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Basic Mechanical Properties of Sand-Coated BFRP BARS

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***Abstract**: Fibre reinforced polymer (FRP) bars have been widely used in structural engineering applications due to their high strength, light weight and excellent corrosion resistance. BFRP bar is a new kind of FRP material in which mechanical properties are not yet fully described. This paper presents an experimental study on the mechanical properties of sand-coated basalt fibre reinforced polymer bars. The following tests to determine the mechanical properties of sand-coated basalt fibre reinforced polymer (BFRP) bars of 8 and 10mm- diameters were conducted: barcol hardness, tension, and compression .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 properties*

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I. INTRODUCTION

In 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].

Several experimental investigations on mechanical properties of basalt fibre reinforced polymer bars were reported. Quagliarini et al. [8] 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. [9] 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^{o}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.[10] 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^{0}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. [11] 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.Sim et al.[12] 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 7days 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^{0}C for 2 h whereas the carbon and glass fibre did not retain their volumetric integrity.

This study aims to introduce the mechanical properties of sand-coated BFRP bars, considering barcol hardness, tensile strength, modulus of elasticity, 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
Mechanical properties		
Barcol Hardness	ASTM D2583-95	5
Tensile (N/mm^2)	ASTM D7205/D7205M-06	8
Compression (N/mm^2)	ASTM D695-10	5

2.3 Mechanical Properties of BFRP bars

2.3.1 Barcol Hardness test

The barcol impressor is used for measuring the hardness of both reinforced and non-reinforced rigid materials (Fig.2).BFRP specimens were prepared for barcol hardness test according to ASTM D2583 guidelines[14]. The BFRP specimen is placed under the indentor of the Barcol impressor and a uniform pressure is applied to the BFRP specimen until the dial indication reaches a maximum valve. The indentor must be consisting of a hardened steel truncated cone having an angle of 26^{o} with a flat tip of 0.157mm in diameter.

$$HBa = 100 - \frac{h}{0.0076} \qquad (1)$$

Where HBa- Barcol hardness valve,h - Indentation depth (mm),0.0076 - Indentation depth for one unit of barcol hardness.

Fig.2 Barcol Impressor

2.3.2 Tensile test

The tensile tests were carried out in accordance with ASTM D7205/D7205M-06[15] 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 3 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.

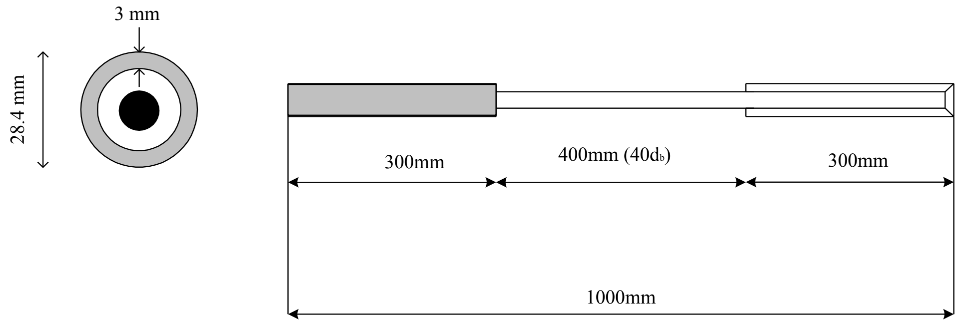

Fig.3. Geometry of tensile test specimens

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.4 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 (2) and (3) respectively.

$$F_{tu} = P_{max} / A \qquad (2)$$

$$E = P_1 - P_2 / (\varepsilon_1 - \varepsilon_2) A \qquad (3)$$

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.

Fig.4. Tensile test setup

2.3.3 Compression Test

Compressive testing is especially useful for quality control and specification purposes. The compressive properties obtained according to ASTM D695-15[16] 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.5. Compression test setup

III RESULTS AND DISCUSSION

3.1 Mechanical properties of BFRP bars

3.1.1Barcol Hardness test

All BFRP specimens were tested by barcol impressor. The hardness of the BFRP specimens of 8mm and 10mm-diameters possesses better valves such as 61 and 63HBa respectively. This is because of the strong interfacial bonding strength between the basalt fibre and resin which greatly increases the hardness of BFRP specimens.

3.1.2 Tensile test

The experimental tensile test results of BFRP bars were shown in Table 2. All BFRP bar specimens were failed in the gauge length due to rupture of fibres as shown in Figure 6.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.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 (Figure 7).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.

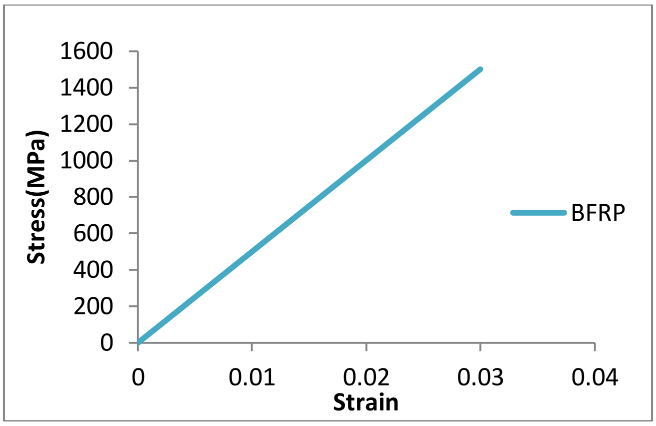

Fig.7 Stress –Strain curve of BFRP bars

Table 2. Mechanical properties of tested BFRP bars

Property	Bar diameter	
	8mm	10mm
Barcol Hardness,HBa	61	63
Tensile strength ,f_u (Mpa)	1378	1475
Tensile modulus,E(Gpa)	48	50
Tensile Strain,e	0.027	0.029
Compressive strength,(MPa)	470.2	480.6

3.1.3 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 Figure 8.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.8. Typical failure mode

IV. CONCLUSION

In this study, the sand-coated BFRP bars of 8mm and 10mm-diameters were tested to exhibit their mechanical properties. Based on the experimental test results, the following conclusions can be drawn.

The barcol hardness of the BFRP specimens possesses higher valves such as 61 and 63HBa respectively.The ultimate tensile strength of the tested BFRP specimens 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 Thus the sand-coated BFRP bars have proven its distinguished qualities throughout the present study.

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