Retrofitting of Reinforced Concrete beams using CFRP Sheets: A Review

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Abstract - *Reinforced concrete (RC) structures are the most functional constructions. RC is a composite material in which low ductility and tensile strength of concrete are frustrated by the formation of reinforcement having higher ductility and tensile strength. Faults exist in the design or construction of the structures, after the lifetime of RC structures and accidents such as earthquakes may lead the structure to be replaced. The complete replacement will be an immense financial concern and absolutely there will be the misuse of natural resources when retrofitting is a better appropriate option. Retrofitting is the process of adding new technology, elements, and features to the old structures. The need for retrofitting of structures arises under two conditions: (i) when the structures need to be used for occasion dealing with additional load contrast to design load and (ii) when old structures are required to be upgraded. This review paper elaborates fiber reinforced polymer (FRP) materials and techniques using for retrofitting of RC beams in the buildings. This paper also focused on the strengthening of RC Haunched Beams (RCHBs) using Carbon FRP (CFRP) and Glass FRP (GFRP) strips. Moreover, the behavior of CFRP and GFRP laminates in the retrofitting of RC beams exposed to elevated temperature has been also explored. The efficiency of different types of FRP materials and techniques has also been taken into account.*

Key Words: fiber-reinforced polymer, Reinforced concrete beam, Retrofitting, Strengthening, Corrosion, Enhance structural performance, Bond behavior.

1. INTRODUCTION

With the development of civil infrastructures in the world, the number of collapse structures is also increasing. There are numerous structures, which are not able to abide by the loads and accomplish the stated requirement. This deficiency may be due to fault exist in the design or construction, upgrading of design codes in later years, use of the building has changed through the year, reinforcement bars' corrosion, and hazards like earthquakes. To redress the deficient capacity, the structure requires to be restored or retrofitted. Complete building renovation is costly and this will contribute to the loss of natural resources that can preserved or used for other functions. This is why it is very important to upgrade or strengthen various structural elements. Retrofitting is the process of adding new technology, elements, and feature to the old structures [1].

Various types of strengthening materials and techniques have been developed and used in practice. Examples of these materials are steel plates, ferrocement, FRP composites. Both bonding external steel plates and FRP composites are effective methods in Retrofitting of RC structures for enhancing the structural performance under ultimate load situation.

FRP has flatter imperceptibly attractive compared to steel plates as FRP are compound materials which manufactured of a polymer matrix reinforced with fibers manifest numerous outstanding mechanical characteristics like superior strength stiffness to weight ratio, corrosion resistance, tensile strength, durability, lightweight, ease of handling, lower maintenance costs and faster installation time. Fibers that reinforce the matrix are mostly carbon, glass, or aramid and the polymer is mostly impregnation resin or an epoxy, polyester, or vinylester. And FRP materials have three types which are carbon fiber reinforced polymer (CFRP), glass fiber reinforced polymer (GFRP), and the most less use FRP which is aramid fiber-reinforced polymer. Furthermore, in FRP materials, may bear structure failure when (i) tensile forces stretch the matrix beyond the fibers, which result the material to shear at the matrix-fiber interface (ii) at the end of the fibers, the tensile forces surpass the matrix tolerances, detach the fibers from just the matrix and (iii) the tensile forces may also excees the tolerances of the fibers that cause the fibers to fracture themselves, resulting in FRP failure [2]. Beams which are important structural elements should have sufficient safety amount against shear and bending stresses so that for most of its life span it will perform effectively. Usually, beams are retrofitted for flexure or shear strengthening. The search for new retrofitting methods and techniques is ongoing, although it is found that a number of materials and methods are effective when experimented

There are two modes of failure which are bending or shear failure of RC beams. The beam provides ample warning in the form of cracks and large deflection in the case of flexural failure mode. Yet in case of beams with little shear reinforcement, brittle shear failure mode takes place.

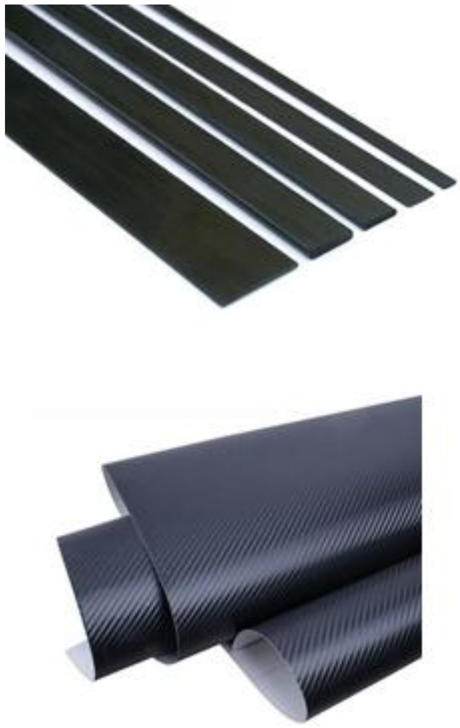

Fig -1: FRP sheets [3]

RC beams in a structure retrofitted by externally attached fiber-reinforced polymer (FRP) that have proved to be intensely worthwhile, refit and enhance the flexure and shear capacities of the beam to the desired degree [4]. Table 1 presents the properties of FRP fabrics that are used in the construction industry.

Table -1: FRP sheet properties

FRP	CFRP	GFRP
Tensile strength (Mpa)	2400-5100	300-4800
Young's Modulus (Gpa)	70-90	390−760
Strain failure (%)	0.5-1.73	3.5-5.5
Density (gm/cm^2)	1.85−1.9	2.5-2.6

2. Literature Review

Complete-wrapping of RC beams using CFRP Laminates give excellent performance in shear and particularly enhance the ductility, as compared to U-wrapped beams. Also strain capacity of complete-wrapped beams is more than U-wrapped beams. From the perspective of failure mode completely wrapped beams' failure mode is CFRP rupture but U-wrapped beams go for sudden debonding of CFRP laminates [5]. On the other hand, by employing the externally bonded CFRP laminates, the ultimate load gets an increase. For retrofitting in flexure resistance, the increase in the ultimate load of the retrofitted beams reached between 7% and 33%. Moreover, the crack width of retrofitted beams gets decreases as compared to control beams. In flexure retrofitting, with increasing the CFRP plate, it makes the CFRP more efficient for concrete repair and strengthening. Furthermore, the stiffness of beams retrofitted with CFRP laminates is increased compared to the control beams [1]. Beams retrofitted with uni-directional and bi-directional CFRP sheets increase the ultimate load capacity by 93% and 120% respectively as compared to control RC beams [6]. As using FRP composites results in reduced deflection ductility of RC beams, but FRP retrofitting is exceedingly effective in increasing the flexural capacity of RC beams. With the increasing of longitudinal steel ratio of RC beams, their deflection ductility decreases and the effectiveness of FRP composites get reduce in RC beams' flexure capacity. For retrofitted beams with FRP end U-wraps, the FRP composites are effective in enhancing the flexure capacity up to , after which FRP composites are inefficient. The term (as) is equal to $\rho_f(E_f/f'_c)^{0.5}$ called the stiffness parameter, where $E_f =$ tensile modulus of FRP laminates; f'c specified compressive strength of concrete; and *pf* is the FRP reinforcement ratio [4].

RC beams strengthened with externally bonded CFRP strips are worthwhile technology to reduce cracking and increase the load-bearing capacity of RC beams, even beams are made of poor quality concrete. Different beams having different steel grade main reinforcement and strengthened with CFRP strips get failed as a result of the intermediate crack. And ultimate forces are more dependent on the main reinforcement properties. Furthermore, with the higher yield point of reinforcement, there will be a higher strain in the CFRP strips [7]. On the other hand, the amount of increase in shear load capacity of reinforced concrete Haunched Beams (RCHBs) retrofitted by CFRP strips varies with respect to the type of RCHBs and the retrofitting strategy. Regarding ultimate load capacity, vertical wrapping of CFRP strips is more effective than inclined wrapping. And failure modes RHCBs retrofitted by CFRP strips are debonding of strips [8].

CFRP retrofitting generates a superior improvement in beams' capacity which is heated at 400 centigrade for two hours. Moreover, CFRP retrofitting refit and enhance the capacity of high strength concrete beam (HSC) bear 600 centigrade heat, by 45% more than that of the HSC unheated control beam [9]. Besides, in the domain of blast retrofitting of RC beams that much attention has not been taken as compared to columns, slabs, and walls. An explicitly experimental study shows that simply supported RC beams retrofitted with CFRP and GFRP laminates could withstand the explosion of 110 kg of ANFO while the non-strengthened control specimen failed in shear [10].

Retrofitting of RC beams using externally bonded CFRP rod panels increase the strength by 95% as compare to non-retrofitted control beam, and failed by concrete cover separation at CFRP rod panel end. With the end-anchored of CFRP rod panel, the strength increases to 195% relative to the control beam, and the failure mode changed to intermediate crack induced debonding. [11]. Furthermore, CFRP straps improve the shear strength of RC beam and make complex contribute with steel stirrups, against the shear resistance. Using CFRP straps avoid the existence of debonding failure. With the using of CFRP straps in the form of anchorage of the CFRP sheet, the increase in flexural strength will be 95%. However, using CFRP sheets alone, an increment of only 15% will be achieved. The failure mode of RC beams with straps is a ductile flexural failure with exorbitant yielding of internal steel. [12]

The torsional moment capacity of RC beams retrofitted with CFRP and GFRP fabrics increases 101.8% and 83.49% respectively with respect to the control beam. From the comparison of CFRP bonded RC beam with GFRP bonded RC beam it has been found out that CFRP fabrics have maximum torsional strength, largest angle of twist, and high ductility factor than GFRP fabrics. The fully U-wrapped configuration of retrofitting by both CFRP and GFRP fabrics is more efficient in torsional strength. The failure mode of CFRP and GFRP fabrics may be due to the debonding of CFRP and GFRP fabrics or crushing of concrete [13].

On the benefaction of FRP to shear resistance. The resistance achieved due to FRP decreases with increasing the depth of the beam. The shear strengthening of FRP retrofitted beams with no transverse steel is affected by the beam size. In conflict with, the FRP retrofitted beams having transverse steel are only barely affected by the size of the beam. Moreover, the benefaction of FRP to the shear resistance of a beam with transverse steel is not so much, in contrast to with equivalent beam having no transverse steel [14].

Using hybrid FRP is efficient in enhancing the ultimate strength and stiffness of a strengthened beam. Different types of FRP affects the characteristics of RC beams retrofitted with hybrid FRP. The beams retrofitted with GFRP show the most improved strength and ductility as compared to the beam retrofitted with CFRP. Strengthened RC beams fail before hybrid FRP sheets reach failure point. This restricts the retrofitting effect of hybrid FRP [15].

CFRP laminate in the scheme of U-wrapped is effective in increasing the strength of corroded RC beams. Such that it increases the level of corrosion from any condition of corrosion (loss up to 31% of the mass of steel) to the levels greater than the strength of the control uncorroded beam. Relative to that of corroded and unrepaired RC beams, CFRP laminates reduce the deflection capacity [16].

For increasing the shear and flexure capacity of RC beams, Near-surface mounted (NSM) FRP rods is a promising technology and a worthwhile technique. It increases the shear capacity of the beam having no steel stirrups to 106% with respect to the control beam. But in the presence of steel stirrups, an increase is up to 35% with respect to the control beam. The failure mode of RC beams, strengthened with NSM FRP is debonding of one or more FRP rods due to the rupture of epoxy cover. By providing a larger bond length with either using 45-degree rods at adequate close spacing or anchoring the NSM rods in flange of the beam the NSP FRP debonding can be prevented [17].

A beam that have become weak due to corrosion can be strengthened with superior amount by GFRP. The load carrying capacity of corroded and corroded GFRP retrofitted beam was 71 % and 102 % of the control beam respectively. The service gain factor of corroded retrofitted beam is 2 % of control beam [18]. Corroded beams give less stiffness. Although, strength of corroded beam was strengthen to the no corrosion state by CFRP sheets. The positions and schemes of CFRP sheets is much important than the quantity of CFRP sheet in the retrofitting of corroded beam. And the U-shaped straps are highly successful in those beam which has high quantity of corrosion [19].

3. CONCLUSIONS

Extension of the structures' life is an inevitable need for a healthy planet. It could be facilitated by the retrofitting of the structures. And from this literature review, it has been observed that retrofitting of RC beams using FRP is an effective method and has flatter imperceptibly attractive compared to other techniques of retrofitting. FRP composites strengthen the RC beam in both flexure and shear. Compare to other orientations of wrappings, U-wrapping of RC beam using CFRP laminate gives excellent performance in both shear and flexure after complete-wrapping technique. As complete-wrapping is practically not possible. Moreover, the flexural strength of RC beams retrofitted with CFRP or GFRP laminates have contrary relation with tension and compression steel ratio of RC beams. Because using FRP laminates results in decreasing of deflection ductility of RC beams. However, CFRP strips which are a worthwhile technology concord with the steel grade of main reinforcement, whereas the higher strain in the CFRP strips achieved with the higher yield point of reinforcement. Furthermore, RC beams retrofitted with CFRP generate a superior improvement against elevated temperature. And an explicitly experimental study shows that simply supported RC beams retrofitted with FRP laminates could withstand with explosion of 110.6 kg of ANFO. Along with shear and flexure, FRP material gives torsional strengthening also. FRP fabrics increases the torsional moment capacity to a desired degree. Moreover, RC beams bonded with CFRP fabrics have maximum torsional strength, largest twisting angle, and high ductility factor than RC beams bonded with GFRP fabrics. The layout of CFRP sheet is very effective rather than much use of use of CFRP sheet in case of corroded beam.

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