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Sustainable ConcreteGround Granulated Blast-furnace Slag Beam: Numerical Investigation Using Hybrid FRP and GFRP Techniques

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Abstract

Cement with GGBS replacement has emerged as an effective alternative to traditional concrete, quickly attracting the attention of the concrete industry owing to its cement savings, energy savings, cost savings, environmental and social advantages. The use of slag in concrete offers many advantages, including lower energy consumption, lower greenhouse gas emissions, and lower raw material use. Nonlinear finite element analysis of a ground granulated blast furnace slag (GGBS) concrete beam utilising steel, hybrid FRP, and GFRP bars was performed in this research. The primary variables are fine aggregate kinds and reinforcing bars. According to the testing results, the optimal proportion of GGBS substitution of cement is 30%. The 70 percent cement and 30 percent GGBS ratio are maintained throughout the mix. The concrete is of M20 grade. Electric strain gauges are installed at steel and concrete structures to detect strain. A total of six beams were modelled. ANSYS finite element software is used to do nonlinear finite element analysis. Finite element analysis: the load is transmitted from the bearing plate to the beam through the bearing plate. Nonlinear material characteristics, as well as a nonlinear stress-strain curve for concrete, are included. The Newton-Raphson technique is used to determine the load increase step. It was discovered that GGBS concrete beams made of Hybrid FRP achieve the maximum strain and stress in concrete.

Keywords: cement, GGBS, Hybrid FRP, GFR, Nonlinear, FEA, sustainable goal

1. Introduction

Concrete is the most widely used building material in the world, with about six billion tonnes manufactured each year. In terms of per-capita use, it is only second to water. However, environmental sustainability is jeopardised due to harm caused by raw material exploitation and CO 2 emissions during cement manufacturing. This put pressure on researchers to reduce cement usage by partially replacing cement with additional materials. These materials may be naturally occurring, industrial leftovers, or byproducts that need less energy. When these materials (known as pozzalonas) are mixed with calcium hydroxide, they show cementitious characteristics. Fly ash, silica fume, metakaolin, and powdered, granulated blast furnace slag are the most frequently utilised pozzalonas (GGBS).

For more than two decades, fibre reinforced polymer has been utilised for rebar or building restoration. FRP offers advantageous properties like strong strength and low density, which help to minimise dead weight. Reinforced bars are used to improve the ductility of a beam. FRP has linear elastic behaviour. It has higher strength and corrosion resistance characteristics than steel bars. Corrosion is a significant issue in the building business nowadays. FRP is an excellent steel substitute. Carbon FRP, Glass FRP, and aramid FRP are the most common fibre reinforced polymers. The stress-strain curve of glass fibre reinforced polymer is linear until tension failure.

ShignaJagadish and Rona P Maria James [1] used FRP bars to perform finite element analysis on a concrete beam. The authors use CFRP and GFRP bars with varying reinforcement ratios (0.5 percent, 1 percent, 1.5 percent and 2 percent). ANSYS workbench does nonlinear finite element analysis. It was found that employing 2% GFRP bars improves ultimate load and reduces deflection in concrete beams. Ibrahim M. Metwally [2] used GFRP bars to perform three-dimensional FEA of a deep beam. A total of twelve deep beams were used, with longitudinal GFRP bars acting as shear reinforcement. The finite element programme ABAQUS is used to do nonlinear analysis. It was discovered that the beam failed due to shear and that the ultimate load and deflection of the deep beam of the GFRP beam is 2 to 4 times more than that of CFRP bars. Maher A. Adam et al. [3] investigated the experimental and analytical behaviour of GFRP-reinforced concrete beams. The GFRP bars are utilised as the primary longitudinal bar, with steel stirrups. The proportion of steel and the quality of concrete are the most important factors. It was discovered that GFRP bars with more than balanced reinforcement fail due to concrete crushing, whereas GFRP bars with less than balanced reinforcement fail due to GFRP bar rupture. Farghaly and Benmokrane [4] conducted research on the Shear behaviour ofDeep FRP-reinforced concrete beams with no web reinforcement It discovered that beams function linearly until they fail. Saleh HamedAlsayed [5] investigated the behaviour of a concrete beam with GFRP bars. It discovered that the anticipated deflection and ultimate loads are 10% and 1%, respectively. HuanziWanga and AbdeldjelilBelarbi [6] used FRP bars to construct a fibre reinforced concrete beam. It was discovered that adding fibre to the concrete increased the ductility index by 30%. Nasr Z. Hassan [7] explores the use of FRP sheets to strengthen RC beams. ANSYS software is used to do nonlinear finite element analysis. It was discovered that the failure of beam strength is enhanced by the FRP sheet surrounding the aperture. Fazla Rabbi Anik et al. [8] compared the RC beam strength of CFRP and GFRP Strip. The author found that a reinforced concrete beam reinforced with a CFRP strip has a greater load-bearing capability than one reinforced with a GFRP strip. Using glass fibre reinforced polymer (GFRP) bars, Kalpana and Subramanian [9] investigated the behaviour of RC beams. Theoretical and experimental study of an RC beam made of steel and GFRP bars. It was discovered that when the grade of concrete and the proportion of GFRP bars rose, so did the strength. Ahmed SagbanSaadoon and Hawraa Sami Malik [10] used ANN to estimate the load-bearing capability of an RC beam made of FRP bars. The final load is predicted using an artificial neural network. A total of 199 beam data points with eight variables were gathered. It was discovered that the anticipated vs experimental value errors are less than 3.6 percent. Smithagopinath et al. [11] examined the shear behaviour of a basalt FRP beam employing steel fibres. It was discovered that the volume of steel fibres and BFRP has an effect on strength. DarmansyahTjitradiet [12] used ANSYS to do finite element analysis on an RC beam. It was discovered that the over-reinforced beam failed due to concrete crushing at the top.

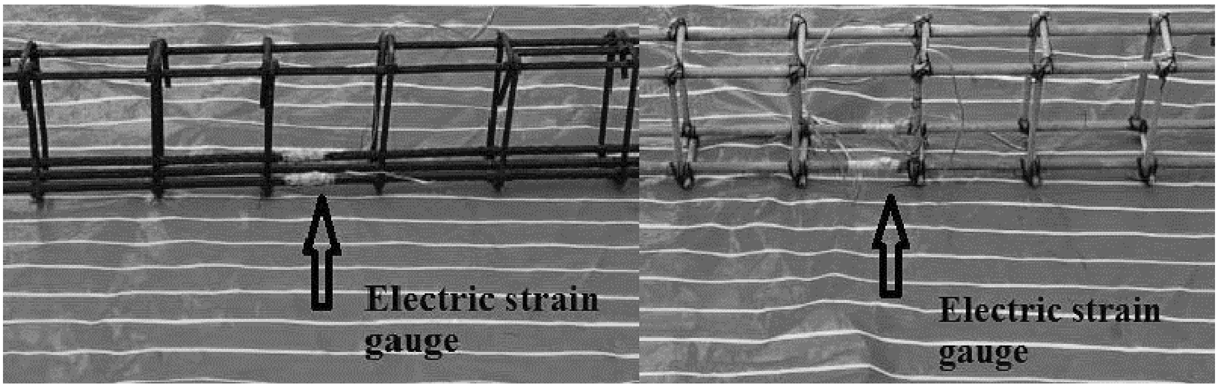
2. Experimental Investigation

2.1 Materials Employed

Ordinary Portland cement 53-grade cement is utilised in this study. Design of M20 grade concrete in accordance with IS 10262-2019. The concrete proportions are 1.78:3.32:0.5. (Cement: Fine aggregate: Coarse aggregate: Water). The cement and GGBS levels in concrete are 70% and 30%, respectively. Fine aggregates made from both river sand and industrial sand are utilised. The coarse aggregate is 20mm in size. The GGBS component replaces approximately 30% of the cement. Concrete has a slump cone value of 124 mm. GGBS concrete has compressive strength, split tensile strength, and flexural strength of 28.23 MPa, 2.83 MPa, and 2.85 MPA.

2.2 Specimen specifics

The beam has a length of 2200 mm and a cross-section of 150 mm x 250 mm. A total of six beams are cast utilising reinforced bars, hybrid FRP bars, and GFRP bars. Beams are tested in their most basic supported configuration. Beam reinforcement was supplied with two 12 mm diameter bars at the bottom and two 12 mm diameter bars at the top, and eight 8 mm stirrups with 150 mm cc spacing. To measure the strain value, two electronic strain gauges are placed in rebars and two in concrete. Figure 1 depicts a strain gauge made of steel and FRP bars.



a) Steel bar b) GFRP bar

Fig 1. Strain gauge implementation in varying bar

2.3. Test Configuration

With an effective span of 2000 mm, the beam was tested under simple support conditions. Under the loading point and mid-span, three liver variable differential transducers (LVDT) are installed. Figure 2 depicts the test setup. Two electric strain gauges are installed in the middle of a concrete beam. Strain indicators are used to calculate the strain for each load increase. Figure 3 depicts an electric strain gauge.

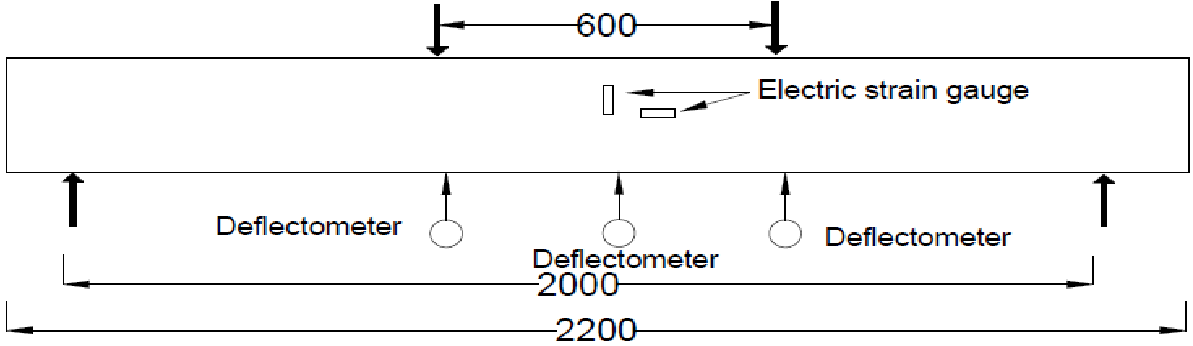


Fig 2. Test setup arrangement

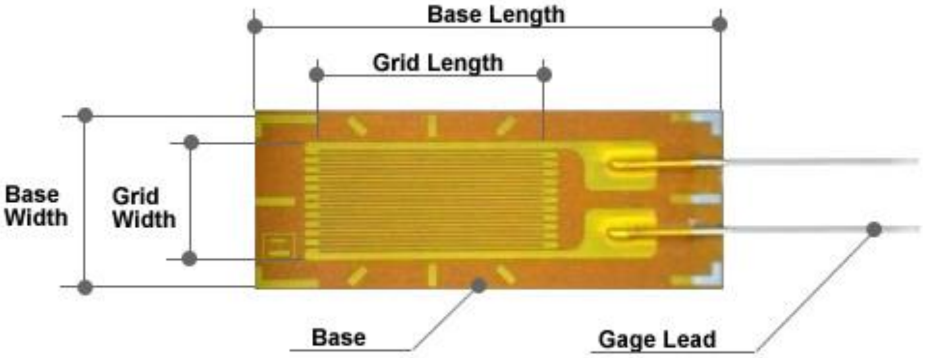
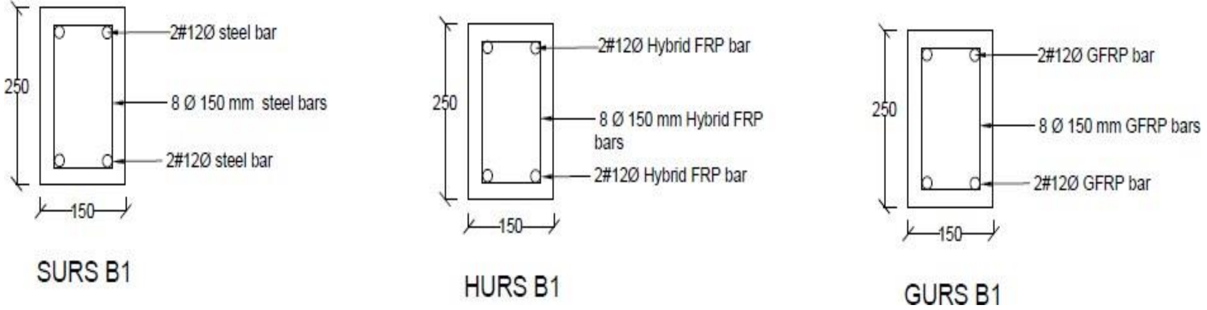


Fig 3. Electric Strain Gauge

Beam specifications are shown in table 1 and geometry configurations of beam shown in fig4.

Table 1: Beam Specifiction/details

		Reinforcement			**Rebar**
Beam Id	**Fine aggregates**	**Bottom**	**Top**	**Stirrups**	
SURS B1	River sand	2 nos of 12	2 nos of 12 mm	8 mm at 150 mm cc	Steel
SUM B1	M sand	2 nos of 12	2 nos of 12 mm	8 mm at 150 mm cc	Steel
HURS B1	River sand	2 nos of 12	2 nos of 12 mm	8 mm at 150 mm cc	Hybrid FRP
HUM B1	M sand	2 nos of 12	2 nos of 12 mm	8 mm at 150 mm cc	Hybrid FRP
GURS B1	River sand	2 nos of 12	2 nos of 12 mm	8 mm at 150 mm cc	GFRP
GUM B1	M sand	2 nos of 12	2 nos of 12 mm	8 mm at 150 mm cc	GFRP



SURS B1 HURS B1 GURS B1

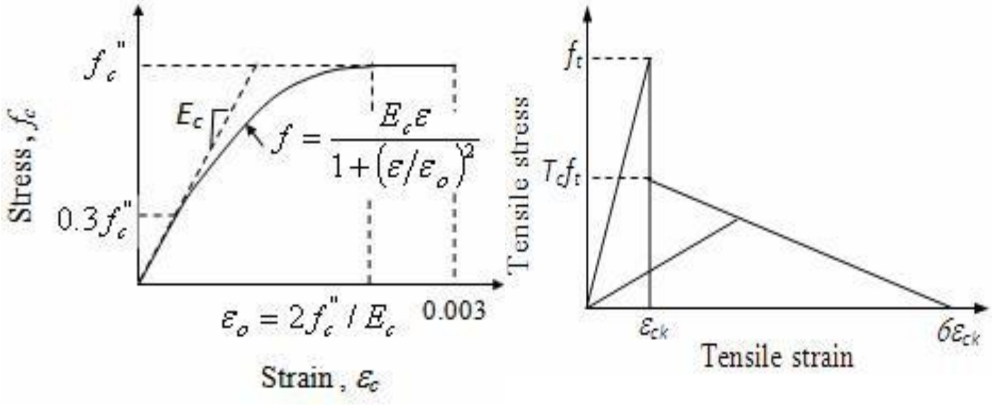
Fig 4. Geometry Configurations

3. Nonlinear Finite Element Analysis

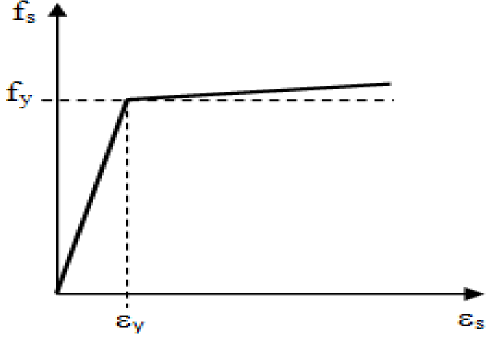
Finite element software ANSYS carries out nonlinear finite element analysis. Finite element software used to solve complex problems in civil engineering. Solid 65 are used for the three-dimensional modelling of concrete. The element is capable of cracking and crushing concrete in both tension and compression. Eight nodded elements with three degrees of freedom at each node is shown in figure 5. Link180 element is used for reinforcement. Solid 185 elements are used for the bearing plate. The properties of materials are shown in table 2. Stress-strain curve for concrete and steel shown in figure 5.

Table 2: Material Characteristics

Details	**Description**	**Value**
Concrete	Grade of concrete	M20
	Compressive strength of concrete	28.23 MPa
	Young's modulus	26566 MPa
	Poisson's ratio	0.2
Steel bar	Young's modulus	2 x 10^5MPa
	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 10^5MPa
GFRP	Ultimate stress	525 Mpa
	Young's modulus	0.46 x 10^5MPa
Bearing plate	Young's modulus	2 x 10^5MPa
	Poisson's ratio	0.3
	Yield stress	250 Mpa



a) Concrete in compression b) Concrete in tension

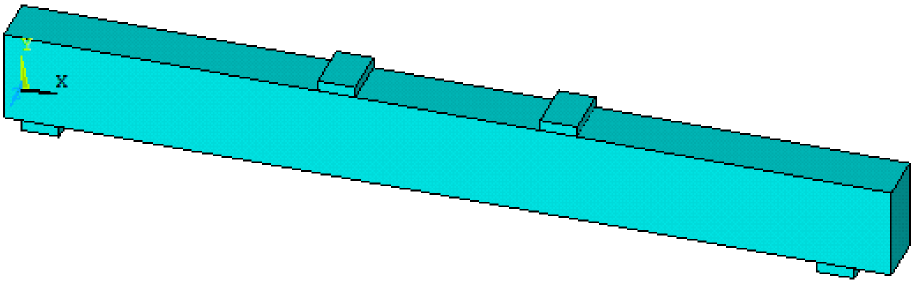


c) Steel

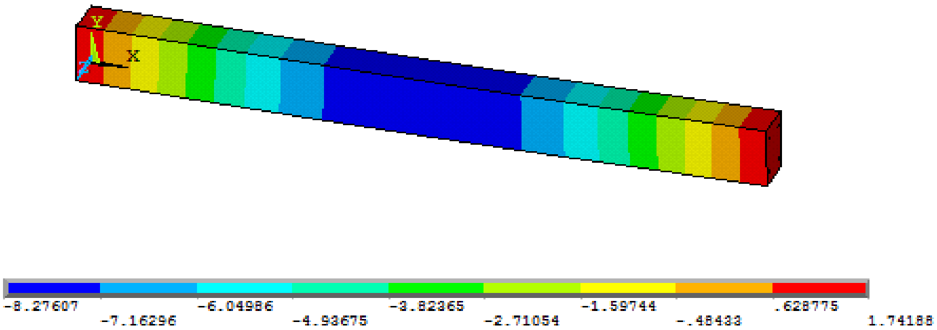
Fig 5. Stress-strain curve for concrete and steel

3.1. Beam SURS BI

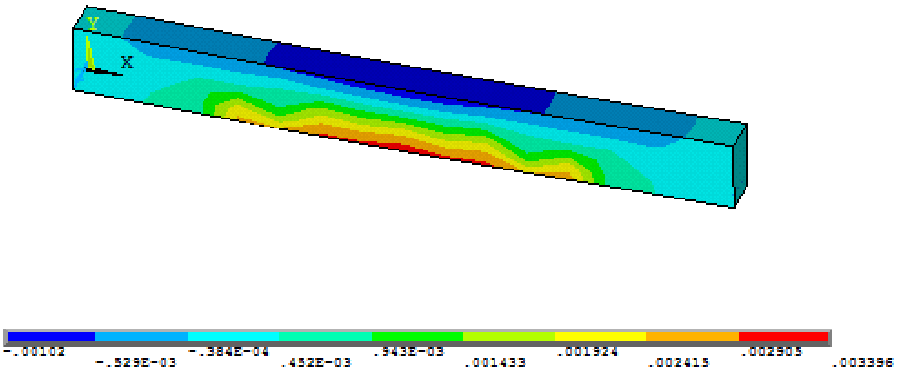
The GGBS based concrete beam using a steel bar. The finite element analysis of the beam is shown in figure 6. It found that the maximum strain in concrete and steel occurs at the bottom of the beam is 0.00339 and 0.002498, respectively. The beam reaches the ultimate stress-strain values. Concrete reaches the maximum compressive stress at the bottom is 24.11 MPa, and steel reaches the maximum compressive stress at the bottom is 499.53 MPa.



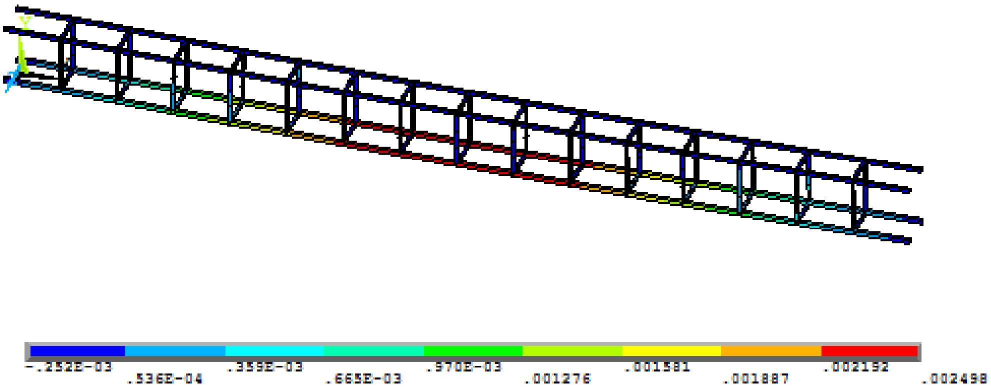
a. Beam model



b. Deflection



c. Strain Concrete

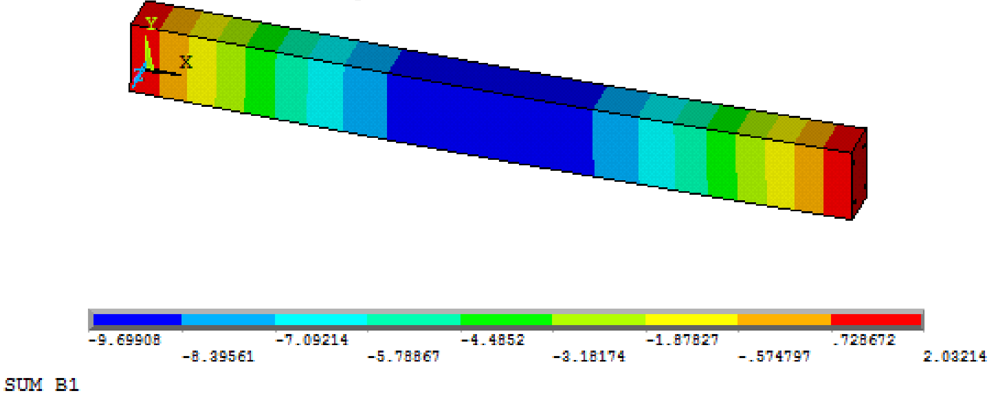


d. Strain in Steel

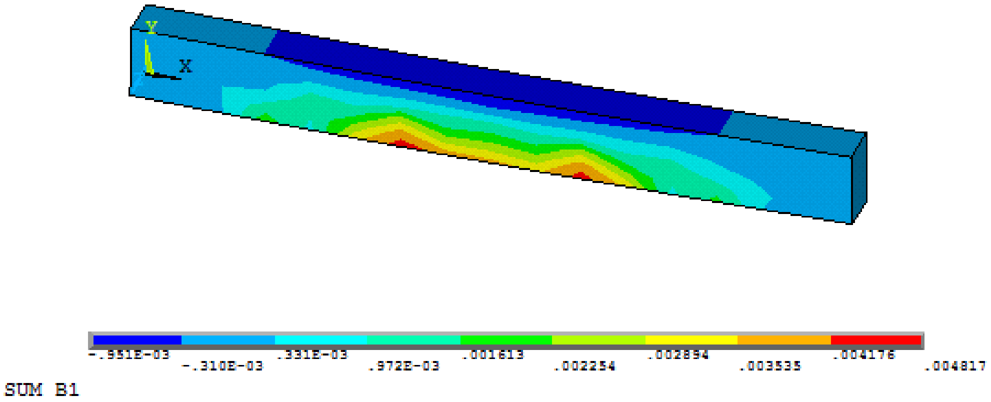
Fig 6. Beam SURS B1

3.2. Beam SUM B1

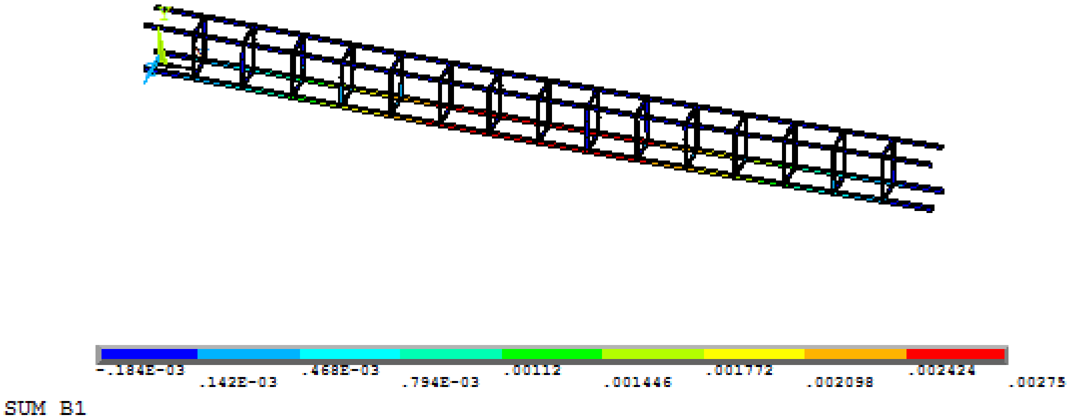
The GGBS based concrete beam using a steel bar. The finite element analysis of the beam is shown in figure 7. It found that the maximum strain in concrete and steel occurs at the bottom of the beam is 0.004817 and 0.00275, respectively. The beam reaches the ultimate stress-strain values. Concrete reaches the maximum compressive stress at the bottom is 24.626 MPa, and steel reaches the maximum compressive stress at the bottom is 550.018 MPa.



a. Deflection



b. Strain in Concrete

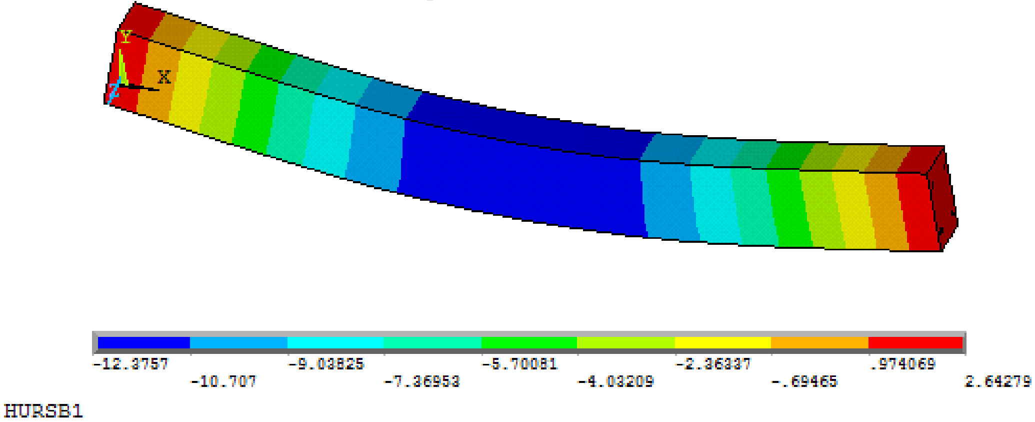


c. Strain in Steel

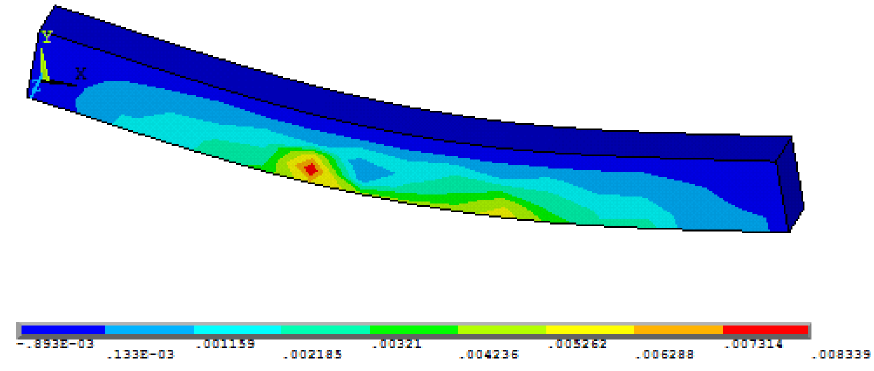
Fig 7. Beam SUM B1

3.3. *Beam HURS B1*

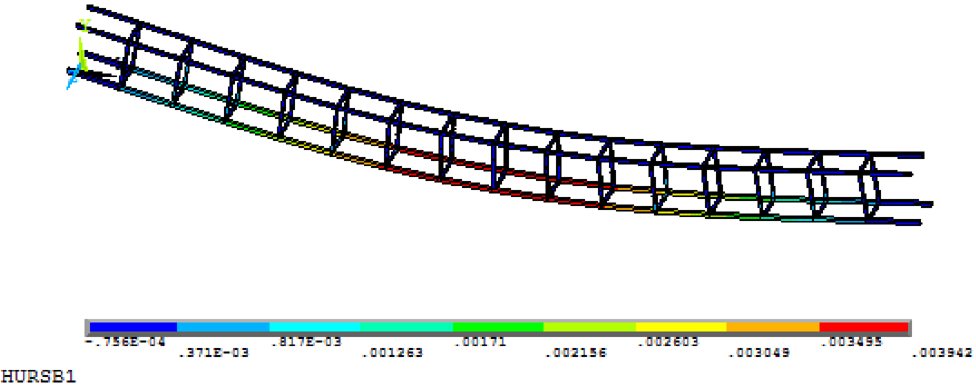
The GGBS based concrete beam using a hybrid FRP bar. The finite element analysis of the beam is shown in figure 8. It found that the maximum strain in concrete and steel occurs at the bottom of the beam is 0.00833 and 0.00394, respectively. The beam reaches the ultimate stress-strain values. Concrete reaches the maximum compressive stress at the bottom is 25.232 MPa, and steel reaches the maximum compressive stress at the bottom is 532.12 MPa.



a. Deflection



b. Strain in Concrete

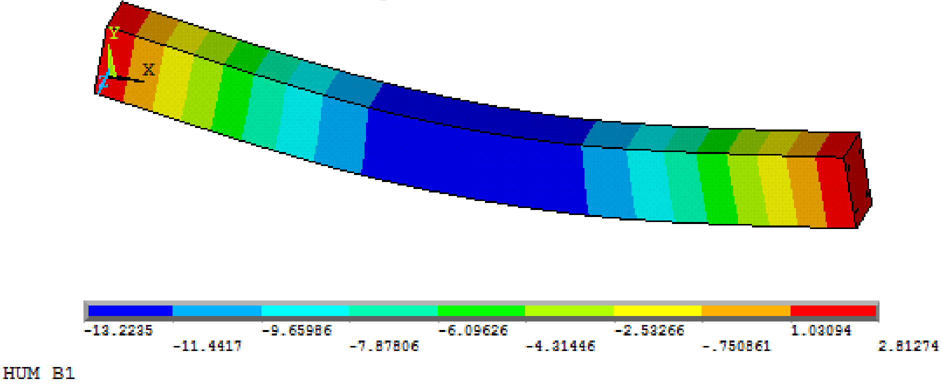


c. Strain in Steel

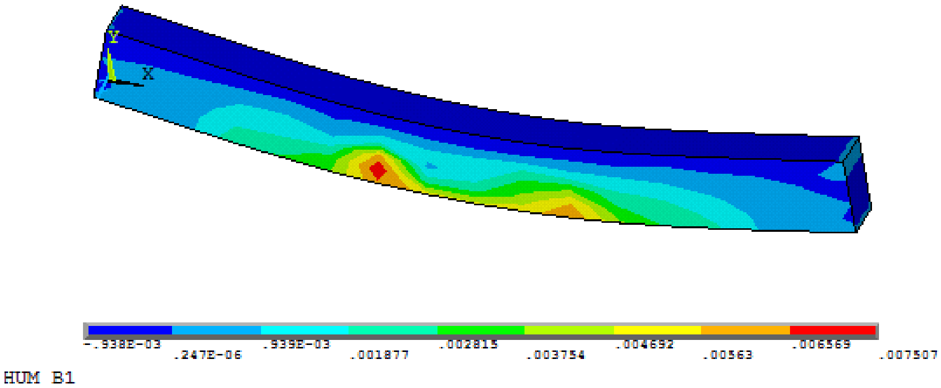
Fig 8. Beam HURS B1

3.4. Beam HUM B1

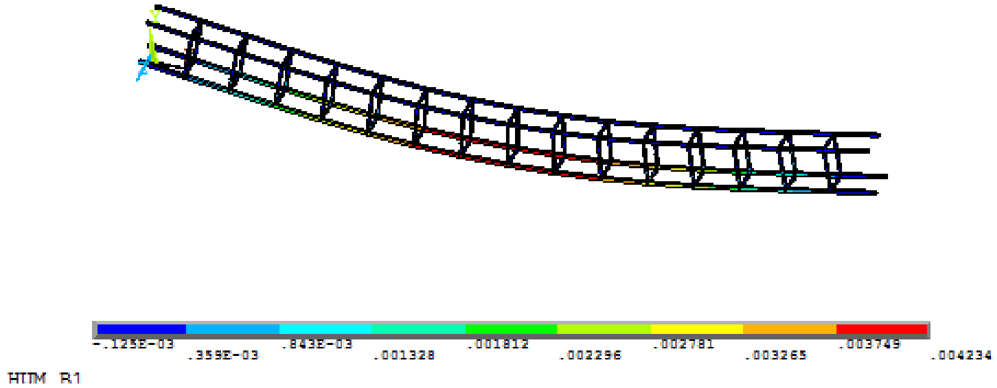
The GGBS based concrete beam using a hybrid FRP bar. The finite element analysis of the beam is shown in figure 9. It found that the maximum strain in concrete and steel that occurs at the bottom of the beam is 0.0075 and 0.00423, respectively. The beam reaches the ultimate stress-strain values. Concrete reaches the maximum compressive stress at the bottom is 26.71 MPa, and steel reaches the maximum compressive stress at the bottom is 571.53 MPa.



a. Deflection



b. Strain in Concrete

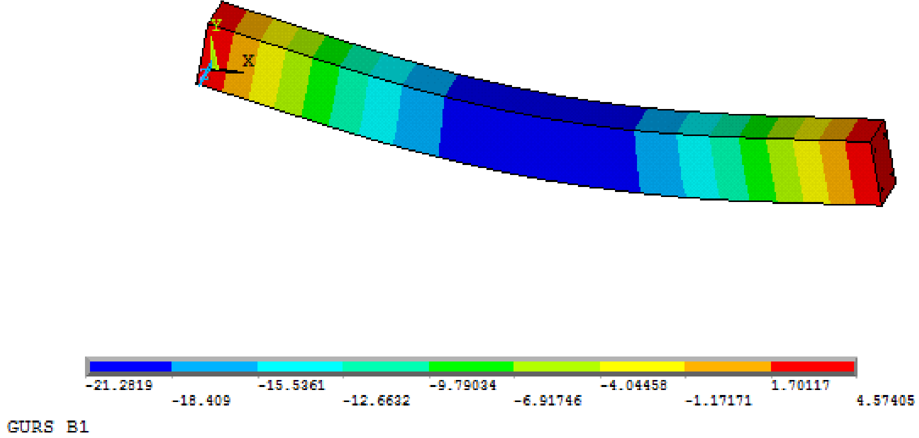


d. Strain in Steel

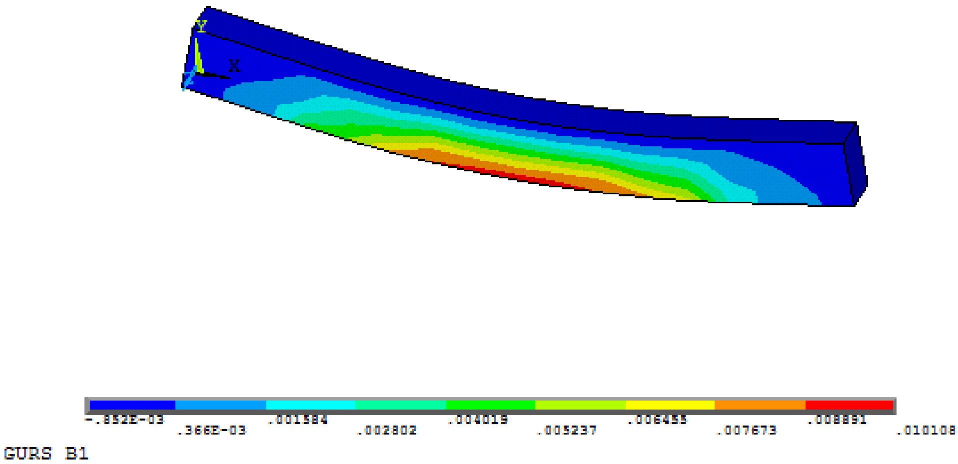
Fig 9. Beam HUM B1

3.5. Beam GURS B1

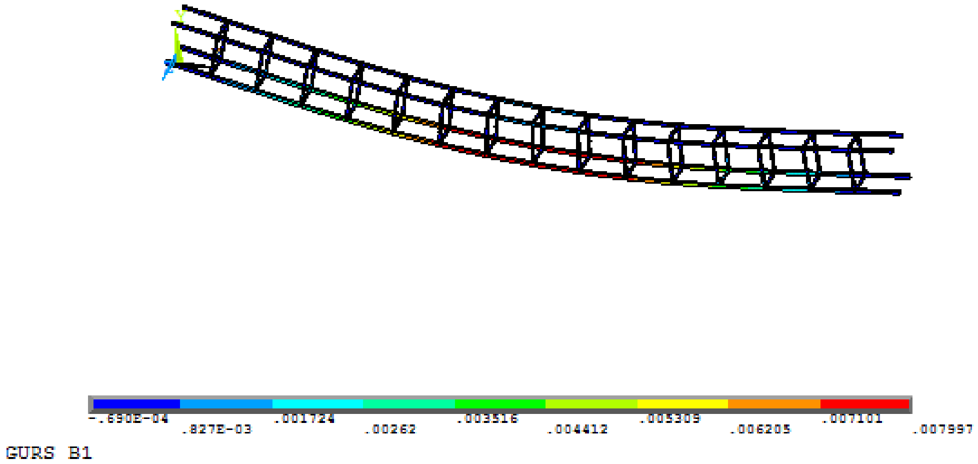
The GGBS based concrete beam using a GFRP bar. The finite element analysis of the beam is shown in figure 10. It found that the maximum strain in concrete and steel that occurs at the bottom of the beam is 0.0101 and 0.00799, respectively. The beam reaches the ultimate stress-strain values. Concrete reaches the maximum compressive stress at the bottom is 23.88 MPa, and steel reaches the maximum compressive stress at the bottom is 367.8 MPa**.**



a. deflection



b. Strain in Concrete

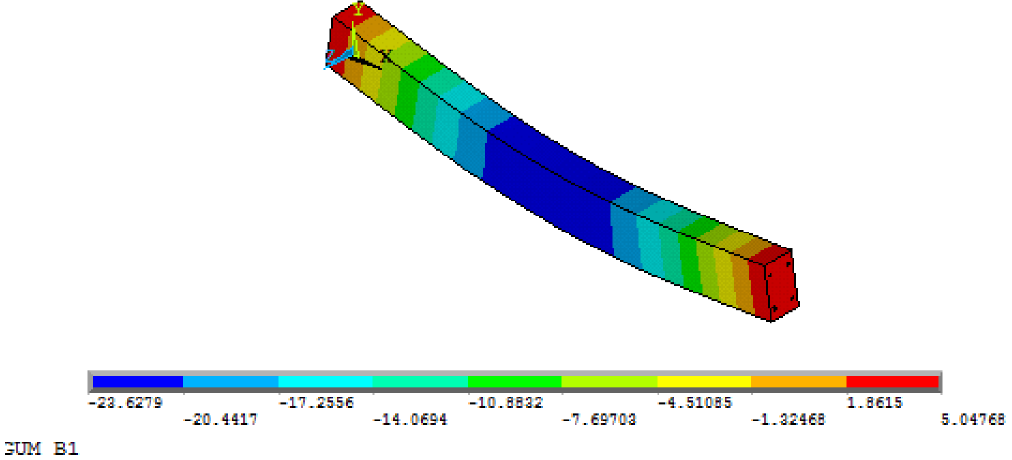


c. Strain in Steel

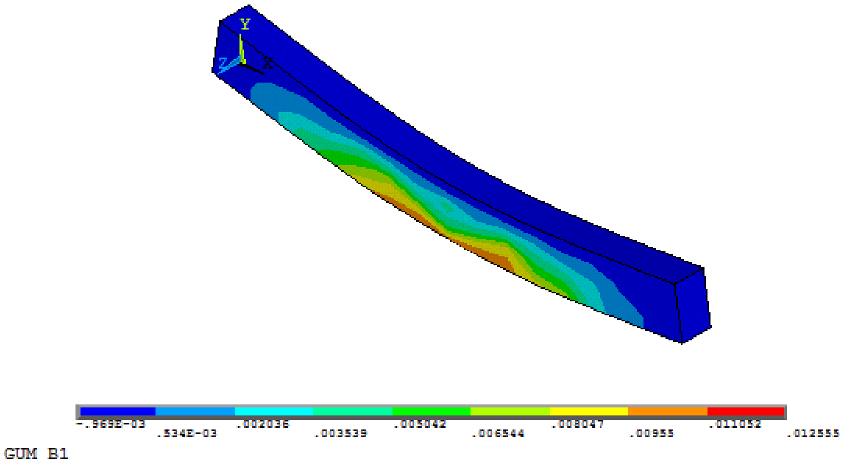
Fig10. Beam GURS B1

3.6. Beam GUM B1

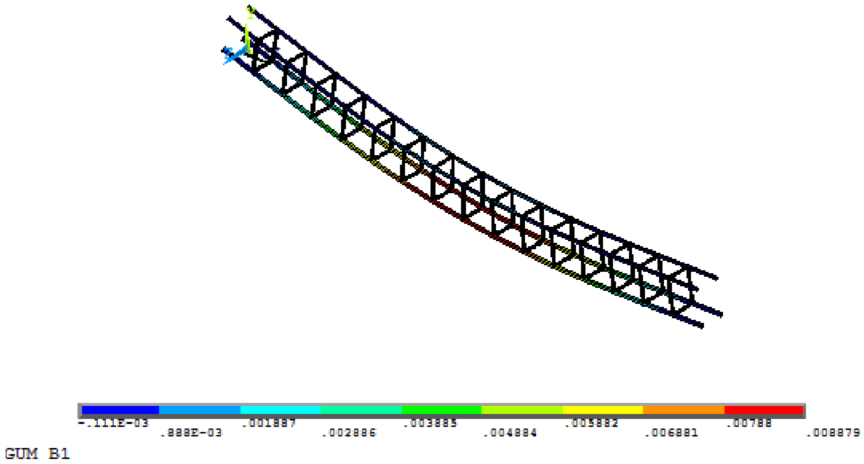
The GGBS based concrete beam using GFRP bar. Finite element analysis of the beam is shown in figure 11. It found that maximum strain in concrete and steel occur at the bottom of the beam is 0.0125and 0.0088 respectively. The beam reaches the ultimate stress strain values. Concrete reaches the maximum compressive stress at bottom is 26.63 MPa and steel reaches the maximum compressive stress at bottom is 408.43 MPa.



a. Deflection



b. Strain in Concrete

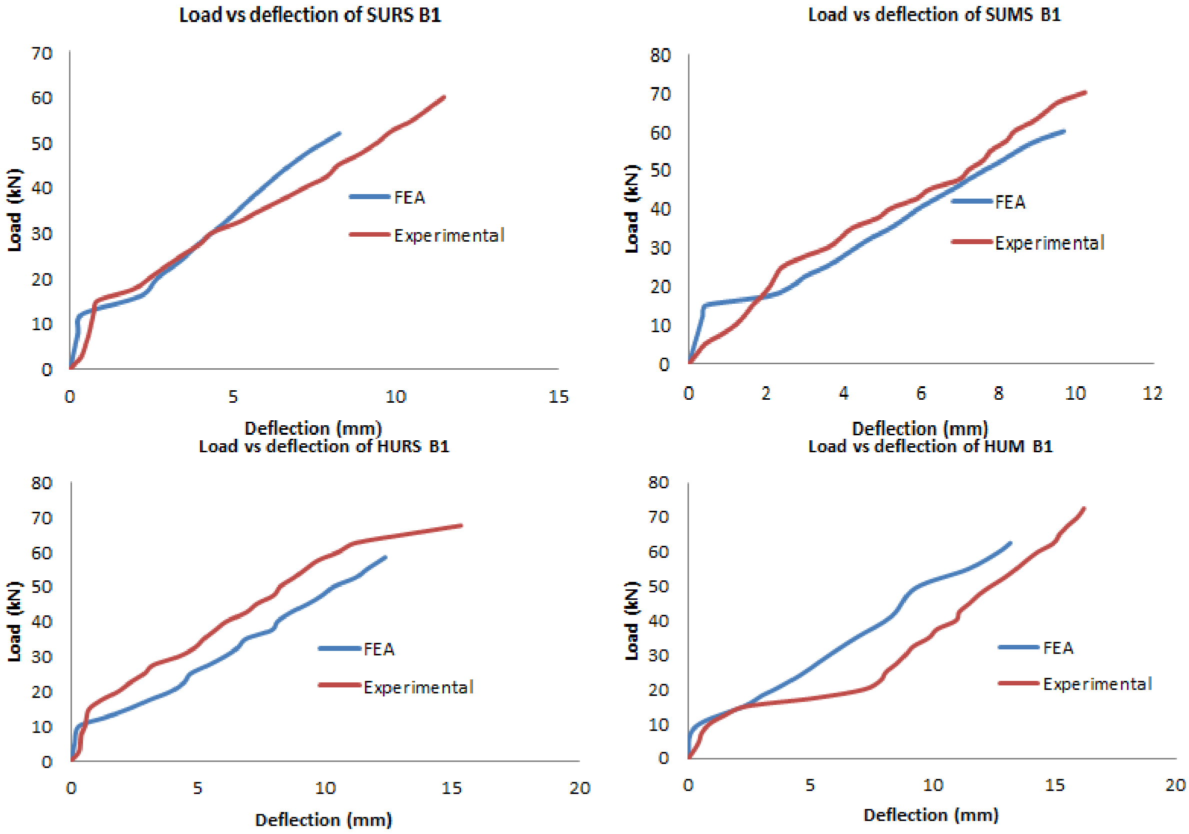


c. Strain in Steel

Fig 11. Beam GUM B1

3.7. Load Vs Deflection Behaviour

Load vs deflection behaviour of all the beams is shown in figure 12. From the load-deflection curve, we found that experimental load and deflection are higher than the finite element results. Finite element analysis shows that the GGBS beams are behaving linearly up to the elastic limit. It gives better agreement with experimental values. The experimental vs numerical values are given in table 3.



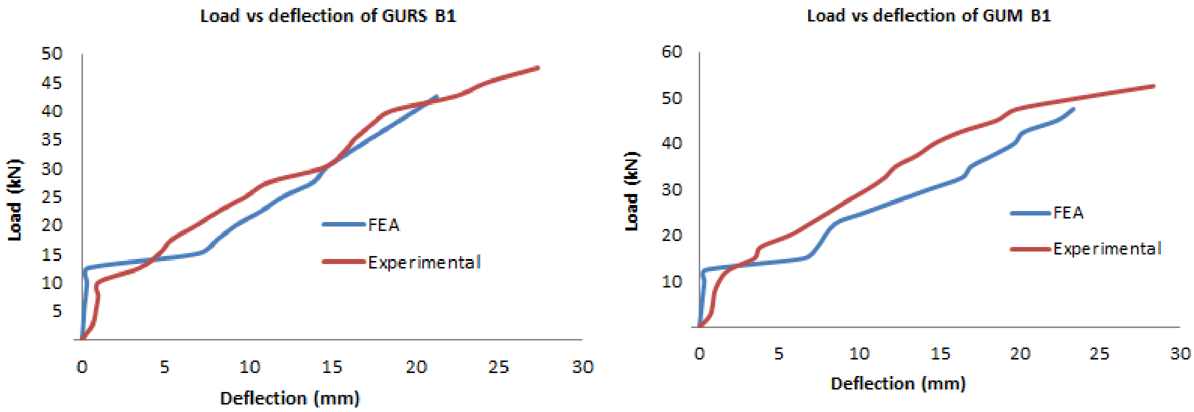


Fig 11. Experimental and numerical load vs deflection [a. Load vs deflection of SURS B1, b. Load vs deflection of SUM B1, c. Load vs deflection of HURS B1, d. Load vs deflection of HUM B1, e. Load vs deflection of GURS B1, f. Load vs deflection of GUM B1;]

Table 3: Experimental vs numerical results

Numerical					***Experimental***			
ID	Load (kN)	Deflection (mm)	Strain		Load (kN)	Deflection (mm)	Strain	
			Concrete	Steel			Concrete	Steel
SUM B1	60	9.699	0.00482	0.00275	70	10.214	0.00520	0.00320
SURS B1	52	8.276	0.00337	0.00250	60	11.24	0.00365	0.00315
HUM B1	62.58	13.223	0.00750	0.00423	72.5	16.234	0.00785	0.00452
HURS B1	58.4	12.377	0.00833	0.00394	67.5	15.34	0.00912	0.00462
GUM B1	47.5	23.334	0.01250	0.00880	52.5	28.34	0.01850	0.00920
GURS B1	42.5	21.281	0.01010	0.00799	47.5	27.34	0.01420	0.00825

4. Conclusion

Nowadays, everyone prefers green constructive material to ensure sustainability and to safeguard the environment in another way. This has motivated the author to carry out this work. Nonlinear finite element analysis is performed on six full-scale GGBS concrete beams made of steel, hybrid FRP, and GFRP bars. The GGBS concrete beam is made using both manufacturing and river sand. It was discovered that GGBS concrete beams made using manufacturing sand had more strength than concrete beams made with river sand. The closest experimental findings are shown by finite element modelling of a GGBS concrete beam employing steel bars. The strain in the concrete of SUM B1 is 42% more than that of SURS B1. In concrete and steel, SURS B1 ultimate stress is less than SUM B1. The GGBS concrete beam made of a hybrid FRP bar is taller than the GGBS concrete beam made of a GFRP bar. In comparison to the whole beam, the HUM B1 beam has the highest stress in concrete and steel. It was discovered that hybrid FRP bars had greater strength and less deflection than GGBS concrete beams utilising hybrid FRP and GFRP bars. In comparison to the other specimens, the GGBS concrete beam with hybrid FRP bars has a greater strain value. The discrepancy between numerical observation and experimental findings is less than 15%. The findings of finite element analysis are more in accord with the experimental values.

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