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Effects of Sand Coated GFRP Bars as Internal Reinforcement in Concrete Beams made with GGBS and M-Sand

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Abstract

The primary goals of this study are to investigate the behaviour of reinforced concrete beams with alternative materials to OPC, river sand, or steel. Making concrete with a lower carbon footprint requires an alternative materials to ordinary Portland Cement (OPC). Using industrial by-products as OPC supplemental material can help reduce CO_2 emissions. The current situation calls for a replacement for river sand in the field. The degradation of riverbeds causes a lack of river sand. So an alternative substance is needed. This study investigates the usage of GGBS and M-Sand as cement and M-sand substitutes. Corrosion of steel reinforcement is more widespread and affects concrete strength and durability. To resolve the consequences of steel reinforcements, replacing them with Glass Fibre-Reinforced Plastics (GFRP) bars can be ideal. The OPC is replaced with 40% GGBS, river sand with 100% M-Sand, and steel with 100% GFRP bars. The flexural behaviour of reinforced concrete beams with GGBS, M-Sand and GFRP bars has been studied using five different types of reinforced concrete beams such as conventional concrete beam, beam with GFRP bars and river sand, beam with GFRP bars and M-Sand, beam with GFRP bars and 40% GGBS and river sand, and beam with GFRP bars, 40% GGBS and 100% river sand. The beam with GFRP bars, 40% GGBFS, and 100% M-Sand performed better than all other beams.

Key Words: GFRP bars, Flexural Behaviour, Partial Replacement, Ultimate Load, Ultimate Deflection.

1. INTRODUCTION

The term alternative is an important and most influential factor in all industrial sectors. The need for an alternative in all sectors mainly emerged due to innovative ideas or to resolve an existing problem. In the construction industry, the idea of using an alternative for traditional materials is of great concern. This is due to the severe effects of the production of construction materials such as concrete, reinforcement rods, bricks, etc. In this study, the effects of the addition of Ground Granulated Blast Furnace Slag (GGBS), M-Sand and GFRP bars in reinforced concrete beams. The impact of continuous use of traditional constructional materials such as Ordinary Portland Cement (OPC), river sand and steel bars leads to some severe issues. The production of cement increases the emission of carbon dioxide, consumption of high energy and high natural resources, which lead to environmental imbalance [1-3]. The use of river sand in making concrete and mortar increase the demand and scarcity of natural river sand due to the degradation of river beds. The degradation of river beads will lead to a decrease in groundwater table levels. The use of steel rods as a reinforcement for concrete members is prone to corrosion. Corrosion in steel causes serious problem in concrete since once steel gets rusted, it is difficult to rectify it completely. The corrosion affects the durability of the concrete members. To resolve the problems such as high carbon emission, high energy consumption, depletion of natural resources and corrosion, the use of alternative materials in the production of reinforced concrete members can be a proper solution. In this study, GGBS is used as a partial replacement for cement, M-Sand is used as a substitute for river sand, and sand coated GFRP bars are used as a substitute for steel bars.

2. LITERATURE REVIEW

In order to better understand the environmental consequences of cementitious materials used in the manufacturing of concrete, a detailed analysis was conducted. To get a better knowledge of the structural features of concrete sections constructed using replacement cement, sand, and steel bars, a detailed analysis of previous research was done. The use of replacement GGBS in cement concrete has an effect on early strength, with the strength of the concrete initially being lower than that of control concrete, while the strength after 28 days is greater than that of conventional concrete. In concrete containing increasing percentages of GGBS, the rise in the water-to-cementitious material ratio has a detrimental effect on the compressive strength. As a consequence, it was found that using 50 percent GGBS for cement replacement was the best option [4]. As the quantity of GGBS in concrete grows, the workability of the concrete improves. The strength and durability of concrete, as measured by compressive strength, split tensile strength, flexural strength, and acid resistance, are up to 40% stronger than those of control concrete in certain instances. The strength and durability of concrete were significantly improved at 40% GGBS substitution, but beyond that point, the strength and durability of concrete started to deteriorate gradually [5]. The usage of GGBS as a cement replacement helps to minimise the amount of energy used in cement manufacturing. By using GGBS in cement concrete, the heat of hydration is reduced. As a consequence, shrinkage and thermal cracks in the concrete are reduced. The addition of GGBS to cement concrete not only makes the concrete less susceptible to sulphate attack, but it also makes the concrete less susceptible to leakage as well [6]. The optimal combination for HPC was revealed to be one containing 100 percent M–sand and 10 percent silica fume, which had greater compressive and flexural strengths. A 20 percent increase in load-carrying capacity was seen when HPC beams composed of 100 percent M-sand and 10 percent silica were compared to the control beams used in the experiment [7]. Despite the fact that the workability of concrete decreased as it absorbed more water, it was shown that concrete beams with 50% M-Sand to have a larger load-carrying capability than any other beams [8]. The deflections in the GFRP beams are higher than in steel-reinforced beams [9]. In recent years, it has been revealed that when the reinforcement ratio increases, the ultimate capacity of slabs increases as well. When the GFRP reinforced slabs break, the flexural stiffness of the slabs is dramatically diminished, resulting in increasing fracture widths and deflection. In recent years, it has been revealed that when the reinforcement ratio increases, the ultimate capacity of slabs increases as well. When the GFRP reinforced slabs break, the flexural stiffness of the slabs is dramatically diminished, resulting in increasing fracture widths and deflection [10]. Because of the low modulus of elasticity and variable bond characteristics of the FRP reinforcements, the deflections and stresses experienced by concrete members reinforced with FRP rods are often greater than those experienced by concrete members reinforced with steel rods [11]. Using smaller-diameter GFRP bars resulted in more deflection enhancement than using larger-diameter GFRP bars when the reinforcement ratio was the same as before. An increase in beam stiffness was seen when the reinforcement ratio was raised, which may be accomplished by adding more bars or by using bars with bigger diameters [12]. The arrangement of the reinforcement and the glass fibre reinforced polymer to steel ratio have a considerable impact on the fracture patterns, stiffness, ductility, and toughness of hybrid RC beams. Using the non-linear deformation model, an analytical model for estimating the steel yielding moment and the ultimate moment of hybrid GFRP/steel RC beams was created and verified. As can be seen, the experimental results closely matched the expected values [13]. GFRP reinforcements outperformed standard steel reinforcements. When comparing GFRP reinforced beams to steel reinforced beams, the ultimate load-carrying capacity of GFRP reinforced beams improves as the percentage of reinforcement increases [14]. The ultimate deflection measured in typical steel reinforced beams decreases as the percentage of reinforcement increases. The ultimate deflection of GFRP reinforced beams follows a similar pattern to that of steel-reinforced beams [15].

3. CASTING AND TESTING OF BEAMS

The materials employed to create the reinforced concrete beams in this research are OPC, river sand, and crushed stone aggregate for conventional reinforced concrete and OPC, GGBS, M-Sand, and crushed stone aggregate for GGBS and M-Sand reinforced concrete beams. IS 12269:2013 [16] specifies the use of OPC 53 grade cement with a specific gravity of 3.14 as a binder. GGBS corresponds to IS 12089–1987 with a specific gravity of 2.85 [17]. GGBS, like cement, is an excellent binding material. Our prior research indicates that when more than 40% of GGBS is used as a partial substitute for cement, the strength of the concrete is reduced [18]. This research is primarily concerned with the flexural behaviour of reinforced concrete beams containing 40% GGBS and 100% M Sand. Filler materials include river sand, M-Sand, and crushed stone. The mix ratio for M-20 grade concrete was determined following the standard for mix design [19]. For conventional concrete, a mix percentage of 1:2.01:3.65 is determined, while for M Sand concrete, a mix proportion of 1:2.03:3.65 is calculated. Concrete was mixed at a water-to-cement ratio of 0.55. The mechanical characteristics of concrete are determined using compression, tensile, and modulus of elasticity testing [18] and are listed in Table 1. CCRS stands for conventional concrete, CCMS for concrete containing M-Sand, CCISRS40 for concrete containing 40% GGBFS and 100% river sand, and CCISMS40 for concrete containing 40% GGBFS and M-Sand. Concrete made with 40% GGBFS and 100% M-Sand was found to be the best choice for replacing cement, and concrete made with 100% M-Sand was the best choice for replacing river sand. In this study, five different numbers of reinforced concrete beams are used to study the flexural behaviour of beam. The dimension of the beams is kept as 3200 mm x 250 mm x 150 mm. The effective length of the beams is 3000 mm. All the beams are reinforced with two 12 mm diameter bars as tensile reinforcement in the tension zone and 8 mm diameter bars as secondary reinforcement. The incremental loads are applied gradually until the beams break. Figures 1 to 3 show the casting of beam. Figures 4 and 5 show beam set up.

Table 1 Mechanical Properties of Concrete Specimens

Sl. No.	Concrete Designation	Compressive Strength (N/mm^2)	Modulus Of Elasticity (N/mm^2)	Split Tensile Strength (N/mm^2)	Flexural Strength (N/mm^2)
1	CCRS	30.00	25300	2.43	3.20
2	CCISRS40	33.23	26400	2.75	3.86
3	CCMS	31.00	26800	2.61	3.40
4	CCISMS40	33.86	27600	3.17	4.20

Fig. 1 Steel Bars Grill in Beam Mould

Fig. 2 GFRP Bars Grill in Beam Mould

Fig. 3 Casting of Beam

Fig. 4 Beam Test Setup

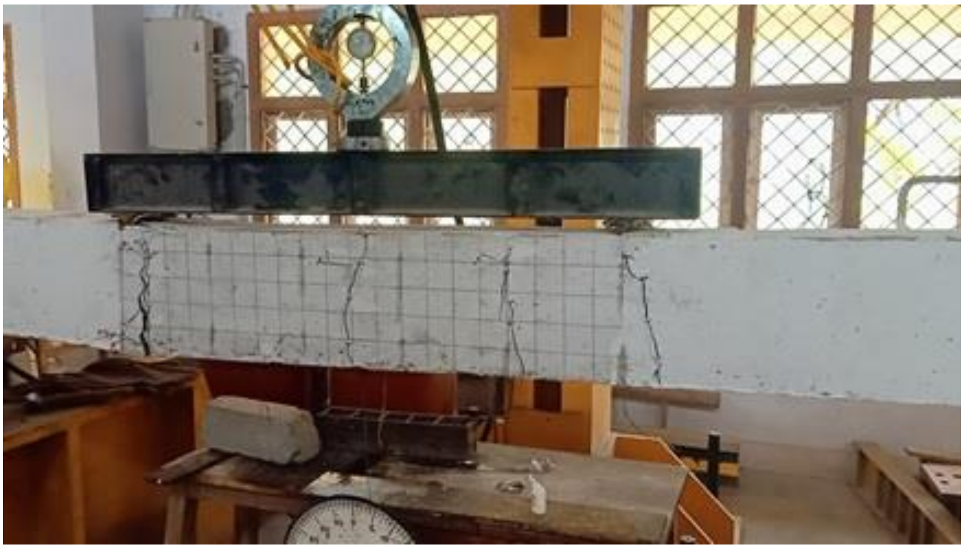

Fig. 5 Beam Test Setup

4. EXPERIMENTAL INVESTIGATIONS

Experimental investigations are carried out to determine the effects of alternative materials on the flexural behaviour of reinforced concrete beams. Totally five number of beams with the same dimensions are cast for testing. Out of five, one beam is a conventional beam, the remaining four beams are made up of alternative materials. The designation of beams is given in Table 2. The load-deflection curve for all the tested beams is shown in Figure 6. The ultimate load and deflection of all the beams are given in Table 3.

Table 2 Designation of Beams

Sl. No.	Beam Designation	Beam Designation Full Form
1	CB1	Concrete Beam Reinforced with Steel Bars
2	CFB1	Concrete Beam Reinforced with GFRP Bars
3	CFMB1	Concrete Beam with M-Sand and Reinforced with GFRP Bars
4	CGFB1	Concrete Beam with GGBS, river sand and Reinforced with GFRP Bars
5	CGMFB1	Concrete Beam with GGBS, M-Sand and Reinforced with GFRP Bars

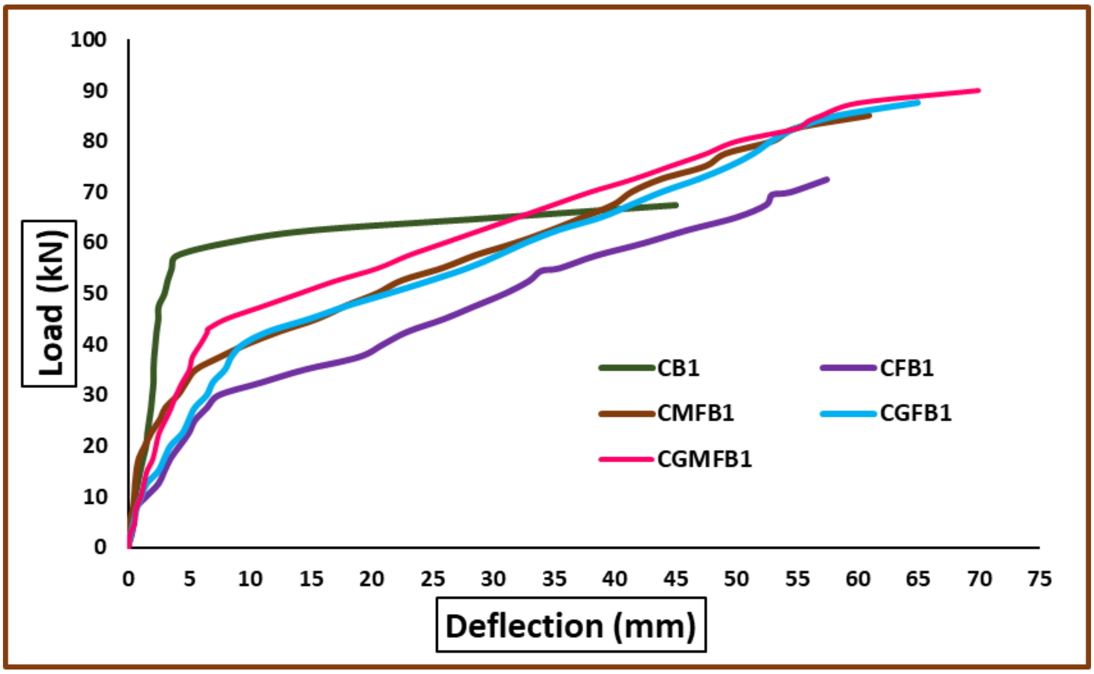

Fig. 6 Load Vs Deflection Curves for Reinforced Concrete Beams

Table 3 Experimental Results of Concrete Beams

Sl. No.	Beam Designation	Ultimate Load (kN)	Ultimate Deflection (mm)
1	CB1	67.5	45
2	CFB1	72.5	57.5
3	CFMB1	85	61
4	CGFB1	87.5	65
5	CGMFB1	90	70

5. RESULTS AND DISCUSSIONS

The results of the experimental investigations and observations demonstrate that the flexural behaviour of reinforced concrete beams has significantly improved. The strength of conventional concrete with the addition of 40 percent GGBS and 100 percent M-Sand has slightly higher compressive strength, tensile strength, and modulus of elasticity. It also has slightly higher compressive strength compared to M-Sand concrete and concrete made with GGBS and river sand. In addition, the load-deflection behaviour of the beams has been enhanced. When compared to typical steel-reinforced beams, the ultimate load-carrying capacity and ultimate deflections of the beams reinforced with 40 percent GGBS, 100 percent M-Sand, and GFRP bars are much greater. The comparison of ultimate load and ultimate deflection of concrete beams are shown in Figures 7 and 8.

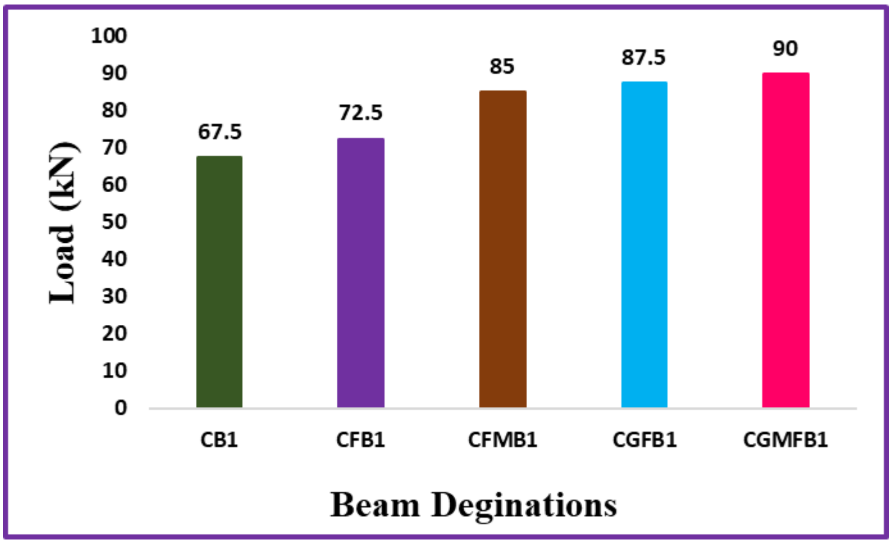

Fig. 7 Ultimate Load for Reinforced Concrete Beams

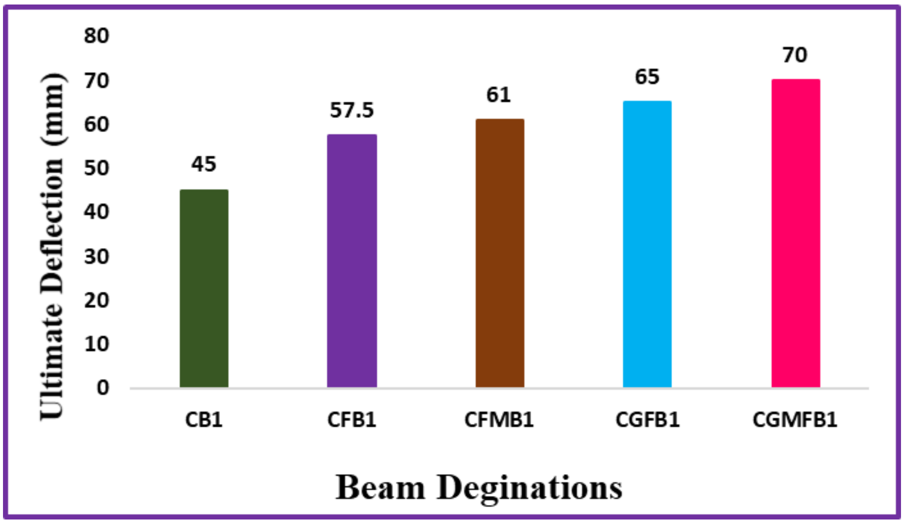

Fig. 8 Ultimate Deflection for Reinforced Concrete Beams

Reinforced concrete beams benefit significantly from the contribution of GGBFS and M-Sand, which are both used in the production of these beams. In addition to calcium and silica, GGBFS contains calcium hydroxide, which combines with unreacted calcium hydroxide in the cement to generate more Calcium Silicate Hydrate (C-S-H). This extra C-S-H gel increases the strength of the concrete matrix while simultaneously decreasing the amount of calcium hydroxide present. The production of ettringite is inhibited, resulting in an improvement in the overall quality of the concrete. The addition of GGBFS to the concrete matrix also has the additional benefit of improving the binding property of the concrete matrix. In the manufacturing industry, M-Sand is highly graded, and the size, shape and texture are all appropriate, which helps to increase the packing of the concrete matrix, which in turn contributes to the overall strength of the concrete matrix by providing additional strength. The fact that GFRP bars have a low modulus of elasticity, which results in greater deflection of beams built using them. The ultimate load-carrying capacity of the reinforced concrete beam with GFRP bars, 40% of GGBS and M-Sand is higher than all other beams and at the same time, the ultimate deflection is also higher. The ultimate deflection trend is similar to conventional concrete beams and the sand coated GFRP bars reinforced concrete beams outperformed the conventional reinforced concrete beam in terms of load-carrying capacity [15].

6. CONCLUSIONS

The following conclusions are made from the experimental investigations made on reinforced concrete beams made with GGBS, M-Sand and GFRP bars.

1. The ultimate load-carrying capacity and ultimate deflection of the CFB1 beam are 7.41% and 27.78 % higher than the conventional reinforced concrete beam respectively.
2. The ultimate load-carrying capacity and ultimate deflection of the CMFB1 beam are 25.93% and 35.56% higher than the conventional reinforced concrete beam respectively.
3. The ultimate load-carrying capacity and ultimate deflection of the CGFB1 beam are 29.63 % and 44.44% higher than the conventional reinforced concrete beam respectively.
4. The ultimate load-carrying capacity and ultimate deflection of the CGMFB1 beam are 33.33% and 55.56% higher than the conventional reinforced concrete beam respectively.
5. The ultimate load-carrying capacity and ultimate deflection of the CGMFB1 beam are 24.14% and 21.74% higher than the CFB1 respectively.
6. The ultimate load-carrying capacity and ultimate deflection of the CGMFB1 beam are 5% and 14.75% higher than the CMFB1 respectively.
7. The ultimate load-carrying capacity and ultimate deflection of the CGMFB1 beam are 2.86% and 7.69% higher than the CGFB1 respectively.

The use of GFRP bars as internal reinforcement can be used in concrete beams with enhanced binder and filler material will enhance the properties of the reinforced concrete members. The corrosion can be eliminated from the concrete members and the use of GGBS and M-Sand enhance the strength of the concrete.

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