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Experimental Performance of Concrete with CFRP and GFRP Wrapping System: A Literature Review

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Abstract: Fiber-reinforced polymer (FRP) is widely used as a composite material in civil engineering application to rehabilitate or strengthen reinforced-concrete structural element. Fiber wrapping is a technique to wrap RCC structural components such as beams, columns and slabs with a confining material in order to improve the performance and durability of existing structure. In terms of parameters such as confinement strength, post-repair ductility, cross-sectional area, weight, corrosion resistance, easy in application and overall project cost. this method has proven superior over time to conventional methods of retrofitting techniques. Whenever repair and strengthening are concerned variables such as seismic resistance, improved ductility, axial strength, impact and blast resistance, increased flexural strength, shear strength and fatigue life are required. In case of damaged structural element due to excessive loading or erosion in exposed environment, repair is necessary. When the structural usage changes or some neighboring load bearing structural components are removed, retrofitting may be required. Though variety of FRP such as glass fiber, carbon fiber and aramid fiber can be used for strengthening, this study mainly focuses on application of carbon fiber polymer (CFRP) and glass fiber polymer (GFRP) in strengthening of structural elements. The aim of this study was to compile an extensive and up-to-date experimental database based on the compression tests performed on square concrete cubes using FRP composite materials. This review presents square concrete cubes wrapped with CFRP and GFRP under axial compression.

***Index Terms* - Square cubes, Carbon fiber-reinforced polymer (CFRP), Glass fiber-reinforced polymer (GFRP), fiber wrapping, Strengthening.**

I. INTRODUCTION

Concrete is a material that exhibits unique behavior under a different condition. It behaves in a different way under static loading as compared to its behavior in the dynamic loading condition. Concrete being basically brittle material fails at some instances for varied reasons. They may fail due to changes in load conditions that they are not designed to withstand, weather conditions, aging, or some unpredictable natural calamities such as earthquake etc. Sometimes the defects are so severe which either could not be repaired or it requires huge cost to repair. The cost of repair also causes a huge burden on nations' economies. Many researchers have simulated structural models integrated with CFRP confined concrete. The performance of FRP confined concrete under static forces, axial loads, flexural actions and cyclic or seismic loads have been constant points of investigations. These investigations have caused FRP technologies to be widely adopted in retrofitting technologies using carbon or glass polymers. Numerous analytical models have been developed and analyzed to study the behavior of FRP confined concrete under different loading conditions. However, all of these models were created by regression analysis of the researchers' experimental data.

Reinforced concrete structures are exposed to seismic activity, harsh environmental conditions, changes in their use or degradation due to age and therefore, changes in loads and durability. The structural deficiencies in civil engineering applications raise questions about the design and more importantly structural safety. In most cases, structural strengthening and rehabilitation are more beneficial, economically and socially, than demolition and reconstruction. Traditional strengthening methods, such as steel or concrete jacketing has been replaced by fiber wrapping, an effective method to improve seismic performance and thereby improve the axial strength, and the deformation capacity of existing reinforced-concrete structures.

This retrofitting technique functions by wrapping transversely concrete structure, using fiber-reinforced polymers (FRP) as the externally bonded strengthening materials. The composite material, typically consist of carbon, glass, or aramid fibers impregnated with in typically organic matrix, originally appeared as a promising material with which to increase the compressive, flexural, and shear capacity of concrete structural elements to achieve the performance required by modern regulations. These FRPs have significant advantages such as high strength, light weight, extremely high durability, availability in long lengths, corrosion resistance, and easy of application. The differences between FRP materials are mostly affected by the properties of the fibers used. Carbon fibers exhibit higher strength, fatigue resistance and modulus, but relatively limited ductility, especially when compared to other fibers such as glass, aramid and even basalt. The cost of carbon fibers, on the other hand, is significantly larger than those of glass, aramid, and basalt fibers. These last three possess quite similar mechanical characteristics. Although basalt fibers are very common in textile-reinforced mortar (TRM) systems, and have been used for confinement, they are not using in FRP systems.

II. LITERATURE REVIEW

The flexural strength of glass fiber reinforced polymers with different glass fiber content in concrete mix is studied by Hibretu Kaske Kassa *et al*. [1]. It was found from the failure pattern of the specimens that the formation of crack was greater in the case of concrete without fiber than in the case of fiber- reinforced concrete. The author concluded from the finding that the percentage increase in flexural, shear and compressive strength of fiber-reinforced concrete beam compared to the control beam (without fiber). D.S. Vijayan *et al*. [2] studied the efficiency of concrete columns filled with reinforced polymer glass fiber. results obtained from tests on concrete columns were enhanced by the external E-glass fiber composite in terms of load-bearing capacity and strains. This study aims to measure the effect of upgrading the carriage capability of GFRP flexible wraps compressed concrete column. For the different grade of concrete column, the different thickness of GFRP sheet is wrapped and the results are to be analyzed. 3 mm to 5 mm thick GFRP sheets are wrapped around short columns and the compressive strength is conducted. It provides a maximum axial compressive strength and young's modulus gets enhanced when it is compared to control column.

Milind V. Tondase *et al*. [3]. presented the rounded sharp increases the load-bearing capacity of the CFRP wrapping by up to 2 layers and the ductility by up to 3 layers of wrapping as compared to the unwrapped column. The toughness index of the reinforced column rises as the concrete grade rises, and as the number of carbon fiber reinforced polymer sheet layers rises, the effect of wrapping CFRP sheets to the concrete column to increase axial load carrying capability for different grades of concrete is described in this research. When compared to plain columns, 1, 2, and 3 layers strengthened columns enhance load carrying capacity by 96.64%, 126.02%, and 103.49%, respectively. Compared with RC columns, 1-layer reinforced column, 2-layer reinforced column and 3-layer reinforced column increase the load capacity by 43.04%, 63.82% and 48.04% respectively. A plain column covered in one layer carbon fibers has 43.04% greater axial capacity than a R.C column. As a result, R.CC column can be replaced with a wrapped plain column.

The structural performance and failure patterns of a total of 10 RC columns were tested under axial compression cyclic load, two of them were test as RC square column while rest of them is confined with PVC and wrapped with CFRP. In case of PVC confined, no warning cracked was observed, failure was abrupt and PVC burst longitudinally is studied by Zahoor Ullah and Fawad Khan [4]. In the partially CFRP-wrapped concrete, warning cracks in the concrete were observed and the failure occurred abruptly, with the CFRP rupturing layer by layer. From all the tested specimens, load/strength enhancement ratio between square RC column and Circular RC column was 12%, PVC confined RC column was 47.8%, CFRP wrapped RC column was 114% and PVC and CFRP confined RC column was 123%. By using CFRP, dead load and size of RC column can be reduced while achieving the target strength. Further, John Bennet.C.S *et al*. [5] studied concrete samples wrapped with glass fiber reinforced polymers. Strength of concrete members confined with GFRP mat is 1.7 times higher than that of the control sample. For future work, FRP-wrapped samples can be checked for different atmospheric conditions, such as high temperature and water conditions etc. If the underwater conditions are successful; it can be used for repairing and retrofitting the old bridges.

Kunal R. Bhoi *et al*. [6] presented the strength of distressed concrete cubes with four-sided GFRP and CFRP wrapping. Total 30 cubes of M20 and 30 cubes of M25 grades of concrete of standard size were casted. All specimens were tested after 28 days of curing time. Compressive strength of conventional concrete M20 grade increases to 41.41% for GFRP and 63.78% for CFRP when cubes were distressed by 50% of average compressive strength. Compressive strength of conventional concrete M25 grade increases to 17.33% for GFRP and 32.68% for CFRP when cubes were distressed by 50% of average compressive strength. Comparing the one wrap of GFRP and CFRP wrapping on M20 and M25 grades, CFRP exhibits higher compressive strength compared to GFRP. Failure of wrapping material was observed at lap joint hence lap length should be increased. Similarly, K. Ganesh *et al*. [7] studied the CFRP wrap bears huge load carrying capacity in reinforced concrete elements, as per test results CFRP wrapped columns performed well than conventional columns even in eccentrical loading. So, CFRP has effective impact performed. A square reinforced concrete column is wrapped in CFRP fabric, a specimen with high load-bearing capacity and ductility under large eccentric loads. From this CFRP fabric has more ductility strength and the fabric has higher mechanical properties. As per test result CFRP wrapped column performed well than conventional columns even in eccentrical loading. This study describes about behavior of purely uniaxial load column by wrapping with CFRP and the cross section of the column is in uniaxial shape. In this work, performance of a column of compound material (concrete, steel, RCC and CFRP) as a flexural column is studied with an eccentric and concentric loading and possible ways of improving the flexural column performance by using carbon fiber-reinforced polymer.

Nitin Mehta and Rakesh Kumar [8] presented the CFRP sheet bounded to the beams with different configuration in order to increasing the service life and load capacity. The studies were carried based on the effect of externally bonded carbon fiber-reinforced polymer sheet on the load bearing capacity of reinforced concrete beam. Also studied about the flexural behavior of RC beam strengthened with carbon fiber-reinforced polymer fabric. From this study the load carrying capacity of the CFRP coated beam is enhanced as compared to the beam without CFRP. The load carrying capacity of the CFRP U wrap increased 26 % more than the beam without CFRP. The flexural Strength of the CFRP U wrap beam is increased as compare to the beams without CFRP. The load carrying capacity of the beams after 28 days without CFRP is 53 KN. It is observed that beam - 2 (U wrap) the load carrying capacity is 67 KN. The behavior of CFRP wrapped reinforced concrete columns under uniaxial compressive loads is studied by A. R. Khan and S. Fareed [9]. More specifically the main objectives of the study were to assess experimentally the behavior of CFRP wrapped plain and reinforced concrete rectangular columns under uniaxial compressive load and to compare the effectiveness of Carbon fiber reinforced polymer wraps on rectangular columns provided by different wrapping techniques (fully wrapped, partially wrapped and intermittent wraps). Fully wrapped columns failed due to the crushing of concrete in concrete cover region with concrete confined in steel core being intact. Partially wrapped (PW) and intermittently wrapped (IW) samples showed similar behavior. Both specimens failed due to concrete crushing in the weak section of the column, resulting in failure of the CFRP. Minor or no damage in the concrete confined in the steel core region was observed. The 2/3rd partial wrapping and intermittent wrapping schemes does not prove to be efficient in increasing the load carrying capacity and ductility of specimens.

The reinforcing columns with CFRP increases their axial load-bearing capacity is presented by Ratish Y Chengala *et al*. [10]. The overall response of the wrapped concrete cylinder was superior to that of the control cylinder exposed to the same environmental conditions. The carbon fiber wrapped columns showed significant improvement in terms of ductility, strength and stiffness in comparison to a similar control cylinder. CFRP wraps are considered effective in strengthening concrete cylinders after exposure to freeze-thaw cycles in terms of strength, stiffness and ductility. FRP wrap was capable of restoring the strength of cylinders exposed to freezing-thawing to that of unwrapped columns at room temperature. CFRP wrapped concrete exposed to freeze-thaw cycling showed a significant increase in strength (up to 57%) when compared to unwrapped specimens exposed to the same conditions. A second layer of CFRP wrap provides an extra 30% increase in strength. Subjecting the wrapped cylinders to freeze-thaw cycles resulted in more catastrophic failure than cylinders at room temperature. Abdul Saboor Karzad *et al*. [11] studied the behavior of reinforced concrete (RC) beams strength with externally bonded carbon fiber-reinforced polymer (EB-CFRP). The repair and retrofitting of the deteriorated structures are essential to maintain and extend their service life. The purpose of this study is the performance of the EB-CFRP repair technique in shear strength recovery of shear deficient beams. The use of 2 layers of EB-CFRP discrete strips with 100 mm width and 150 mm spacing resulted in approximately 95% increase in shear strength compared to the original capacity of the reference beams.

Anilkumar D D *et al*. [12] They have studied Carbon fiber reinforced polymer sheets are used as external adhesive reinforcement in concrete structures to improve flexural and shear strength, retrofitting works and concrete containment. The columns are wrapped in carbon fiber sheet impregnated with pure epoxy glue. The carbon fiber reinforced is also used for structural repair and Strengthening has increased steadily in recent years. The increase in number of FRP layer and FRP contact area with concrete have a greatly increase in stiffness and ultimate load. Strengthening the sides of the column will improve with FRP will help in controlling the width and propagation of the shear cracks and providing confinement to the column. As the number of layers of CFRP increase the strength of the column increased by 20-25 percent per layer increased in wrapping. The strengthening scheme showed the best results considering all parameters such as strength, ductility, toughness and compressive strength. A better understanding of the structural behavior of FRP fitted structures along with their failure mechanisms, which are often brittle in nature through experimental and numerical simulation, is necessary.

Further, Drishya Babu and Rajesh A.K [13] studied the comparison of strengths obtained when glass fiber mixed with concrete as well as the glass fiber wrapping with the concrete columns to the results obtained from the analysis using ANSYS software. The analysis is based on the behavior of the GFRP wrapped concrete columns under uniaxial compression. Also consider the compressive strength for the study. With increase in the percentage of glass fiber the characteristic compressive strength of glass fiber also increased. The characteristic strength can be varied with the amount of glass fiber add to concrete mix. Addition of glass fibers does not affect the workability of concrete. The experimental results as well as the analytical results are almost same in sense. Compressive strength of wrapped cylinders is higher than that of the cylinders without wrapping. By comparing results from both experimental and analytical methods the variation was very less and it is negligible.

Similarly, Gad Vikas V *et al*. [14] presented the useful data about the preparation and testing of different structural model like cubes, Beams and Columns. Compression test, tensile test, and flexural test are performed. The compressive strength of the carbon fiber sheet is 8% higher compared to the unwrapped cubes. The tensile strength of carbon fiber wrap to column is 55% more as compared to unlamented column. The flexural strength of carbon fiber wrap made to beam is 55% more as compared to unlamented beam. Carbon fiber wrap improves tensile strength and flexural strength over compressive strength. Further study should be carried out to check the use of carbon fiber as partial replacement for steel. Further, Bhagyashri D Sangai and Ankush R Pendhari [15] studied cubes retrofitted with glass fiber reinforced polymer. In this study concrete with an average strength of 20 MPa is used. The experimental study is carried out on a short column with the specimen of sizes 100 x 100 x300 mm and 100 x 150 x 300 mm with aspect ratio of 1 and 1.5 respectively. The specimens were singly and doubly wrapped with glass fiber. The experimental results clearly conclude that GFRP wrapping can improve the strength of concrete columns under axial loading. Confinement by GFRP enhances the performance of rectangular concrete columns. GFRP wrapping is more effective for aspect ratio 1 than aspect ratio 1.5, i.e., for M20 grade of concrete, percentage increased in strength are 43.4% and 39.8% respectively for column with single layer of GFRP. Compressive Strength of the Concrete Columns increases with increase in the number of layers of GFRP. For M20 grade of concrete, percentage increase in strength from single layer to double layer of GFRP are 24.4% and 24.19% for aspect ratio 1 and 1.5 respectively.

R. Sudhakar and P. Partheeba [16] studied the improvement of axial compressive strength of RCC columns retrofitted by GFRP system that oriented in the direction of the applied axial load. A reinforced concrete column was designed and modeled under axial loading. The axial crushing strength of the RCC column wrapped with single-layer GFRP increased by 15.31% compared to the control column. Increase of axial compressive strength in double layered GFRP wrapped column is 31.35% compare with control column. The decrease in deflection was 53.5% for the single-layer GFRP-wrapped column and 64.68% for the double-layered GFRP-wrapped column compared to the control column. Santosh Kumar Behera *et al*. [17] presented general review, method to increase the inherent strength of the ribs are proposed by CFRP and GFRP wrapping. The rib strength is greatly increased, thus avoiding stability problems during depillaring and avoiding surface subsidence. untreated cylindrical coal samples and cylindrical coal samples wrapped with Carbon Fiber Reinforced Polymer single layer (CFRP-1), Carbon Fiber Reinforced Polymer double layer (CFRP-2), Glass Fiber Reinforced Polymer single layer (GFRP-1), Glass Fiber Reinforced Polymer double layer (GFRP-2) it is found that overall, 2 to 3 times strength increases. Also, as per numerical analysis, after externally strengthening the rib pillars, deformation of roof has been reduced considerably and an increased factor of safety is observed.

The effect of high temperature on the performance of concrete externally confined with FRP sheets is presented by Mahesh Kumar M *et al*. [18]. For M25 grade of concrete the rate of increase in compressive strength was 67%, 129%, 150% respectively for 1,2,3 layers of GFRP wrapped concrete when compared to conventional concrete. due temperature effect (at 2000c), For M25 grade of concrete the rate of increase in compressive strength was 74%, 157%, 185% respectively for 1, 2, 3 layers of GFRP wrapped concrete when compared to conventional concrete. The rate of decrease in compressive strength at 2000c was 21%, 15%, 8%, 6% respectively for 0, 1, 2, 3 layers of GFRP wrapped concrete when compared to the test which has been carried out in normal room temperature. K. P. Jaya and Jessy Mathai [19] studied the behavior of beam-column wrapped with GFRP and CFRP. One specimen without FRP wrapping, three specimens with 2, 4 and 6 layers of GFRP and two specimens with one layer of CFRP were tested. The column specimens wrapped with two layers, four layers and six layers of GFRP shows 8%, 28% and 32% increase in the load carrying capacity respectively compared to the specimen without wrapping. The specimens wrapping with CFRP have an average of 98.3% increase in the strength capacity compared to the specimen without CFRP wrapping.

Further, A. Belouara *et al*. [20] presented the axial compression behavior of square RC columns confined externally with CFRP. Increasing the amount of CFRP sheets increases the compressive strength of the confined column, but the percentage is low compared to its deformation capacity which almost proportional to the CFRP strengthening ratio. The CFRP confined on low-strength concrete specimens produced higher results in terms of strength and strains than for high-strength concrete similar specimens. Therefore, the effect of CFRP confinement on the bearing and deformation capacities decreases with increasing concrete strength. The results clearly show that the composite wrapping can improve the structural performance of square RC columns in terms of maximum ductility and strength. The effects of test parameters are evidenced and compared.

Similarly, J. M. Lees *et al*. [21] presented the feasibility of using non-laminated carbon fiber reinforced polymer (CFRP) straps as external post-tensioned shear reinforcement in concrete. Experiment carried out an unstrengthen control beam and beam strengthened with external CFRP straps. A concrete beam strengthened with CFRP straps have significantly improved load-bearing capacity compared to unstrengthen beam. The presence of the straps appeared to increase the crack angle, resulting in a much stiffer structure than the corresponding unstrengthen members. Further work is needed to study the effects of load arrangement, prestress level and strap arrangement on the behavior of strengthened beams. Further, S.A. Rasal *et al*. [22] studied the recycled aggregates recovered from concrete specimen produce good quality concrete. The workability and strength parameters of prepared concrete samples with different aggregate percentage were experimentally demonstrated. Compressive strength, flexural strength and split tensile strength of prepared concrete samples are analyzed and 25% replacement of natural aggregate with RCA gives satisfactory results as of fresh concrete. When the recycled aggregates were used in the ratio of 50:50 to the fresh aggregates, the results were far lower than that got by using 100% fresh aggregates. When the recycled aggregates were used in the ratio of 25:75 to the fresh aggregates, the results were nearby to that we got by using 100% fresh aggregates. Further, Aniket Mestri *et al*. [23] They have studied the concrete mix of M35 grade was designed and assembled by replacing Granulated Blast Furnace Slag (GBFS) partly with fine aggregate and Bagasse Ash (BA) in part with cement. Mixing ratios were made with different percentages of bagasse ash, including a control mixture of GBFS. Bagasse ash in concrete was replaced with 0%, 5% and 10% with cement by weight and GBFS in concrete was replaced with 0%, 10%, 20%, 30% and 40% with fine aggregate by weight. Various strengths are considered in the study, including compression, flexural and split tensile tests. Based on these findings it can be stated that the partial replacement of cement with BA and partial replacement of fine aggregate with GBFS improve the compressive strength as well as split tensile strength of the concrete.

III. SUMMARY AND CONCLUSION

On perusal of literature, in the various study it has been observed that different types of materials have been used for strengthening of concrete such as steel jacketing (reinforcement jacketing), angle jacketing, high density polyethylene (HDPE) tube, unplasticized polyvinyl chloride (UPVC), polyvinyl chloride (PVC), CFRP, GFRP.

- Most of the researchers has been concentrated on CFRP and GFRP, as they are superior to conventional methods of retrofitting.
- CFRP and GFRP used for retrofitting purpose because of its post ductility, cross sectional area, weight, corrosion resistance, and easy in application.

- CFRP and GFRP is highly effective in structural strengthening work to upgrade member capacity to carry a new heavy load.
- It is also helpful in seismic upgrade of building and has shown fantastic result in its performance.
- CFRP and GFRP have higher compressive, shear and tensile strength than steel.

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