Review on Flexural and Shear Strengthening of RCC Beams using Externally Bonded FRP Laminates

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Abstract - *This paper presents a literature review related to role of Fibre Reinforced Polymer (FRP) Laminates used in retrofitting of RCC Beams. Several investigators carried out experimental and theoretical investigations on concrete beams retrofitted with various fibre reinforced polymer (CFRP, GFRP, etc.) composites in order to study their effectiveness. The construction industry have progressed much post-independence. But many failure are observed in the structural members which are needed to be reduced for the safety of life and latter. The addition of fibre-reinforced plastic (FRP) laminates bonded to the tension face of concrete members is becoming an attractive solution to the rehabilitation and retrofit of damaged structural systems. Many practical applications worldwide now confirm that the technique of bonding FRP laminates or fabric to external surfaces is a technically sound and practically efficient method of strengthening and upgrading of reinforced concrete load-bearing members that are structurally inadequate, damaged or deteriorated. This paper reviews some articles on strengthening and rehabilitation of reinforced concrete (RC) beams using FRP laminates. Flexural strength is enhanced with this method but the failure behavior of the system can become more brittle, often involving delamination of the composite and shear failure of the members. This study first reviews failure modes with and without the use of FRP to rehabilitate various concrete structures and discusses methodologies used to characterize the failure processes of the system. A thorough literature is been studies and reviewed. Different retrofitting techniques using FRP laminates have been studied the results were observed and compared for various different types of FRP laminates. Finally the study concludes the comparison between various retrofitting techniques used to increase the flexural and shear strength of RCC beams while reducing it's failures.*

Key Words: **Retrofitting, Fibre Reinforced Plastic, FRP Laminates, GFRP, CFRP, Aramid FRP.**

1. INTRODUCTION

The rapid deterioration of infrastructure is becoming a principal challenge facing concrete and bridge industries worldwide. Traditional structural rehabilitation methods such as external post-tensioning and bonded steel plates often suffer from inherent disadvantages ranging from difficult application procedures to lack of durability, leaving the growing repair and rehabilitation market in need of cost-effective and efficient restoration techniques. Advances in the fields of plastics and composites have resulted in the development of high-strength, fiber - reinforced plastics (FRP) that offer great potential for lightweight, cost-effective retrofitting of concrete structures, including bridges. These high-performance materials can be bonded to the tension face of concrete members to increase the strength and stiffness of the structure with savings in application costs and improved durability over conventional methods. Recently, the use of FRP bonded to deteriorated, deficient, and damaged reinforced concrete structures has gained popularity in Europe, Japan, and North America. The application of FRP as external reinforcement to concrete infrastructure has been studied by many groups. FRPs have been used to retrofit concrete members such as columns, slabs, beams, and girders in structures such as bridges, parking decks, smoke stacks, and buildings. Among these, the application of FRP to strengthen concrete beams has perhaps received the most attention from the research community; many researchers have reported improvements in strength and stiffness of retrofitted beams. Theoretical gains in flexural strength using this method can be significant; however, researchers have also observed new types of failures that can limit these gains. These failures are often brittle, involving delamination of the FRP, debonding of concrete layers, and shear collapse, and can occur at loads significantly lower than the theoretical strength of the retrofit system. Thus, there is a need for an improved understanding of these and other failure mechanisms of laminated concrete beams.

1.1 AIM

To review the literature on flexural and shear strengthening of RCC beam by using externally bonded FRP laminates.

1.2 OBJECTIVES

a. To study different failure modes occurring in RCC beam.
b. To study different retrofitting techniques being used.

c. To study literature about strengthening using Fibre Reinforced Plastic Laminates.
d. To enhance flexural and shear strength of RCC beam to reduce shear failure and increase load carrying capacity.

2. LITERATURE SURVEY

For many decades, the structural engineers have been trying to make the structures more resistant to the variable forces. Many research works have been done to find innovative and effective ways to increase the strength of RCC structure by using FRP laminates. The following literature review is done with the preview of some of the prominent research in strengthening of RCC structural members and retrofitting using various FRP laminates.

2.1 LITERATURE REVIEW

In the research done by M. S. Abdel-Jaber, P. R. Walker and A. R. Hutchinson (2003), shear strengthening of reinforced concrete beams using externally bonded carbon fibre reinforced plastic plates (CFRP) was studied. Eighteen reinforced concrete beams of 1.8 m length were constructed and tested and were described. The relative performance of a group of sixteen beams with the same steel reinforcement but with different amounts of shear strengthening is discussed. All the beams were designed to fail in shear using a spreadsheet program. The spreadsheets were designed to ensure that the beams' flexural capacity exceeded the shear capacity after strengthening. The variables were: main reinforcement ratio, spacing between links in the shear span and different configurations of CFRP plates on shear spans. The concrete had an average compressive strength of 61.76 N/mm2. The majority of the beams tested showed a significant improvement in shear strength by the addition of CFRP plates, with increases of between 19-22% over the control beams.

In the research study done by A. Bruckner, R. Ortlepp and M. Curbach (2006), Using test results it is demonstrated how thin layers of concrete with textile reinforcement can be used for strengthening for reinforced concrete (RC) members. The enhancement of bending capacity is illustrated with flexural strengthened RC-slabs. It is also established that the shear capacity may be increased through strengthening of RC-beams, and that properties of serviceability are improved, in particular the reduction of deflections and crack widths. The detailed problem of force transfer from the textile reinforced strengthening layer to the existing concrete of RC members is then explained and subsequently the relation between the transferable bond force and the associated bond length is shown. A simple model for dimensioning the flexural strengthening of RC-slabs is presented and necessary model extensions are additionally pointed out. The properties of textile reinforcement were investigated with slabs with a thickness of 100mm and an effective span of 1.60 m. Each slab had a percentage of 0.2% or 0.5% steel reinforcement. The test results indicate that RC-members can be strengthened with textile reinforced concrete. Both, the load carrying capacity and the shear loading capacity, can be increased with an additional strengthening layer. Beside the ultimate load, the serviceability (the displacement of the strengthened RC-members) will be improved.

In the research study by A.G. Silva (2011), the confinement of reinforced concrete columns with transverse reinforcement has been extensively studied and it is known that the response of concrete cylinders subjected to equivalent levels of pressure depends on how that lateral pressure is transmitted, and not on its magnitude alone. When confinement is, additionally to that given by steel stirrups, provided by external jackets of fiber reinforced polymers (FRP) the complexity and the scarcity of experimental data increase and tests to gain insight into the structural behavior and consequent design procedures are still required. The present study reports tests performed on axially loaded RC columns, with and without jackets. The FRP tested were made either of carbon fibers reinforced polymers (CFRP) or aramid (AFRP) wraps and the geometry of the specimens included square and circular cross-sections. Comparison of gains of axial strength and ductility were presented and aspects of the variation of the lateral pressure and rupture of FRP jackets were examined.

In the research done by Imran A. Bukhari · Robert Vollum · Saeed Ahmad · Juan Sagaseta (2012), the results of a series of tests on short span reinforced concrete beams which were strengthened in shear with various arrangements of externally bonded carbon fibre reinforced polymer (CFRP) sheets were presented. The objective of the tests was to determine the effect of changing the area and location of the CFRP sheet within the shear span. A total of fifteen 150 mm × 300 mm × 1,675 mm concrete beams were tested of which four were un-strengthened control specimens. The remaining 11 beams were strengthened with varying configurations of CFRP sheets. Parameters varied in the tests included the area of CFRP sheet, its anchorage length and the distance of the CFRP sheet from the support. The experimental results revealed that the CFRP is more effective when it is placed close to the supports and even small areas of CFRP can give significant increases in shear strength. The experimental results were compared with the three different existing shear prediction models for estimating shear contribution of CFRP sheets .A simple strutand- tie model is presented which gives reasonable predictions of shear strength for the beam specimens, which were strengthened with CFRP over the full depth of the beam. The superposition method of design is replaced in EC2 by the variable angle truss model in which all the shear is assumed to be resisted by the truss mechanism.

In the research study by Amir Mofidi and Omar Chaallal (2013), Numerous investigations of RC beams strengthened in shear with externally-bonded (EB) fibre-reinforced polymer (FRP) sheets, plates and strips have been successfully conducted in recent years. These valuable studies have highlighted a number of influencing parameters that are not captured by the design guidelines like experimentally and analytically the influential parameters on the shear contribution of FRP to RC beams strengthened in shear using EB FRP sheets and strips and to develop a set of transparent, coherent, and evolutionary design equations to calculate the shear resistance of RC beams strengthened in shear. In the experimental part of this study, 12 tests were performed on 4,520-mm long T-beams. The specimens were strengthened in shear using carbon FRP (CFRP) strips and sheets. The test variables were: (1) the presence or absence of internal transverse-steel reinforcement; (2) use of FRP sheets versus FRP strips; and (3) the axial rigidity of the EB FRP reinforcement. In the analytical part of this study, new design equations were proposed to consider the effect of transverse-steel in addition to other influential parameters on the shear contribution of FRP. The accuracy of the proposed equations has been verified in this study by predicting the FRP shear contribution of experimentally tested RC beams.

In the research done by Jiangtao Yu, Xingyan Shang; and Zhoudao Lu (2016), they investigated the efficiency of externally bonded L-shaped fiber-reinforced polymer (FRP) laminates in strengthening seismically damaged reinforced concrete (RC) interior joints. Ten ½-scale interior beam-column joints, including two reference specimens, were constructed and then damaged under simulated cyclic lateral loads. In addition to repairing visual cracks with epoxy injections, four of eight specimens were strengthened with externally bonded L-shaped carbon fiber–reinforced polymer (CFRP) laminates and the rest were strengthened with basalt fiber–reinforced polymer (BFRP) laminates. Retesting after retrofitting showed that the average peak strength of the CFRP-strengthened and BFRP-strengthened specimens increased by approximately 20 and 10%, respectively. The two strengthening systems also clearly enhanced the deformability of the specimens. Further analysis indicated strength increase was controlled by the end debonding of FRP laminates near critical sections of the specimens, thus the bending strengthening formulas, which were extensively used in practice, overestimated the strengthening efficiency. To solve this problem, alternative formulas accounting for the end debonding of FRP were proposed to predict the peak strength and FRP strain of the specimens. The predictions showed acceptable agreement with the test results, demonstrating the proposed formulas were applicable to predict the efficiency of externally bonded L-shaped FRPs in strengthening damaged interior framed joints.

In the research work done by Natalie Williams Portal, Lars Nyholm Thrane and Karin Lundgren (2016), evaluates the flexural behaviour of carbon textile reinforced TRC slabs both experimentally and numerically along with the characterization of the material and interaction level properties. The experimental results characterizing the bond behaviour were linked to the experimental behaviour of a rectangular TRC slab in bending through numerical analyses. A 2D macro-scale FE model of the tested TRC slab was developed based on the related experimental input. Comparison of the numerical results to the experiments revealed that the flexural failure was governed by bond, and reasonable agreement was obtained in terms of crack development, deflections, maximum load, and failure mode. Accordingly, the experiments further indicated that the flexural behaviour of TRC slabs is greatly influenced by the bond quality.

In the research work done by Fasil Mohi ud din (2017), the experimental investigation was carried out on various types of fibres to find the use of the fiber in the structural engineering in particular and civil engineering in general. Various testing procedures were adopted to find the effectiveness and compatibility of fibre in concrete. In this paper the study was conducted about engineering and mechanical properties of Kevlar Fibre and in comparison with other fibers, testing of Kevlar fibre under various conditions and the very systematic comparative study was been carried out on the properties of Kevlar with respect to other fibers. The main objective of the study is to find out the mechanical properties and compatibility of fibre so that it can be used in concrete to enhance its properties and to increase its durability.

In the research work done by Dheeraj Kumar and Shivani Bhardwaj (2018), the phenomenon of retrofitting is explained and found that many of the existing structures of the of reinforced concrete structure throughout the world are in urgent need of rehabilitation , due to various factor like corrosion lack of detailing , failure of bonding between bean-column joint etc. But using the aramid kevlar fiber fabric stripes reinforcement (akffr) and synthetic steel fiber (ssf) for the wrapping of structure. These material used to our structure are very strong and seismic activity resistance. It presents an experimental study on (AKFFR) Aramid Kevlar fiber fabric reinforced concrete beam retrofitted with various type of fibre like synthetic steel fiber (SSF). This study also investigates the behavior of concrete beam after retrofitting using of synthetic steel fiber and Aramid Kevlar fiber(AKFFR)etc.

In another research done by Ankit Dasgupta (2018), an understanding of the properties and performances of fiber reinforced polymers (FRP) has been developed through the study of their different applications for structural retrofitting. Design guidelines and recommendations should be made more readily available to ensure more rapid and effective applications of FRP as a seismic material. This innovative technique shows a great potential when disruption of traffic or activity of the building is not possible or only for a limited time. Indeed, applying fiber reinforced polymers (FRP) layers is very quick and does not require specialized equipment's (crane, etc). With increasing acceptance by the industry over the past years, FRP have become commonly used in different types of structural retrofitting. The standard comparison highlights the limitations of the use of fiber reinforced polymers as most of the differences in the calculation come from security coefficient related to the adherence of the fiber reinforced plates to the concrete.

In the research done by Rajashekhar Siddappa Talikoti and Sachin Balkrishna Kandekar (2019), showed the durability of structures can be extended by selecting an appropriate method of strengthening. FRP wrapping is one of the easiest methods for repair, retrofit, and maintenance of structural elements. Deterioration of structures may be due to moisture content, salt water, or contact with alkali solutions. Using FRP, additional strength can be gained by structural elements. This paper investigates the durability of aramid-fiber-wrapped concrete cube specimens subjected to acid attack and temperature rise. The study focuses on the durability of aramid-fiber-wrapped concrete by considering the compressive strength parameter of the concrete cube. Concrete cubes are prepared as specimens with a double wrapping of aramid fibers. Diluted hydrochloric acid solution is used for immersion of specimens for curing periods of 7, 30, and 70 days. The aramid-fiber wrapping reduces weight loss by 40% and improves compressive strength by 140%. In a fire resistance test, the specimens were kept in a hot air oven at a temperature of 200 _C at different time intervals. Even after fire attack, weight loss in specimens reduced by 60%, with about 150% enhancement in compressive strength due to aramid fiber.

In the research done by Mohammed Hisham et. Al. (2019), focused on the Kevlar fiber composite, the demand of Kevlar composites increasing day-by-day because it's light weight and good mechanical properties. There are different types of fiber composites are available like Carbon, Basalt, Glass, Jute, Kenaf, Flax, Hemp and Kevlar etc. Out of these available material Kevlar is one of the most favorable composite material. Properties of Kevlar include high rigidity modulus, toughness, thermal stability and most importantly strength. Moreover, the properties of Kevlar composite can be increased by applying the different hybridization and treatment process. The aim of this study, to explore the different types of hybridization and treatments that can be applied for improving the mechanical properties of Kevlar composite.

2.2 SUMMARY OF LITERATURE

Following points can be summarized from the literature survey: -

[1] Usual retrofitting techniques are very tedious and time consuming.
[2] Use of fibre reinforced polymers (FRP) are emerging and favorably used now a days for retrofitting of the structures as it is easily applicable.
[3] There are various fibres available in the market. Which are Carbon, Basalt, Glass, Jute, Kenaf, Flax, Hemp and Kevlar etc.
[4] Amongst all Carbon and AR-Glass FRP are widely used. But they are brittle in nature and many times failure occurs within the fabric prior to the structure.
[5] RC beams suffered brittle shear failure even designed according to current codes.
[6] Use of CFRP in concrete members, produces an increase in strength, but this phenomenon is strongly influenced by the aspect ratio of the cross-section.
[7] Maximum strength and ductility of post-heated beams was increased significantly by wrapping with a single layer of GFRP or CFRP jackets.
[8] The load carrying capacity of the column decreased, with increase in aspect ratio of the cross-section.
[9] CFRP confinement was a very good alternative for strengthening of circular and square RC columns.
[10] Increasing the number of FRP layers in RC beams strengthening decreases the strains in both the transverse steel ties and fiber materials.
[11] Kevlar is way more dutile and have similar properties to that of glass and carbon fibre.
[12] Very less study is made in the use of Kevlar fabric as an retrofitting material.

3. FRP USED IN RETROFITTING REINFORCED CONCRETE BEAMS

FRPs exploit the advantages of high tensile strength fibers and are characterized by excellent corrosion resistance, fatigue resistance, low densities, and high specific stiffness and strength. Commonly used fibers include AR-glass, Kevlar/Aramid, and carbon; these can be pre-impregnated in matrices, lined uni-directionally in two sheets, or woven into bidirectional fabrics. Application usually involves preparation of the concrete surface through mechanical or chemical means followed by a primer. If a fabric or tow sheet is used, an epoxy is applied to the concrete followed by the fiber in a process called "wet layup." Here, the adhesive is also the matrix, creating a stronger bond but also subjecting the fibers to debonding stresses with uneven concrete surfaces. Preimpregnated FRP sheets and plates may be roughened, then attached to the concrete with an epoxy layer. Here the choice of adherent stiffness is crucial for effective stress transfer to the laminate. Thicknesses of installed plies usually range from 1 to 3 mm. The implementation of this technique in strengthening existing reinforced concrete infrastructure has been demonstrated around the world. First applications of FRP to concrete structures include the use of carbon fiber-reinforced plastic (CFRP) laminates to strengthen a bridge with a damaged prestressing tendon; a mobile platform was used at night to restore the integrity of the bridge. Glass fiber-reinforced plastic (GFRP) sheets were used to retrofit a roadway bridge to reduce the steel stresses in the tendon couplers. Additionally, prestressing the FRP laminate before application has been investigated. It was found that high levels of prestress can result in shear failure in the concrete at the anchorage zone. These early studies, among others, have investigated a variety of retrofit systems and presented their responses under loading; many researchers have concluded that failure processes and their governing criteria need further study.

4. TYPES OF FAILURE MODES IN RCC BEAMS

4.1 FLEXURAL FAILURE

Flexural strength, also known as modulus of rupture, bend strength, or fracture strength, is a material property, defined as the stress in a material just before it yields in a flexure test. The flexural strength represents the highest stress experienced within the material at its moment of rupture. It is measured in terms of stress. To overcome this type of failure, main steel is provided at the bottom/top of the beam. Flexural failure occurs at mid span of beam. There are many causes of flexural failure.

Fig -1 : Flexural Failure in RCC Beam

4.2 SHEAR FAILURE

Shear strength is the strength of a material or component against the type of yield or structural failure where the material or component fails in shear. A shear load is a force that tends to produce a sliding failure on a material along a plane that is parallel to the direction of the force. In the simple word, shear stress is max at 45 degree in the cross section of beam hence diagonal crack is foems in shear failure and shear failure occurs at the end of the beam where beam connect to column. To avoid this type of failure stirrups are provided.

Fig – 2 : Shear Failure in RCC Beam

4.3 TORSIONAL FAILURE

Usually beams are subjected to torsion along with bending moment and shear force. Bending moment & shear force occurs as loads acts normal to the plane of bending. However, loads away from the bending plane will causes torsional movement leads to torsional failure of RCC beams.

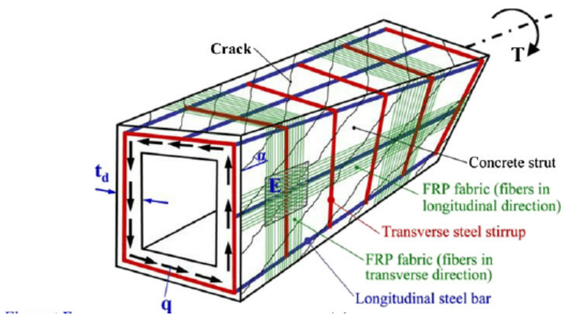

Fig – 3 : Torsional Failure in RCC Beam

4.4 DEBONDING FAILURE

A RC frame building is studied for calculating the base reaction with fixed base condition situated in zone IV and on medium soil. The following data is used for analytical calculation to calculate the total base reaction V_b of the structure using M20 grade of concrete and Fe415 grade of steel with reference of IS 1893 : 2016

Fig – 4 : Debonding Failure in RCC Beam

6. CONCLUSIONS

Researchers have concluded that failure criteria for laminated systems need to be studied more precisely. For this, however, a thorough understanding of the behavior of these systems is necessary. Many studies have presented a wide variety of failure modes observed in retrofit concrete beams, these failure types can be grouped into different types. The criteria for each of these failures are affected by various parameters in the design of a FRP retrofit concrete beam. It has been recommended that failure of these systems should occur with yielding of steel and ultimately rupture of the laminate before compressive concrete failures. This can be accomplished by optimizing the FRP and the steel-reinforcement ratio through traditional reinforced concrete design methods. Some other modes of failure, such as shear and debonding failures, can depend on other parameters such as existing shear reinforcement, crack configuration prior to strengthening, laminate length, and relative laminate/adherent/concrete stiffnesses. It has been observed, modes of failure include flexural compression of the concrete, shear failure in the concrete beam, delamination of the FRP, and debonding of a layer of concrete at the flexural steel level. The failures occur in a brittle manner with a sharp, explosive fracture. Strengths were increased Deflections in the beam were reduced compared to the un-retrofitted section, and the beam stiffness was increased. The ultimate strengths and stiffnesses of the beams with these flexural failures can be accurately predicted using strain or stress compatibility theories. It can be concluded that the FRP along the bottom of the beam does not significantly add to the shear strength of the section. Shear failure occurred at relatively low applied loads, but these loads agreed with traditional reinforced concrete shear-strength theory. Other types of failures in FRP retrofit concrete involve a variety of debonding mechanisms, these include failure of the concrete layer between the FRP and the steel, and delamination or "peeling" of the FRP from the concrete. The laminate-concrete interfaces have been concluded to be susceptible to relative vertical displacements of shear cracks in the concrete beam. Thus, it has been shown that addition of FRP laminate can result in failure modes other than flexural failure and that these shifts in failure modes can alter the strength and ductility of the system. FRP's can play key roles in meeting the challenges. Advancements through research in this area are identified along with areas in need of further study. It is observed that a complete understanding of the effects, these materials have on the performance of retrofit systems has not been achieved. More studies are needed to develop a better understanding of the shear capacity of retrofit sections, the effects in the anchorage regions of the FRP laminate, and failure mechanisms of debonding and delamination. Topics of future study should also include effects of material compatibilities and their resistances to degradation through both environmental and load cycles, and the assessment of retrofitted system integrity through the use of nondestructive evaluation.

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