Compressive and Flexural Behaviour of Glass Fibre Reinforced Blast Furnace Slag Based Material

Daipayan Mandal and B. Ram Rathan Lal

Abstract For sustainable development, conventional fill material required to be replaced by industrial by-products. In this experimental work, Blast Furnace (BF) slag was used as a base material to develop a new material which could replace the use of conventional fill material in civil engineering works. To achieve the aim the BF slag was blended with cement, glass fibre and water. The mix consists 10% cement by dry weight of BF slag and the optimum water content of BF slag. The mixture of slag-cement was reinforced with glass fibres in four different mix ratios of 0.3, 0.6, 0.9 and 1.2%. For each mixing ratio three different aspect ratios (AR) 385, 769 and 1154 of glass fibre were used. The glass fibre reinforced blast furnace slag based material was then moulded into cylinders and beams. The size of cylinder and beam specimen, used in the experimental study was 75 mm diameter 150 mm long and 50 × 50 × 400 mm respectively. The specimens were then cured for 7, 14 and 28 days curing under room temperature. The effect of mix ratios, aspect ratio and curing periods on density, initial tangent modulus, stress–strain relationship, compressive and flexural strength were studied and results were incorporated in the paper. The relationship between the mix ratio and both compressive, flexural strengths was found to be non-linear. The specimens reinforced with AR 1154 glass fibre yield higher compressive strength at 0.6% mix ratio, and flexural strength at 0.9% mix ratio.

Keywords Blast furnace slag · Mix ratio · Glass fibre

1 Introduction

From many past years, humans continuously exploit natural resources to meet their needs without taking much concern about future sustainability. Exploitation of natural resources and the urge for rapid growth in society leads to the scarcity

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of natural resources and increased the cost of raw materials. In the construction sector, the rapid construction growth raises the scarcity of raw material required for the construction. Sand and gravel are the most primary inputs and are most extracted material worldwide causing scarcity of these materials in construction [1]. On the other hand, the rapid industrialization in and around the world generated a huge amount of industrial by-products (e.g. slag, fly ash, bottom ash, marble, etc.). These industrial by-products have a threat to the environment since the industrial by-products were so harmful that they cause a serious health hazard to humans. The past reports of many researchers show that for the sustainable development, the conventional fill material (like sand, mushroom, etc.) used in civil engineering applications can be replaced by the industrial by-product [2]. Using the industrial by-product as a replacement of conventional material found to cut the cost of construction and saves the natural resource [3]. This idea motivated many researchers in the past to replace conventional fill material by industrial by-product such as fly ash, bottom ash, slag.

Blast Furnace Slag (BFS) is a by-product of the manufacture of iron by the reduction in a blast furnace. The slag is formed by the fusion of limestone (and/or dolomite) and other fluxes with the ash from coke and the siliceous and aluminous components of the iron ore burden. The slag floats on the surface of the molten iron and is separated when the furnace is tapped [4]. According to the Indian Bureau of mines reports in India 2.4 million tonnes BF slag was produced annually. It is an inorganic material contains mainly oxide of silicon, calcium, magnesium, iron and aluminium. According to the Indian Bureau of Mines, the BF slag can be divided into air-cooled, granulated and expanded blast furnace slag mainly depending on the method used for cooling the hot molten slag. Most of the BF slag produced in India used by the cement industries. Further consumption of BF slag was a matter of concern [5]. In 1994 Mantel [6] investigated the hydraulic activity of five different blast furnace slags with eight different Portland cement. The author found that the hydraulic activity of slag is mostly predominated by the particle size distribution and percentage of glass in slag.

Fibre reinforcement is an effective and reliable technique of improving the strength and stability of geotechnical materials. The technique is used in a variety of application from retaining structures and embankments to stabilization beneath footings and pavements. The fibre reinforcement technique was found to be effective for improving the mechanical property of cohesive and non-cohesive soil [7]. Randomly distributed fibres in compacted fine-grained soil results in greater strength and toughness. The fibre reinforcement is significant in both engineering practice and nature. A soil reinforced with natural fibres or plant roots contributes to the shear strength of soils and stability of natural slopes.

Commodity or general-purpose fibres are called E-glass. They are characterized by universal applicability, large sales volumes and low unit cost. They represent 99% of the commercial glass fibre market [8]. The alkali-resistant glass fibre in comparison to other types of glass fibre gives better durability with the Portland cement matrix [9]. Since ordinary Portland cement was used for binding the mix in the present study, an alkali-resistant type glass fibre was used for the reinforcement in the present study.

In the present study, blast furnace slag and cement were mixed together. By incorporating the glass fibre in different percentage (mix ratios) and aspect ratios in the mix the mechanical behaviour of mix under compressive and flexural load was studied. The variation in densities, compressive strength and flexural strength with respect to variation in mix ratios and aspect ratios was analyzed and results are incorporated. The pattern of failure, stress–strain curve and load–deflection curve was also studied and discussed.

2 Materials Characterization

2.1 Blast Furnace Slag

Blast furnace slag was procured from Bhilai steel plant (Bhilai, Chhattisgarh, India) and used as the primary material in the present study. The specific gravity of the BF slag used in the experimental study was 2.24. The proctor test result shows that the BF slag had maximum dry unit weight is 13.2 kN/m^3 and Optimum Moisture Content (OMC) 10%. The coefficient of uniformity is 1.56 and coefficient of curvature is 1.00 represents a poorly graded material.

2.2 Glass Fibre

The glass fibre used as reinforcement material in the present study was procured from Danish Doogaji Solution Ltd., Nagpur. Figure 1 shows the photograph of glass fibre. The physical properties were obtained from the manufacturer. It is an alkali-resistant type glass fibre. The specific gravity of fibre is 2.7; the filament diameter is 13 microns. The ratio of length to the diameter of fibre filament is termed as Aspect Ratio (AR) in the present study. Therefore, three different aspect ratios of glass fibre were chosen for the experiments which are 385, 769 and 1154.

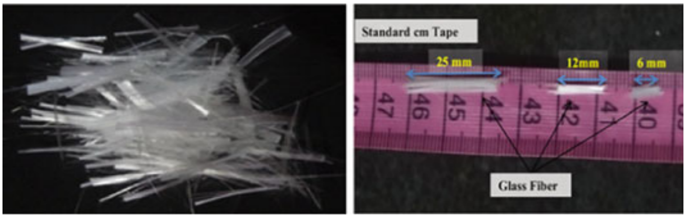


Fig. 1 Photograph of glass fibre

2.3 Cement

Ordinary Portland Cement (OPC) grade 53 was used for binding the BF slag and glass fibre together. The cement was procured from the local vendor at Ramtek, Nagpur. The bulk density of cement is 1429 kg/m^3.

3 Experimental Programme

3.1 Mix Ratios and Specimen Preparation

The ratio between the weight of glass fibre and weight of slag is termed as mix ratio and in the present study they are expressed in terms of percentage. The mix ratios considered were 0.3, 0.6, 0.9 and 1.2%. For each mix ratio three different aspect ratio of glass fibre 385, 769 and 1154 were used. The material calculation for mix ratio was based upon previous research works [10]. After weighing, the mixing of material is done by hand with the help of a trowel. First the slag and cement were blended together and then water was added equal to OMC (10%). Mixing technique was taken from Kaniraj and Gayathri [11]. After, mixing the materials together the mix was filled into metallic cylindrical moulds of 150 mm long and 75 mm diameter in three layers. Each layer is compacted well before filling the next layer. After that the moulds were left for 24 h at room temperature for setting. Thereafter, the 24 h the specimen were removed from the mould and put into the curing tank for 7, 14 and 28 days curing, respectively. For flexural test beams were moulded using the same procedure. The mould used for casting the 400 × 50 × 50 mm beam specimens. All total 78 cylindrical and 78 beam specimens were prepared for the test experiment and cured for 7, 14 and 28 days. Figure 2 shows the specimens and moulds used.

Fig. 2 Photograph of moulds and specimens used in the experiment

3.2 Experimental Procedure

To measure the compressive strength and flexural strength the test was performed after the concerned curing period. Two specimens for each curing period were taken out of curing tank and kept for air drying. Thereafter, the weight of the specimens was taken with the help of a digital weighing machine. Next, the loading frame of 50 kN capacities was prepared to perform the test. A load cell and Linearly Varying Displacement Transducer (LVDT) was calibrated and assembled with the load frame to measure the applied load and respective displacement of the specimen while testing. For compression test the strain rate was set to 0.12 mm/min and for flexural test strain was reduced to 0.012 mm/min since during experimentation it was found that the beam specimen fails quickly initially under higher strain rates. The test data were obtained from the experiment and results were incorporated. To check the reproducibility of specimens for each mix ratio, aspect ratio and curing period, two specimens were prepared and tested. The repeatability of the test results was encouraging with 3–6% deviation.

4 Results and Discussion

4.1 Failure Pattern

The failure pattern under compressive and flexural load was observed and interpreted in this section. Under compressive load it was observed that the specimen with lower fibre content tends to develop vertical cracks parallel to the direction of the applied load. Figure 3a, b show the failure pattern of specimens having low fibre content. When the fibre content was increased in the specimens than it was observed that cracks propagate in a transverse direction in the specimen. Figure 3c, d show the failure of the specimen with high fibre content. This type of failure shows increase in ductility in GFRBFS based material with the inclusion of fibre. Under flexural load

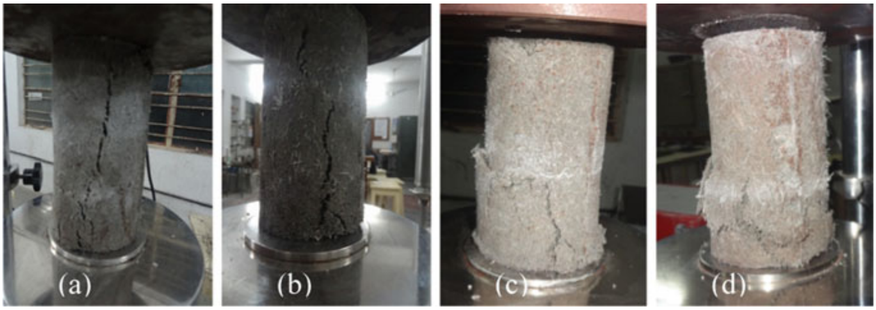


Fig. 3 Failure pattern of specimens under compressive loading

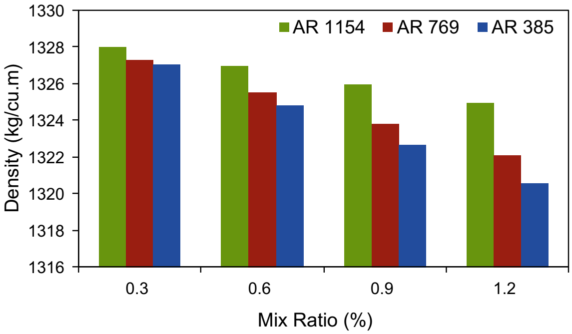
Fig. 4 Failure pattern of specimens of flexural loading

the beam specimen found to develop vertical crack parallel to the direction of the applied load. Figure 4 shows the broken beam specimens failed under flexural load. It was observed that in all specimens cracks develop at bottom of beam first then propagate to the upper side. The failure pattern satisfies the usual failure pattern of a beam under flexural.

4.2 Density Pattern

The density of GFRBFS based material found to affect by the mix ratio and aspect ratio of glass fibre. Figure 5 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. Overall the density found to vary from 1321 to 1328 kg/m^3 depending upon the mix ratio and aspect ratio. The denthesity ranges 1700–1900 kg/m^3 for conventional fill material found by the previous researcher [12]. The density range of the newly developed material was found to be lower than the conventional fill material.

Fig. 5 Density variation with respect to mix ratio



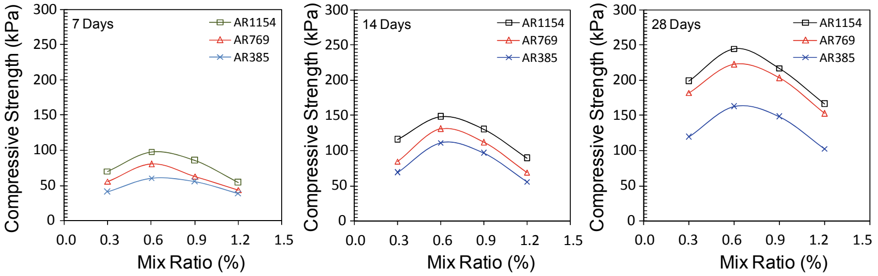


Fig. 6 Variation of compressive strength with respect to mix ratio for three different aspect ratios

4.3 Compressive Strength

The compressive strength was determined from the stress–strain curve. The peak stress from the stress–strain curve was taken as compressive strength. The unreinforced specimen shows failure at lower strain as compared to reinforced blast furnace slag. All the specimens fail in strain varying from 1.07 to 2.53%. Figure 6 shows the variation of compressive strength of GFRBFS based material for different mix ratios, aspect ratios and curing periods. The compressive strength varies non-linearly with respect to mix ratio. The maximum compressive strength was found for 0.6% mix ratios for all aspect ratio and curing periods. The compressive strength found to increase with an increase in aspect ratio. For all mix ratios and curing period the compressive strength found maximum for specimens reinforced with glass fibre aspect ratio AR1154 (15 mm long). Also, the compressive strength found to increase with the curing period for the mix ratios and aspect ratios.

4.4 Flexural Strength

Two specimens for each combination of variables were prepared and cured for 7, 14 and 28 days, respectively. Figure 7 shows the typical variation of flexural strength with mix ratios, aspect ratios and curing periods. The 28 days flexural strength of GFRBFS found to increase by 1.5–2.5 times the flexural strength of unreinforced BFS. The relationship between flexural strength and mix ratio was found to be non-linear. The flexural strength of GFRBFS material found to vary from 28.8 to 96.0 kPa.

4.5 Initial Tangent Modulus

The initial tangent modulus (E_i) was plotted and shown in Fig. 8. The initial tangent modulus is the slope of the line drawn from the origin of the stress–strain curve. The

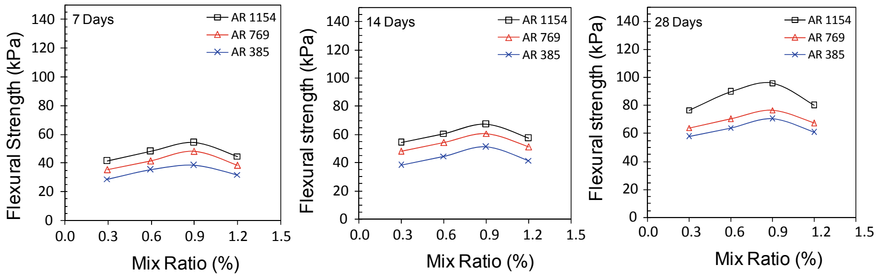


Fig. 7 Variation of flexural strength with respect to mix ratio for three different aspect ratios

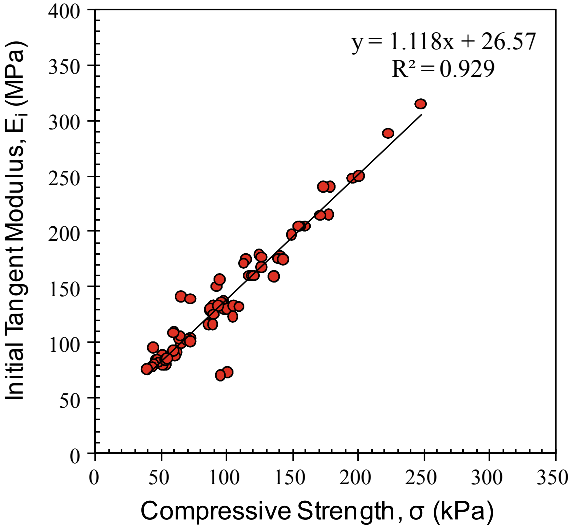


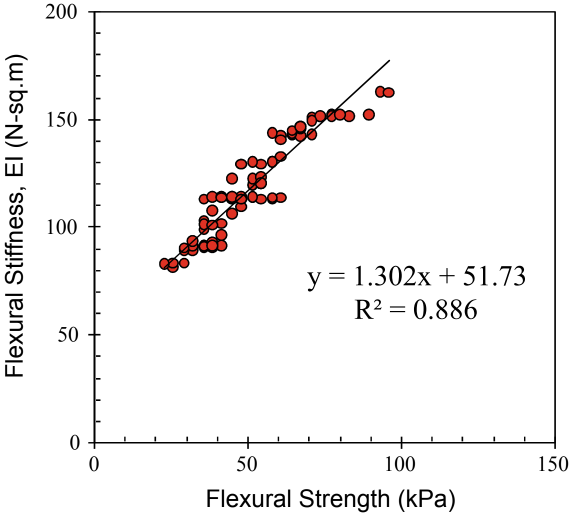
Fig. 8 Initial tangent modulus for compressive strength

initial tangent modulus is useful to determine the behaviour of the material under low stress. The compressive strength of GFRBFS found to increase with the initial tangent modulus. The value of E_i ranges from 67 to 315 MPa. This value is lower than the E_i (79–555 MPa) for lightweight fill material reported by Liu et al. [12].

4.6 Flexural Stiffness

The flexural stiffness (EI) is the measure of deformability under the given set of bending load. It depends on two factors first the elastic modulus (E) of the material and the moment of inertia (I), the function of cross-sectional geometry. The result of EI and the corresponding flexural strength was shown in Fig. 9. The relation between the EI and flexural strength fitted well in the linear trend line. With the

Fig. 9 Flexural stiffness for flexural strength



increase in flexural strength the EI found to increase. Since, the flexural strength and mix ratio vary non-linearly explained in the earlier discussion. The behaviour of EI and mix ratio relation also found to be non-linear. The EI found to vary from 80.73 to 162.5 N-m^2.

5 Conclusion

The density of GFRBFS based material decreases marginally with an increase in mix ratio for both compressive and flexural samples. For all the samples GFRBFS density was found on an average 26.4% less than the density of conventional sand.

The Compressive strength blast furnace slag and cement mix found to increase with glass fibre reinforcement. The compressive strength and mix ratio found to vary non-linearly. The maximum compressive strength found for mix ratio is 0.6%. The strength of unreinforced blast furnace slag increased from 1.14 to 2.72 times with the inclusion of fibre 0.3–1.2% after 28 days curing. Compressive strength found to increase with an increase in aspect ratio and also with curing period.

The flexural strength unreinforced BFS was found to increase by 1.5–2.5 times by inclusion of glass fibre. The relation between flexural strength and mix ratio found is non-linear and the maximum strength found for mix ratio is 0.9%. The relation between the flexural strength and aspect ratio found linear. The initial tangent modulus varies from 65 to 315 MPa. It increases with compressive strength. The flexural stiffness found to vary from 80.73 to 162.5 N-m^2.

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