Compressive strength behaviour of glass fibre reinforced blast furnace slag-based material

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ABSTRACT: This paper explains the effective utilisation of Blast furnace slag (BFS) in civil engineering applications, in a direction to reduce its dumping which causes environmental pollution and also to save conventional materials for sustainable development. The proposed material was made by blending BFS and glass fibre (GF) with a binder such as ordinary Portland cement. GF used in the experimental study was of three different aspect ratios (AR) 461, 922 and 1844. For each aspect ratio experiments were performed by adding GF by 0.3, 0.6, 0.9 and 1.2% by weight with respect to BFS. The cement to blast furnace slag (C/BFS) ratio is taken 10% for the present study. The compressive strength of the newly developed material was evaluated after curing of 7, 14 and 28 days respectively. The effect of various mix ratios on the density, compressive strength and initial tangent modulus was studied and results are incorporated. The test results show that the density of geomaterial reduces marginally with the addition of GF from 0.3 to 1.2%. For all the aspect ratios and curing periods the mix ratio, 0.6% had shown maximum value for compressive strength. For all the mix ratio and curing period the mix made with GF aspect ratio 922 shown the maximum compressive strength. The initial tangent modulus value was found, maximum for 0.6% mix ratio and aspect ratio 922. A nonlinear relationship was found between compressive strength and mix ratios.

Keywords: Blast furnace slag, Sustainable development, Glass fibre, Aspect ratio, Compressive strength

1 INTRODUCTION

Nowadays, due to rapid civilization all over the world, the use of conventional material like sand, muroom and aggregate is increasing day by day for the construction work. Due to rapid infrastructural growth, there has been the shortage of conventional materials; this tends to increase the cost of conventional materials, which ultimately increases the cost of construction. Moreover, the rapid industrialization in the world has resulted in the generation of large quantities of wastes. A large quantity of the wastes does not find any effective use and create environmental and ecological problems apart from occupying the valuable cultivable land. In the study by the Central Pollution Control Board (2006), the fly ash and slag are the major waste in India. The slag generated by iron and steel industries is 14 million tonnes per annum in which 10 million tonnes per annum is Blast Furnace Slag (BFS) and 4 million tonnes per annum is steel slag. At the global level, it is estimated that 240 million tonnes of BFS are generated worldwide (Solific et al. 2012). The proposed paper is a step-in to use the BF slag in more effective way.

1.1 *Blast furnace slag*

The slag produced during pig iron manufacture is called Blast Furnace Slag (BFS). Usually, the BFS is used in the cement manufacturing process and in other unorganized work, such as landfills and railway ballast. A very small quantity is also used by the glass industry for making slag wool fibres. BFS is used in Portland cement manufacture due to its pozzolanic property (Indian Mineral Yearbook 2016). Using BFS as an admixture enhance the engineering properties of the expansive soil (Manjunath et al. 2012). In an experimental program, it was found that the BFS blended with soft soil to a certain percentage increases the unconfined compressive strength of soft soil (Yadu and Tripathi 2013). The BFS based cement mortar shows slow but equal strength as compare to Portland cement based mortar (Barnett et.al. 2006).

1.2 *Glass fibre*

Glass fibres are produced in a process called fiberization, in which molten glass is drawn in the form of filaments, through the bottom of a heated platinum tank or bushing (Wallenberger et al. 2001). Glass fibres exhibit useful properties such as hardness, transparency, resistance to chemical attack, stability, and inertness, as well as desirable fibre properties such as strength, flexibility, and stiffness (Bentur and Mindess 2007). Due to their properties, it is proposed to use glass fibres for reinforcement in the experiment. Cement matrix is highly alkaline in nature and conventional glass fibres were found vulnerable to alkaline environment. To reduce this effect, in 1967 the scientists of the United Kingdom Building Research Establishment (BRE) formulated an alkali resistant glass fibre (ACI Committee 544 1996). Since, the cement was used for binding in the present experimentation; therefore, the alkali resistant glass fibre was used for reinforcement. Fibre reinforcement technique found to increase the material strength of composites by many researchers (Cristelo et. al. 2017, Kaniraj and Gayatari 2003, Dwight 2000).

This paper mainly focuses on the compressive strength behavior of newly developed Glass Fibre Reinforced Blast Furnace Slag (GFRBFS) based material prepared by mixing glass fibre, blast furnace slag and a binder such as cement. The effect of different mix ratios, aspect ratios and curing period on the compressive strength, density and initial tangent modulus were studied and incorporated. The prepared GFRBFS material is light weighted than the conventional fill material. Therefore, the prepared GFRBFS can be used where conventional fill material causes excessive overburden pressure resulting settlement, also it can be used as backfill for bridge abutments and retaining walls, which do not yield. The GFRBFS can be used in place of Expended Polystyrene (EPS) geofoam block also. Since, the EPS geofoam blocks cannot be used to fill irregular shapes, volumes and site prerequisites. The GFRBFS can provide better solution in terms of strength and stiffness.

2 MATERIALS

2.1 *Glass fibre*

The glass fibre used as reinforcement material in present study was procured from Danish Doogaji Solution Ltd., Nagpur, Maharashtra, India. Table 1 gives the physical properties of the glass fibre obtained from the manufacturer. The bulk densities of glass fibre with different aspect ratios were found according to ISO 10119-2 by Pycnometer method.

Table 1. Density of glass fibre

Aspect Ratio	**Bulk Density (Kg/m^3)**
461	826
922	892
1844	1032

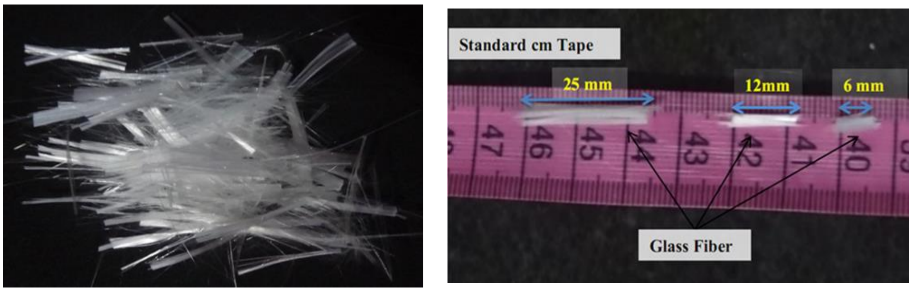

Figure 1. (a) Glass fibre photograph (b) Lengthwise classification of glass fibre

2.2 *Blast furnace slag*

Blast furnace slag was procured from Bhilai steel plant (Bhilai, Chhattisgarh, India) and used as primary material in the present study. The physical properties are given in Table 2.

Table 2. Blast furnace slag properties

Property	Value
Specific gravity	2.24
D_{10} (mm)	0.10
D_{60} (mm)	0.25
Uniformity coefficient (C_u)	1.56
Coefficient of curvature (C_c)	1.00
Dry unit weight (KN/m^3)	13.2
Optimum moisture content (%)	10

2.3 *Cement*

Commercially available Ordinary Portland Cement (OPC) grade 53 was used in the experiment as a binder. The density of cement was 1.429 gm/cc found according to ASTM C188-95.

3 EXPERIMENTAL PROGRAM

In this experimental study, the effect of inclusion of glass fibre on density, compressive strength and initial tangent modulus of newly developed material was investigated. A series of compressive strength test were performed on GFRBFS based material for different mix ratios, aspect ratios and curing periods. A cylindrical specimen of 75 mm diameter and 150 mm long was used for testing.

3.1 *Mix ratios and specimen preparation*

In the present study, the mix ratio is defined as the ratio between weight of glass fibre and BFS. The mix ratios 0.3, 0.6, 0.9 and 1.2% was adopted for the present study. For each mix ratio, three different mixes with three different glass fibre aspect ratio AR 461, 922 and 1844 were prepared. Table 3 gives the mix ratios and material percentages used to prepare GFRBFS based material. Each sample is cured for 7, 14 and 28 days. The materials calculations are based on previous research works (Ram Rathan Lal and Badwaik 2015, Ram Rathan Lal and Nawkhare 2016). To determine the material for desired mix ratio, the volume of specimen (V_s) is taken equal to sum of volume of slag (V_{slag}), volume of cement (V_{cmt}) and volume of glass fibre (V_{gf}). The V_{slag} is taken equal to $\Upsilon_{slag}.W_{slag}$, where, Υ_{slag} is dry density of BFS and W_{slag} represent the weight of BFS. The V_{cmt} is taken equal to $\Upsilon_{cmt}.W_{cmt}$, where, Υ_{cmt} is dry density of cement and W_{cmt} represent the weight of cement.

Table 3. Mix ratios and material percentage

Mix ratio (%)	Aspect ratio	Cement content (%)	Water content (%)
0.3	AR 461, AR 922, AR 1844	10	10
0.6			
0.9			
1.2			

The addition of the glass fibre in BFS matrix is done, as per the method followed by previous research work (Kaniraj and Gayathri 2003). According to which fibre should be added after preparing wet mix of BFS and cement. This process would avoid the clumping of fibre together at one place. Figure 3(a) shows the dispersion of fibre over wet BFS mix. To measure ingredient accurately, weighing was done with the help of an electronic weighing balance having accuracy of 0.01 g. After mixing to desired mix ratio, the cylindrical moulds of 75 mm dia and 150 mm long were filled in three consecutive layers followed by manual compaction in accordance to the ASTM D 698. Thereafter, the filled moulds were left for 24 hours at an ambient condition for setting. After 24 hours, the specimens were removed from the moulds and cured in water filled tank for 7, 14 and 28 days respectively. Figure 2(b) shows the curing of the specimens.

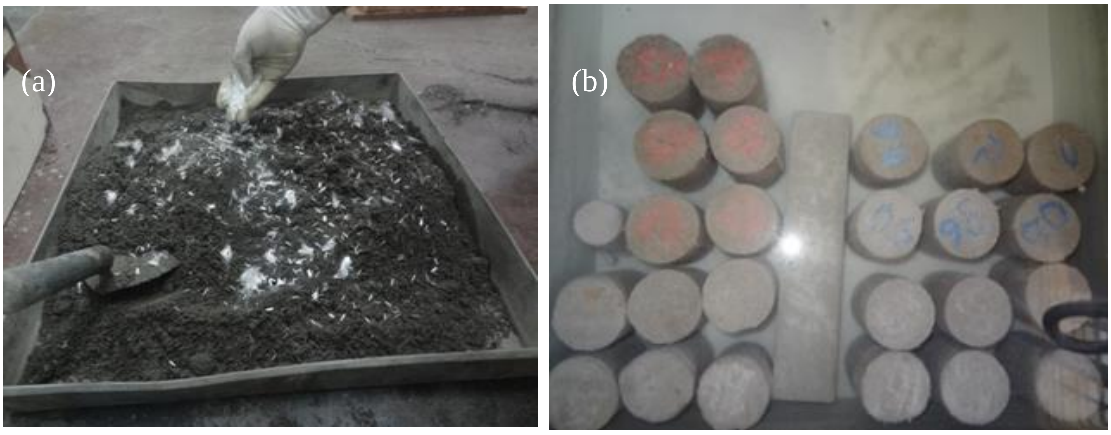

Figure 2. (a) Dispersion of glass fibre over wet BFS mix (b) Curing of compression specimen

3.2 *Test procedure*

After curing the specimens were air dried and weighted. The compressive test was performed over every specimen to measure their compressive strength. The test was conducted at a constant displacement rate of 0.12 mm/min, over a compression machine accommodating a cylindrical specimen of size 75 mm dia and 150 mm long. To measure compressive load and displacement of specimen, a load cell and Linearly Varying Displacement Transducer (LVDT) was used respectively. The values of load and displacement were recorded in a data logger which was calibrated before use. For a particular mix ratio, aspect ratio and curing period two test specimen were prepared. Likewise, all total 78 cylindrical specimens were prepared including the unreinforced specimens.

4 RESULTS AND DISCUSSION

The effect of mix ratio, aspect ratio of glass fibre and curing periods on density, compressive strength, stress strain relationship and initial tangent modulus were discussed in this section. Before that the failure pattern of the GFRBFS under compressive load test is discussed.

4.1 *Density*

The density of unreinforced compression specimen was found to be 1329 kg/m^3. The density of GFRBFS based material found to affect by the mix ratio and aspect ratio of glass fibre. Figure 3 (a) shows the variation of density with respect to mix ratios. The variation of density with mix ratio found to declining linearly with the increase in the mix ratio. Figure 3(b) shows the variation of density with aspect ratio of glass fibre. It has been observed that the density of GFRBFS based material decreases linearly with increase in aspect ratio. Overall the density found to vary from 1321 to 1328 kg/m^3 depending upon the mix ratio and aspect ratio. The density ranges 1700 to 1900 kg/m^3 for conventional fill material found by previous researcher (Liu et. al. 2006). The density range of new developed material was found to be lower than the conventional fill material. The GFRBFS based material can be used in the places where overburden pressure of conventional fill material cause settlement problem.

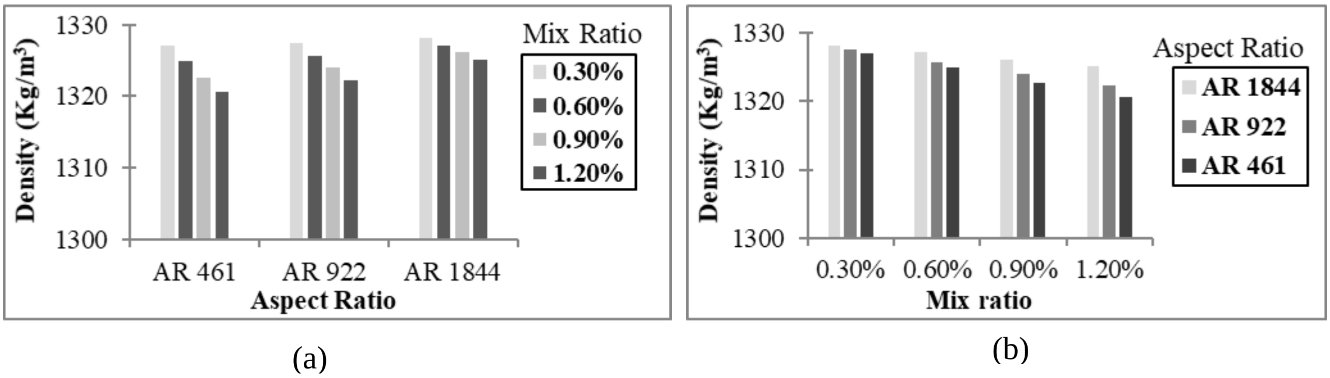

Figure 3. (a) Density variation with mix ratios (b) Density variation with aspect ratios

4.2 *Failure pattern*

The failure patterns of GFRBFS cylinders under compressive loading are shown in Figure 4. Specimen under compressive load found to fail through cracks develops in vertical direction and diagonal direction.

Figure 4. Failure pattern under compressive strength test

4.3 *Compressive strength*

The result of compressive strength test on GFRBFS based material found to be effected by the mix ratios, glass fibre aspect ratio and curing period. Figure 6 shows the variation of compressive strength of compression specimen with respect to mix ratio, aspect ratio and curing period. It was observed that the compressive strength varies non-linearly with mix ratios for all the aspect ratios. The higher value of compressive strength was observed at 0.6% mix ratio for all the aspect ratios and curing periods. The similar kind of behavior was observed in case of fibre reinforced sand (Gray and A1-Refeai 1986, Maher and Gray 1990).

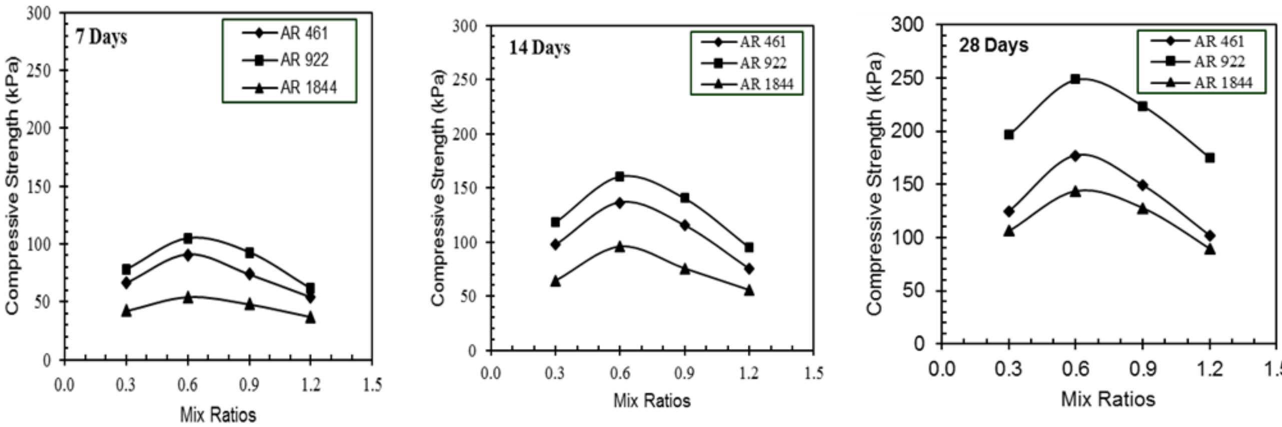

Figure 5. Compressive strength with to mix ratios, aspect ratios and curing period (a) 7 Days (b) 14 Days and (c) 28 Days

4.4 *Stress strain pattern*

The 28 days stress-strain diagrams were shown in figure 7. The ductility of unreinforced BF slag found to increase with increase in volume content of glass fibre up to a certain level. Beyond that the ductility of GFRBFS found to decline below the unreinforced BFS.

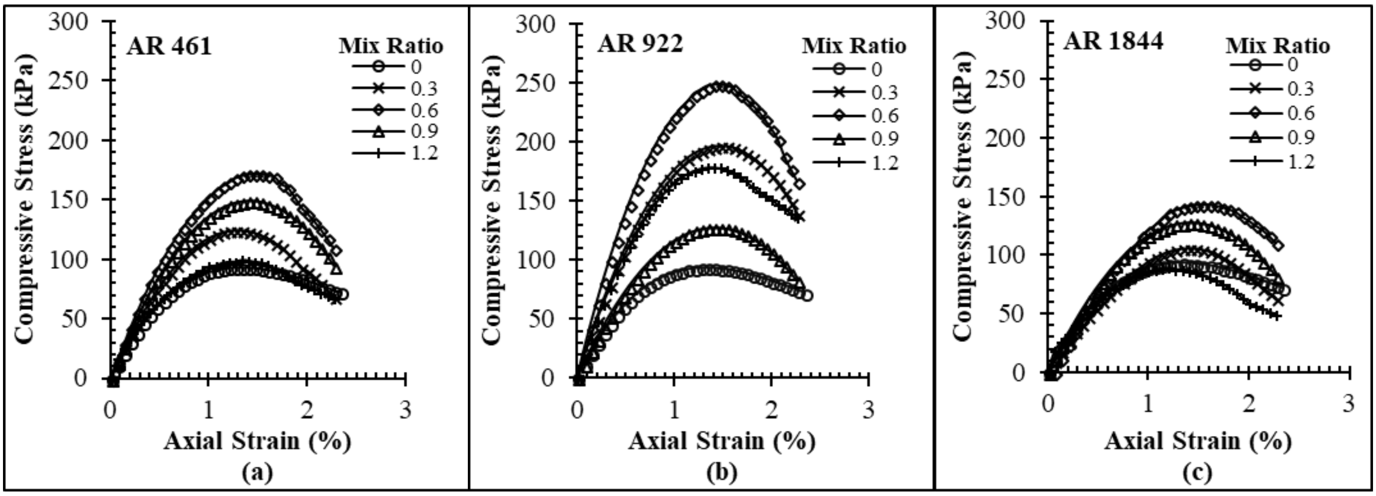

Figure 6. Stress strain curve for compressive strength test result after 28 days of curing (a) AR 461 (b) AR 922 (c) AR1844

4.5 *Initial tangent modulus*

The initial tangent modulus (Ei) was plotted and shown in figure 6. The compressive strength of GFRBFS found to increase with the initial tangent modulus. The value of Ei ranges from 67 to 315 MPa. This value is lower than the Ei (79-555 MPa) for lightweight fill material found by Liu et al. (2006).

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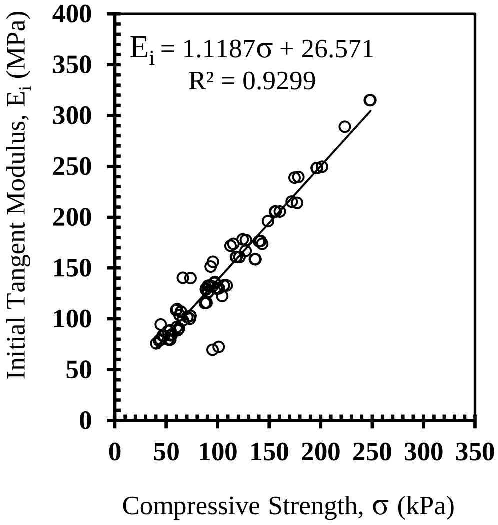

Figure 7. Initial tangent modulus

5 CONCLUSION

Main conclusions of the present work briefly mentioned below.

1. The density of GFRBFS material decreases with increase in mix ratio for all the aspect ratios. With decrease in aspect ratio density of GFRBFS material also decreases. The density value ranges from 1321 to 1328 kg/m3.
2. The compressive strength of unreinforced BF slag found to increase by reinforcement of glass fibre. The strength of GFRBFS material varies non-linearly with increase in mix ratio and aspect ratio. Maximum compressive strength was found for mix ratio 0.6% and AR 922.
3. Non-linear relation observed between stress and strain. All the specimens found to fail in strain ranging from 1.00 to 1.53%. The ductility found to increase with addition of glass fibre in BF slag.
4. The initial tangent modulus increases with compressive strength for GFRBFS material. The value of E_i found to vary from 67 to 315 MPa.

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