear crack Shear compressio n Flexural
Kachlakeva 4880x 230x380	CB4-2S CB6-3S CB7-1S	CFRP CFRP CFRP	2 3 1	31	1.4 1.4 4.78	Epoxy resin	260 275 256	Concrete crushing
Grace 3620x 150x250	B1C-90 B1G-90 B2C-90 B2C-90	CFRP GFRP CFRP CFRP	1 2 1 1	27.54 31	1.6 2.1 0.18 0.18	Epoxy resin	119 107 414 420	Flexure Flexure Flexure Flexure
Sundarraja 2050X150X200	FG1 FG2 FG4 FC1 FC2	GFRP GFRP GFRP CFRP CFRP	1 2 4 1 2	37.5	1.3 1.3 1.3 1.0 1.0	Epoxy resin	70.40 82.40 105.90 81.90 103.10	Concrete crushing
Adhikary 150 x200 x2600 mm	B-1 B-2 B-3 B-4 B-5 B-6 B-7 B-8	CFRP	- 1 2 1 2 2 1 1	30.5 34.4 33.5 31.5 31.0 33.7 34.4 35.4	No No No No No No No	Primer and epoxy	39.2 50.5 63.6 58.6 60.3 80.8 68.5 85.8	shear

III.ABSERVATIONS ON THE ACTUAL STATE OF ART

From the above review of literature, illustrates that although substantial research has been conducted on strengthening of reinforced concrete beams still, the behaviour of laminate strengthened beams in shear was young as compared with strengthened beams in flexural. There is no design guideline for optimizing and choosing the thickness of HDPE sheet/laminate for strengthening RC beams. From the researchers conducted on RC rectangular and T-Beams sections which, were strengthened in shear with laminate and which were strengthened with 1, 2 and 3 layers of laminate.

IV.PROPOSED METHOD OF STREGTHENING

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 HDPE laminate for strengthening reinforced concrete beams. Finally, the proposed study is to improve the understanding of reinforced concrete beams retrofitted with HDPE and this proposal brings new challenges for professionals and who are working in the field of structural repair and strengthening of reinforced concrete structures and due to the latest technologies in binding the delamination concept can be totally eradicated. In the proposed work five beams will casted of which one beam will be kept as controlled and another four beams will be retrofitted with HDPE. The controlled beam will be tested upto ultimate load and remaining beams will be tested for 70% of ultimate load.

V.GENERAL CONCLUDING REMARKS

This paper reviewed the existing research works on reinforced concrete beams strengthened by various laminates. The beam strengthened with more than one layer of laminate unnecessarily increased the strengthening time as well as cost by providing more than one layer of laminate. The importance of the study in the strengthening of the beam using HDPE laminate in the strengthening system provides an economical and versatile solution for extending the service life of reinforced concrete structures. From the literature, it is evident that epoxy resin is favoured in strengthening and also used to eliminate the debonding failure. Future research is needed for a complete awareness for strengthening reinforced concrete beams with HDPE, with the aim to efficiently contribute in the concrete structures repair tasks as well as, to decrease the dimensional stability of the structure.

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