International Research Journal of Education and Technology
Peer Reviewed Journal
ISSN 2581-7795

STRENGTH PROPERTIES OF BASALT FIBRE REINFORCED POLYMER REBARS

V. Pavalan [a] ,D.Jeevanantham [b] N. Gokulraj [c]

[a]Assistant Professor, [,b,c] M.E Scholar , Department of Civil Engineering, Sengunthar Engineering College Tiruchengode, Tamil Nadu, India

Abstract

The use of non-metallic fibre reinforced polymer (FRP) bars in concrete structures has widely increased in the construction sector due to their high mechanical performance. BFRP bars are a quite new FRP material for which mechanical and thermal properties are not yet completely defined. This paper presents the significant properties which are essential to make use of BFRP bars as reinforcements in concrete structures have been determined and discussed. The following tests to determine the mechanical properties of sand-coated (BFRP) bars of 8 and 10mm- diameters were conducted: tension, compression, pullout. Using ASTM (American Society for Testing and Materials) standards, the sand-coated BFRP bars have been tested. From the experimental test results, it has been observed that the sand-coated BFRP bars show excellent qualities in all aspects.

Keywords: ASTM standards, BFRP bars, Mechanical characteristics

1.Introduction

In the last two decades, fibre reinforced polymers (FRPs) have been gradually used in the concrete structures particularly in severe environmental situations as an alternative reinforcement owing to their advantages, e.g., low density, high corrosion resistance and fatigue resistance. Recently, the use of basalt fibre reinforced polymer (BFRP) bars have increased in structural engineering applications due to their low cost compared to other type of FRPs such as Glass, Carbon and Aramid. Moreover, the basalt FRP bars have outstanding chemical stability and excellent resistance to high temperature than glass FRP bars. Basalt fibres are an environmentally safe and nontoxic material as they are made from volcanic rocks without additives.

Several experimental investigations on mechanical and thermal characteristics of basalt fibre reinforced polymer bars were reported. Quagliarini et al. (2012) investigated the tensile characterization of basalt fiber rods and ropes. They reported that basalt fibre reinforced polymer rods and basalt fiber ropes could be good alternative to other fibre reinforced polymer rods. The tested BFRP rods seems to be not so rigid (less than glass FRP rods) but rather deformable and with good tensile strength (better than glass FRP rods). . Elgabbas et al. (2015) concluded that the transverse coefficient of thermal expansion of BFRP specimens ranging from 18.4 x 10^{-6} /^{o}C to 26.8 x 10^{-6}/^{o}C, which is less than 40 x 10^{-6}/^{o}C as stated by Canadian standards association(CSA). Ayadin (2018) examined the thermal expansion coefficient of Glass FRP, Carbon FRP, Aramid FRP and Basalt FRP bars and concrete. The longitudinal coefficients of thermal expansion values of GFRP, CFRP, AFRP, BFRP bars were 4.43 x 10^{-6}/^{o}C, 1.05 x 10^{-6}/^{o}C,-5.18 x 10^{-6}/^{o}C and 1.92 x 10^{-6}/^{o}C. The transverse coefficients of thermal expansion values of FRP bars were 22.5 x 10^{-6}/^{o}C, 93 x 10^{-6}/^{o}C, 51 x 10^{-6}/^{o}C and 17.1 x 10^{-6}/^{o}C, respectively. The longitudinal coefficients of thermal expansion of concrete were 6-8 x 10^{-6}/^{o}C in different strengths. GFRP bar has been identified as the most stable material in its thermal behaviour whereas AFRP bar as the most unstable one.Refai et al. (2015) studied the bond behavior of basalt fibre reinforced polymer bars to concrete. Thirty six concrete cylinders reinforced with BFRP bars and twelve cylinders reinforced with GFRP were tested in direct pull-out conditions. The results showed that BFRP bars with small diameters have better adhesion to concrete at initial stages of loading than bars with large diameters. Average adhesion of 10mm-diameter BFRP bars were 0.67MPa compared to 1.09MPa for GFRP bars. BFRP bars exhibited higher residual stress than that of GFRP bars with an average valve of 9 and 10MPa (compared to 7.72 and 5.75MPa for GFRP bars) at unloaded and loaded ends respectively. In this paper, the tensile, compression, pull-out and thermal expansion coefficient test results of sand coated BFRP bars are presented.

2. Experimental Program

2.1 Mechanical characteristics

2.1.1 Tensile test

The tensile specimens were prepared according to the provisions of ASTM D7205/D7205M-06(2011).The total length of the tensile specimen was 1000mm and the free length was 400mm. A 300mm- long steel tube anchor with an outside diameter of 25.4mm and thickness of 3mm was used. Steel Plugs and PVC caps drilled on their centre slightly larger than the bar diameter were used to close at both ends of steel tubes and to insert the bar at the centre of the steel tube. Fig. 1 shows the details of the tensile test specimens. The BFRP bars fixed in the steel tubes were placed vertically in a wooden frame for proper alignment. Then the steel tube was filled with mixture of epoxy resin and hardener. After 24 hours, the first anchor was flipped to cast other anchor. The specimen was cured at 7 days in typical indoor laboratory conditions.

Fig. 1 Details of the tensile specimens

The tensile tests were carried out by gripping the steel tube into the wedges of MTS testing machine that has a capacity of 1000kN (Fig.2). A loading rate of 250MPa/min was used during the test. An extensometer was attached to the BFRP bar to measure strain of the specimen with gauge length of 50mm. The applied load and BFRP bar extension was electronically recorded by a computerized data acquisition system. The ultimate tensile strength and modulus of elasticity were calculated by using following equations (1) and (2) respectively.

$$F_{tu} = P_{max} / A \quad (1)$$

$$E = P_1 - P_2 / (\varepsilon_1 - \varepsilon_2) A \quad (2)$$

Where F_{tu} is ultimate tensile strength (MPa), $P_{max}$is the maximum force prior to failure(N),A is the cross-sectional area of the bar(mm^2). E -elastic modulus (MPa);P_1- 50% maximum load(N) ;P_2 -20% maximum load(N)and ε_1 the strain corresponding to 50% of the maximum load; ε_2 the strain corresponding to 20% of the maximum load.

International Research Journal of Education and Technology
Peer Reviewed Journal
ISSN 2581-7795

Fig.2. Tensile test setup

2.1.2 Compression Test

Compressive testing is especially useful for quality control and specification purposes. The compressive properties obtained according to ASTM D695-15 standards cannot be used for design purposes. The length of the compressive specimen was twice the diameter of the BFRP bar. The specimen was placed axially between the platens of the compression testing machine. The load was applied at the rate of 1.0 to 1.3mm per minute till the specimen fails and the failure load was noted from the computerized data acquisition system. Fig.3 shows the typical test setup for compression. The compressive strength of the BFRP bar was calculated as P_{max}/A, where P_{max} is Maximum applied force (N), A is the cross-sectional area of the bar (mm^2).

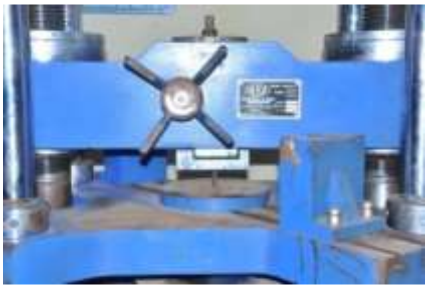

Fig.3. Compression test setup

2.1.3 Pull-out test

The pullout specimens consisted of concrete cubes, 200mm on each edge, with a single 1200mm long BFRP bar embedded vertically along the central axis in each specimen .The embedded length of the BFRP bar was five times the diameter of the BFRP bar. The embedded bar was inserted within polyvinyl chloride (PVC) pipe to prevent bonding at top of each specimen ,and additionally the PVC pipe was used to avoid splitting of concrete during the pull-out test. Steel tubes were used as anchors at the loaded end of the BFRP bars and were cast with epoxy resin and hardener. The pullout specimens were casted in accordance with C192/C192M. Then, the moulds were removed from the specimens after 20 hours of casting. Immediately after removing the moulds, the specimens cured until the time of testing. The pullout specimens were tested at an age of 28 days.

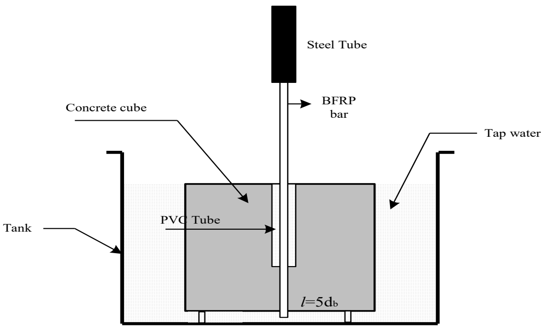

Fig.4 Geometry of the pullout specimens

The average bond stress was calculated as the maximum force observed during the test divided by the surface area of the bar bonded to the concrete cubes.

$$\tau = \frac{F}{C_b l} \quad (3)$$

International Research Journal of Education and Technology
Peer Reviewed Journal
ISSN 2581-7795

Where τ is the average bond stress (MPa), *F* is the tensile force (N), C_b is the equivalent circumstance of FRP bar, calculated as 3.1416 d_b and *l* is the bonded length (mm).The slip of the BFRP bars in concrete can be achieved by,

$$s = s_L - s_F \qquad (4)$$

Where s is the slip of the BFRP bars (mm); s_L is the loaded end slip of the BFRP bar(mm); s_F is the free end slip of the BFRP bars(mm).

The bond strength of the BFRP bar was evaluated by testing of eight specimens in accordance with ASTM D7913/D7913M-14.This test was conducted at Strength of materials laboratory, Department of Civil & Structural engineering, Annamalai University, Chidambaram. The pullout specimens were placed in a universal testing machine. The steel tube anchorages were used to protect from crushing of the BFRP bar. This steel tube was tightened by conventional wedge frictional grips at machine's lower jaw. The pullout performed by pulling the steel tube at one end. One linear variable differential transformer (LVDT) was fitted to the top of extended free end of the BFRP bar at outside of the concrete cube and then load was applied at a constant loading rate of 20kN/min until failure. The pullout load and displacement (slip) values were recorded during the test by a computer-controlled data acquisition system.

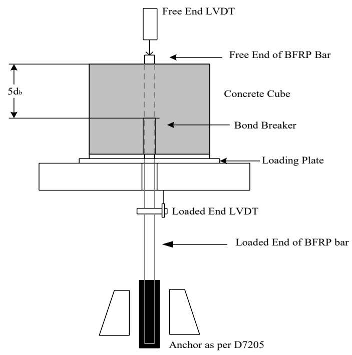

Fig.5 Pullout test setup

3. Results and Discussion

3.1. Mechanical characteristics

3.1.1 Tensile test

The ultimate tensile strength and modulus of elasticity of BFRP and conventional steel bars were tabulated in Table1.All of the BFRP specimens failed in the free length through the rupture of fibres as shown in Fig.3. According to the test results, the ultimate tensile strength of the BFRP bars was 3 times higher than that of conventional steel bars, and the modulus of elasticity was about 1/4 of the conventional steel bars. After tensile testing, the steel tube anchors of the specimens were cut through saw blade at both ends to notice the condition of the BFRP bars

Table 1 Tensile test results of Sand-coated BFRP bars

Specimen ID	Peak Tensile load [kN]	Peak Tensile Extension [mm]	Ultimate Tensile Strength [MPa]	Elastic modulus [GPa]
BF-8-1	70.2	20.1	1396.5	49.5
BF-8-2	68.3	19.4	1358.7	48
BF-8-3	69.7	19.8	1386.5	49.4

BF-8-4	69.5	19.7	1382.5	48.7
BF-8-5	69.6	19.5	1364.6	48.6
BF-10-1	114.8	38.9	1461.6	50.3
BF-10-2	116.2	40.3	1479.5	50
BF-10-3	115.7	39.3	1473.1	50.6
BF-10-4	117.1	40.4	1490.8	50.9
BF-10-5	115.2	39.3	1470.7	50

Fig. 6 Failure of tensile specimens

According to the tensile stress and strain valves collected in the experiment, the stress-strain curve of the BFRP bars are plotted (Fig.8).From the figure we can see that the stress-strain curves of the BFRP bars are linear, does not have any yield point up to the failure .The stress-strain curves of the BFRP bars are almost similar with different diameters.

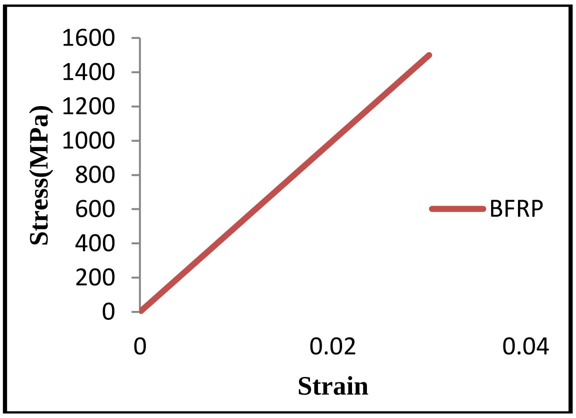

Fig.7 Stress –Strain curve of BFRP bars

3.1.2 Compression Test

The peak compressive stress of tested BFRP bars was given in Table 2. Typical failure mode of the BFRP bars under compression as shown in Fig.9. It is observed that the failure of BFRP bars occurred due to crushing of longitudinal fibres. According to the compression test results, the ultimate compressive strength is three times lesser than the ultimate tensile strength of the BFRP bars. The ultimate compressive strength of the BFRP bars varies a smaller amount with the increase of diameter.

Table 2 Compression test Results of sand-coated BFRP bars

Specimen ID	Peak Compressive Load (kN)	Peak Compressive Deformation (mm)	Compressive strength (MPa)
BFRP8	30.5	0.40	470.2
BFRP10	37.1	0.45	480.6

Fig.8 Typical failure mode

3.1.3 Pull-out test

The bond strength of sand-coated BFRP bars of 10mm- diameter was given in Table 3. All BFRP specimens failed in typical pullout mode. No visual cracks were noticed on the BFRP-reinforced concrete cubes. The pullout specimens were split after testing to visually assess the conditions of the bar and concrete surface along the embedded length. It can be observed that the bar and concrete surface was not damaged at loaded end. Close to the free end, the surface layer of the bar was partly peeled off.

Table 3 Pull-out test results of Sand-coated BFRP bars

Specimen	Compressive Strength (MPa)	Pullout Load (kN)	Bond Strength (MPa)	Failure Mode
B10-L60-1	48.5	33.06	17.53	P
B10-L60-2	48.5	35.62	18.89	P
B10-L60-3	48.5	31.68	16.81	P

B10-L60-4	48.5	29.31	15.54	P
B10-L60-5	48.5	33.70	17.87	P

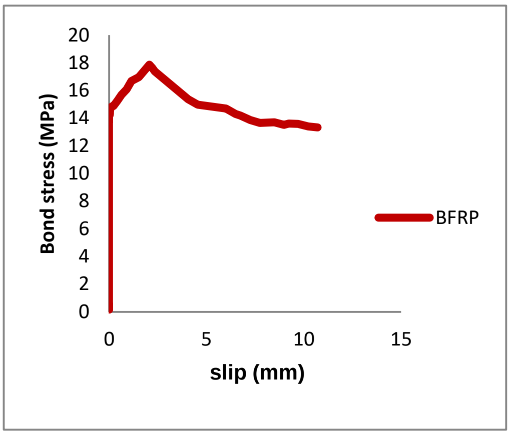

Fig.9 Bond stress-slip response of BFRP specimens

In this test, the bond stress and corresponding slip noted at both the loaded and unloaded ends of the BFRP bar. Fig.10. shows the bond stress-slip response of BFRP specimens. The bar slip was not obtained in all the specimens at free ends (unloaded ends) until the specimen reached to ultimate load whereas the loaded end slip was obtained in all the specimens at all stages of loading. The maximum bond stress and corresponding slip was noted in all the specimens at free ends, these slips are very smaller (0.09mm). At loaded ends, the slips of 3.65mm were reached at maximum bond stress. The bar slip of free ends were notably smaller than the loaded ends at all stages of loading. However, the high initial stiffness was observed between BFRP bar and concrete at loaded and unloaded ends.

4. Conclusion

In this study, the sand-coated BFRP bars were tested to exhibit their mechanical characteristics. Based on the experimental test results, the following conclusions can be drawn.

The ultimate tensile strength of the tested BFRP bars is about 1378 to 1475 MPa, the elastic modulus is about 48 to 50 GPa. BFRP bars achieved a compressive strength value which is half of its tensile strength value. The ultimate compressive strength of the BFRP bars varies a smaller amount with the increase of diameter. The average bond strength of sand-coated BFRP bars has been achieved 70% that of the conventional steel bars. Thus, the sand-coated BFRP bars have proven its distinguished qualities throughout the present study.

References

[1] E.Qualliarini, F. monni, S.Lenci, F. Bondioli, “Tensile characterization of basalt Fiber Rods and Ropes: A First Contribution,” *Construction and Building Materials*, 34, pp372-380, 2012.

[2] F.Elgabbas, E.A Ahmed, B.Benmokrane, “Physical and mechanical characterestics of new basalt-FRP bars for reinforced concrete structures,” *Construction and building materials*, 95, 623-635, 2015.

[3] A.El. Refai, P.E, M.A .Ammar and R. Masmoudi, “Bond performance of basalt fiber-reinforced polymer bars to concrete,”*Journal of composite construction*, 11, 2014.

[4] Ayadin.F, “Experimental investigation of thermal expansion and concrete strength effects on FRP bars behavior embedded in concrete,” *Construction and Building Materials*, 163, 1-8, 2018.

[5] ASTM: D7205/7205M, “Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars,” *ASTM International*, USA, 2006.

[6] ASTM: D695,“Standard Test Method for compressive properties of rigid plastics,” *ASTM International*, USA 2015.

[7] ASTM: D7913/D7913M, “Standard Test Method for bond strength of fiber-reinforced polymer matrix composite bars to concrete by pull out testing”, *ASTM International*, USA, 2014.

[8] ASTM: E228, “Standard test method for Linear thermal expansion of solid materials with a push-rod dilatometer,” *ASTM International*, USA, 2011.