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A Parametric Study on Ground Granulated Blast Furnace Slag-based Reinforced Cement Concrete Using Fibre Reinforced Polymer Bars

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Abstract

This research focuses on a parametric study of ground granulated blast furnace slag-based reinforced cement concrete using fibre reinforced polymer bars. The major variables are fine aggregates and reinforcement bars. Fine aggregates like river sand and manufactured sand (M-sand) were used with reinforcement bars such as steel, hybrid FRP, and GFRP bars. The replacement of cement by GGBS is constant. The optimum percentage of GGBS is 30 % for all 12 beams. Limited researches are available on reinforced concrete (RC) beams using fibre reinforced polymer bars. Nonlinear finite element analysis is carried out using finite element ANSYS software. The load-carrying capacity of the conventional RC beam using M-sand is 13.33 % higher than the beam using river sand. The ultimate load of B6 (M-sand with hybrid FRP beam) is 4.12 % and 24.09 % higher than the B2 (M-sand with steel reinforcement) and B10 (M-sand with GFRP beam). The strain value of concrete reaches a maximum in B12 (M-sand with 3-GFRP-bottom bars) about 0.0134 and strain in steel reaches 0.089 for beam B10 (M-sand with GFRP beam). This study finds that the effects of M-sand and FRP bars will influence the strength of GGBS based RC beams.

Disciplinary: Civil & Structural Engineering.

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1 Introduction

This research studies the parametric study on ground granulated blast furnace slag (GGBS) based concrete beam using FRP bars. The GGBS is more popular in the construction industry it's a kind of replacement material for cement. It has a lot of significance like eco-friendly material, cost-effective, high strength, and durable. Fibre-reinforced polymer (FRP) is one of the better alternative materials for steel. Corrosion is the biggest problem in the construction field it reduces the life span of buildings. FRP is a non-corroded material and has high tensile strength and low weight. Different types of FRP are available in markets such as carbon fibre, glass fibre, and aramid fibre. A lot of research is available on reinforced concrete (RC) beams using GGBS and RC beams using steel and FRP bars. Limited studies are carried out on RC beams using GGBS and FRP bars. A parametric study is very important in the civil engineering field. A parametric study is carried to avoid the cost of preparing and testing materials and time-consuming. Nowadays, a lot of finite element software is available to reduce the human effect. In this project, the parametric study was carried out by finite element software ANSYS.

Singh et al. [1] carried out the finite element analysis of reinforced concrete beam using ANSYS. FRP bar is laminated over the RC beam to study the behaviours. Rameshkumar et al [2] carried out RC beams externally bonded with aramid fiber. The validation experiment is done with ANSYS. M25 grade concrete is used and the dimensions of beams are 150 mm x 150 mm in cross-section and 1200 mm in length. Solid 65 element is used for concrete, link 8 is used for steel, and solid 45 for AFRP. The ultimate load of single and double layer AFRP is increased by 27.59 % and 48.27 % respectively. Badiger and Malipatil [3] carried out a parametric study on RC beams using ANSYS. The dimension of beams is 250 mm x 450 mm with 4400 mm long is subjected to two-point loading. It was concluded that varying the tension is not affected the initial cracks and ultimate load carrying capacities vary depends on the percentage of reinforcements. Vasudevan [4] carried out a parametric study on nonlinear finite element analysis on flexural behaviours of RC beams using ANSYS, under different convergences for deflection and load. It was observed that convergence does not influence strength. Sangeetha and Raj [5] studied finite element analysis of RC beams with GGBS using ANSYS. Totally six beams with two control beams. Analytical load is in good agreement with experimental values. Revathi and Devdas Menon [6], based on the nonlinear finite element analysis of RC beams, the analytical values were in good agreement with the experimental obtained. Uma et al [7] found that the difference of experimental to numerical does not exceed 20 %. Jagadish and James [8] carried out the studies on finite element analysis of concrete beams reinforced with fibre reinforced polymer bars. The percentage of reinforcement bars is a major variable. It’s varies for 0.5%, 1%, 1.5% and 2%. It found that ultimate load is increased with an increasing percentage of reinforcement and beam using CFRP bars shows better results than GFRP bars. Metwally et al. [9] carried out the studies on numerical investigation of concrete deep reinforced concrete beams with GFRP bars. Major variables are effective depth, shear span/ depth ratio, concrete strength, and reinforcement ratio. It observed that numerical results are well suited with experimental observation. Al Musallam et al. [10] investigated experimental and numerical investigation for the flexural strengthening of RC beams using near-surface mounted steel or GFRP bars. It found that experimental and numerical comparison is well suited. Niranjan and Patil [11] analysed RC deep beam by finite element method and found that the shear effect is predominant in spear span ratio less than or equal to 2. Chafale and Reddy [12] analysed deep beams using the finite element method. The major variable is the number of elements. It observed that shear stress, bending stress, and deflection are not influenced by convergence study. Mostofinejad and Talaeitabab [13] studied the nonlinear modeling of RC beams subjected to torsion using the smeared crack model. It found that the torsional cracking development and shape predicted up to the fracture. Banjara and Ramanjaneyulu [14] carried out experimental and numerical investigations on the performance evaluation of shear deficient and GFRP strengthened reinforced concrete beams. It observed that load defection and crack pattern. Tjitradi [15] carried out the study on 3D ANSYS numerical modeling of reinforced concrete beam behavior under the different collapsed mechanisms. Crack pattern, load vs deflection, and strain were observed. El-Shaer et al. [16] did an experimental and numerical investigation of flexural behaviour of new DSG reinforced concrete mixes reinforced with GFRP bars. The numerical result is in good agreement with experimental results. Patil et al [17] investigated GGBS as a partial replacement of OPC in cement concrete–an experimental study. It concluded that 20 % replacement of cement with GGBS shows better results. Rughooputh and Rana [18] studied partial replacement of cement by ground granulated blast furnace slag in concrete. The optimum percentage of replacement of cement by GGBS is achieved at 50 %. Manjunatha and Jeevan [19] studied early-age properties and behaviour of concrete with GGBS as partial replacement of cement and found that 15 % of replacement of GGBS shows better results. Hawileh et al [20] investigated the performance of reinforced concrete beams cast with different percentages of GGBS replacement to cement. It concluded that replacement GGBS up to 70 % is allowed to replace the cement.

2 Material Properties

Material properties are arrived from based on experimental investigation. OPC 53 grade cement is used and 20 mm coarse aggregate is used. River sand and M-sand are used as fine aggregates. M20 grade concrete and Fe500 steel is used.

Table 1: Strength properties of GGBS concrete (MPa).

GGBS concrete	M-sand	river sand
Compressive strength	29.5	2.92
Split tensile strength	29.5	2.83
Flexural strength	2.93	2.85
Modulus of elasticity	26566	25654

3 Beam Details

The overall length of each beam is 2200 mm, with an effective length of 2000 mm. The cross-section of each beam is 150 mm x 250 mm. The beams are group into three types. One is GGBS based concrete beam using steel bars, the second is GGBS based concrete beam using hybrid FRP bars and the third is GGBS-based concrete beam using GFRP bars. River sand and M-sand are used as fine aggregates. Table 2 shows the details of each beam.

Figure 1 shows the reinforcement details of steel rebar beams, Figure 2 shows the reinforcement details of hybrid FRP rebar beams and Figure 3 shows the reinforcement details of GFRP rebar beams.

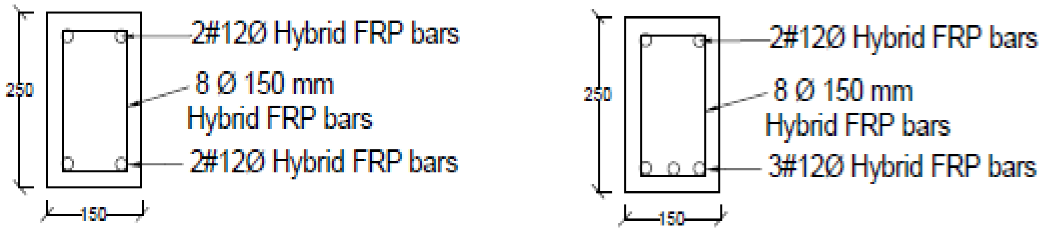
Table 2: Beam details

ID	Fine aggregates	Reinforcement
B1	River sand	Steel
B2	M-sand	Steel
B3	River sand	Steel
B4	M-sand	Steel
B5	River sand	Hybrid FRP
B6	M-sand	Hybrid FRP
B7	River sand	Hybrid FRP
B8	M-sand	Hybrid FRP
B9	River sand	GFRP
B10	M-sand	GFRP
B11	River sand	GFRP
B12	M-sand	GFRP

B1 and B2

B3 and B4

Figure 1: Reinforcement details of steel rebar beams



B5 and B6

B7 and B8

Figure 2: Reinforcement details of hybrid FRP rebar beams

B9 and B10

B11 and B12

Figure 3: Reinforcement details of GFRP rebar beams

4 Nonlinear Finite Element Analysis

Nonlinear finite element analysis is carried out by finite element software ANSYS. Table 3 shows material properties. William-Wranke failure theory is used for the nonlinear modelling of concrete. The solid 65 three-dimensional solid elements with three degrees of freedom at each node are used for concrete is shown in Figure 4. Link 180 two noded truss element for rebar is shown in Figure 5. Figure 6 shows a bearing plate using solid 45 elements. Interface TARGE 170 and CONTA 175 elements are used to transfer the force from the bearing plate to the concrete beam, see Figure 7.

Table 3: Material properties

Materials	Properties	Values
Steel bar	Young's modulus	2 x 10^5 MPa
	Poisson's ratio	0.3
	Yield stress	550 Mpa
	Ultimate stress	625 Mpa
Hybrid FRP	Ultimate stress	1679 Mpa
	Young's modulus	1.35 x 10^5 MPa
GFRP	Ultimate stress	525 Mpa
	Young's modulus	0.46 x 10^5 MPa
Bearing plate	Young's modulus	2 x 10^5 MPa
	Poisson's ratio	0.3

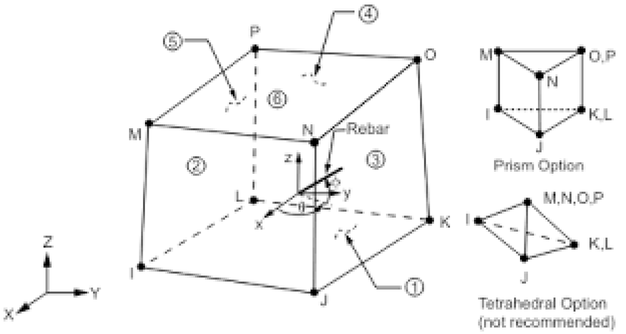


Figure 4: Solid 65 element for concrete

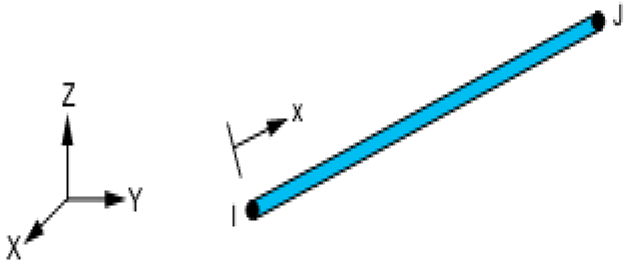


Figure 5: Link 180 element for rebar

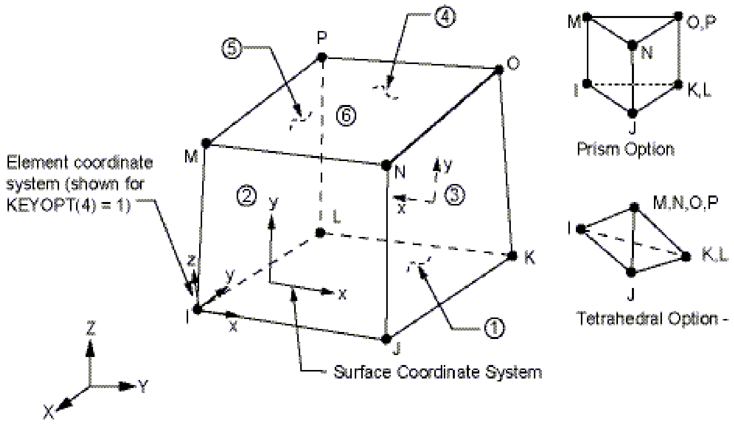


Figure 6: Solid 45 element for bearing plate

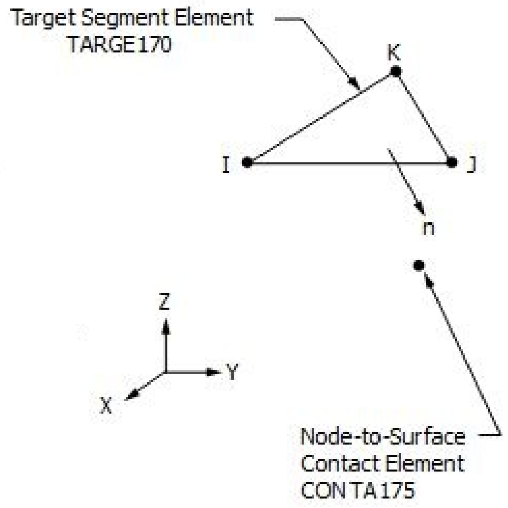
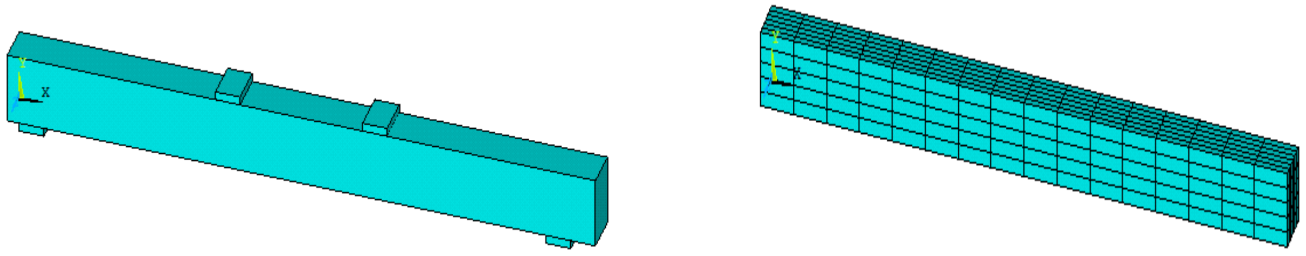


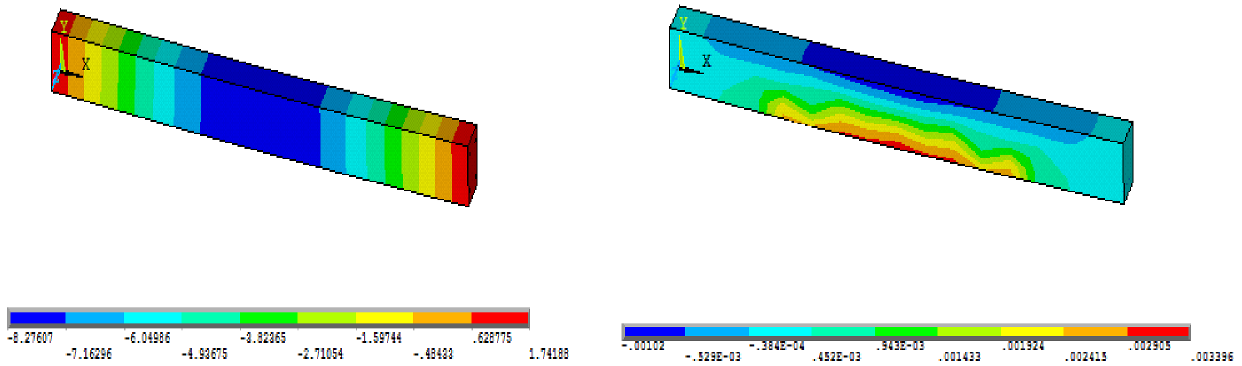
Figure 7: TARGE 170 and CONTA 175 element



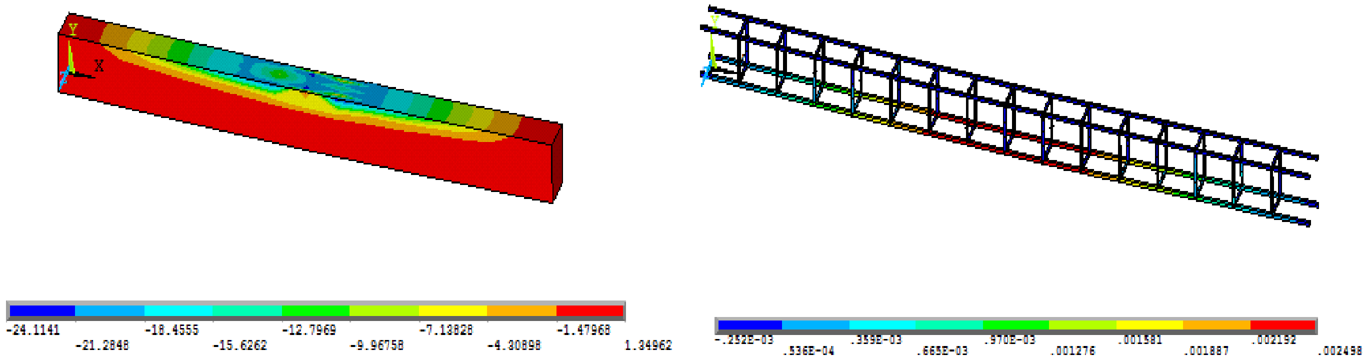
a) Modelling b) Meshing.

Figure 8: Modelling and Meshing

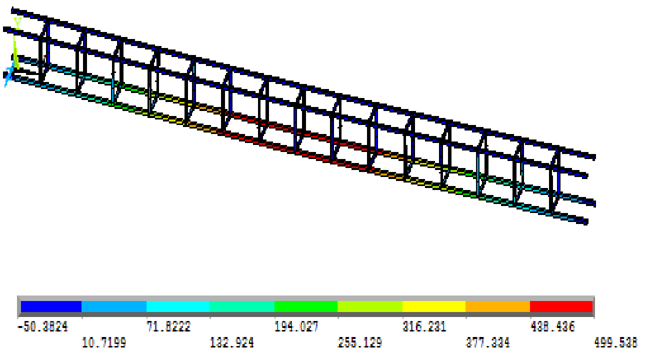
The modelling and meshing of the beam are shown in Figure 8. Figure 9 shows finite element analysis of the B1 beam, as an example.



a) Deflection b) Strain in concrete



c) Stress in concrete d) Strain in steel



e) Stress in steel

Figure 9: Deflection, the stress in steel and concrete, strain in steel and concrete for B1

5 Result and Discussion

The GGBS based concrete beam using steel bar and river sand as a fine aggregate B1 is shown in figure 9. The deflection at failure is observed at 8.27 mm. B1 is found that strain occurred in concrete and steel occur at the bottom of the beam is 0.00339 and 0.002498 respectively. The stress in the concrete beam reached its max value. The crushing stress of concrete at the bottom is 24.11 MPa and the cracking stress of concrete at the bottom is 1.349 MPa. The tensile stress of steel reaches 499.53 MPa at the bottom. Finite element analyses of all the beams are shown in Table 4 and deflection of the beam is shown in figure 10 for GGBS based concrete beam using river sand Figure 11 shows for GGBS based concrete beam using M-sand.

Table 4: Ultimate load vs deflection

ID	Ultimate Load (kN)	Deflection (mm)	Strain	
			Concrete	Concrete
B1	52	8.276	0.0034	0.0025
B2	60	9.699	0.0048	0.0028
B3	78.5	9.143	0.0035	0.0025
B4	83.98	9.782	0.0048	0.0027
B5	58.4	12.377	0.0083	0.0039
B6	62.58	13.223	0.0075	0.0042
B7	66.29	10.16	0.0043	0.0031
B8	72	12.309	0.0052	0.0037
B9	42.5	21.281	0.0101	0.008
B10	47.5	23.334	0.0125	0.0089
B11	48.75	18.560	0.0085	0.0065
B12	60	22.328	0.0134	0.0078

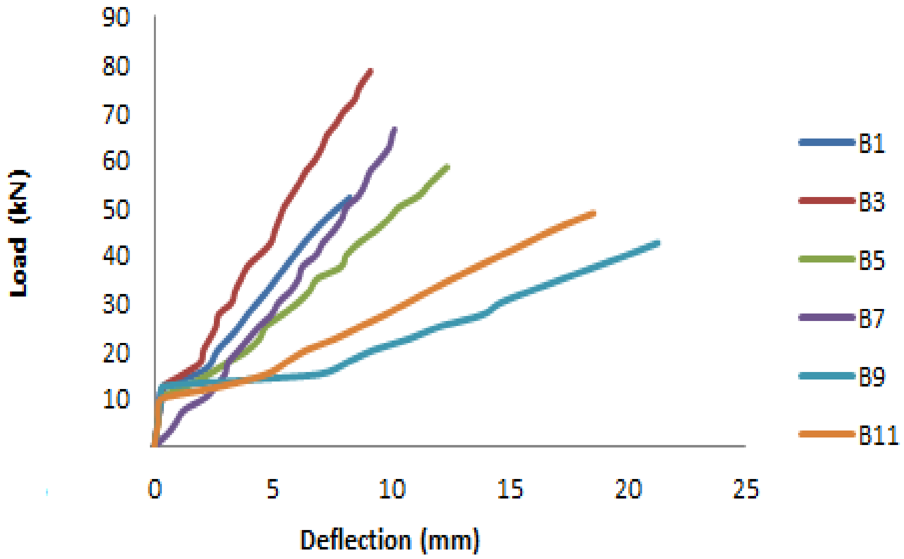


Figure 10: GGBS based concrete beam using river sand

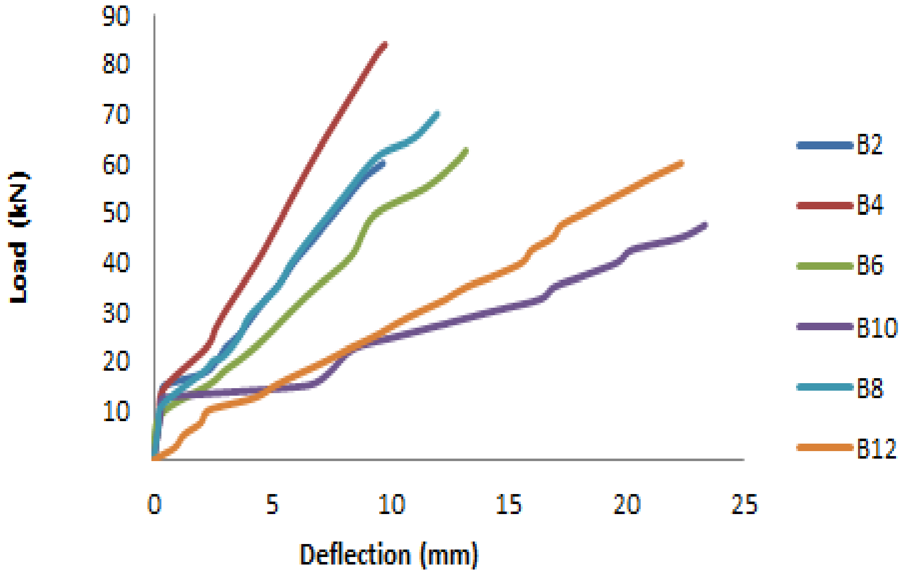


Figure 11: GGBS based concrete beam using M-sand

6 Conclusion

Nowadays, parametric is necessary to save the cost for casting and testing and time-saving. In this study, nonlinear finite element analysis is carried out using finite element software ANSYS. Parametric studies are reported on twelve RC beams using steel, hybrid FRP, and GFRP bars. Major variables are types of fine aggregate and types of reinforcement bars. GGBS content is maintained at 30 % for the entire beam. It is observed that the fine aggregate and rebar influence the behaviour of beams in terms of ultimate load, deflection, and strain.

Load vs deflection behaviour for the entire beam is linear up to the elastic limit and followed by nonlinear. It found the various percentages steel it affects the behaviour of reinforced concrete beam. GGBS based concrete using river sand and steel rebar beam (B1) has an ultimate load of 52 kN and the corresponding deflection is 8.276 mm. GGBS based concrete beam using M-sand (B2) has higher strength than B1 and lesser than B4.

The ultimate load of GGBS based concrete beam using M-sand and hybrid FRP bar (B8) has 18.88 %,13.08 %, and 7.93 %, higher than B5, B6, and B7. The ultimate load of GGBS based concrete beam using M-sand, and GFRP bar (B12) has 29.16 %, 20.83 %, and 18.75 %, higher than B9, B10, and B11. The ultimate load of GGBS based concrete beam using M-sand and hybrid FRP bar (B8) has 16.66 % higher than B12.

GGBS based concrete using M-sand and hybrid FRP bars have higher strength than beam using GFRP bars.

7 Availability of Data and Material

Data can be made available by contacting the corresponding authors.

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