Flexural behaviour of GGBS concrete beam with steel, hybrid FRP and GFRP bars

Karikalan A T[1], Prabaghar A[2] and Saravanan J[3]

[1] Research scholar, Department of Civil and Structural Engineering, Annamalai University, Chidambaram, Tamil Nadu 608 002,
[2] Associate Professor, Department of Civil and Structural Engineering, Annamalai University, Chidambaram, Tamil Nadu 608 002.
[3] Associate Professor, Department of Civil and Structural Engineering, Annamalai University, Chidambaram, Tamil Nadu 608 002.

Article History: Received: 11 January 2021; Revised: 12 February 2021; Accepted: 27 March 2021; Published online: 10 May 2021

Abstract:

In this research, partial replacement of cement using GGBS content, The percentage of replacement is 5 %, 10%, 15%, 20%, 25%, 30%, 35% and 40%. The content of GGBS will influence on the strength of concrete. The compressive strength, split tensile strength and flexural strength tests are carried out to find the behaviour of concrete. Nowadays the unavailability of river sand is increases. We also study the behavior of GGBS concrete beam using river sand and M sands. GGBS concrete beam using steel bars, hybrid FRP and GFRP bars also incorporated. FRP and GFRP bars are more popular in construction industry. The load vs deflections were measured. In this study shows that the GGBS concrete beam using hybrid FRP are superior to GFRP bars. The GGBS concrete beam using hybrid FRP beam fail by shear and GGBS concrete using GFRP beam fails by both shear and flexure.

Keywords : GGBS, M sand, River sand, hybrid FRP, GFRP

1.Introduction,

Cement is unavoidable building material in construction industry. In the world the production of cement generate 2.4 billion tonnes of CO_2 every year. The production of cement is high expensive and very harmful to environment. So in order to reduce the consumption of cement the alternate remedies is mineral admixtures. Nowadays, Different types of mineral admixtures are available like fly ash, silica fume, Metakaolin, rich hush ash and ground granulated blast furnace slag (GGBS). The mineral admixtures are primarily to reduce the cost of construction industry. Most of the mineral admixtures are used to reduce the cost of cement in construction industry.

In the research, GGBS concrete beam using hybrid FRP and GFRP rebars. Ground granulated blast furnace slag are used to partial replacement of cement was done. Ground granulated blast furnace slag is a byproduct of iron in blast furnace. The partial replacement of GGBS by cement the strength at early stage is low and later the strength was increased. Oner and Akyuz [1] carried out experimental study on optimal usage of GGBS in concrete. It concluded that strength of concrete increase as GGBS content increases up to a certain point. They got an optimal percentage of replacements is 55 % -59% of replacement of cement. Reddy suda and srinivasa rao [2] carried out the optimum usage of micro silica na d GGBS for strength characteristics of concrete. It concluded that the GGBS increase the workability of concrete and 15 % micro silica and 20 % GGBS gives high early strength in concrete. Rami hawileh et al [3] carried out performance of reinforced concrete beams with different percentage of GGBS. The optimum percentage of GGBS was achieved at 55 % and 77 % respectively.

Hybrid fibre reinforced polymer and glass fibre reinforced polymer bars are more popular. Its having high durable and corrosion free property. The FRP bars are improving the ductility to the beam and reduce the brittle failure. Kalpana and Subramanian [4] carried out the Behavior of concrete beams reinforced with GFRP bars. It concluded that theoretical strength of GFRP bars are lower than conventional steel bar. An experimental and numerical result shows that GFRP bars having better performance in high strength as well as normal concrete. Ashour [5] carried out the shear and flexural behavior of concrete beam with GFRP bars. Totally 12 no of beams wer tested without shear reinforcement. Beams are failed by flexure due to rupture of GFRP bars. Suzan et al [6] carried out the behavior of beam with hybrid FRP and steel bars. It concluded that provide the FRP bar as lower reinforcement and steel as top reinforcement. The HFRP beam has higher strength the GFRP bars. Ali S. Shanour [7] carried out the investigation of concrete beam using GFRP bars. It concluded that GFRP mechanical properties are better than locally available fibre. Failure of GFRP beam is more than the balanced reinforcement. Mohamed A. Safan [8] carried out the experimental and design aspect of beam using GFRP bars. It concluded that GFRP bar are bottom to control the crack and cracking control also good in GFRP bars. Ahmed Abouzied & Radhouane Masmoudi [9] carried out the structural performance of new fully and partially concrete-filled rectangular FRP-tube beams. It concluded that the strength of FRP member increases and weight of structure is reduces. Doo-Yeol Yoo et.al [10] carried out Flexural behavior of ultra-high-performance fiber-reinforced concrete beams reinforced with GFRP and steel rebars. It concluded that first cracking load and deflection are simila and ma crack width decreases with increasing of GFRP bars.

2.Materials

Ordinary Portland cement 53 grade was used in this study. The Fine aggregates both river sand and manufacturing sand was used. Coarse aggregate of size 20 mm is used. Portable water available from laboratory it's free from suspended particles. The physical properties of materials are shown in table 1. The Hybrid FRP and GFRP bars are used as rebars and its properties shown in table 2.

Table 1: Physical properties of materials

Properties	Cement	GGBS	Fine aggregates		Coarse Aggregate
			River sand	M sand	
Specific gravity	3.12	2.89	2.67	2.61	2.7
Fineness modulus (%)	3 %	4 %	2.8%	2.95 %	6.75%
Initial setting time	32 min	-	-	-	-
Final setting time	480 min	-	-	-	-

Table 2: Mechanical properties of Rebars

Properties	Steel	Hybrid FRP (Carbon)	GFRP
Youngs modulus (MPa)	200000	135000	46000
Ultimate stress (MPa)	500	1623	550

3.Experimental Investigation

The M20 grade concrete is used. Concrete mix was design as per IS 10262-2019. The ratio is 1:1.78:3.32:0.5 (Cement: Fine aggregate: Coarse aggregate: Water). The cement OPC 53 grade was used. The slump cone test was carried out for fresh concrete and Compressive and split tensile strength was carried out for harden concrete. The 150 mm x 150 mm x150 mm were casted for compressive strength test, 150 mm diameter and 300 mm cylinders were casted for split tensile strength and 150 mm x 150 mm x 700 mm prism were casted for flexural strength test. The slump cone values are shown in table 3, compressive strength values are shown in table 4, split tensile strength values are shown in table 5 and flexural strength shown in table 6. The casting of cubes, cylinders and prism are shown in figure 1. Machine mixing were adopted.

a) Mixing

b) Casting of specimen

Figure 1: Mixing and casting of specimen

Table 3: Slump cone values

Sl.no	Cement (%)	GGBS (%)	Slump Value (mm)
1	100	0	120
2	95	5	115
3	90	10	125
4	85	15	115
5	80	20	120
6	75	25	125

7	70	30	125
8	65	35	120
9	60	40	115

Table 4: Compressive strength values

Sl.no	Cement (%)	GGBS (%)	7 days Compressive strength (MPa)	28 days Compressive strength (MPa)
1	100	0	18.41	27.4
2	95	5	16.5	20.2
3	90	10	16	23.3
4	85	15	17.2	24.5
5	80	20	16.5	25.3
6	75	25	16.8	26.7
7	70	30	15.23	28.23
8	65	35	14.23	26.3
9	60	40	13.61	23.6

Figure 2 shows that effect of GGBS on compressive strength of M20 grade concrete. The cement replaced by 5 % 10 %, 15 %, 20 % and 25 % of GGBS the strength of concrete reduced by 26 %, 14.9 %, 10.58 %, 7.66 %, 2.55 %. Further the GGBS added to the concrete the strength of increased. The 30 % of GGBS in concrete the strength is 2.19 % increased after adding 35 % and 40 % strength decreased about 4 % and 13.86 % respectively.

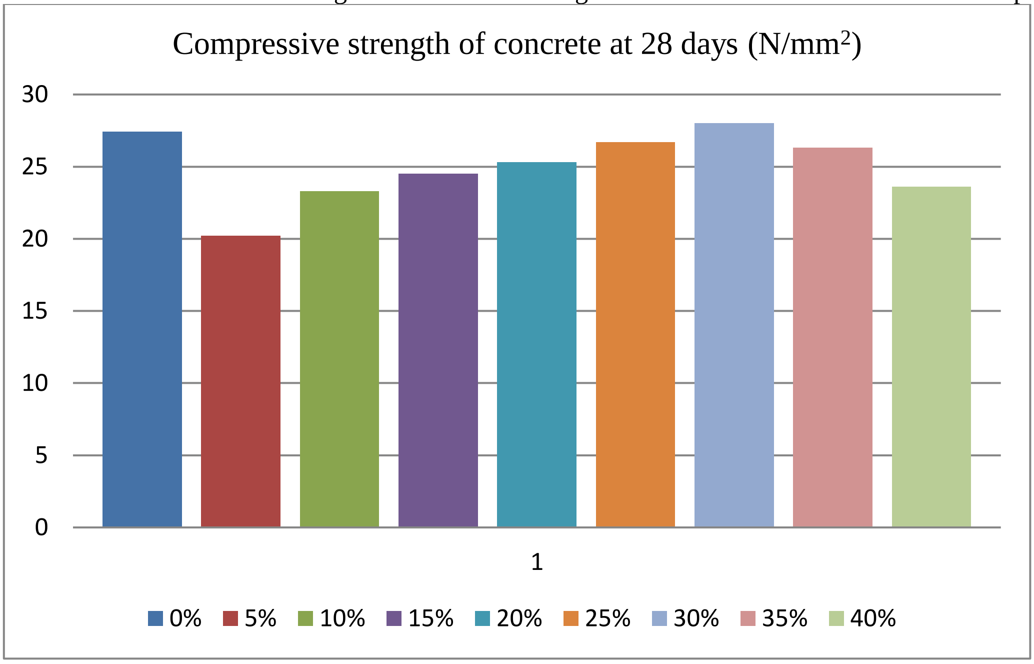

Figure: 2 Compressive strength of concrete at 28 days

Table 5: Split tensile strength values

Sl.no	Cement (%)	GGBS (%)	28 days Split tensile strength (MPa)
1	100	0	2.6
2	95	5	1.95
3	90	10	2.23
4	85	15	2.32
5	80	20	2.43
6	75	25	2.57
7	70	30	2.83
8	65	35	2.54

9	60	40	2.2

Figure 3 shows that effect of GGBS on split tensile strength of M20 grade concrete. The cement replaced by 5 % 10 %, 15 %, 20 % and 25 % of GGBS the strength of concrete reduced by 25 %, 14.23 %, 10.73 %, 6.53 %, 1.15 %. Further the GGBS added to the concrete the strength of increased. The 30 % of GGBS in concrete the strength is 8.84 % increased after adding 35 % and 40 % strength decreased about 2.3 % and 15.38 % respectively.

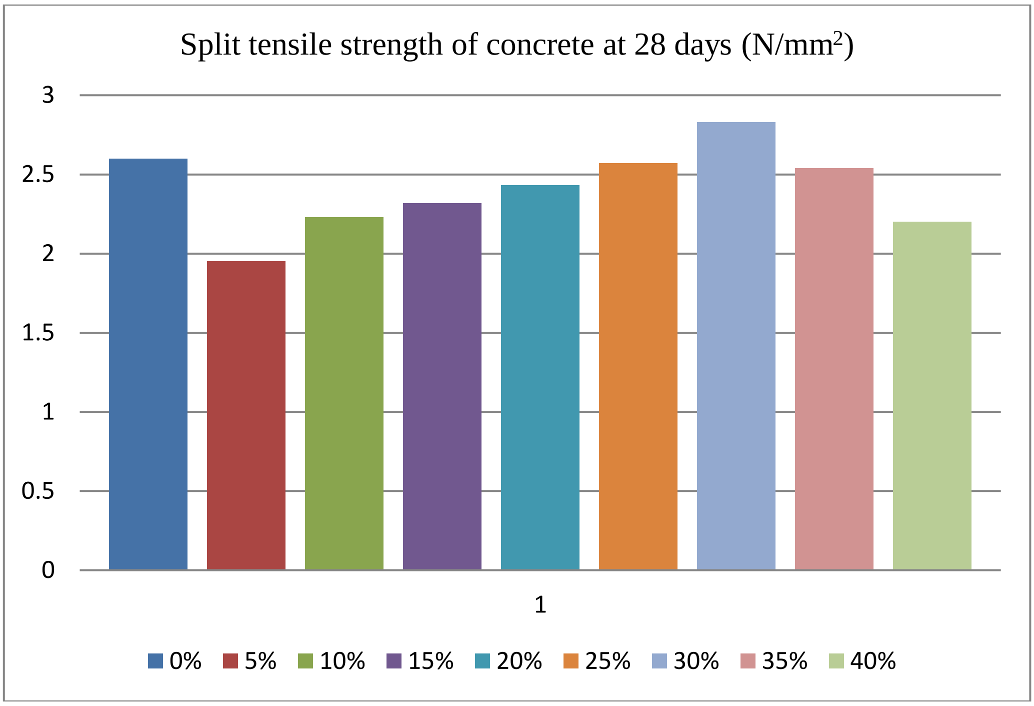

Figure: 3 Split tensile strength of concrete at 28 days

Figure 3 shows that effect of GGBS on flexural strength of M20 grade concrete. The cement replaced by 5 % 10 %, 15 %, 20 % and 25 % of GGBS the strength of concrete reduced by 17.4 %, 14.44 %, 12.96 %, 10 %, 4.81 %. Further the GGBS added to the concrete the strength of increased. The 30 % of GGBS in concrete the strength is 5.55 % increased after adding 35 % and 40 % strength decreased about 10 % and 12.59 % respectively.

Table 6: Flexural strength values

Sl.no	Cement (%)	GGBS (%)	28 days Flexural strength (MPa)
1	100	0	2.70
2	95	5	2.23
3	90	10	2.31
4	85	15	2.35
5	80	20	2.43
6	75	25	2.57
7	70	30	2.85
8	65	35	2.43
9	60	40	2.36

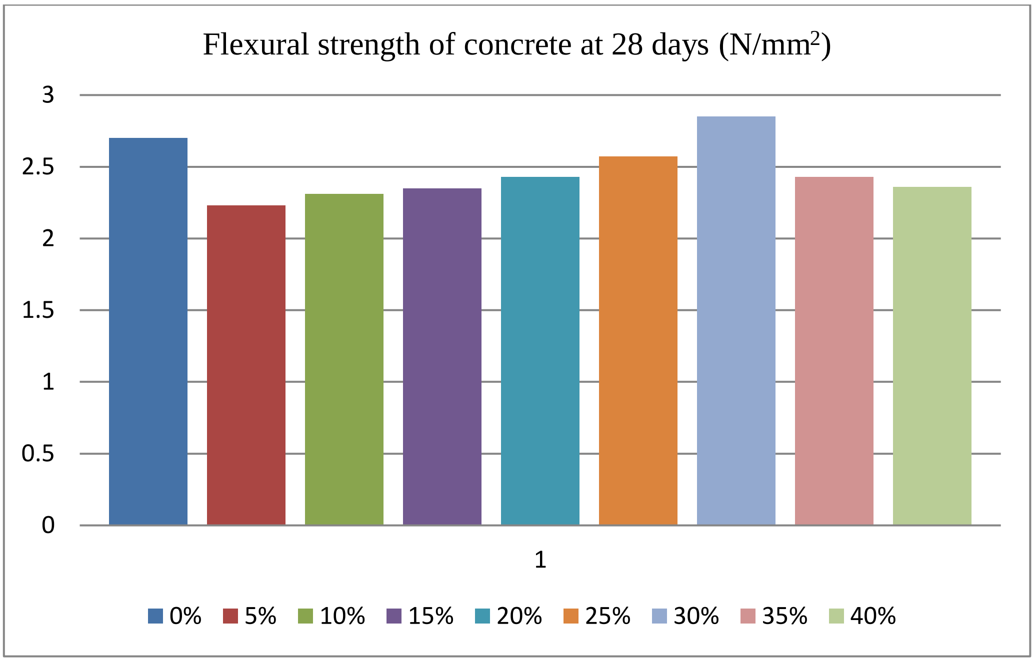

Figure: 4 Flexural strength of concrete at 28 days

The harden concrete testing are shown in figure 2

a) Compression test **b) Flexural test**

Figure 2: Testing of hardened concrete

3.1. Effect of GGBS in concrete

Cement is partially replaced with GGBS with 5 %, 10%, 15%, 20%, 25%, 30%, 35% and 40%. The amount of GGBS increase the early strength was decreases. The average of three samples was taken for every testing age. It was observed that 28 days compressive strength upto 25 % of replacement of GGBS the strength was decrease as compare to normal concrete. Strength was increases at 30 % of replacement of GGBS. The 30 % replacement the split tensile strength and flexural strength also increases. The replacement greater than 30 % the strength was decreases. It was observed that 30 % replacement of cement by GGBS gives better results compare to other percentage.

3.2 Beam details

Totally 12 nos of beam were casted and tested with different types of rebars. The length of beam is 2200 mm in length and 150 mm x 250 mm in cross section. Both under and over reinforced beams were casted. The under reinforced beam 2 nos of 12 mm bottom reinforcement and 2 nos of top reinforcement with 8 mm stirrups at 200 mm cc spacing and for over reinforced beam 3 nos of 12 mm bottom reinforcement and 2 nos of top reinforcement with 8 mm stirrups at 200 mm cc spacing. The loading arrangement is shown in figure 5. The entire beams were casted with M20 grade concrete. The optimum GGBS content (30 %) is maintained for all the mixes. Mould and casting of beams are shown in figure 3.

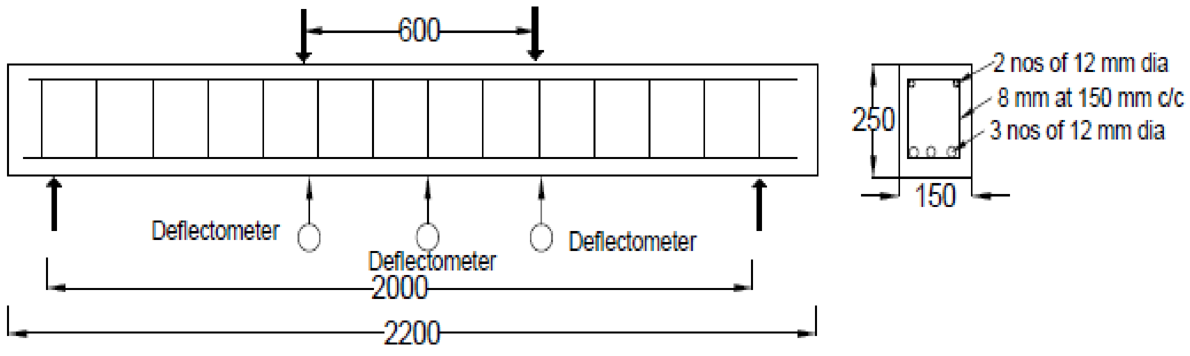

Figure 5: Loading arrangement

The beam details are shown in table 6

Table 6: Beam details

Beam Id	**Fine aggregates**	**Reinforcement**			**Rebar**
		Bottom	**Top**	**Stirrups**	
Over reinforced beam					
SORS B1	River sand	3 nos of 12	2 nos of 12 mm	8 mm at 150 mm cc	Steel
SOM B1	M sand	3 nos of 12	2 nos of 12 mm	8 mm at 150 mm cc	Steel
HORS B1	River sand	3 nos of 12	2 nos of 12 mm	8 mm at 150 mm cc	Hybrid FRP
HOM B1	M sand	3 nos of 12	2 nos of 12 mm	8 mm at 150 mm cc	Hybrid FRP
GORS B1	River sand	3 nos of 12	2 nos of 12 mm	8 mm at 150 mm cc	GFRP
GOM B1	M sand	3 nos of 12	2 nos of 12 mm	8 mm at 150 mm cc	GFRP
Under reinforced beam					
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

3.3 Casting

Steel mould is used for casting of beam to get required shape before casting the mould is properly clear and free from dust. The reinforcement details are shown in figure 6. Reinforcement is placed with proper clear cover. The concrete is mixed and poured into the mould by three layers and each layers and compacted by needle vibrator. Mould and casting of beam are shown in figure 7.

a) Steel bar **b) Hybrid FRP** **c) GFRP**

Figure 6: Reinforcement details

Figure 7: Mould and casting of beams

3.4 Loading setup

The beam was tested under simply supported boundary condition. The 500 kN loading frame were used. Three deflectometer were placed under the beam to monitor the displacement due to loading. One deflectometer placed under mid span and two under the loading points. The loading setup is shown in figure 8. The proving ring is used to measure the loading. The two point load was applied through spreader beam to beam. The load was applied at a increment of 2.5 kN. The deflection was measured corresponding to deflection of beam up to the failure.

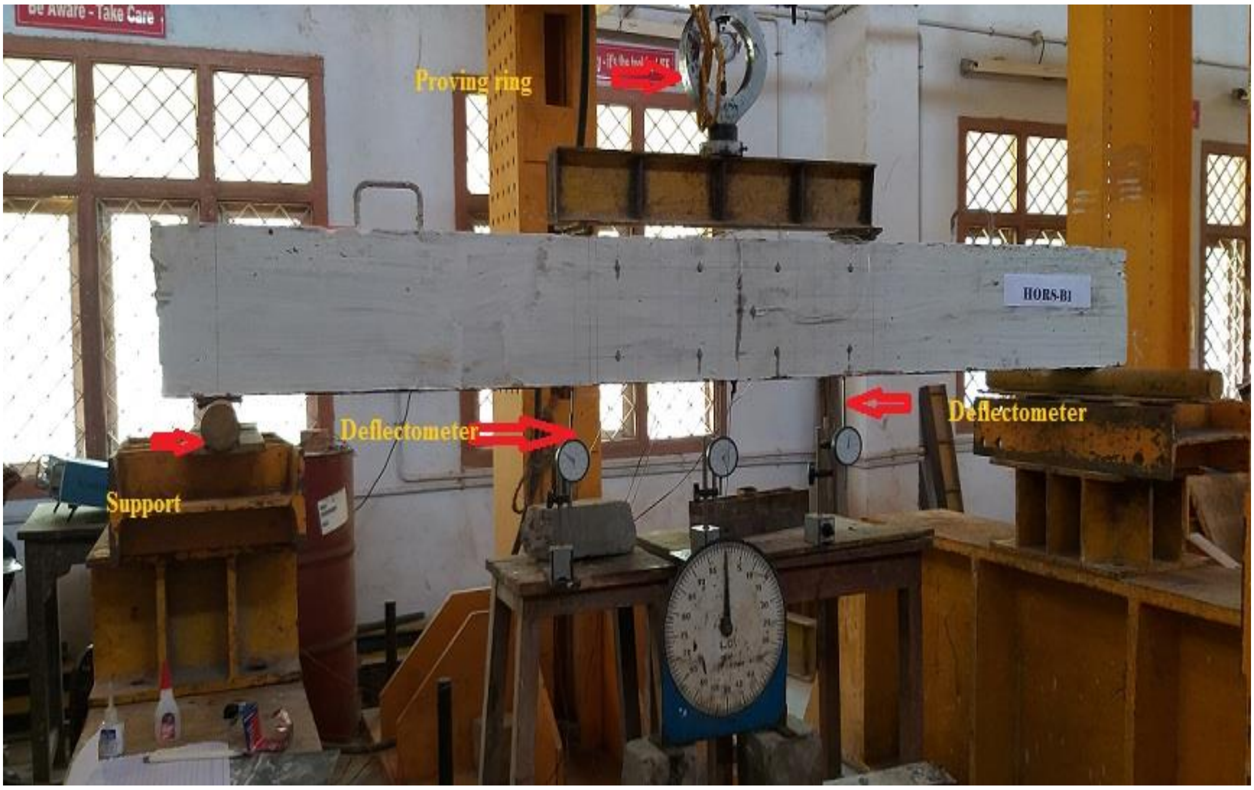

Figure 8: Loading setup

3.5 Load vs deflection behaviour

The ultimate load vs deflection of beam is shown in table 7. It was observed that the GGBS concrete beam using M sand has higher strength compared to GGBS concrete beam using river sand. The ultimate load and deflection of GGBS beam using steel bar has better performance compared to all the specimens. The failure beams are shown in figure 9. Compare to hybrid FRP and GFRP, the hybrid FRP (carbon) has higher load carrying capacity. The percentage of reinforcement increases the strength of beam also increases. The Figure 10 & 11 shows load vs deflection of beam using M sand and river sand.

Table 7: Load vs deflection

Beam ID	Load (kN)	Deflection (mm)
SOM B1	95	14.52
SORS B1	85	14.45
SUM B1	75	10.24
SURS B1	60	11.49
HOM B1	82.5	17.23
HORS B1	75	14.25
HUM B1	72.5	16.23
HURS B1	67.5	15.34
GOM B1	65	23.56
GORS B1	55	23.67
GUM B1	52.5	28.34
GURS B1	47.5	27.34

Figure 9 shows the failure of GGBS concrete beam using steel, hybrid FRP and GFRP bars. The GGBS concrete beam using steel bars shows that the shear cracks are develop in the support ad loading point and flexural cracks are developed in mid span. GGBS Concrete using hybrid FRP bars shows that the failure will occur due to the flexural alone. GGBS concrete beam using GFRP bars the beam fail by both shear and flexural.

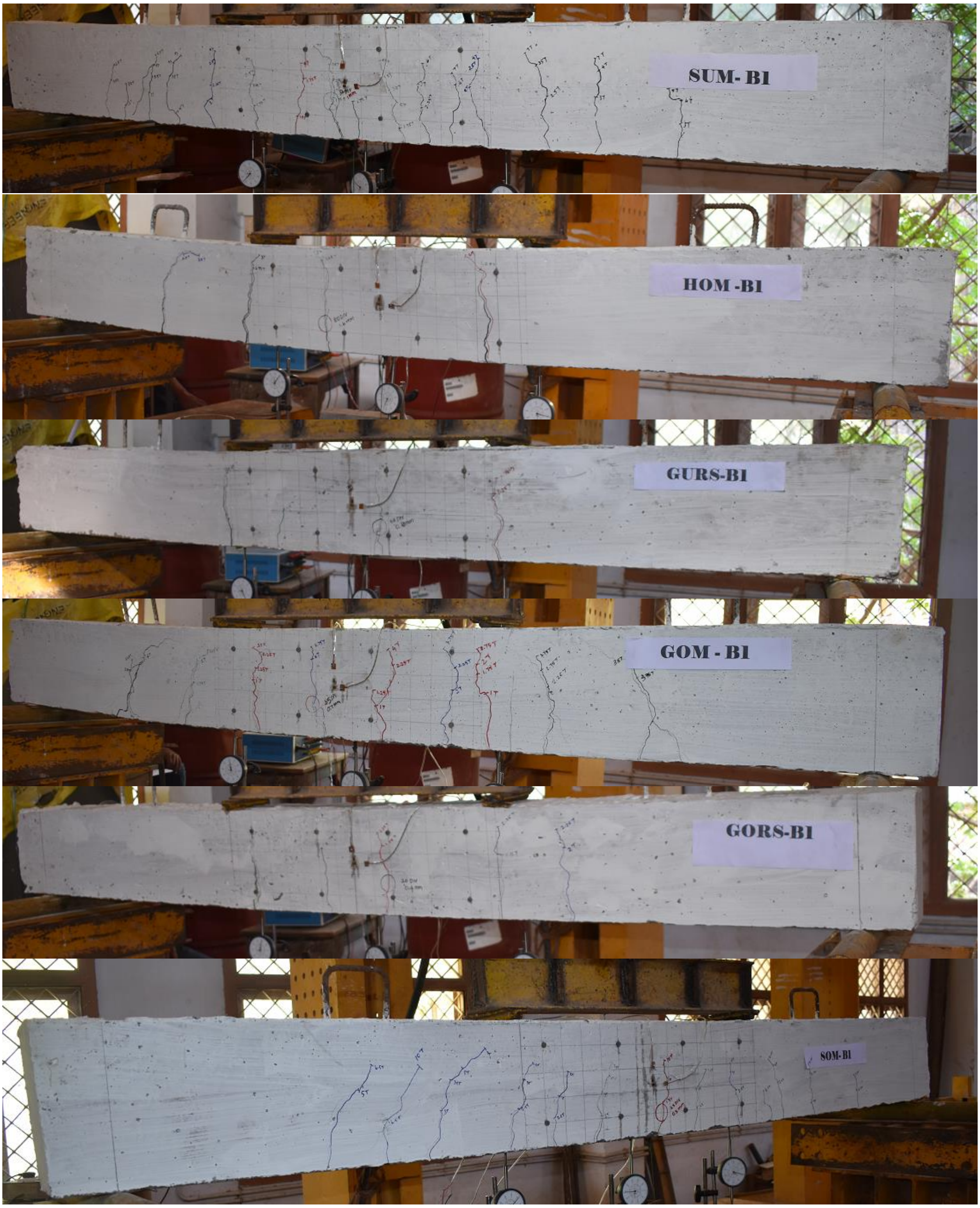

Figure 9: Failure of beams

Figure 10 shows all the beams are linear upto elastic limit and its obeys the hooks law. The over reinforcement beam having more load carrying capacity than under reinforced beam. The hybrid FRP beam has more load carrying capacity than GFRP bars about 11.53 % and lower than the 2.5 % lower than the steel bars. The over reinforced hybrid FRP bar has higher strength about 13.79 % than under reinforced hybrid FRP. The ultimate load of GGBS concrete using hybrid FRP bar is 82.5 kN and corresponding deflection is 17.23 mm. The over reinforced GGBS concrete beam using GFRP bars has higher strength than under reinforced section is about 23.8 %. The GGBS concrete beam using hybrid FRP bars has lesser deflection is about 36.2 %. The ultimate load of under reinforced GGBS concrete beam using steel bars is 75 kN and deflection is 10.24 mm. Ultimate load of SOM B1 is 95 kN and deflection is 14.52 mm. Deflection of GGBS concrete beam using steel bar is lower than hybrid FRP and GFRP bars.

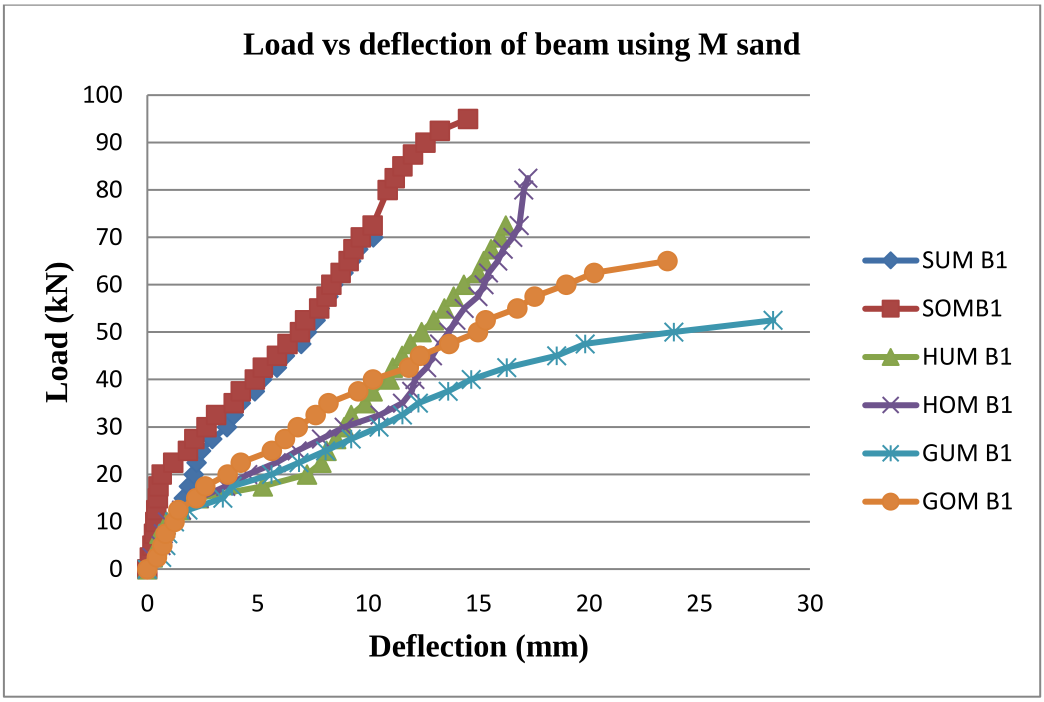

Figure 10: Load vs deflection of beam using M sand

Figure 11 shows all the beams are linear upto elastic limit and its obeys the hooks law. Load vs deflection of all the specimens is linear upto 20 kN. The GGBS concrete beam using river sand has lesser strength than beam using M sand. The ultimate load of over reinforced GGBS concrete beam using steel bar is 85 kN and corresponding deflection is 14.45 mm. The GURS B1and GORS B1 linear upto the 10 kN after that every increment of load its under large amount of displacement as compare to steel bars. Ultimate load of HORS B1 is 75 kN and corresponding deflection is 14.25 mm.

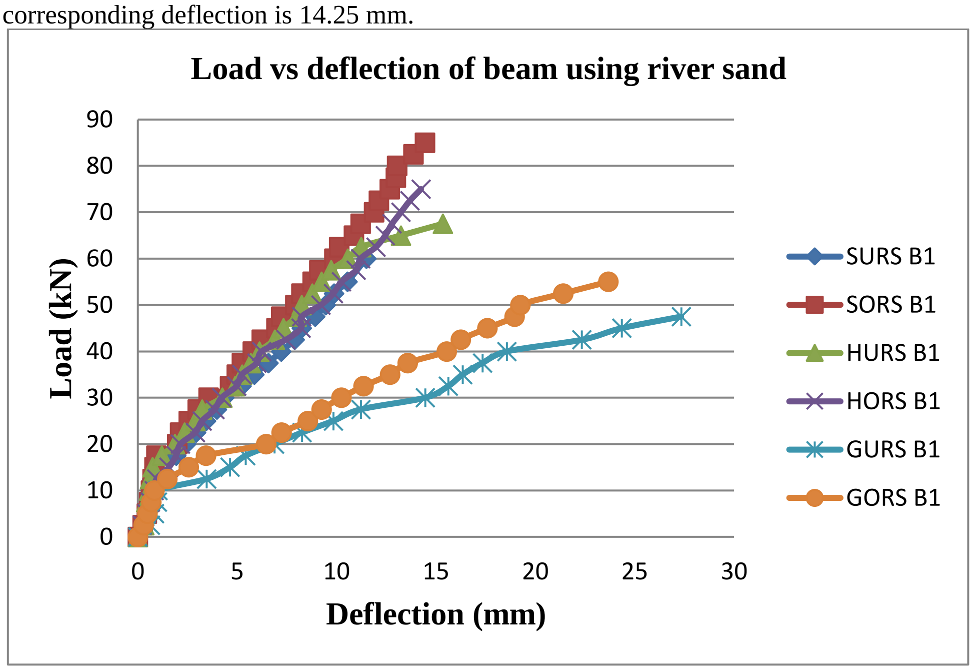

Figure 11: Load vs deflection of beam using river sand

4. Conclusion

In this research, the cement replacement by GGBS shows the better results. The partial replacement of cement using GGBS with 5 %, 10%, 15%, 20%, 25%, 30%, 355 and 40%. It was observed that the strength of concrete is reducing upto the 25 % of GGBS content. The 30 % GGBS content its shows the strength was good and after 30% again the results was falling. It concluded that the optimum percentage of replacement of cement by GGBS is 30%. The compressive strength of GGBS concrete is 28.23 N/mm^2. Split tensile strength is 2.83 N/mm^2 and flexural strength is 2.85 N/mm^2.

Totally 12 nos of beam were casted and tested with different types and various bars like steel, GFRP, hybrid FRP. The ultimate load of SOM B1 is 95 kN and deflection is 14.52 mm. The ultimate load of SORS B1 is 11% lesser than the SOM B1 and 12 % higher than the HORS B1. The ultimate load of HOM B1 is 10 % higher than the HORS B1 and 14 5 lesser than SOM B1. The ultimate load of HUM B1 is 72.5 kN and corresponding deflection is 16.23 mm which is higher than the HURS B1. The ultimate load of GOM B1 is 16 % higher than the GORS B1 and 32 % lower than SOM B1. Finally concluded that, GGBS concrete beam using hybrid FRP bars are higher strength than GGBS concrete beam using GFRP bars. The amount of FRP increases the strength was increases.

Reference:

1. Oner and Akyuz (2007), "An experimental study on optimum usage of GGBS for the compressive strength of concrete", cement and concrete composite,vol29, pp.505-514.
2. V.B. Reddy Suda a , P. Srinivasa Rao (2020), "Experimental investigation on optimum usage of Micro silica and GGBS for the strength characteristics of concrete", Archives of civil and mechanical engineering, vol27, issue3, pp.805-811.
3. Rami A. Hawileh, Jamal A. Abdalla, Fakherdine Fardmanesh, Poya Shahsana, Abdolreza Khalili (2017), "Performance of reinforced concrete beams cast with different percentages of GGBS replacement to cement", Archives of civil and mechanical engineering, vol17, issue3, pp.511-519.
4. Kalpana and Subramanian (2011) "Behavior of concrete beams reinforced with GFRP bars", Journal of Reinforced Plastics and Composites, vol 30, pp.1915–1922.
5. Ashour (2006), "Flexural and shear capacities of concrete beams reinforced with GFRP bars", Construction and Building Materials, vol 20, pp.1005–1015.
6. Suzan A.A. Mustafa and Hilal A. Hassan (2018), "Behavior of concrete beams reinforced with hybrid steel and FRP composites", Housing and Building National Research Center, vol 14,pp.300-308.
7. Ali S. Shanour, Ahmed A. Mahmoud, Maher A. Adam, Mohamed Said (2014), "Experimental investigation of concrete beams reinforced with GFRP bars", International Journal of Civil Engineering and Technology Vol 5, pp.154-164.
8. Mohamed A. Safan (2012), " Behavior and design aspects of concrete beams reinforced with hybrid steel-GFRP bars, Engineering Research Journal, Vol. 35, pp.137-145.
9. Ahmed Abouzied, Radhouane Masmoudi (2015), "Structural performance of new fully and partially concrete-filled rectangular FRP-tube beams", Construction and Building Materials, vol 101, pp 652–660
10. Doo-Yeol Yoo, Nemkumar Banthia and Young-Soo Yoon (2016), "Flexural behavior of ultra-high-performance fiber-reinforced concrete beams reinforced with GFRP and steel rebars", Engineering Structures, vol 111, pp 242-262.
11. A.M. Neville, Properties of Concrete, 4th ed., Wiley, New York, 1997.
12. IS: 16714-2018 Ground Granulated Blast Furnace Slag for using Cement, Mortar and Concrete- Specification, Bureau of Indian standards, New Delhi.
13. IS 12089-1987, Specification for Granulated Slag for the manufacture of Portland Slag Cement, Bureau of Indian standards, New Delhi.
14. IS: 3025-3003 (Part 22) Methods of Sampling and Test (physical and chemical) for water and waste water – Acidity, Bureau of Indian standards, New Delhi.
15. IS:3025-1964 (Part23), Methods of sampling and test (physical and chemical) for water and waste water – Alkalinity, Bureau of Indian standards, New Delhi
16. IS: 10086–1982, Specification for Moulds for use in Tests of Cement and Concrete, Bureau of Indian standards, New Delhi.
17. IS: 516-1959, Method of Tests for Strength of Concrete, Bureau of Indian standards, New Delhi.
18. IS: 5816–1956, Method of Tests for Strength of Concrete, Bureau of Indian standards, New Delhi.