BOND PERFORMANCE OF BFRP REBAR IN CONCRETE

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ABSTRACT: Basalt fiber reinforced polymer (BFRP) bars have the benefit of corrosion resistance, high strength, lightweight and having introduced advanced material fluctuate to traditional steel. In these present articles the (BFRP) bonding strength was tested through immerse into the cubic
Concrete specimen. From the accessible previous literatures studies the mechanical properties of (BFRP) concrete structures, stretch the bond-slip performance of(BFRP) rebar, which is a key component impact the service and safety life of concrete structures, has not been clarified yet.

Bond between concrete and reinforcement is a fundamental aspect of the composite action of reinforced concrete. This paper presents factors affecting the bond strength between BFRP reinforcement and concrete, when comparing with steel reinforcement and concrete.

1. INTRODUCTION: FRP (Fiber-reinforced polymer) reinforcement is used in structural construction as steel reinforcement is poor corrosion.

In case of corrosive conditions BFRP rebar are perfectly used as reinforcement in concrete structures. Bond refers to correspondence with traditional steel and the surrounding concrete, which enable conduct of tensile stress from the traditional steel in to the concrete. They are two various types of concrete bonding agent [a] cementitious latex-based [b]epoxy-based. These types of bonding agents are used in different applications similar to repairing, flooring, decorative, and marine Engineering.

Many research studies were done using BFRP and GFRP bars as reinforcement and on bond performance in concrete.

In an investigation, three different size of diameter rebar was tested via 10mm, 12mm&16mm respectively. The ultimate bond stress takes in 10mm size diameter rebar is 69kN, 12 mm size diameter rebar is 88 kN & 16mm size diameter rebar is130kN. The effective cover and concrete grade are same in all specimen, but takes change in diameter only [1].

The Hydrothermal environment destitute pretentious the bond behavior of the CFL-concrete interface. Compared to the reference sample, the maximum load decreased as much as 27.9% when the specimens exposed to the hydrothermal environment of 60°C and 95% RH [2].

The ultimate bond stress and corresponding slip decreased gradually with the increase of corrosion age, and ultimate slip also decreased sharply from10.0mm to 5.2 mm.The ascending segment of bond-slip curve tends to be more rigid and the descending segment tends to be softer after corrosion, and the corrosion has much more significant effect on the bond-slip behavior of large size BFRP bars in concrete [3]

The anchorage length of BFRP rebar increased, the bond strength decreased. The average bond strength of BFRP decreased with the rise of the diameter of rebar. The bond strength of BFRP rebar embedded in 0.1% basalt fiber capacity fraction was superior to those in other fiber capacity fraction concrete [4].

The bond strength was conducted by different parameters similar to[a]diameter of rebar [b]length embedment and[c]environmental conditions. Using GFRP rebar's number of works were carried out on these area [5-10].

The author concluded entire pullout test and the bond strength was measured and reached about 14N/mm^2.The effective cover under the value of [5Db] deploy the failure. The performance of ductile are absorbed [11].

Traditional steel & eccentric bond strength result shows in between 5- 22N/mm^2 with different parameters are conducted. The ductile curve are in nature [12]

2. EXPERIMENTAL PROGRAM

2.1 Materials

2.1.1 Concrete: The concrete of normal strength was prepared based on stipulations provided in IS standards. The composition details of materials are given in Table-1.

OP Cement of 53 grade, coarse aggregate of maximum size 20mm, and fine aggregate of size in the range between 0 to 4.75mm. A mold made in plywood of required dimension was used to cast the concrete cube.

Table 1. Composition and characteristics of concrete

CONCRETE MIX	M40
Cement (kg/m^3)	430
Water (kg/m^3)	165
Fine Aggregate (kg/m^3)	663.78
Coarse Aggregate (kg/m^3)	1173.69
Average compressive strength (N/mm^2)	48.50
Superplastizer (%)	0.5

2.1.2: Fiber Reinforced Polymer (FRP) bars: In this experimental study BFRP bars with diameter of 10mm were used and purchased the required quantity of bars from M/S. Arrow Technical Textiles Pvt. Limited, Mumbai. These bars (BFRP) had a fiber content of 80.3%. The testing of properties of tensile strength of BFRP bars were been determined through the testings' conducted on five specimens by following ASTM D7205 instructions which are the part and parcel of ACI Method. The tests were carried in the Material Testing Laboratory of AnnamalaiUniversity, Chidambaram, Cuddalore District, and Tamilnadu, India. Finally, through the results, it is observed that the ultimate tensile strength of BFRP bar of 10mm diameter was found as 1465Mpa.

Table.2:TENSILE TEST RESULT OF BFRP

SPECIME ID	PEAK TENSILE LOAD [kN]	PEAK TENSILE EXTENSION [mm]	ULTIMATE TENSILE STRENGTH Mpa	ELASTIC MODULUS Gpa
BFRP-10	113.55	38.4	1465.21	50.20

2.1.3Apparatus& Preparation of Test Specimen: The bond strength of BFRP bars were assessed by the pullout test. The pullout specimens were prepared in concrete of normal strength with a mean compressive strength of 48.5MPa. The BFRP pullout bar specimen of 1200mm long was embedded centrally in the concrete cube (200×200×200mm) as mention in Figure5.The embedded bar was sleeved with a steel tube concentric with PVC pipe to avoid bonding and splitting of concrete in the course of pullout test. The bonded length (L) was 150 mm of the BFRP bar. Steel tube is used as anchor at the loaded end of the BFRP bar and was casted with 1:2 mixtures of epoxy resin and hardener. The pullout specimens are casted on par with ASTM D7913-14. After 20 hours of casting, the moulds are removed from specimens and kept for curing in water up to 28 days.

ALL PRELIMINARY SET UP FIGURES SHOWS:FIGURE: [1] Wooden Mould [2] PVC Tube [3] Anchor as per ASTM D7205 [4] Arrangement of Pull-out [5]Casting of concrete cubes[6]Test Specimen

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Fig:1WoodenMould



Fig:2PVC Tube



Fig.3 Anchor as per ASTM D7205



FIG:4Arrangement of Pullout Test Specimen



FIG:5Casting of concrete Cubes



FIG:6 Test Specimen

2.1.4Test Procedure: The pullout specimens were placed in an UTM of capacity 100kN. The steel tube was tightened at machine's lower wedge grip.

The pullout test is carried by pulling the steel tube at one end [Fig.7] shows the experimental setup for pullout test. [Fig-8] shows one LVDT is attached at free end of the BFRP bar that extended outside of the concrete cube and then the pullout force is applied at a rate of 1.2mm/min. During the test, a computer-controlled data acquisition setup has grasped the readings of load and slip at a rate of 5 readings. Fig.7 Pullout Test Setup Fig.8 LVDT attached in Free End of BFRP



Fig.7 Pullout Test Setup



Fig.8 LVDT at Free End of BFRP Bar

2.1.5Modes of Failure

2.1.5Modes of Failure The encountered failure modes of all tested specimens are exhibited in Table 2.All BFRP specimens were failed in typical pullout mode as noted in Fig.9 No visual cracks are noticed on the BFRP-reinforced concrete cubes. The specimens of pullout were split up after testing to assess the nature of the bar and concrete surface along the embedded length Fig 10 visually. It has been observed that the bar and concrete surface are not damaged at loaded end. Nearer to the free end, the surface of the bar was partly peeled off.



Fig.9 Pullout Failure



Fig.10 Failure Pattern of BFRP Bar in Concrete

2.1.6 Bond Stress-Slip Response

2.1.6 Bond Stress-Slip Response In this test, the stress for bond and corresponding slip were noted at both the loaded and unloaded ends of the BFRP bar. Till the bar reaches its maximum load the slip is not noticed at free ends (unloaded ends) but the slip is obtained loaded end in all the specimens at all stages of loading.

The maximum bond stress and corresponding slip is noted in all the specimens at free ends, these slips are very smaller (0.07mm). At loaded ends, the slips of 3.75mm are reached at maximum bond stress. The bar slip of free ends are notably smaller than the loaded ends at all stages of loading. However, the high initial stiffness is observed between BFRP bar and concrete at both loaded and unloaded ends.

3.RESULT AND DISCUSSION

Experimental findings of bond strength of BFRP bars and ferrous bars associated in concrete of normal strength are mentioned in Table 3 and 4.The theoretical results are also mentioned.

1. It is confirmed that the bond stress-slip response has been mainly controlled by the surface treatment of the Basalt Fiber Reinforced Polymer bars.
2. Better result found in the bond stress-slip response and it has been mainly controlled by the surface treatment of the Basalt fiber Reinforced Polymer bars.
3. It is also observed that sand-coated BFRP bars were proved better adhesion to concrete at initial stages of loading than conventional steel bars

Table 3: Test Results of BFRP Bars

SPECIMEN	COMPRESSIVE STRENGTH(Mpa)	SPLITTING STRENGTH(Mpa)	PULL OUT LOAD(kN)	BOND STRENGTH(Mpa)	FAILURE MODE
BFRP-10-L60-1	48.00	4.31	40.14	21.30	**P**
BFRP-10-L60-2	48.00	4.31	34.42	18.27	**P**
BFRP-10-L60-3	48.00	4.31	37.21	19.75	**P**
BFRP-10-L60-4	48.00	4.31	33.25	17.65	**P**
BFRP-10-L60-5	48.00	4.31	40.07	21.27	**P**

Note: P = PulloutFailure

Table 4:Test Results of Steel Bars

SPECIMEN	COMPRESSIVE STRENGTH(Mpa)	SPLITTING STRENGTH(Mpa)	PULL OUT LOAD(kN)	BOND STRENGTH(Mpa)	FAILURE MODE
STEEL-10-L60-1	48.00	4.31	52.33	27.78	**P**
STEEL-10-L60-2	48.00	4.31	50.04	26.56	**P**
STEEL-10-L60-3	48.00	4.31	53.08	28.17	**P**
STEEL-10-L60-4	48.00	4.31	51.22	27.19	**P**
STEEL-10-L60-5	48.00	4.31	50.51	26.80	**P**

Note: P = Pullout Failure

Ultimate bond strength $\sigma_b = \frac{Pb}{\pi * d * l}$

Where,

σ_b–Ultimate bond strength

P_b – Pull out load (or) Bond failure load

d – Diameter of bar

l- Gauge length

4. THEORETICAL CALCULATIONS:

As per IS 456-2000, the design of bond stress can be calculated by using the following formula

$$\tau_{bd} = \frac{\Phi * \sigma s}{4 + ld}$$

Where,

σ_s= Stress in bar

(0.87 fy)=Design load

τ_{bd} =Design bond stress

Φ =diameter of bar

l_d= Development length

As per code for bond stress in case of deformed bars conforming to IS 1786 the value will be increased by 60%

So far deformed bars:

$$\tau_{bd} = \frac{\Phi * \sigma s}{4 x ld x 1.6}$$

Table.5 Results of theoretical calculations

Φ (mm)	fy (N/mm^2)	l_d (mm)	σ_s=(0.87 fy) (N/mm^2)	τ_{bd} (N/mm^2)
10	500	150	435	4.53

5. CONCLUSIONS

In view of the experiment conducted for the performance of bond strength for BFRP bars in concrete, the following are the conclusions. Average bond stress relationships and failure mode for each of the tested bars were experimentally determined.

- Concrete strength will increase if the peak pond stress increases or will decrease if it decreases.
- Average bond strength and defect mode for each of the tested bars gained to 70% that of the ferrous bars.
- Defect of the bond was determined due to length of embedment and bar surface.
- Splitting defect due to length of embedment.

- Thebondslip curve of sand-coated BFRP bars consists of initial hardening, nonlinear behavior before peak stresses and softening when pullout failure takes place which is as same as of conventional steel bars.
- Since no universal models are applicable to describe the bond slip behavior.

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