International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 04 Issue: 04 | Apr -2017 www.irjet.net p-ISSN: 2395-0072

Influence of Exposure to Acid Environment on the Bond Strength of Basalt Fiber Reinforced Polymer Bars and Steel Bars Embedded Concrete Blocks

Aiswarya Sreehari[1], Kavitha P E[2]

[1]M.Tech Student, Dept. of Civil Engineering, Sree Narayana Gurukulam College of Engineering, Ernakulam, Kerala, India
[2]Associate Professor, Dept. of Civil Engineering, Sree Narayana Gurukulam College of Engineering, Ernakulam, Kerala, India

***

Abstract - *Concrete is reinforced with steel bars to take care of the tensile stresses. Thus sufficient bond is required for the combined action of steel and concrete. But in certain aggressive environments, the bond will be eliminated due to the corrosion of steel bar. This led to the usage of non corrosive FRP bars instead of steel bars. Amongst all the FRP's, basalt fiber reinforced bars (BFRP) is a latest innovation in which limited research is conducted based on the practicability of reinforcing concrete structures. This paper hence studies the applicability of using BFRP bars in an acid environment for 28 days exposure duration to assess whether the bond strength satisfies the limits recommended in the IS 456:2000, in comparison with steel bars. The bond failure modes was also studied by performing a series of pull out test on concrete blocks with variations in grade of concrete such as M25, M30 and M35 and diameter of bars such as 10 mm, 12 mm and 20 mm. The bond stress was found to be higher for higher concrete grades and the bond stress decreased with an increase in the surface area of bar.*

Key Words: **Tensile Stress, Corrosion, BFRP, Bond Strength, Bond failure modes, Pull out test**

1. INTRODUCTION

Concrete is a widely used construction material. As concrete is a heterogeneous material, it possess a low tensile strength compared to compressive strength. Thus to take care of the tensile stress induced in a structure, concrete will be reinforced with steel bars resulting in a reinforced concrete structure. In circumstances where certain structures are directly exposed to harsh environments for instance sea water, high temperature, acidic environment etc. can reduce the life span of structures due to the corrosion of steel bars which results in the weakening of concrete structures. This forced the civil engineering community to look for an alternative reinforcing materials, as the repair cost of deteriorated structures is relatively expensive. Thus fiber reinforced polymer bars came into existence. For the last few decades, GFRP bars were widely used over steel bars until durability problem for some of their mechanical properties was discovered. Of late, BFRP bars were introduced to replace with GFRP bars. The studies that are conducted regarding the durability of BFRP bars to concrete are inadequate due to their recent existence. To be specific, bond durability of BFRP bars is of the greatest importance in upholding the structural integrity of any building. Most of the previous researches indicate that, the bond strength is influenced by the type of resin used for manufacturing the bar. Epoxy resin made BFRP bars shows superior performance compared to vinyl ester made BFRP bars [3, 6]. As the frictional force increases, the bond strength also increase, which is confirmed when sand coated bars were used [1, 2, 3, 5]. As the bar diameter and bar embedment length increases, the bond strength decreases. This is because as the bar diameter increases, on account of poisons effect there will be more reduction in the bar diameter when subjected to longitudinal stresses and as the embedment length increases, there will be a non linear distribution of bond stress along the surrounded portion of the bar [5, 6]. The corrosion due to acid attack increases the bond stress, the increase is remarked due to the friction caused by the swelling of bar [1, 4]. In an alkaline environment, the bond stress reduces due to the formation of reaction products which results in peeling of the outer layer surface of bars, therefore reducing the frictional force [1, 4]. High temperature seems to be corrosive for BFRP bars, as it reduces the bond strength. At high temperature the elastic modulus of bar diminish resulting in poor bond strength [2].

The majority of the current researches have focused only on a comparison involving GFRP and BFRP bars. This paper aims to conduct studies on the bond durability of BFRP bars in comparison to steel bars, by exposing to 5 % sulphuric acid solution for 28 days as per ASTM C267 – 01, with variations in bar diameter and grade of concrete, to assess whether the BFRP bars assures the minimum bond strength required for each grade as per IS 456:2000.

2. EXPERIMENTAL INVESTIGATION

2.1 Concrete Mix Details

The commonly used mix of 25 MPa, 30 MPa and 35 MPa were used for this study. The concrete mix design was done as per IS 456:2000 and IS 10262:2009. The materials were tested for various properties needed for the mix design. The cement used for the entire experiment is ordinary portland cement of grade 53 cement. The coarse aggregates were of size 20 mm and downgraded and the fine aggregate used was M-sand. Admixture of type MASTER GLENIUM SKY 8433 produced by BASF Incorporation was added to increase the workability of concrete and to minimize the amount of water-to-cement ratio, for obtaining a desired slump range of 75 mm–125 mm for normal RCC work as per IS 456:2000, Clause 7.1. After various trials for the three grades, the final mix ratios arrived for casting all the specimens is shown in Table -1.

Table -1: Mix proportions of M25, M30 and M35

Mix	Cement	Fine aggregate	Coarse aggregate	w/c ratio	Admixture
M25	1	1.8413	3.139	0.40	0.2 %
M30	1	1.7848	3.095	0.38	0.25 %
M35	1	1.675	2.956	0.36	0.3 %

2.2 Properties of BFRP and Steel bars

BFRP and Steel bars with nominal diameters of 10 mm, 12 mm and 20 mm were used in this study. Ribbed BFRP bars were collected from Arrow Textiles, Mumbai and steel bars used were Thermex TMT steel bars of grade Fe 500, as shown in Fig -1 and Fig -2. As per the manufacturer's specification, the guaranteed modulus of elasticity of BFRP bars is 50 GPa and for steel is 210 GPa. A comparison of weight of BFRP and steel bars is shown in Table -2.

Fig -1: Ribbed BFRP bars used in the study

Fig -2: Ribbed steel bars used in the study

Table -2: Comparison of weight of BFRP and Steel bars

Diameter	Weight of BFRP bar (g/m)	Weight of steel bar (g/m)	% reduction in weight of BFRP bar with respect to steel bar
10 mm	166	547	30.35 %
12 mm	246	739	33.3 %
20 mm	570	2261	25.2 %

2.3 Preparation of test specimen

The specimens for the pull out tests were prepared according to the recommendations given in IS: 2770 (Part 1) -1967. The geometry of the pullout samples consists of a concrete cube with size of the test specimens according to the Clause 3.1, for 10 mm and 12 mm diameter bar is 100 mm and for 20 mm diameter bar is 150 mm. The bar was extended for a length of 750 mm above the top surface of the cube which is necessary to provide sufficient length of bar to extend through the bearing blocks and the support of the testing machine and to provide an adequate length to be gripped for application of load and a length of 25 mm beyond the bottom surface of the cube for attaching the dial gauge. The embedment length provided for 10 mm and 12 mm diameter bar is 100 mm and for 20 mm diameter bar is 150 mm.

2.4 Sulphuric acid test

According to ASTM C267 – 01 Clause 9.4, the specimens were cured for a period of 28 days in normal water. Afterwards as per Clause 11.2, the specimens were conditioned in 5 % sulphuric acid solution for a period of 28 days. After conditioning, the specimens were tested.

2.5 Pull out test

Pull out tests were carried out as per IS: 2770 (Part 1) -1967. After the curing period and corroding period, the bar-concrete bond strength was determined through the pull out tests, conducted using Universal Testing Machine of capacity 1000 kN. The pull out test set up is shown in Fig -3. The maximum load for all the specimens was recorded.

Fig -3: Pull out test set up

2.6 Determination of Bond Stress

Nominal bond stress was obtained from the equation below

$$\tau = P/\pi DL \qquad (1)$$

where, τ is the nominal bond stress in N/mm^2, P is the load at failure in N, D is the diameter of the bar in mm and L is the embedment length in mm.

3. RESULTS AND DISCUSSION

3.1 Bond Strength of acid conditioned specimens

The results of bond behaviour between the BFRP bars and steel bars with the surrounding concrete after acid immersion for a period of 28 days of grades M25, M30 and M35 are shown in Table -3, Table -4 and Table -5 respectively. Conditioning significantly affected the bond strength of the tested specimens.

Table -3: Variation of bond stress in M25 grade concrete

Sl. no	Diameter	M25		
		Control specimens	28 days acid conditioned specimens	
		Bond stress (N/mm^2)	Bond stress (N/mm^2)	% increase in bond stress
1.	Steel – 10 mm	11.968	15.406	28.73 %
2.	BFRP – 10 mm	8.148	12.54	53.9 %
3.	Steel – 12 mm	8.965	10.822	20.7 %
4.	BFRP – 12 mm	7.268	9.178	26.28 %
5.	Steel – 20 mm	7.745	9.443	21.92 %
6.	BFRP – 20 mm	6.238	8.064	29.27 %

Table -4: Variation of bond stress in M30 grade concrete

Sl. no	Diameter	M30		
		Control specimens	28 days acid conditioned specimens	
		Bond stress (N/mm^2)	Bond stress (N/mm^2)	% increase in bond stress
1.	Steel – 10 mm	13.369	16.8	25.6 %
2.	BFRP – 10 mm	9.485	14.069	48.33 %
3.	Steel – 12 mm	10.027	12.84	28.05 %
4.	BFRP – 12 mm	8.594	11.353	32.1 %
5.	Steel – 20 mm	8.382	9.85	17.5 %
6.	BFRP – 20 mm	6.79	8.7	28.13 %

Table -5: Variation of bond stress in M35 grade concrete

Sl. no	Diameter	M35		
		Control specimens	28 days acid conditioned specimens	
		Bond stress (N/mm^2)	Bond stress (N/mm^2)	% increase in bond stress
1.	Steel – 10 mm	14.515	17.58	21.11 %
2.	BFRP – 10 mm	12.287	16.5	34.28 %
3.	Steel – 12 mm	11.618	13.85	17.21 %
4.	BFRP – 12 mm	10.61	12.512	18 %
5.	Steel – 20 mm	10.93	11.14	1.93 %
6.	BFRP – 20 mm	8.754	9.231	5.45 %

According to IS 456:2000 Clause 26.2.1.1, the minimum bond strength required for M25 is 2.24, for M30 is 2.4 and for M35 is 2.72. It can be observed that there is an increase in the bond strength for both steel and BFRP embedded specimens after 28 days of acid immersion. The increase in the bond strength is attributed to (a) The sulphate attack blocking the micro cracks in the concrete; thereby increasing its strength as reported by Yuan Wu *et.al* [7] and (b) Due to the curing of concrete in its early stage as notified by Ahmad Altalmas *et.al* [1]. It can be seen that there is more percentage increase in the bond strength for BFRP specimens compared to steel specimens after acid conditioning. This could be due to the friction that was developed between the BFRP bars and the concrete, due to the existence of products (brownish traces) that resulted from the reaction between the bars and the acid as reported by Ahmad Altalmas *et.al* [1]. Ahmed EI Refai *et.al* [2] explained that the brownish colour was observed due to the presence of iron ions in the composition of BFRP bars.

3.2 Influence of bar diameter on bond strength

The magnitudes of bond stress for smaller diameter bars were comparatively larger than the bars with larger diameter, as reported by Marta Baena *et.al* [5], and Roman Okelo *et.al* [6] . This is because small diameter bars shows better adherence to concrete than large diameter bars. According to the equation (1), the increase in the bar diameter ultimately causes reduction in the bond stress. This is observed in the case of all the three grades of concrete as shown in Chart -1, Chart -2 and Chart -3.

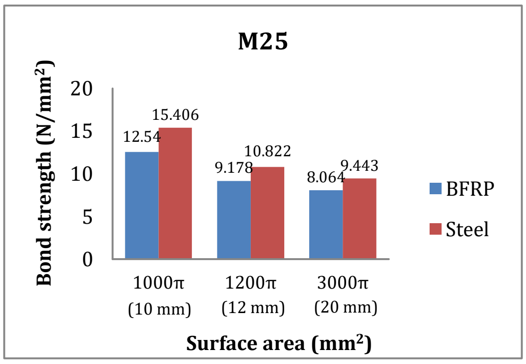

Chart -1: Variation of bond stress with surface area for M25

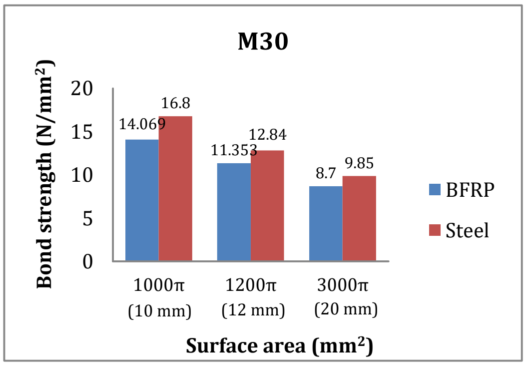

Chart -2: Variation of bond stress with surface area for M30

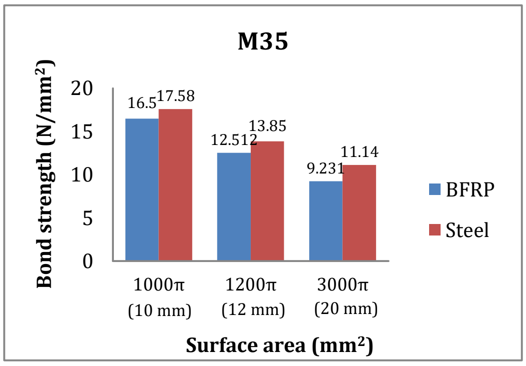

Chart -3: Variation of bond stress with surface area for M35

3.3 Influence of grade of concrete on bond strength

Ahmed Altalmas *et.al* [1] reported that the concrete compressive strength plays a major role in the development of the bond stress of FRP bars to concrete. By increasing the concrete strength, a result occurs in increasing the bond strength between the bars and the surrounding concrete. The same trend of variation in bond stress for M25, M30 and M35 grade concrete was observed for BFRP bars and steel bars as plotted in Chart -4 and Chart -5 respectively.

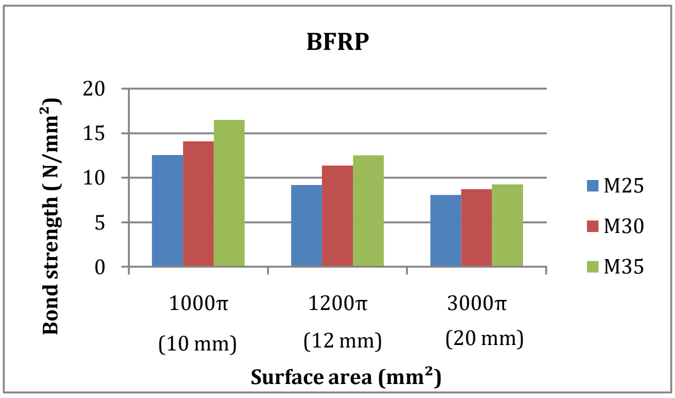

Chart -4: Variation of bond stress with change in grade of concrete for BFRP bar

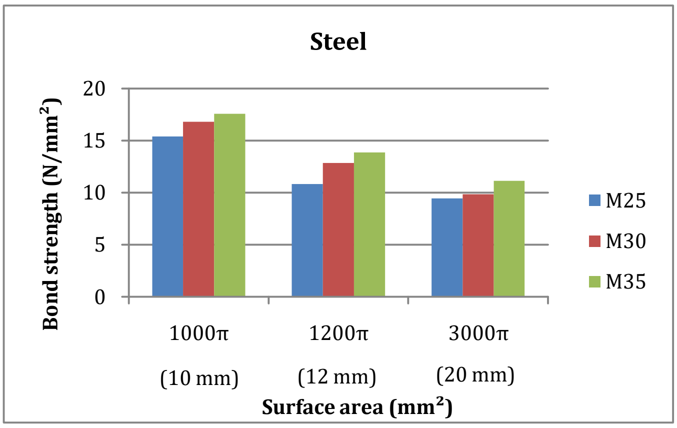

Chart -5: Variation of bond stress with change in grade of concrete for Steel bar

It can be observed that the bond stress increases with increase in the compressive strength of concrete. In M30 and M35 grade concrete, for 10 mm BFRP bar the bond stress increased by 12.2 % and 31.5 % respectively compared to M25 grade. In M30 and M35 grade concrete, for 12 mm BFRP bar the bond stress increased by 23.7 % and 36.3 % respectively compared to M25 grade. In M30 and M35 grade concrete, for 20 mm BFRP bar the bond stress increased by 7.8 % and 14.46 % respectively compared to M25 grade.

3.4 Bond failure modes

Splitting of concrete specimens in a brittle mode of failure was observed for all the acid conditioned BFRP and steel specimens as shown in Fig -4, except one specimen M2SD1AE1, where the bar ruptured before attaining its bond strength which is the Steel Rupture failure mode as shown in Fig -5. This can be due to that the bond strength between the concrete and steel was greater than the tensile strength of the steel.

Fig -4: Concrete splitting mode of failure

Fig -5: Steel rupture mode of failure

In some BFRP specimens, colored spots (brownish traces) were observed on the BFRP bar as shown in Fig -6, indicating the existence of reaction products on the bar surface, this phenomenon was observed by Ahmad Altalmas *et.al* [1] and Ahmed EI Refai *et.al* [2], where the brownish traces were formed due to the presence of iron ions in BFRP bars.

Fig -6: Brownish traces observed in the bar

4. CONCLUSIONS

Following conclusions are drawn based on the results obtained from experiment.

i. The weight of BFRP bars reduces by 25.2 % - 33.3 % compared to steel bars. Thus the self weight of the structure reduces a lot when BFRP bars are used in construction as they are light in weight compared to steel bars.

ii. All the BFRP specimens possess a bond stress greater than the minimum bond stress given in IS 456:2000 Clause 26.2.1.1 for all the three grades of concrete.

iii. The bond strength of control (28 days water curing) BFRP specimens is less than the steel specimens. This could be due to the lower elastic modulus of BFRP bars, type of resin used for manufacturing the bar and its anisotropic behavior.

iv. The bond stress decreases with increase in the surface area of bar i.e., in M25, M30 and M35 grade concrete, for 20 mm BFRP bar the bond stress decreased by 35.7 %, 38.16 % and 44.05 % respectively compared to 10 mm diameter bar.

v. The bond stress increases with the increase in the compressive strength of concrete cube i.e., in M30 and M35 grade concrete, for 10 mm BFRP bar the bond stress increased by 12.2 % and 31.5 % respectively compared to M25 grade.

vi. Splitting of concrete specimens in a brittle mode of failure was observed for all the acid conditioned BFRP and steel specimens, except one specimen where the bar ruptured before attaining its bond strength which is the Steel Rupture failure mode. This can be due to that the bond strength between the concrete and steel was greater than the tensile strength of the steel.

vii. In M25, M30 and M35 grades, there is an increase in the bond strength for both steel specimens and BFRP specimens after 28 days of acid immersion. It is attributed due to the sulphate attack blocking the micro cracks in the concrete, thereby increasing its strength and the curing of concrete in its early stage.

viii. The highest percentage increase in the bond strength is for BFRP specimens compared to steel specimens after acid conditioning. This could be due to the friction that was developed between the BFRP bars and the concrete, due to the existence of products (brownish traces) that resulted from the reaction between the bars and the acid.

ix. Considering all the factors of BFRP specimens to steel specimens in the aspects discussed above, a detailed durability analysis has to be conducted for a long duration of exposure to extreme conditions, in order to study the bond behavior.

REFERENCES

[1] Ahmad Altalmas, Ahmed Ei Refai, Farid Abed, "Bond Degradation of Basalt Fibre- Reinforced Polymer Bars Exposed to Accelerated Aging Conditions", Journal of Construction and Building Materials, ELSEVIER 81, March 2015, pp. 162-171, doi:10.1016/j.conbuildmat.2015.02.036.

[2] Ahmed EI Refai, Farid Abed and Ahmad Altalmas, "Bond Durability of BFRP Bars Embedded in Concrete Under Direct Pullout Conditions", Journal of Compos.Constr © ASCE 19(5):04014078, May 2015, doi:10.1061/(ASCE)CC.1943.5614.0000544.

[3] E.Cosenza, Manfredi and Realfonzo, "Behaviour and Modelling of Bond Rebars to Concrete", Journal of Compos.Constr © ASCE 1(2), May 1997, pp. 40-51.

[4] Gang Wu, Zhi-Qiang, Xin, Ying, "Prediction of Long Term Performance and Durability of BFRP bars under the Combined Effect of Sustained Load and Corrosive Solutions", Journal of Compos.Constr © ASCE 19(3):04014058, January 2015, doi:10.1061/(ASCE)CC.1943-5614.0000517.

[5] Marta Baena, Lluis, Albert, Cristina Barris, "Experimental Study of Bond Behaviour Between Concrete and FRP Bars Using a Pull Out Test", Journal of Composites: Part B, ELSEVIER 40, July 2009, pp. 784-797, doi:10.1016/j.compositesb.2009.07.003.

[6] Roman Okelo and RobertYuan, "Bond Strength of Fiber Reinforced Polymer Rebars in Normal Strength Concrete", Journal of Compos.Constr © ASCE 9(3), June 2005, pp. 203-213, doi:10.1061/(ASCE)1090-0268.

[7] Yuan Wu, Heng Lin, Shu Zhou and Znong Fang (2016), "Degradation Model of Bond Performance Between Deteriorated Concrete and Corroded Deformed Steel Bars", Journal of Construction and Building Materials, ELSEVIER 119, May 2016, pp. 89-95, doi:10.1016/j.conbuildmat.2016.04.061.