Fiber Reinforced Polymer (FRP) as Reinforcing Material: An Overview

Zishan Raza khan, Faheemuz Zafar, Sabih Ahmad, Md. Sarfaraz Ali

Abstract— **Corrosion of steel reinforcement is a very big problem especially in coastal areas. The increase volume of steel bar leads to deterioration of concrete structure that has led to need for alternative type of reinforcement such as Fibre Reinforced Polymer (FRP). The use of Fibre Reinforced Polymer (FRP) in civil engineering practice is increasing day by day. FRP bars offer many advantages over conventional steel bars, including a density of one-quarter to one-fifth that of steel, greater tensile strength than steel, and no corrosion even in harsh chemical environments. Many researchers and practitioners have demonstrated potential of its application in various civil engineering aspects, such as retrofitting and internal reinforcement.**

Keywords: Ductility, Fiber reinforced polymer (FRP), Flexure, Shear

I. INTRODUCTION

The corrosion problem of steel bar is the major factor in limiting the life period of RC structures. Many environmental conditions such as use of de-icing salts, moisture, chemical products, and marine conditions accselerate the corrosion process of steel bar that ultimately decreases the life of these structures. FRP reinforcement is made from high strength fibres such as glass, aramid and carbon produced in variety of shapes due its flexibility. FRP bars may offer many advantages over conventional steel bars, including a density of one-quarter to one-fifth that of steel, greater tensile strength than steel, and no corrosion even in harsh chemical environments (El-Salakawy et al. 2003; Benmokrane et al. 2006, 2007) [3], [4]. The purpose of this paper is to introduce wide application of FRP in civil engineering.

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Zishan Raza Khan pursuing PhD from UPTU. Presently working as associate professor in Department of Civil Engineering at Integral University, Lucknow. He has authored numerous papers in National/International Journal.

Faheemuz Zafar is currently pursuing M.Tech in Structural Engineering from Integral University, Lucknow. He has authored a paper in National Conference

Sabih Ahmad pursuing PhD from Integral University. Presently working as associate professor in Department of Civil Engineering at Integral University, Lucknow. He has authored numerous papers in National/International Journal

Table 2: Usual mechanical properties of reinforcing bars [1]

Properties	Steel	GFRP	CFRP	AFRP
Nominal yield stress (MPa)	276 -517	N/A	N/A	N/A
Tensile strength(MPa)	483 -690	483 -1600	600 -3690	1750 -2540
Elastic Modulus(Gpa)	200	35 -51	120 -580	41 -125
Yield strain (%)	0.14 -.25	N/A	N/A	N/A
Rupture strain (%)	6 -12	1.2 -3.1	0.5 -1.7	1.9 -4.4

II. STRUCTURAL PERFORMANCE OF FRP

Based on various researchers, it is observed that CFRP reinforcement can be used as longitudinal and lateral reinforcement. It enhances confinement efficiency and ductility. In case of individual straight bar, tie, there should be tight bond between lateral and longitudinal reinforcement. It can be an alternative to the conventional reinforcing material steel to have better result considering other advantages like noncorrosive, light weight and high strength with only drawback as brittle material.

A. Flexural Behaviour

Experimental data on FRP reinforced concrete members show that flexural capacity can be calculated based on assumptions similar to assumptions made for members reinforced with steel bars (Faza and GangaRao 1993a; GangaRao and Vijay 1997a)[7][15]. Iman and fellows[8] observed flexure behaviour of beams reinforced with FRP and compare the results with ACI code provisions 10 specimens were taken and casted with fix diameter of FRP bars and Length but different width and depth. Flexure behaviour of RC beam reinforced with GFRP bars, ultimate moment capacity, deflection, first crack are identified under loading. Results taken from the experimental tests have been compared with ACI 440 and they show that deflections, width of cracks and the cracks extent are further used toward the usual RC beams**.** In addition, it can be said that the amount of the balanced bar provided by ACI 400 is not an exact criteria to determine the type of failure, and it is only in cases where the ratio of bars are lower than the balanced mode that ruptures occur in reinforcement area

Fig.: *Flexural failure of specimen*

B. Compressive Behaviour

The behaviour of FRP bars in compression members is a relevant issue that still needs to be addressed. The compressive strength of GFRP bars was found to be 55% lower than the tensile strength by (Mallick 1988 and Wu 1990) [12].FRP as compression reinforcement is not detrimental for column performance and may be allowed when design is for only vertical loads even though the FRP contribution to compressive strength should be neglected in the computation of the ultimate axial load capacity (Luca et al 2009)[5]. Alsayed et al. (1999)[4] investigated the effect of replacing longitudinal and lateral steel reinforcing bars by an equal amount of GFRP bars. Based on the results of tests performed on small-scale columns under concentric loads, it was reported that replacing longitudinal steel reinforcing bars with GFRP bars reduced the axial capacity of the columns by on average 13%. It was observed that, irrespective of the type of longitudinal bars, replacing steel ties with GFRP ties reduced the axial capacity of the column by about 10%. Seffo et al (2012) [11] study the behavior of concrete cylinders externally wrapped with carbon fiber-reinforced polymer (CFRP). They observed that the percentage increase in compressive strength and ductility was more for normal strength concrete than that in high-strength concrete

C. Shear Behaviour

Stirrups used for shear reinforcement are normally located as an outer reinforcement with respect to the flexural reinforcement and therefore are prone to severe environmental effects due to the minimum concrete cover provided. In some cases, stirrups are even exposed from the beam surface to provide composite action with the slab which is normally cast at a later stage, during this period corrosion could be serious. Ahmed Khalifa et al[3] study the shear performance and the modes of failure of reinforced concrete beams strengthened with externally bonded carbon fiber reinforced polymer (CFRP) wraps. They foud that the contribution of externally bonded CFRP to the shear capacity is significant; results show that an increase in shear strength of 22 to 145% was achieved. Ehab Abdul Majeed Ahmed[6] investigates shear behaviour of concrete beam reinforced with shear stirrup. Seven large-scale T-beams were tested with FRP and steel stirrup. Three beams reinforced with FRP stirrups, three with GFRP stirrups and one with steel stirrups. Beams were tested in four points bending over a span of 6 meter till failure to investigate the modes of failure and ultimate capacity of stirrups in beam action. Result concludes that six beams failed in shear due to FRP (carbon and glass) stirrup rupture or steel stirrup yielding. Seventh beam, reinforced with CFRP stirrups spaced at *d/4,* failed in flexure due to yielding of the longitudinal reinforcement followed by crushing of concrete

Fig: *Shear failure of test specimen (E.A. Ahmed et al 2008) [6]*

D. Ductile Behaviour

Jaya et al (2012) [10] study the behaviour of conc. beam-column with and without GFRP and CFRP wrapping subjected to reverse cyclic loading. Result showed a significant increase of ductility and energy absorption capacity of RC beam-column strengthened with CFRP and GFRRP jacket. CFRP gives better load carrying capacity while GFRP provide good ductility in comparison to each other. Afifi et al (2013) [13] examines the circular concrete column reinforced with CFRP bars and spiral. They found that the effect of CFRP spiral spacing on confinement efficiency and ductility was much more pronounced than on strength capacity. Confinement efficiency of the concrete core can be improved by using smaller size CFRP spirals with closer spacing than by using larger diameter spirals with larger spacing. The CFRP specimens with closer spacing and smaller diameters showed ductile behaviour.

Material is in investigation level and extensive research is going on worldwide. Previous researches indicate that tie spacing plays a relevant role in ductility and confinement. Authors have recommended small spacing to avoid brittle failure; therefore further work is required on spacing and size of tie bar.

III. DURABILITY

The degradation of polymer upon exposure to adverse conditions depends on the presence of additives, and the presence of contaminants and fiber/ matrix interface damage. Glass Fiber Reinforced Polymer (GFRP) materials are sensitive to salt water. On the other hand CFRP materials are immune to attack by salt water and therefore well suited to marine structure. Jansen et al [9] exposed CFRP composite to salt water at elevated temperatures with no changes in strength and modulus of composites. Pando et al [14] stressed that the mechanics of strength and stiffness loss considered are related to moisture absorption, fiber/matrix interface damage. The absorbed moisture can act as a plasticizer of the resin, and can cause matrix cracking and Fiber-matrix debonding.

IV. FIRE ENDURANCE

The use of FRP reinforcement is not recommended for structures in which fire resistance is essential to maintain structural integrity. Because FRP reinforcement is embedded in concrete, the reinforcement cannot burn due to a lack of oxygen; however, the polymers will soften due to the excessive heat.

A. Abbasi [2] and fellows observed the behaviour of glass fiber reinforced polymer (GFRP) rebar reinforced concrete beams when exposed to fire. The beams were designed and constructed as per Euro code 2 and ACI-440 guideline. Thermo set resin GFRP rebars were used for reinforcing beam 1 and GFRP rebars with thermoplastic resin were used for reinforcing beam 2. Shear reinforcement for beam 1 was GFRP stirrups and for beam 2 steel stirrups were used. Degradation in the flexural capacity due to fire was evaluated and compared. Also the fire resistance of the GFRP reinforced concrete (RC) beams has been observed. Result indicates that the average temperature at the end of heating for bottom reinforcement in beam 1 was 462 °C and for beam 2 was 377 °C. The heating time for beam 1 was 143 min with maximum central deflection of 185 mm and the heating time for beam 2 was 104 min with maximum central deflection of 157.5 mm. The fire resistance rating (load bearing capacity) for beam 1 was 128 min and for beam 2 was 94 min. Fire tests results show that concrete beams reinforced with GFRP rebar will meet the fire design requirements for the minimum periods of fire resistance (fire endurance) for the load.

CONCLUSION

It is evident from reviews that a large number of works has been done on material properties and structural performance of such material. Specimens internally reinforced with GFRP bars behaved very similar to the conventional steel reinforced one. Based on the review, it can be concluded that use of FRP as compression reinforcement is not detrimental for column performance, therefore needs further studies. Long term durability under different conditions is also a major concern and therefore needs significant studies.

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