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# Mechanical Characterization of Basalt Fibre Reinforced Polymer Bars for Reinforced Concrete Structures

**P.Thiyagarajan[1], V.Pavalan[2] and R. Sivagamasundari[3]**

*[1] Research scholar, Department of Structural Engineering, Annamalai University, Tamil Nadu, India.*

*[2]Research scholar, Department of Structural Engineering, Annamalai University, TamilNadu, India.*

*[3] Assistant Professor, Department of Structural Engineering, Annamalai University, Tamil Nadu, India.*

**Abstract**

The use of fibre reinforced polymer bars in concrete structures have been increased in the construction sector due to their excellent corrosion resistance, high tensile strength and lightweight characteristics .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 basalt fibre reinforced polymer bars of 8, 10 and 12 mm- diameters. The tensile, interlaminar shear and compression properties of these bars were tested according to ASTM D7205/7205M-06 (tension test), ASTM D4475-02(short beam shear test) and ASTM D695-15 (compression test) standards. The experimental test results showed that the BFRP bars have good mechanical behaviour than conventional steel bars.

**Keywords:**ASTM standards, BFRP bars,steel bars, mechanical characterization

## INTRODUCTION

In recent years, the fibre reinforced polymer (FRP) bars have been widely used in the construction fields owing to their excellent physical and mechanical properties compared to conventional steel bars. The typical internal and external reinforcements of FRPs are made from glass, carbon and aramid fibres [1].Glass fibre reinforced polymer (GFRP) and carbon fibre reinforced polymer (CFRP) are often used in concrete structures in place of conventional steel reinforcement. Nevertheless, these FRP materials are affected in high temperature and alkaline conditions. Thus, a plenty of research works have been performed on FRP reinforced concrete structures[2]. Basalt fibre based FRP (BFRP) bar is a new type of composite reinforced material and it has obtained broad attention in rehabilitation of concrete structures. Basalt fibres are made from basalt rocks by way of melting process. It is known that the basalt fibres have higher ultimate tensile strength than glass fibres.

Several experimental investigations on mechanical properties of basalt fibre reinforced polymer bars were reported.Sim et al.[3] 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.

Lu et al.[4] conducted the tensile tests on basalt fibre at elevated temperatures and found that the temperatures increasing from room temperature to $200^0$C, the ultimate tensile strength and modulus of elasticity was reduced by 8.3% and 9.7% for basalt fibre roving, respectively. The basalt fibre roving compared to glass fibre roving showed better tensile properties and temperature resistance. Elgabbas et al.[5] examined the physical, mechanical and durability characteristics of BFRP bars. The BFRP bars showed remarkable degradation and reduction in mechanical properties of alkali conditioned specimens. BFRP bar possess a better water resistance compared to alkali resistance. Quagliarini et al.[6] studied the tensile characterization of basalt fibre reinforced polymer rods. The experimental results confirm that the basalt FRP rods had good tensile strength compared to glass FRP rods. The stress-strain curves of the basalt FRP rods showed a linear behaviour until a fragile rupture.

Serbescu et al.[7] 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.Wei et al.[8] investigated the tensile behaviour of basalt and glass fibres after chemical treatment. They reported that the basalt and glass fibres damaged greatly in the HCl and NaOH solutions with a concentration of 2mol/l. The tensile strength of the basalt and glass fibres decreases with increasing treatment time. It seems that in the same acid environment the effect of the treatment time on the strength reduction of the basalt fibres is not as evident as that the glass fibres. As for alkaline environment, the variation of the strength with treating time is similar to each other for both the basalt and glass fibres.

Wu et al.[9] determined the tensile behaviors of BFRP and basalt yarn under four different strain rates (40, 80,120, and 160 $s^{-1}$) and four variant temperatures(25,50,75, and $100^0$C) using a drop-weight dynamic testing machine. The results revealed that BFRP has high tensile strength, maximum strain, and toughness, but lower modulus of elasticity than basalt yarn at the same strain rates, whereas BFRP has higher modulus of elasticity, tensile strength, maximum strain, and toughness than basalt yarn at elevated temperatures. Xiaochun et al. [10] studied the mechanical properties of BFRP bars. The results show that the tensile strength of BFRP bars is about 3 times higher than that of conventional steel bars, and the modulus of elasticity is about 1/5 of the conventional steel bars. In this paper, the tensile, inter-laminar shear, compression test results of sand coated BFRP bars are presented.

## EXPERIMENTAL PROGRAM

### Tensile test

The specimens for the tensile test were prepared according to the ASTM D7205[11] guidelines. The length of the tensile specimen was 1000mm.The free length between the steel tube anchors L was 400mm.A steel tube with an outside diameter $D_o$ of 28.4mm, inside diameter $D_i$ of 25.4mm, and $L_a$ =300mm was used.Fig.1&2 shows the BFRP tensile specimen and photograph of the BFRP bars. Steel plugs and PVC caps equipped with holes slightly larger than the bars of 8,10 and 12mm-diameters were used to close the ends of the steel tubes and to place the bar in the centre of the tube (Fig.3).The steel tubes and bars were placed vertically in the wooden frame for proper alignment. Then, the epoxy resin and hardener was used to fill the gap between the steel tubes and bars. After 24 hours, the first anchor was turned upside down and the same procedure was repeated for the second anchor. According to the specifications provided by resin manufacturers, the total setting time for both the anchors of a specimen was at 72 hours in typical indoor laboratory conditions.

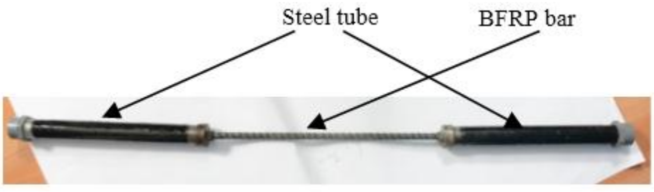



**Figure 1.** BFRP tensile specimen

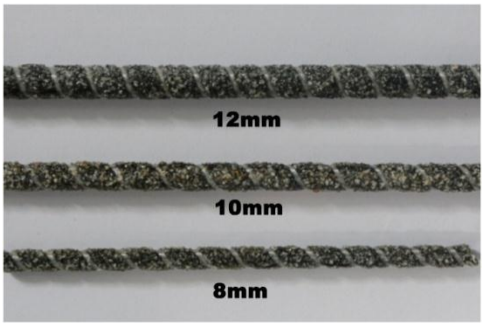



**Figure 2.** BFRP bars

**Figure 3.** Steel Plugs and PVC caps

The tensile test was conducted using a universal testing machine with a capacity of 1000kN at strength of materials laboratory, Department of civil & structural engineering, Annamalai University. The tensile specimen was fixed between two adjustable grips as shown in Fig.5.The loading rate was at 2mm/min until the failure of the tensile specimen. The tensile strength of the BFRP bars was calculated by the following formula.

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

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($mm^2$).

The elastic modulus was calculated by the following formula.

$$E = P_1\text{-}P_2/\,(\varepsilon_1\text{-}\varepsilon_2)A \quad (2)$$

Where E -elastic modulus (MPa);$P_1$- 50% maximum load(N); $P_2$ -20% maximum load(N)and $\varepsilon_1$ the strain corresponding to 50% of the maximum load; $\varepsilon_2$ the strain corresponding to 20% of the maximum load.


**Figure 4.** Tensile test set-up

### Short beam shear test

An inter-laminar shear strength of the BFRP bars was calculated by the short-beam testing method according to ASTM D4475-02[12].The short beam tests were performed to assess the bond strength between resin and reinforcing fibres. The specimens of BFRP bars with 8,10 and 12mm diameters were tested.Fig.4. shows the short beam shear test specimen.

**Figure 5.** Short beam shear test specimen

The short- beam tests were carried out with a 500kN MTS testing machine. The ends of the BFRP bar rested on two supports as shown in Fig.2 .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,

$$S = 0.849P/d^2 \qquad (3)$$

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).

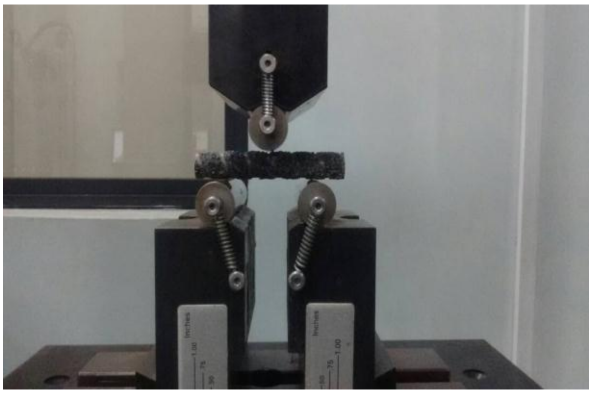


**Figure 6.** BFRP bar in the MTS testing machine

### Compression Test

Compressive testing is especially useful for quality control and specification purposes. The compressive properties obtained according to ASTM D695[13] standards cannot be used for design purposes. The length of the compressive specimen was twice the diameter of the BFRP bar.

For the compression test, the specimen was placed axially between the platens of the compression testing machine. The load was applied at the uniform rate till the specimen fails and the failure load was noted from the dial indicator, the load dial gauge was adjusted to read zero before the load application. Fig.7 shows the typical test setup for compression. The compressive strength can be determined by,

$$\text{Compressive strength} = P_{max}/A \qquad (4)$$

Where $P_{max}$ is Maximum applied force (N), A = Cross-sectional area of the bar ($mm^2$).


**Figure 7.** Compression test setup

## RESULTS AND DISCUSSION

### Tensile test

The experimental test results of BFRP bars and steel bars were shown in Table 1. All of the BFRP specimens failed in the gauge length due to rupture of fibres whereas the steel specimens failed with a cup and cone geometry as seen in figure 8.According to the tensile test results, the ultimate tensile strength of the BFRP bars is about 3 times of conventional steel bars, and the elastic modulus is about 1/4 of the conventional steel bars. The ultimate tensile strength and the elastic modulus of BFRP bars varies little with the increase of diameter.

**Table 1.** Tensile test results of BFRP and steel bars

| Specimen ID | Peak Tensile load [kN] | Peak Tensile Extension [mm] | Ultimate Tensile Strength [MPa] | Elastic modulus [GPa] |
|---|---|---|---|---|
| BFRP-8 | 68.3 | 19.6 | 1362.3 | 48.0 |
| BFRP-10 | 114.8 | 38.9 | 1461.6 | 50.3 |
| BFRP-12 | 179.2 | 40.3 | 1585.6 | 52.0 |
| STEEL-12 | 66.2 | 37.4 | 590.8 | 200 |

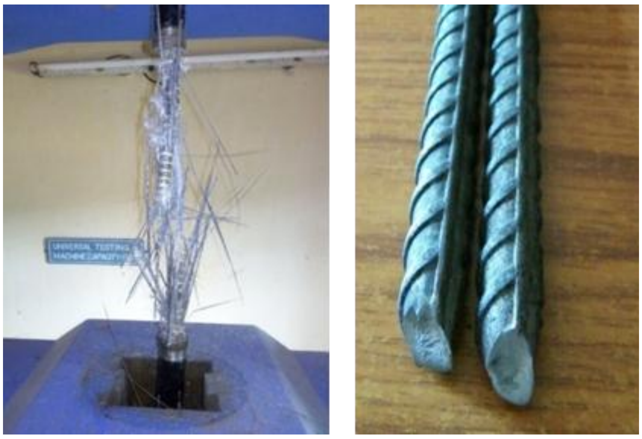
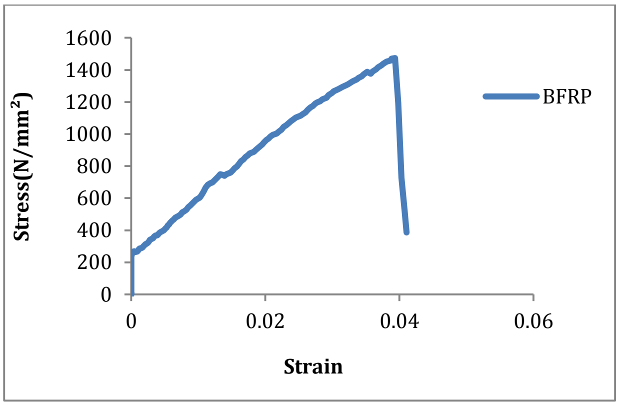


**Figure 8.** Typical failure modes of BFRP and conventional steel bars



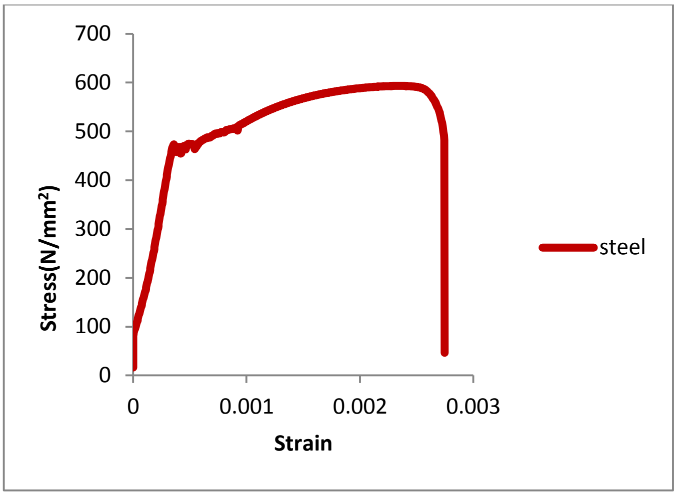




**Figure 9.** Stress-strain curve of BFRP and Conventional Steel bars

From the figure 9, 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. The stress-strain curve of the conventional steel bars beyond the elastic portion, yielding occurs at the beginning of plastic deformation.

### Short beam shear test

The interlaminar shear strength of the BFRP bars were given in Table 2. The specimens failed in the form of interlaminar shear failure as shown in figure 10. The BFRP bars exhibited the highest interlaminar shear strength (53.2MPa).The high value of interlaminar shear strength represents a better interface between the resin and reinforcing fibres.

**Table 2.** Short beam Shear Test Results

| Specimen ID | Peak Load (kN) | Interlaminar Shear strength (MPa) |
|---|---|---|
| BFRP8 | 3.1 | 40.8 |
| BFRP10 | 5.5 | 47.0 |
| BFRP-12 | 7.4 | 53.2 |

**Figure 10.** Specimens at failure

**Compression test**

The peak compressive load and deformation of tested BFRP bars were given in Table 3.The typical failure mode of the BFRP bars in compression as shown in Figure 11. It is observed that the failure of BFRP bars occurred due to crushing of longitudinal fibres.It was found that the compressive strength is two times lesser than the tensile strength of the BFRP bars.

**Table 3.** Compression test Results

| 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 |
| BFRP-12 | 56.3 | 0.51 | 495.3 |

**Figure 11.** Failure mode

## CONCLUSION

The salient conclusions have been drawn based on test data obtained in this paper:

In this study, the ultimate tensile strength of the tested BFRP bars is about 1360 to 1585 MPa, the elastic modulus is about 48 to 52 GPa.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.

## ACKNOWLEDGEMENT

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