



Physical and Mechanical Properties of Basalt Fibre Reinforced Polymer Bars

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Abstract: Fibre reinforced polymer (FRP) bars have gradually gained wide acceptance in structural engineering applications due to their unique advantages including their high tensile strength, light weight and excellent corrosion resistance. BFRP bars are a quite new FRP material for which physical and mechanical 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 physical and mechanical properties of sand-coated basalt fibre reinforced polymer (BFRP) bars of 8 and 10mm- diameters were conducted: fibre content, density, water absorption, tension, interlaminar shear, compression and pullout of bars embedded in concrete. 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, Physical properties, Mechanical properties

I. Introduction

During the last few years, the use of fibre reinforced polymers (FRPs) have widely increased in the construction sector due to the outstanding characteristics of FRPs such as high strength-to-weight ratio, excellent corrosion resistance and good non-magnetization properties [1-5]. Carbon fiber reinforced polymer (CFRP) and glass fiber reinforced polymer (GFRP) are the most popular FRPs used in civil engineering components. In recent years, basalt fibre reinforced polymer (BFRP) has been developed as one of alternatives of glass and even carbon fibre reinforced polymer in many application fields [6]. Comparatively, the basalt fibre reinforced polymer is considered as one of the environmentally friendly and non-hazardous materials because it is produced directly from volcanic rocks [7-9].

Previous studies on physical properties of sand-coated BFRP bars were very limited and most of them were conducted on mechanical properties of sand-coated BFRP bars. Quagliarini et al. [10] 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. [11] investigated the physical, mechanical and durability characteristics of three types of basalt fibre reinforced polymer bar (BFRP) bars. The durability and long-term performance were assessed by conditioning the BFRP bars in alkaline solution simulating the concrete environment (up to 3000h at 60°C). Thereafter, the properties were assessed and compared with the unconditioned valves. The test results revealed that the BFRP bars had good mechanical behaviour and could be placed in the same category as grade II and grade III GFRP bars (according to tensile modulus of elasticity). Their tensile strength, however, was higher than that provided by CAN/CSA S807-10 for CFRP bars. Serbescu et al. [12] tested one thirty two BFRP specimens comprising two types and seven different diameters under tension after conditioning in pH9 and pH13 solutions at 20, 40, and 60°C for 100; 200; 1000; and 5000h. The BFRP bars exhibited a guaranteed tensile strength of around 1300MPa, an modulus of elasticity of 40GPa, and they are estimated to maintain about 72 and 80% of their tensile strength after 100 years exposure to concrete and mortar environment, respectively. Fan et al. [13] investigated the tensile properties of basalt fibre reinforced polymer bars and showed that the ultimate tensile strength of BFRP bars is about three times higher than the ordinary steel bars, and the modulus of elasticity is about 1/5 of the ordinary steel bars. Refai et al. [14] 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 value of 9 and 10MPa (compared to 7.72 and 5.75MPa for GFRP bars) at unloaded and loaded ends respectively. Sim et al.[15] investigated the durability and mechanical performance of basalt, carbon, glass fibres. The basalt fibre exhibited the ultimate tensile strength was 1000MPa, which was about 30% of the carbon and 60% of the glass fibre. When the three different type of fibres immersed into an alkaline solution, the basalt and glass fibres lost their volumes and strengths about 50% at 7 days and 80% at 28 days. On the other hand, the carbon fiber did not show remarkable strength reduction. Nevertheless, the basalt fibre kept about 90% of the strength after exposure at 600°C for 2 h whereas the carbon and glass fibre did not retain their volumetric integrity. Meng et. al.[16] studied the bond stress-slip constitutive relation between BFRP bar & basalt fibre recycled aggregate concrete, 81 central pull out specimen were tested. The results showed that adding basalt fibre into recycled- aggregate reduces the bond stress between the BFRP bar and recycled-aggregate concrete but enhances the ductility of bond property. The bond stresses increases with the increasing fiber length and grade of concrete. Wang et al.[17] examined the bond behaviour between BFRP bar and engineered cementitious composite. The test results indicated that the bond strength between the BFRP bar and cementitious matrix decreases with an increase in the bar diameter, and the specimen with a shorter embedded length achieves a higher bond strength. Wenjie Ge et al.[18] studied the flexural behaviours of hybrid concrete beams reinforced with BFRP bars and steel bars. The test results showed that the bond strength of BFRP bars with concrete is similar to the bond strength of steel bars with concrete and thus having good bond performance. This study aims to introduce the physical and mechanical properties of sand-coated BFRP bars, considering fibre content, unit weight, water absorption, tensile strength, modulus of elasticity, interlaminar shear, compression and bond strength of BFRP bars. Two different diameter bars (8 mm and 10 mm) were used to assess these properties. According to the ASTM (American Society for Testing and Materials) Standards, the tests have been carried out and the results were discussed.

II. Experimental program

2.1 Materials

The sand coated BFRP bars of 8mm and 10mm- diameters supplied by Nickunj eximp enterprises private limited were used in current study. These BFRP bars were manufactured by pultrusion process, then the bars were applied with standard epoxy resin and braided with nylon wire, after that the quartz sand was coated on the bars as shown in Figure1.



Fig.1 Sand-coated BFRP bars

2.2 Specimen Details

The preparation of specimens and physical and mechanical properties of the sand-coated BFRP bars were carried out in accordance with American Society for Testing and Materials (ASTM) test standards. Table 1 compiles the test methods as well as the number of specimens tested for each type of test.

Table 1. Summary of the Test Methods and Number of Specimens

Properties	Test Method	No. of Specimens
Physical properties		
Fiber content by weight (%)	ASTM D3171-15	5
Density(kg/m ³)	ASTM D792-13	5
Water absorption at 24 h (%)	ASTM D570-98	5
Mechanical properties		
Tensile (N/mm ²)	ASTM D7205/D7205M-06	8
Interlaminar shear (N/mm ²)	ASTM D4475-02	5
Compressive (N/mm ²)	ASTM D695-10	8
Pull-out (N/mm ²)	ASTM D7913/D7913M-14	8

2.3 Physical properties of BFRP bars

2.3.1 Burn off test

The fibre content of the BFRP bar was determined according to the ASTM D3171-15[19] guidelines. The specimens were used in the burn off test weighed around 0.5 g. Each specimen is weighed and placed into a desiccated crucible. Then, the crucible containing specimens are placed into a muffle furnace. The specimens are then to be heated to 600°C that will burn off the matrix and leave the reinforcement (fibre). The maximum time for burn off should be 6h. At the completion of the heating process, the crucibles are removed from the muffle furnace, cooled to room temperature in a desiccator, and weighed to determine its mass. The fibre content by weight and volume was calculated according to the following equation (1) and (2),

$$W_r = (M_f/M_i) \times 100 \quad (1)$$

$$V_r = (M_f/M_i) \times \rho_c/\rho_m \times 100 \quad (2)$$

Where M_i is the initial mass of the specimen (g), M_f is the final mass of the specimen (g) after combustion, ρ_c is the density of the reinforcement or fibre (g/cm^3) and ρ_m is the density of the specimen (g/cm^3).

2.3.2 Density test

The density of the BFRP bar was determined experimentally using ASTM D792-13[20]. This standard requires the analytic scale to have 0.1 mg precision. The specimen is weighed in air is recorded. Then, the specimen is immersed in distilled water at 23°C using a sinker (holder) and wire to hold the specimen completely submerged (Figure 2). Also, the totally immersed sinker in distilled water is weighed and noted. The specific gravity of the specimen was found using Equ.1. The specimen density is determined by multiplying the experimental specific gravity and density of the water (Equ.4).

$$\text{Specific gravity } 23^\circ\text{C} = a / (a + w - b) \quad (3)$$

$$\text{Density } 23^\circ\text{C} = \text{specific gravity } 23^\circ\text{C} \times 997.5 \text{ Kg/m}^3 \quad (4)$$

Where a is the apparent mass of specimen, without wire or sinker, in air, b is the apparent mass of the specimen (and of sinker, if used) completely immersed and of the wire partially immersed in water, w is the apparent mass of the totally immersed sinker (if used) and of partially immersed in wire.

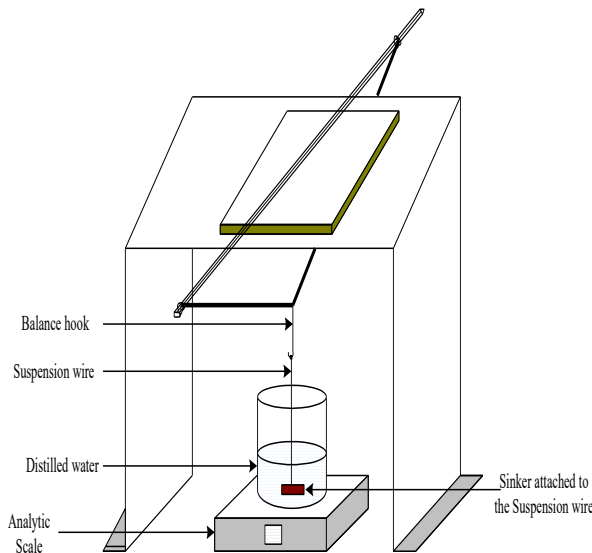


Fig.2. Density test setup

2.3.3 Water Absorption Test

The specimens for water absorption test were prepared according to the ASTM D570-10[21] guidelines. This test was conducted using the BFRP bars of 8mm and 10mm-diameters. The length of each specimen was 25.4mm. The specimens were dried in an oven at specific time and temperature and then cooled the specimens in a desiccators. Immediately, the conditioned weight of the specimen was noted. After, the conditioned specimens were immersed in distilled water for 24 hours (Figure 3). At the end of 24 hours, the specimens were removed from the water one at a time, all surface water wiped off with a dry cloth, and then wet weight of the specimen was noted. The percentage increase in weight during the immersion was calculated by using the following formula.

$$\text{Increase in weight, \%} = \frac{\text{Wet weight} - \text{conditioned weight}}{\text{conditioned weight}} \times 100 \quad (5)$$



Fig.3. Specimens immersed in distilled water

2.4 Mechanical Properties of BFRP bars

2.4.1 Tensile test

The tensile tests were carried out in accordance with ASTM D7205/D7205M-06[22] standards. 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. Figure 4 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.

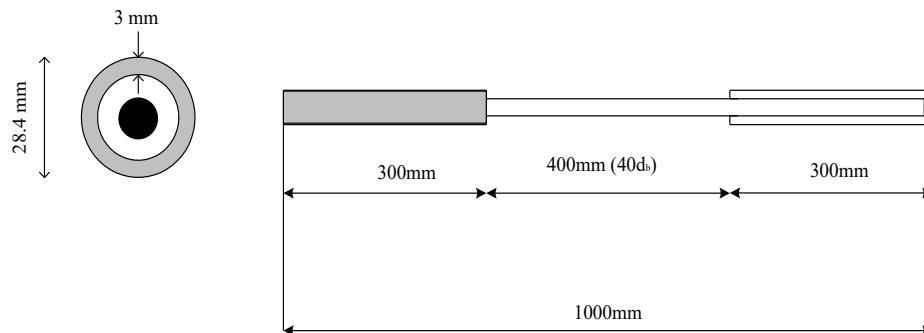


Fig.4. Geometry of tensile test specimens

The tensile tests were carried out by gripping the steel tube into the wedges of MTS testing machine that has a capacity of 1000kN. A loading rate of 250MPa/min was used during the test. An extensometer shown in Fig.5 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 (6) and (7) respectively.

$$F_{tu} = P_{max}/A \quad (6)$$

$$E = P_1 - P_2 / (\epsilon_1 - \epsilon_2) A \quad (7)$$

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(mm²). 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.



Fig.5.Tensile test setup

2.4.2 Short beam shear test

An inter-laminar shear strength of the BFRP bars were calculated by the short-beam testing method according to ASTM D4475-02[23]. The short beam shear tests were performed to assess the bond strength between resin and reinforcing fibres. The short- beam shear tests were carried out with a 500kN MTS testing machine. The ends of the BFRP bar rested on two supports as shown in Figure 6 .The load being applied by loading nose at midpoint along the supported span. The BFRP bar was tested at a rate of crosshead motion of 1.3mm/min. The inter-laminar shear strength of the BFRP bars was calculated by $S=0.849P/d^2$, where S is the inter-laminar shear strength (MPa), P is the breaking load (N), and d is the diameter of the BFRP bar (mm).



Fig.6. Short beam shear test setup

2.4.3 Compression Test

Compressive testing is especially useful for quality control and specification purposes. The compressive properties obtained according to ASTM D695-15[24] 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. Figure 7 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.7. Compression test setup

2.4.4 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 as shown in Figure 8.

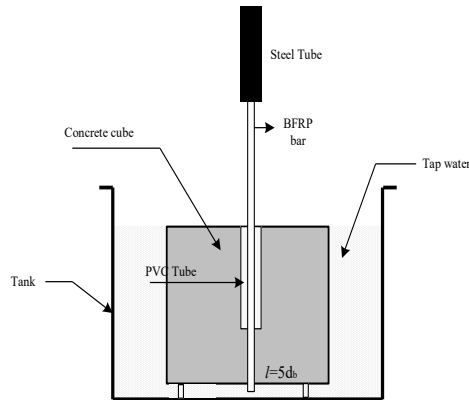


Fig.8. Geometry of the pullout specimens

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.

$$\tau = \frac{F}{C_b l} \quad (8)$$

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

$$s = s_L - s_F \quad (9)$$

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[25]. 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.

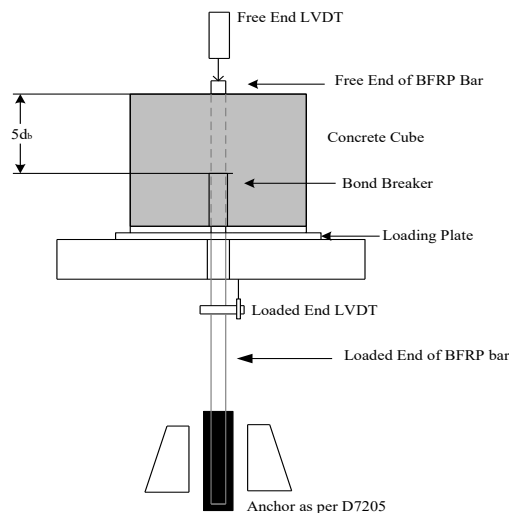


Fig. 9. Pull-out test setup

The pullout performed by pulling the steel tube at one end. Figure 9 shows 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.

III. Results and discussion

3.1 Physical properties of BFRP bars

3.1.1 Burn off test

Table 2 shows that the fiber content increased slightly with bar diameter, from 80.1% of fibers by weight for the 8mm bars to 83.0% for the 10mm bars. However, that the limits specified in CSA S807 (CSA 2010) for the fibre fraction by weight is only 70%. These results show that the complete fabricated composites are dominated by fibres in weight and volume composition, which also similar to the results obtained in previous study [11].

3.1.2 Density test

Density of the composite specimen completely depends on the relative proportion of fibre reinforcement and matrix. From the table 2. It can be seen that density of BFRP bar increase with increasing fiber content. On the other hand, the BFRP bars of 8mm and 10mm –diameters possess lighter densities such as 2044 and 2065 kg/m³ which is almost three times lesser than that of conventional steel bars.

3.1.3 Water Absorption Test

The maximum absorption of the BFRP bars of 8mm and 10mm- diameters after 24 h was 0.18% and 0.24%, respectively. For FRP reinforcing bars, the limit of water absorption after 24 h specified in CSA-S807 (CSA 2010) is 0.25%. The values at saturation are 1 and 0.75% (high durability) in ACI 440.6M (ACI 2008) and CSA-S807 (CSA 2010), respectively. This shows that the water absorption of the BFRP bars with different diameters is well within the allowable specified limit in current standards.

Table 2. Physical properties of tested BFRP bars

Property	Bar diameter	
	8mm	10mm
Fibre content (%)	80.1	80.3
Density(Kg/M ³)	2044	2065
Moisture uptake (%)	0.18	0.24

3.2 Mechanical properties of BFRP bars

3.2.1 Tensile test

The experimental tensile test results of BFRP bars were shown in Table 3. All BFRP bar specimens were failed in the gauge length due to rupture of fibres as shown in Figure 10. According to the tensile test results, the ultimate tensile strength and modulus of elasticity of the BFRP bars with a diameter of 10mm is slightly higher than the ultimate tensile strength and modulus of elasticity of the BFRP bars with a diameter of 8mm.



Fig.10. Failure of tensile specimens

According to the tensile stress and strain values collected in the experiment, the stress-strain curve of the BFRP bars are plotted (Figure 11). 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.

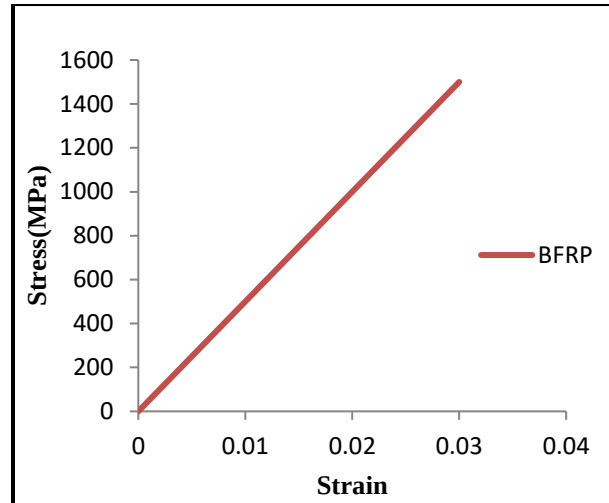


Fig.11. Stress –Strain curve of BFRP bars

3.2.2 Short beam shear test

The interlaminar shear strength of the BFRP bars were given in Table 3. The specimens failed in the form of interlaminar shear failure. Figure 12 shows an obvious local yield behaviour before the shear failure. The BFRP bars exhibited the highest interlaminar shear strength (60.4 MPa). The high value of interlaminar shear strength represents a better interface between the resin and reinforcing fibres.

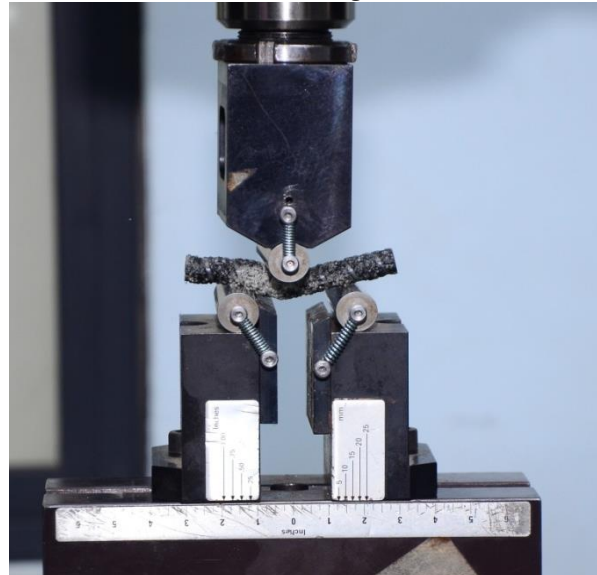


Fig.12. Specimen at failure

Table 3. Mechanical properties of tested BFRP bars

Property	Bar diameter	
	8mm	10mm
Tensile strength, f_u (Mpa)	1378	1475
Tensile modulus, E (Gpa)	48	50
Tensile Strain, ϵ	0.027	0.029
Interlaminar shear strength, S (Mpa)	53.2	60.4
Compressive strength, MPa	470.2	480.6
Bond strength, τ (Mpa)	16.9	17.3

3.2.3 Compression Test

The peak compressive stress of tested BFRP bars was given in Table 3. Typical failure mode of the BFRP bars under compression as shown in Figure 13. 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.



Fig.13. Typical failure mode

3.2.4 Pull-out test

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.

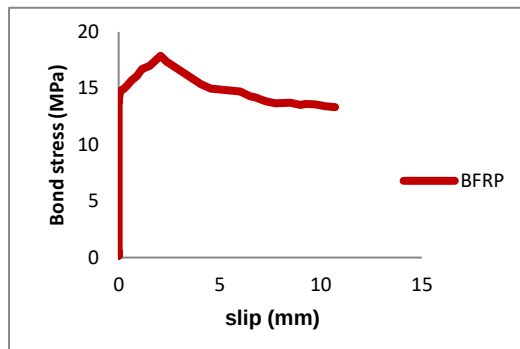


Fig.14. Bond stress-slip response of BFRP specimens

In this test, the bond stress and corresponding slip noted at both the loaded and unloaded ends of the BFRP bar. Fig.14. 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.

IV. Conclusion

In this study, the sand-coated BFRP bars of 8mm and 10mm-diameters were tested to exhibit their physical and mechanical properties. Based on the experimental test results, the following conclusions can be drawn. The basalt fiber content by weight of sand-coated BFRP bars were 80.1% and 80.3% respectively. The unit weight of sand-coated BFRP bars ranged between 2044 to 2065 kg/m³. The maximum water uptake of the BFRP bars were 0.18% and 0.24%. The ultimate tensile strength of the tested BFRP bars is about 1378 to 1475MPa, the elastic modulus is about 48 to 50GPa. The interlaminar shear strength of the tested BFRP bars showed a better interface between resin and reinforcing fibres. 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% higher than that of the conventional steel bars. Thus the sand-coated BFRP bars have proven its distinguished qualities throughout the present study.

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References

- [1] F.micelli and A.Nanni, "Tensile characterization of FRP rods for reinforced concrete structures,"*Mechanics of composite materials*, 39, pp293-304,2003.
- [2] B.Wei,H. Cao, S.Song, "Tensile behaviour contrast between basalt and glass fibres after treatment,"*Materials and design*, 31, pp 4244-4250,2010.
- [3] G.Wu, Z.Dong, X.Wang, Y.Zhu, Z.Wu, "Prediction of long term performance and durability of BFRP bars under the combined effects of sustained load and corrosive solutions,"*Journal of composites for constructions*, 19, 04014048/1-0401,2014.
- [4] P.Banibayat,A.Patnaik, "Variability of mechanical properies of basalt fiber reinforced polymer bars manufactured by wet-layup method,"*Materials and design*,56,898-906,2014.
- [5] A. Altalmas,A.El. Refai, F.Abed, "Bond degradation of basalt fiber-reinforced polymer (BFRP) bars exposed to accelerated aging conditions," *Construction and building materials*, 81,162- 171, 2015.
- [6] Y. Yang, Z. Li, T. Zhang, J. Weiand, Q. yu "Bond-Slip behaviour of basalt fiber reinforced polymer bar in concrete subjected to simulated marine environment: Effects of BFRP bar size, Corrosion age and concrete strength,"*International journal of polymer science*, 9, 2017.
- [7] J.Shi,X.Wing,Z.Wu,Z.Zhu, "Effects of radial stress at anchor zone on tensile properties of basalt fiber-reinforcedpolymer tendons,"*Journal of reinforcedplastics& composites*,1-13,2015.
- [8] Q.S.Khan,M..Sheikh,M..S.Hadi, "Tension and compression testing of fibre reinforced polymer(FRP) bars,"*The 12th International symposium of fibre reinforced concrete structures & The 5th Asia-pacific coferrence on fiber reinforced polymers in structures*,14-16,2015.
- [9] Z.Y Lu,G.J. Xian,H. Li, "Effects of elevated temperatures on the mechanical properties of basalt fibres and BFRP Plates", *Construction and building materials*, 127, pp1029-1036,2016.
- [10] 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
- [11] F.Elghabbas, 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.
- [12] A.Serbescu,M. Guadagnini, K.Pilakoutas, "Mechanical Characterization of basalt FRP rebars and Long-Term strength Predictive model,"*Journal of composites for constructions*, 12, 04014037 / 1-04014037/ 13,2014.
- [13] X.Fan,T.Xu,Z.Zhou,X.Zhou, "Experimental study on the mechanical properties of BFRP bars,"*Material science and Engineering*, 250,2017,012014.
- [14] 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.
- [15] J.Sim, C.Park, D.Moon, "Characterestics of Basalt fiber as a strengthening material for concrete structures,"*Composites: Part B*,36, pp. 504-512,2005.
- [16] W.Meng,H.Liu,X.Kong and X.Wang, "Bond-slip constitutive relation between BFRP bar and Basalt fiber recycled-aggregate concrete", *KSCE journal of civil engineering*,1-11,2015.
- [17] Z.Wang, X.L.Zhao,G.Xian, G.Wu, R.K.SinghRamanS.A.Saadi, "Durability study on interlaminar shear behaviour of basalt-,glass- and carbon-fibre reinforced polymer bars in seawaterconcrete environment," *Construction and Building Materials*, 156,985-1004, 2017.
- [18] W. Ge, J. Zhang, D .Cao,Y. Tu, "Flexural behaviours of hybrid concrete beams reinforced with BFRP bars and steel bars,"*Construction and Building Materials*, 87,28-37, 2015.
- [19] ASTM : D3171, "Standard test method for constituent content of composite materials,"*ASTM International*, 100 Barr harbor drive, PO Box C700, West Conshohocken, PA 19428-2959, United states, 2015.
- [20] ASTM : D792, "Standard test method for density and specific gravity (relative density) of plastics," *ASTM International*, 100 Barr harbor drive, PO Box C700, West Conshohocken, PA 19428-2959, United states, 2013.
- [21] ASTM : D570, "Standard test method for water absorption of plastics,"*ASTM International*, 100 Barr harbor drive, PO Box C700, West Conshohocken, PA 19428-2959, United states, 2010.
- [22] ASTM: D7205/7205M, "Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars,"*ASTM International*, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959: United States, 2006.
- [23] ASTM:D4475, " Standard Test Method for Apparent horizontal shear strength of pultruded reinforced plastic rods by the short-beam method," *ASTM International*, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959: United States, 2002
- [24] ASTM: D695,"Standard Test Method for compressive properties of rigid plastics," *ASTM International*, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959: United States, 2015.
- [25] ASTM: D7913/D7913M, "Standard Test Method for bond strength of fiber-reinforced polymer matrix composite bars to concrete by pull out testing," *ASTM International*, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959: United States, 2014.