GFRP AS INTERNAL REINFORCEMENT IN RC BEAMS

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Abstract

This paper presents an assessment of the bond between GFRP bars and concrete, investigated through a set of centric and eccentric pull-out specimens. Unlike steel reinforcement, GFRP materials have different properties, which may result in different force transfer mechanism between GFRP reinforcement and concrete. The structural performance of concrete structures reinforced using glass-fiber-reinforced-polymer (GFRP) rebars is sometimes compromised by debonding failure. For pull-out specimens, GFRP, as well as steel rebars with a constant embedment length of five times the bar diameter, were used. Main parameters under investigation are bar diameter, concrete mechanical properties, and concrete cover. Eccentric tests showed the possibility of a proper prediction of the bonding behavior of structural components.

Keywords: *Bond, Cover, Eccentric, GFRP bar, Pullout, RC.*

1. Introduction

Steel rebar has been used for its effectiveness and cost efficiency for years now. The main problem with steel bars is corrosion which reduces its strength. In a tropical country like India, where approximately 80% of the annual rainfall takes place in two monsoon months, rusting related problems are very common, especially in residential and industrial structures. The spalling reduces the effective thickness of concrete. This could be extremely dangerous for constructions such as nuclear reactor containment structure, chemical tanks, mine construction, etc. Recently composite materials made by embedment of fiber in a polymeric resin also known as fiber reinforced polymers FRP have to emerge as an alternative to steel reinforcement for concrete structures. Because of nonmagnetic and non-corrosive properties of FRP materials, the problems of electromagnetic interference and steel corrosion can be avoided. Additionally, FRP materials high tensile strength makes them suitable for use as structural reinforcement. The behavior of FRP reinforcement differs from the behavior of steel reinforcement.
A Rolland et.al (2018) performed Pull-out tests on glass, carbon, and aramid FRP rebars, as well as on deformed steel rebars. They studied the influence of bar size, fiber type and surface geometry on bond behavior. They found that the sand coating plays a major role in bond. The sand coating of GLASS-S was found to provide higher bond performances compared to that of CARBO-S series or ARA-S series.

M Baena et.al (2009) they prepared 88 concrete pull-out specimens according to ACI 440.3R-04 and CSA S806-02 standards, they used CFRP and GFRP and steel rebars, with a constant embedment length of five times the rebar diameter. They analyzed the influence of the rebar surface, diameter and concrete strength on the bond–slip curves. and found that Increase in bond strength and changes in failure mode and failure surface are observed when changing concrete compressive strength.

M. Rezazadeh et.al (2017) prepared numerical models predicting the bond behavior of GFRP rebar and concrete two damage-based approaches were presented for GFRP rebar bond damage evolution. his Results of FE modeling matched well with corresponding experimental measurements.

Ana Veljkovic et.al (2017) investigated bond behavior between GFRP bars and concrete through a set of centric and eccentric pull-out specimens. Main parameters under investigation are bar external surface, concrete mechanical properties, and concrete cover. They found that increasing concrete mechanical properties always enhance bond strength and delayed cracking of concrete cover. Ribbed GFRP bars showed excellent bonding performance when combined with a low concrete cover.

All the above mentioned and some other works show plenty of work done on bond behavior, but there are still some unsolved issues. Various types of FRP bars are in the market, differing in many aspects, so it is difficult to deliver global conclusions since each product has its own particular characteristics. Gathering more data about the behavior of different bar types helps in understanding this reinforcement. In this context, the present experimental investigation intends to give a contribution to the influence of some parameters affecting the bond between GFRP bar and concrete. This research aims to contribute to the present data available for the bond behavior of GFRP material within variable parameters.

1.1 GFRP Reinforcement

FRP products are composite materials consisting of a matrix (resin) and reinforcing fibers. As shown in Fig 1the fibers are stronger than the matrix. The mechanical properties of the final FRP product depend on the fiber quality, orientation, shape, volumetric ratio, adhesion to the matrix, and on the manufacturing process.

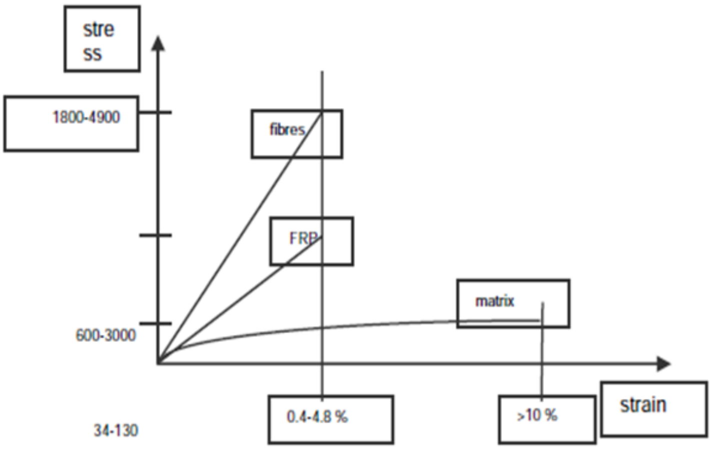

Fig.1 Stress-strain relationships for fibrous reinforcement and matrix [6].

1.2 Manufacturing Process

Pultrusion is the technique used for manufacturing continuous lengths of FRP bars that are of nearly constant profile. A schematic representation of this technique is shown in Fig 2. Continuous strands of reinforcing material are drawn from creels, through a resin tank, where they are saturated with resin, and then through a number of wiper rings into the mouth of a heated die. The speed of pulling through the die is calculated by the curing time needed. To ensure a good bond with concrete, the surface of the bars is usually braided or sand-coated.

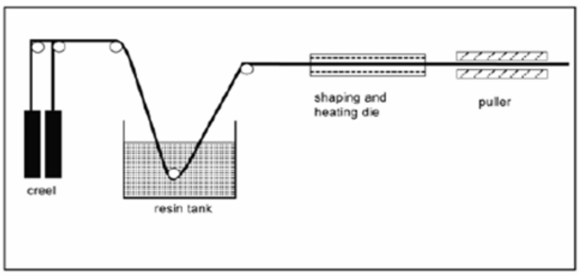

Fig.2 Pultrusion process [6]

2. MATERIAL AND METHODS

2.1 Concrete mix proportions for m30 grade concrete

Mix design is done using Indian Standard method (IS: 10262 - 2009) for the grade of concrete and the proportions for the mix are shown below.
For Concrete mix design of grade M30
Cement = 340 kg/m3
Fly ash = 60 kg/ m3
Water = 190 kg/ m3
Fine aggregates = 810 kg/ m3
Coarse aggregate = 1112 kg/ m3
Water-cement ratio = 0.475

2.2 GFRP rebars

As shown in fig.1 Glass Fiber Reinforced Polymer bars having with a helical wrapping surface the manufacturing involves a combination of pultrusion and wrapping processes. The external surface of the bars has a spiral yarn wound along the length (pitch close to the nominal diameter) to increase the bond to concrete. The bars having the properties as

Manufacturer- ASLAN
Density- 2100 kg/m3
Modulus of elasticity- 45 Gpa
Ultimate strength- >750Mpa
Ultimate shear strength- >150
Ultimate strain- 2.5%

Fig. 3 GFRP Rebars

The bars considered in the investigation had nominal diameter 8mm and 12mm.

2.3 Method

The pull-out tests were performed according to 2770-1967 standards. A 150 mm cubic mould was used to manufacture the pull-out specimens. The embedment length of the bars (lb = 5db) was properly marked and the bars were placed at the bottom of the concrete cube reinforcing bar embedded vertically along a central axis in each specimen. The concrete was poured with the FRP rebars in position inside the mould, in the middle of the specimen. After moulding, the specimens were transferred to a curing room for 24 h. Thereafter, the concrete cubes were de-moulded, marked and transferred again to the curing room at room temperature. Specimens were tested using a universal testing machine. The influence of 1) bar diameter 2) concrete mechanical properties and 3) concrete cover was investigated.

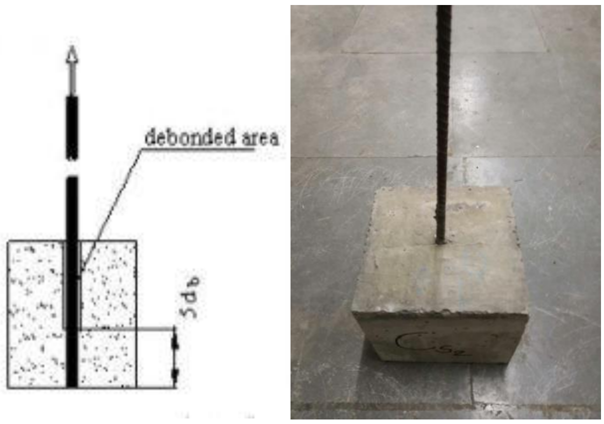

Fig. 4 Pull-out specimen

2.4 Experimental setup

Specimens were tested for pull-out using the universal testing machine. As shown in fig 5 the cube specimen was inserted from the upper arm of the machine and the bar is gripped by the middle arm. The bar was gripped for a length of 15cm for ensuring a firm grip, and then the load was applied at a gradual increment of nearly 2250kg/min. the maximum load was measured before the load started rolling back the slip of the bar was also measured at the maximum load. After a slip of 2.5mm occurred the specimens were unloaded and removed.
The details of specimens casted are given in table no 1. Each type of sample 3 no of specimens in it and there are 4 types of variations.

Fig 5 Universal testing machine

Table 1 Detail of specimens used for the pull-out test

Type	Designation	Concrete grade	Bar dia.	Bar Material	Details
Type I) For grade of concrete effect	Cs20-8	M20	8mmø	Steel	
	Cg20-8	M20	8mmø	GFRP	
	Cs30-8	M30	8mmø	Steel	
	Cg30-8	M30	8mmø	GFRP	
Type II) For Dia of bar effect	Cs30-12	M20	12mmø	Steel	
	Cg30-12	M20	12mmø	GFRP	
Type III) For concrete cover effect	Cs30-12-25	M30	12mm	Steel	25mm eccentric cover
	Cg30-12-25	M30	12mmø	GFRP	25mm eccentric cover
	Cs30-12-40	M30	12mmø	Steel	40mm eccentric cover
	Cg30-12-40	M30	12mmø	GFRP	40mm eccentric cover

3. Results and analysis

The influence of concrete strength, bar diameter and concrete cover on the bond behavior is analyzed. As the distribution of stress is not constant along the embedded length of the bar average bond stress is calculated as:

$$\tau = P/\pi.d_b.l_b$$

Where P is tensile load, d_b is the diameter of bar and l_b is embedment length of the bar which is 5 times d_b.

Table 2 Results of pull-out tests

Designation	Failure load (KN)	Bond strength (τ)	Pattern observed
Cs20-8	10.3	10.21	Bar slipped
Cg20-8	6.9	6.86	Bar slipped
Cs30-8	11.3	11.28	Bar slipped
Cg30-8	8.3	8.32	Bar slipped
Cs30-12	30.3	13.40	Bar slipped
Cg30-12	17.9	7.93	Bar slipped
Cs30-12-25	24.2	10.72	Crack in specimen
Cg30-12-25	14.6	6.48	Bar slipped
Cs30-12-40	27.8	12.30	Bar slipped
Cg30-12-40	15.9	7.02	Bar slipped

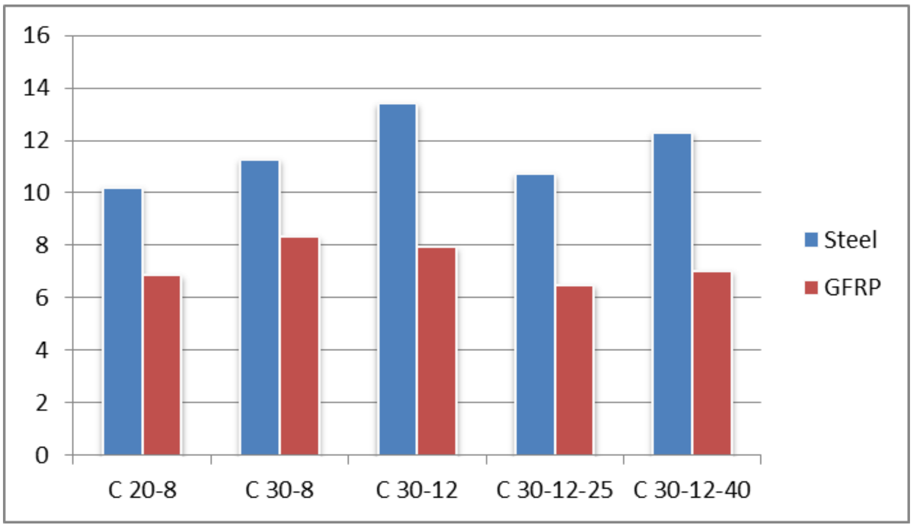

Fig. 6 Summary of the bond strengths (τ) obtained for the various specimens

Nearly all specimens, failure occurred by slipping of the rebar out of the concrete cube, which was the expected pull-out failure mode, Excepts the one specimen where the specimen was failed with a crack in the concrete. All the steel bars exhibit more bond strength than the GFRP bars. For steel bars of 8mm ø and M20 and M30 grade of concrete nearly 33% and 26% of the difference was observed between the bond strength of steel and GFRP rebars.

For M30 grade of concrete with 12mm ø bars a difference of 40% was observed and for both the eccentric samples with 25mm and 40mm cover a difference of 40% was observed.

A difference of 10-20% in results of centric and eccentric tests was observed. The bond strength seems to be increasing with an increase in concrete properties whereas it unexpectedly decreased in case of GFRP rebar when the size of the bar was increased.

Sudden debonding of GFRP rebars was observed during the tests No layer was observed on the surface of FRP rebars the bond failure occurs at the surface of the FRP rebars. These types of bars can also be combined with low concrete cover as they are non-reactive to the environment. And it is also seen from the literature that transverse reinforcement is accepted as an effective solution to increase the bond strength of GFRP bar to concrete.

4. Conclusions

1. Increase in bond strength is seen with an increase in concrete properties.
2. The decrease in the bond strength of GFRP is observed for increasing the size of rebar which is inverse of the steel rebars.
3. Increase in bond strength with increase in concrete cover, which also leads to higher confinement pressure on the bars, reducing the possibility of developing more cracks in the concrete surrounding the bars and therefore delaying the splitting failure.
4. As the bond strength of GFRP is nearly 50% less 1.5 times the development length needs to be provided in beams.
5. Helical wrapping in the bar is contributing to the bond strength at the price of reduced tensile strength.
6. Eccentric pull-out tests show the potential of predicting the proper bond behavior of rebar in structure.

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