A REVIEW ON FLEXURE STRENGTH OF REINFORCED CONCRETE BEAM USING FRP SHEET

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Abstract*— This paper presents the review on flexure strength of reinforced concrete (RC) using fiber reinforced polymer (FRP). Now a day Rehabilitation and strengthening of old structures using advanced materials is modern research in the field of civil engineering or Structural Engineering. During past two decades, much research has been performed on flexural strengthening of reinforced concrete beams using different types of fiber reinforced polymers and epoxy resins. The excellent properties of polymer composite materials high strength, low weight, high corrosion resistance, high stiffness, long life and good chemical resistance etc. This paper reviews fifteen articles on strengthening and rehabilitation of reinforced concrete (RC) beams using FRP plates or sheet. This paper reviews the different properties of Carbon Fiber Reinforced Polymer (CFRP) and Glass fiber reinforced polymer (GFRP) composites and epoxy resin, effect of sizes of beams and loading rate beginning failure. This paper presents review on effect of different parameter such as different configuration, dimension of structure, type of FRP sheet, number of layers of FRP sheet etc. on the manners of RC beam in flexure. The paper suggests an improved retrofitting or strengthening technique for flexural members.

***Keywords* — Flexural Strengthening; FRP Sheet; Epoxy Resins; Reinforced concrete;**

I. INTRODUCTION

There are many existing bridge, building, stadiums, marine structure etc. throughout the world, which do not achieve specified design requirements. This may be due to upgrading of the design standards, overloading, corrosion of steel reinforcement, construction errors and poor construction, inadequate selection of materials and natural disasters such as earthquakes. Therefore, the structure requirements complete replacement or strengthening. The explanation in such cases is complete dismantling and new construction or increasing the load carrying capacity through strengthening of the performed structures in various ways. Because of the high-priced cost of replacing large number of deteriorated structures all over the world, research efforts have focused on many methods of strengthening of structures. The strengthening and retrofitting of concrete structures represents one of the most challenging problems faced by civil engineers nowadays.

At present, there are many research teams all over the world responsibility of research in this area. The main advantages of FRP fabrics, sheets and plates are their good mechanical properties, high strength-to-weight ratio, excellent fatigue performance, high corrosion resistance and good chemical resistance etc. The previous property leads to great comfort in site handling reducing labor cost and disruptions to existing services, when latter make sure durable performance. FRP sheet or plate are generally at least two times but can be over 10 times as strong as steel plates, although their weight is only 20% of that of steel. Aerospace industry used in FRP material for many years and their excellent properties are well known.

Fiber reinforced polymer is limited use in civil engineering because their high cost. But, their permitting wider use in civil engineering after FRP material prices are coming down quickly. Then FRP application in the strengthening of structures, the material cost is just one aspect and may be a small portion of the total cost involved including labor cost, loss due to interruptions to services. FRP composites regularly provide the most cost effective whole solution to civil engineering applications.

Fiber Reinforced Polymer (FRP)

Fiber reinforced composite materials be made of fibers of high strength and modulus surrounded in or bonded to a matrix with separate interfaces between them. In this form, both fibers and matrix retain their chemical and physical identities, however they produce a combination of properties that cannot be accomplished with either of the constituents acting alone. Fibers are the principal load carrying members, although the matrix keeps them in the desired orientation, position and protect them from environmental damages. They are commonly used in strengthening of civil structures such as beams, slab, columns, pier, abutment, girders and frames.

There are three most commonly used FRP composites used for rehabilitation of structural members in civil engineering works such as glass, carbon, and aramid fiber. However, the most normally used one is classified as carbon fiber reinforced polymer (CFRP) which is chosen due to its better advantages to be used as reinforcing bars, and externally bonded reinforcement for strengthening, retrofitting and repairing of deficient ageing bridges and building.

II. LITERATURE REVIRW

M.R. Esfahani et al. [10] experimentally studied flexural behavior of reinforced concrete beams strengthened using Carbon Fiber Reinforced Polymers (CFRP) sheets. They manufactured total Twelve concrete beam specimens with dimensions of 150 mm width, 200 mm height, and 2000 mm length. They designed beam sections with three different reinforcing ratios and they used as longitudinal tensile reinforcement in specimens. Nine specimens were strengthened CFRP sheets and Three control specimens. They concluded that flexural strength and stiffness of the strengthened beams increased compared to the control specimens. Test results showed that the effect of CFRP sheets in increasing the flexural strength of beams with small reinforcing bar ratio values compared to maximum code value. In the large reinforcement bar ratio failure of the CFRP sheet strengthened beams occurred with adequate ductility. They also showed that simplified solution to design FRP sheet strengthened beams with low reinforcement ratios.

S.H. Hashemi et al. [13] investigated the effectiveness of externally bonded CFRP sheets to increase the flexural strength of reinforced high strength concrete (HSC) beams. Four-point bending flexural tests on six concrete beams and they observed flexural tests to complete failure on concrete beam. so, these strengthened with different arrangement of CFRP sheets were conducted. Then they checked Three-dimensional nonlinear finite element (FE) models by ANSYS and they examined the behavior of the test beams. Then they also checked the strength and ductility of the beams as the number of FRP layers and tensile reinforcement bar ratio changed. Finally, authors concluded that the energy ductility value is about two times more than the displacement ductility values. They also found that the crack patterns in the reinforced high strength concrete beams was also presented.

Jiangfeng Dong et al. [9] experimentally studied Structural behavior of RC beams with external flexural and flexural–shear strengthening by FRP sheets. They tested total seven concrete beams out of six were flexural strengthened with each single layer or two layers of CFRP sheets and one control beam. They concluded that the increase on the overall flexural capacity of the CFRP strengthened beams varies between 41% and 125% over the control beam and on the shear capacity of the GFRP or CFRP strengthened beams between 31% and 74%. They found that control development of cracks and increase ductility of the beams. They also theoretically predicted the flexural strength and the ultimate shear carrying capacity which show reasonably good correlation to experimental results.

Al-Saidy et al. [2] studied experimentally results of damaged/repaired RC beams strengthened with CFRP. They tested total 10 reinforcement rectangular beam out of six beam specimens were strengthened with CFRP sheet using three different strengthening schemes. Author provided tensile reinforcement of six beams strengthened and three corroded to an impressed electrical current the experimental programed consisted of RC rectangular beam specimens exposed to accelerated corrosion. They described the corrosion rate was varied between 5% to 15% which represents loss in cross-sectional area of the steel reinforcement in the tension side. They repaired bonding CFRP sheets to the tension side by corroded beam. They observed CFRP sheet for strengthening corroded RC beam was efficient of maintaining the structure integrity and increasing ultimate strength to the reference beam. They concluded that the U-shaped straps was more applicable in beams with greater rate of corrosion.

Alnadher Alia et al. [3] carried out De-bonding of carbon fiber reinforced polymers (CFRP) sheets and plates from the concrete alternate was one of the major reasons behind premature failures of beams there were externally strengthened with such CFRP materials. They investigated to delay or prevent de-bonding and therefore increasing the load carrying capacity of strengthened beams, several anchorage systems were developed and used to externally strengthen reinforced concrete beams under flexure. They tested sixteen reinforced concrete beams were externally strengthened in flexure with bonded CFRP sheets and plates and at the time fixed to the soffit of the beams' using various patterns of CFRP anchors. They observed that the CFRP plates begins to separate from the beams as soon as de-bonding occurs in specimens without CFRP anchors, when beams with CFRP anchors de-bonding was delayed superior to increase in the load carrying capacity over the un-anchored strengthened beams.

Sergio F. Breña et al [14] carried-out study on Increasing Flexural Capacity of R.C Beams Using Carbon Fiber-Reinforced Polymer Composites. They tested total of 20 rectangular beams out of which Eighteen of the beams were strengthened four different arrangements using composite material and two control specimens. They used two different sizes of beam because of the differences in strength of the composite materials. They concluded that four of the strengthened beams failed because longitudinal composites ruptured. Beam failure didn't exceed 60% of deformation capacity of control beam specimens. They applied loads on beam after generated flexural cracks within shear span. They also observed that Steel, CFRP and Concrete strains. Then they measured maximum CFRP strains and tests were generally dependent on local effects such as debonding or cracking.

S.E. El-Gamal et al. [12] carried out experimental study on behavior of reinforced concrete (RC) beams strengthened in flexure with near surface mounted (NSM) technique using glass and carbon fiber reinforced polymers (GFRP & CFRP). A total of 10 full scale reinforced concrete beams rectangular cross section 200 × 300× 2760 mm were constructed and strengthened in flexure with FRPs. They were included four parameters: technique used (NSM or Hybrid), type of FRP used (carbon or glass), amount of FRP used, and steel reinforcement ratio. They tested four point bending set-up was all beam. The test results included ultimate capacity, strains, cracking, deflection, and mode of failure. They concluded that all strengthened beam increase in the capacity reaching between 31 and 133% compared with the reference beams. Authors also found that the NSM-CFRP strengthened beams excellent ultimate capacities than the NSM-GFRP beams but they showed less ductile behavior. The NSM-GFRP strengthened beam found better ductile behavior with high deflection values at ultimate load.

N. Attari et al. [11] experimentally investigated Flexural strengthening of concrete beams using CFRP, GFRP and hybrid FRP sheet. They tested total of seven flexural strengthened R.C beams was manufactured and tested under repeated loading sequences using a 4-point bending device to complete a failure analysis. They result for strength, stiffness, ductility and failure modes were discussed for the various strengthening solutions and they also developed an analytical model to predict the flexural failure of strengthened concrete elements. They concluded that the determine the model predicts strengthened concrete beam behavior under applied loads exactly. They also found that U anchorage strengthening shape improvement the flexural strength. Then they checked also reveal the cost-effectiveness of twin layer glass–carbon FRP fabric as a strengthening shape for reinforced concrete structures and a single layered hybrid composite having a good elongation at rupture was improve ductility.

Byong Y. Bahn et al [5] Experimented flexural behavior of reinforced concrete beams bound with carbon fiber reinforced polymer sheet and epoxy mortar. They examined the effect of the end anchorage on strength, deflection, flexural strain, and interfacial shear stress and they were better the debonding behavior in RC beams strengthened with CFRP sheet, by using effective epoxy mortar. Total 11 beams were tested with different six anchorage configurations epoxy mortar, anchor bolt, U shaped CFRP, anchor bolt with U shaped CFRP, flat bonding surface and wavy bonding surface. Finally, authors concluded that premature debonding failure of R.C beams strengthened with CFRP sheet can be delayed or prevented by using epoxy mortar patch end anchorages and after an improved analytical procedure for calculating the flexural capacity of R.C beams strengthened with CFRP sheets and epoxy mortar end anchorage was developed.

Barbara G. Charalambidi et al. [4] experimentally investigated of the response of carbon-fiber-reinforced polymer (CFRP) strengthened reinforced concrete (RC) beams of large scale under fatigue loading. They casted total 10 Reinforced concrete beams both with rectangular and T cross-sections, with web dimensions of 200 mm wide × 500 mm deep and 3,050 mm in length. They also casted cylinders standard 150 × 500 mm. Beams were strengthened in flexure with two different techniques externally bonded CFRP laminate and NSM CFRP laminates. They were tested under fatigue loading, with load-unload cycles of 2 Hz frequency by all specimens and Two different amplitudes of cycles were investigated. Finally, authors concluded that NSM FRP laminates better than externally strengthened beams with FRP laminates because externally bound beam debonding problem. Author also found that NSM strengthened beam was 30% increased of flexural capacity.

E.U. Chowdhury et al [6] experimentally researched on Residual Behavior of Fire-Exposed Reinforced Concrete Beams Pre-strengthened in Flexure with Fiber-Reinforced Sheets efficiently and economically to repair and retrofit deteriorated or understrength concrete structures. FRP materials was being expansively applied in the rehabilitation of deteriorated bridges, but buildings have been limited use because of insufficient knowledge about the FRP materials performance in fire. Then they enable further applications of FRPs in buildings. Total four reinforced-concrete RC T-beams were pre-strengthened with externally bonded FRP sheets and provided with an additional fire protection system by residual strength test of fire. Results suggested that the RC beams strengthened with FRPs previous to fire exposure retained most of their initial un-strengthened flexural capacity after fire. They were concluded that the temperature of the internal concrete and reinforcing steel was kept to below 200°C.and 593°C.

A.F. Ashour [1] carried out Flexural strengthening of RC continuous beams using CFRP laminates. They casted 16 reinforced concrete (RC) continuous beams with three different arrangements of internal steel bars and external carbon fiber reinforced polymer (CFRP) laminates. They included that one unstrengthened control beam designed to fail in flexure by each group. They checked different parameters including the length, thickness, position and form of the CFRP laminates. Finally, they observed three failure modes of beams with external CFRP laminates, namely laminate separation, laminate rupture and peeling failure of the concrete cover attached to the laminate. They concluded that the ductility of all strengthened beams was lower compared with unstrengthened control beam and exhibited higher load capacity of beam was compared reference beam. They also found that increasing the CFRP sheet length to cover the all positive or negative moment zones didn't prevent peeling failure of the CFRP laminate and was recognized the failure mode by tensile rupture of the CFRP sheet.

Guang Qin et al. [7] experimentally found of Fatigue and durability behavior of RC beams strengthened with CFRP under hot-wet environment since the main reinforced concrete structural members of bridges were served under vehicle loads and environment coupling action. They investigated total 30 beams outs of 10 beam uncoupling hot-wet environment and 20 beam coupling hot wet environment by fatigue load. Specimen were divided into three group; group A in temperature was 50°C. and relative humidity 95%, uncoupling action of environment test method; group B in temperature and relative humidity same but coupling action tested; group C in temperature 50°C. and relative humidity 85%, test method coupling method. They concluded that relative humidity was unchanged because the relative fatigue limit decreased as temperature increasing and environment temperature continued unchanged because the relative fatigue limit decreased as humidity increasing. For environment and load coupling test, as environment temperature and humidity increased, environmental fatigue limit of specimen gradually decreased, fatigue limit of group C and group B was respectively 87.6% and 77.0% of the specimens tested at room temperature. They Compared with traditional environment fatigue experiment (uncoupled), fatigue limit of strengthened beams under coupling action was relatively reduce (decreased 20%) in high temperature and humidity environment (50 ºC, 95% R.H).

WANG Wenwei et al. [15] carried out Seven reinforced concrete beams strengthened in flexure using carbon fiber reinforced polymer (CFRP) sheets subjected to different sustaining loads were constructed and tested specimens. All beam has rectangular cross-section 150 × 250 × 2700; same size of all beam. Then they examined externally bonded CFRP sheets was effects of initial load and load history on the ultimate strength of strengthened Reinforced concrete beams. They included that the main experimental parameters included different levels of sustaining load at the time of strengthening and load history. Then Experimental results showed that sustaining load levels at the time of strengthening have important influences on the ultimate strength of strengthened RC beams. If the initial load was the same, the ultimate strength of RC beams strengthened with CFRP sheets was almost the same regardless of load history at the time of strengthening. They found that CFRP external reinforcement better than damaged beam because increased the load carrying capacity compared of damaged beam by 22.5% to 41.2%.

H. Toutanji et al [8] experimentally researched on Flexural behavior of reinforced concrete beams externally strengthened with carbon fiber reinforced polymer (CFRP) sheets bonded with an inorganic matrix and analyzed total of eight RC beams. They tested one reference beam without CFRP sheet and seven beams reinforced with three to six layers of CFRP sheets bonded by an inorganic epoxy. They subjected to a four-point bending test under load control while load, deflection, mid-span strain and failure mode were recorded up to failure by all specimens. Author found that the load carrying capacity increases with the number of layers of CFRP sheet up to 170.2% of the reference beam strength. They showed beam with three and four layers of FRP sheet failed by rupture of FRP, at the same time beams with five and six layers of FRP sheet failed by FRP delamination. The ductility of the FRP strengthened beams is highly reduced compared to the reference beam. They focused on the debonding failure of FRP bonded to RC beams for future study and moment deflection model was developed.

III. CONCLUSION FROM LITERATURE REVIEW

- The flexural strength and stiffness of the strengthened beams increased compared to the reference beam or control beam.
- The improved on the overall flexural capacity of the CFRP strengthened beams varies between 41% and 125% over the reference beam or control specimens.
- The CFRP strengthened beams presented greater capacities than the GFRP strengthened beams.
- CFRP external reinforcement increased the load carrying capacities of damaged/repaired RC beam by 22. 5% to 41.2%.
- Overall, there is lack of comparison of different arrangement other than full side wrapping and U- wrapping for beams strengthened in shear and flexure.
- FRP application primes to a variation of some of the important structural aspects like the cracking pattern and deformation levels in shear reinforcing systems.
- There is no any effect of different environmental conditions on the strength of strengthened beam.
- Strengthened beam showed better load vs deflection characteristics than the control specimen beam.
- CFRP or GFRP failure may be due to debonding of CFRP or GFRP or Severe concrete.
- When increase of number of layers of CFRP sheet or plate the strength of beam increase but at decreasing at rate.
- Hence, we can say that CFRP sheet or plate plays an important role providing strength and strengthening to structure.

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