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Flexural Behaviour of Reinforced Concrete Beams Replacing GGBS as Cement and Slag Sand as Fine Aggregate

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Abstract: **The utilization of industrial waste produced by industrial processes has been focus of waste reduction research for economical, environmental and technical reasons. GGBS (Ground Granulated Blast Furnace Slag) and GBF Slag Sand is one such waste product of the iron manufacturing industry, whose use and production has increased many folds during last decades is used in this experimental work as alternative binder and filler materials for Ordinary Portland Cement (OPC) and River Sand respectively in concrete. M40 grades of concrete was considered for a water content (w/c) 0.4 and slag sand replaced 40% with river sand and GGBS replacements of 0%, 30%, 40%, 50% with cement to investigate the properties of compressive strength, split tensile strength, flexural strength of concrete mix. The strength of cube specimens varied from 39.25N/mm^2 to 44.45 N/mm^2. The marginal strength of concrete mix (41.14N/mm^2) having 40% slag sand and 40% GGBS replacement was considered to cast the reinforced concrete beams. The beams casted were tested for flexure, under two point loading condition. Different structural parameters were investigated.**

Keywords: **GBFS sand, GGBS, Compressive strength, Flexural strength, Split tensile strength and Flexural strength of RCC beams.**

I. INTRODUCTION

Sustainable concrete is the main emphasis given to the present generation to produce concrete so as to overcome the scarcity of natural river sand and the environmental destruction (i.e. global warming) caused due to the emission of CO_2 during the hydration process of cement concrete. Hence, a concrete that can be sustained for a very long period of time and for the future generations to come is to be focused and stressed on. Concrete, that is most versatile building material used all over the globe in the construction industry has to be eco-friendly, economical and sustainable in terms of technical and non-technical aspects. Isayuksela [1], he presents investigation of how the usage of bottom ash (BA), granulated blast furnace slag (GBFS), and combination of both of these materials as fine aggregate in concrete affects the concrete durability. Veena G. Pathan [2], made an experimental investigations carried out to evaluate effects of replacing GGBS as cement in concrete to with respect to workability, compressive strength. Concrete mix with 40% replacement of cement with GGBFS gave higher compressive strength. Mohammed Nadeem [2], Experimental investigation of using slag as an alternative to normal Aggregates (coarse and fine) in concrete. He present results of experimental investigations carried out to evaluate effects of replacing aggregate (coarse and fine) with that of slag on various concrete properties. Hemanth V. [4], experimental investigations were carried out to evaluate the effects of replacing the fly ash with cement and slag sand with river sand i.e. fly ash was kept constant as 30% and Slag sand was varied from 10% to 50% with 10% variation. The fresh and hardened concrete properties were evaluated. The optimum results were incorporated in to singly reinforced RCC beams with varying tensile reinforcement ratio to evaluate the flexural behavior of beams.

II. EXPERIMENTAL PROGRAMME

2.1 Materials Used: In present work various materials is used with their respective properties namely: OPC 53 Grade, GGBS, Fine aggregates: Natural River sand and Slag sand (SS), Coarse aggregate, Super-plasticizer, Water.

a. Cement: Ordinary Portland cement of 53 grades conforming to IS: 12269-1987 has been used. The physical properties of the cement obtained on conducting appropriate tests as per IS: 12269-1987.

b. GGBS: GGBS used in this experimental work is procured from JSW Cements. The physical were: Specific Gravity= 2.90, Standard Consistency= 34%, Initial setting time= 180 minutes as per IS: 4031– 1988.

c. Fine Aggregates: Locally available clean river sand passing through IS-480 sieves have been used. The results of sieve analysis conducted as per the specification of IS: 383-1970. The fine aggregate was of Zone II, Fineness Modulus = 2.60, Specific Gravity= 2.66 and loose bulk density of 1.47 g/cc.

d. Slag Sand: The Granulated Blast Furnace Slag used in the present investigation was collected from JSW steel plant, district of Bellary. The tests on granulated blast furnace slag were carried out as per IS: 383-1970. Slag sand was of Zone I. Fineness Modulus=3.195, Specific gravity= 2.48, loose bulk density of 1.27 g/cc.

e. Coarse Aggregates: The coarse aggregate used is crushed (angular) aggregate conforming to IS 383: 1970. The maximum size of aggregate considered is 20mm IS sieve passing and minimum size of aggregate considered is 12.5mm IS sieve passing. The results of sieve analysis conducted as per the specification of IS: 383-1970. Fineness Modulus = 7.30, Specific Gravity= 2.60.

f. Water: Clean potable water is used for casting and curing operation for the work. The water supplied in the campus is of the potable standard of pH value= 7.50 are used.

g. Super Plasticizer: To improve the workability of fresh concrete sulphonated naphthalene based super plasticizer i.e., Conplast SP 430 was used supplied by FOSROC chemicals, 1.2% (max 2%) dosages was used to increase the workability of concrete.

2.2 Mix Proportion: Concrete mix design of M40 grade was designed conforming to IS: 10262-2009 is prepared and trial mixes were attempted to achieve workable concrete mix. Cubes of standard size 150x150x150mm, Prisms of size 500x100x100mm and cylinders of diameter 150mm and height 300mm were casted and cured at room temperature and were tested at 7 and 28 days.

TABLE1: CONCRETE MIX DESIGN

Unit of batch	Water (Liters)	Cement (Kgs)	Fine aggregates (Kgs)	Coarse Aggregates (Kgs)	Super-plasticizer
Cubic meter content	168	420	760	1053	4.2
Ratio of ingredients	0.40	1	1.80	2.50	1.2%

2.3 Fresh Concrete Properties: The test results showed that slump flow have improved as the GGBS content is increased the slump value is increased compared to the control mix. However all the concrete mixes were homogeneous and cohesive in nature also the slump had shear type of failure as the GGBS content was increased. No segregation and bleeding in any of the mixes were observed.

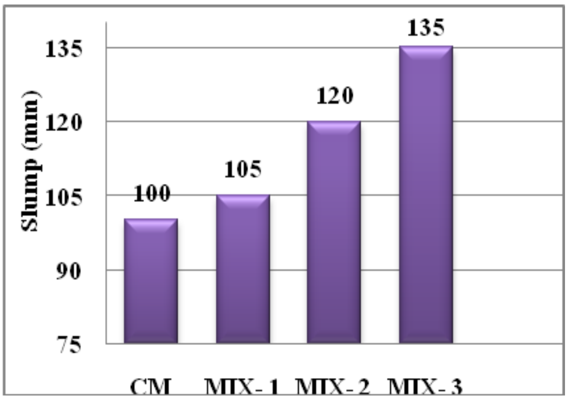


FIG 1: SLUMP VALUES FOR DIFFERENT MIX

FIG 2: SLUMP TEST FOR FRESH CONCRETE

2.4 Hardened Concrete Properties: Compressive strength, splitting tensile strength and modulus of rupture of different mixes were determined.

2.4.1 Compressive Strength: The cubes of size 150mm×150mm×150mm are casted for various percentages of GGBS by (0%, 30%, 40% and 50%) and Slag sand (SS) 40%. The cubes are cured and tested for 7 and 28 days. Testing was made in 2000kN testing machine with loading rate of 140kg/cm/m^2. The average of 3 cubes for each curing and each replacement is noted down to get the compressive strength of concrete.

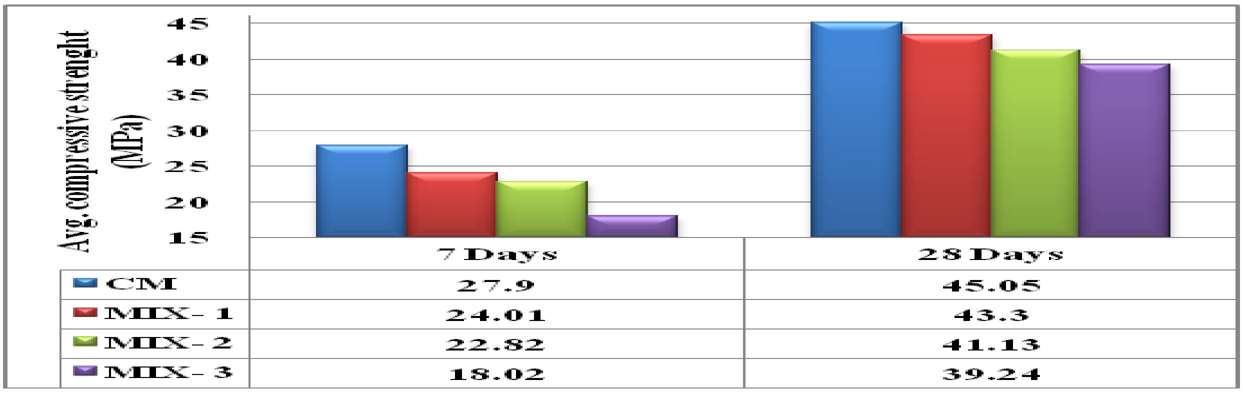


FIG 3: COMPRESSIVE STRENGTH OF VARIOUS MIXES

2.4.2 Split Tensile Strength: The splitting tensile strength is well known indirect test used for determining the tensile strength of concrete as it is one of the most important fundamental properties of concrete. Three cylinders of size 150mm diameter and 300m in length are casted for various percentages of GGBS by (0%, 30%, 40% and 50%) and Slag sand (SS) 40% and cured for 28 days for each replacement of GGBS and Slag sand (SS). Testing was made in 2000kN testing machine at rate of loading as (1.2 to 2.4) (π/2) l*d, N/min. The average of three cylinders for each replacement is noted down to get the strength spilt tensile of concrete.

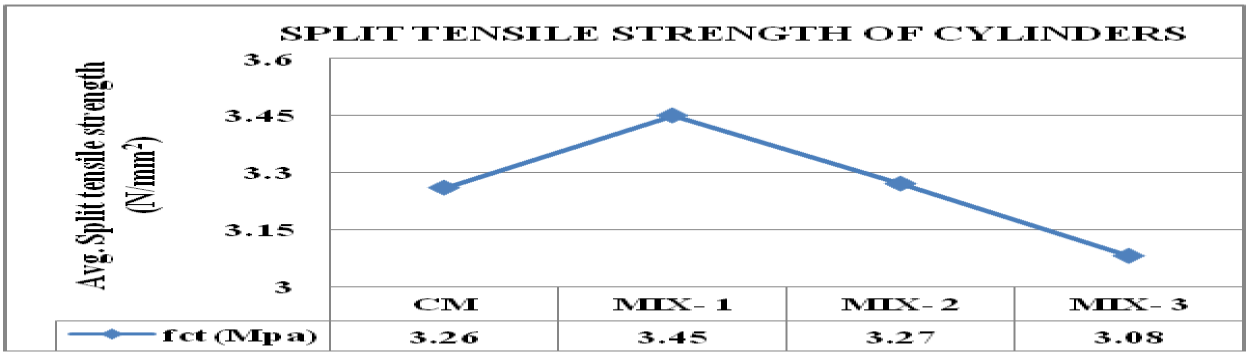


FIG 4: SPLIT TENSILE STRENGTH OF VARIOUS MIXES

2.4.3 Flexural Tensile Strength: Flexural strength is defined as a materials ability to resist deformation under load. Three beams of size 100mm×100mm×500mm are casted for various percentages of GGBS by (0%, 30%, 40% and 50%) and Slag sand (SS) 40% and cured for 28 days for each replacement of GGBS and Slag sand (SS). Testing was done under two point loading in flexural testing machine. The modulus of rupture is calculated based on the distance of the crack from the nearer support "a" measured on the centre line of the tensile face of the specimen are recorded.

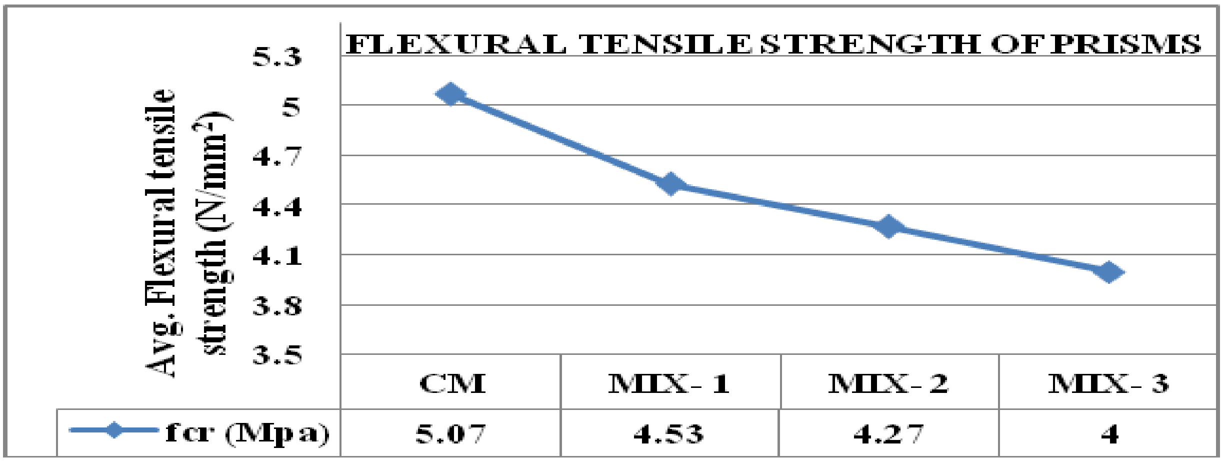


FIG 5: FLEXURAL TENSILE STRENGTH OF VARIOUS MIXES

2.5 Flexural Behavior Of RCC Beams With GGBS As Cement And Slag Sand As Fine Aggregate:

2.5. 1 Production of Test Beams: The geometry of the test beams are selected based on the parameters like capacity of the loading frame, capacity of hydraulic jack, distance between the loading supports for the beam, capacity of proving ring, dial gauge, etc.. Hence the geometry of the test beam specimen is designed as follows:

Overall length, L= 1400mm
Effective length, L_{eff} = 1200mm
Total depth, D= 200mm
Effective depth, d= 170mm
Breadth, b= 130mm
Clear cover on all faces for the reinforcement= 20mm.

TABLE 2: DETAILS OF TEST BEAMS

Tests beams specimens	Type of mix	Beam geometry (mm)	Reinforcement		Tensile reinforcement ratio, %
			Hanger bar	Tension	
TB-1, TB-2	CM	130×200×1400	2 # 8	2 # 10	0.72
TB-3, TB-4	MIX-2	130×200×1400	2 # 8	2 # 10	0.72
TB-5, TB-6	CM	130×200×1400	2 # 8	2 # 12	1.03
TB-7, TB-8	MIX-2	130×200×1400	2 # 8	2 # 12	1.03

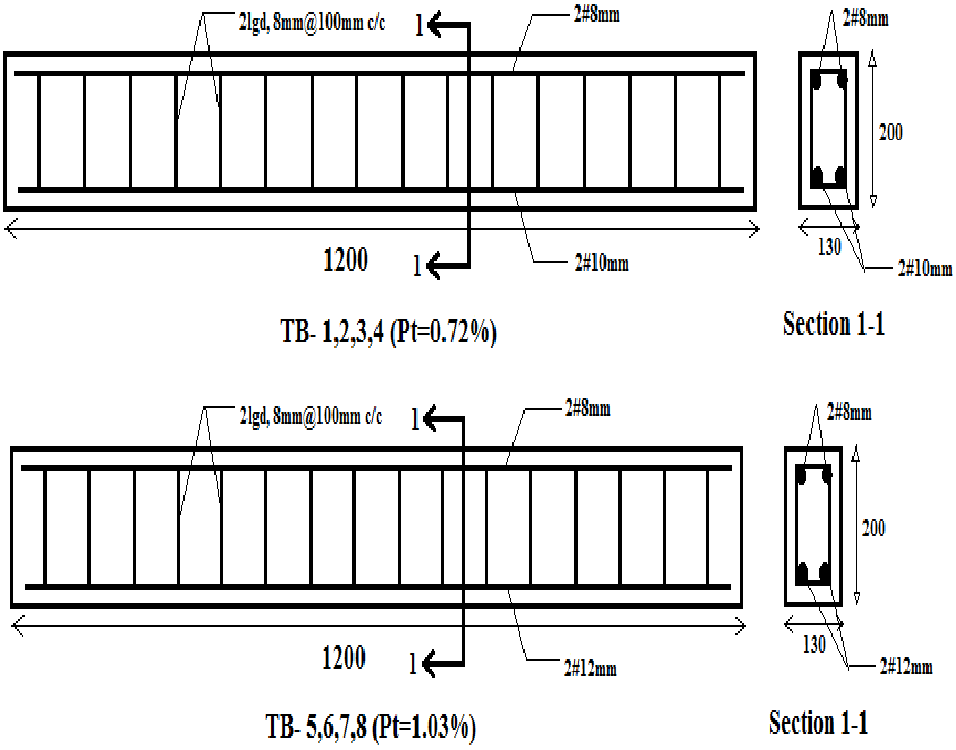


FIG 6: DETAILING OF ALL TEST BEAMS

2.5. 2 Instrumentation and Set-Up: The beam specimens casted were tested for pure bending under two-point loading case. All the beams are simply supported over the span of 1200 mm and test loading frame of capacity 500kN. Three dial gauge of least count 0.001mm are placed on the tension face of the beam to measure the deflection along the length. Demec gauge with least count of 0.002 was used to measure the surface strains in tension and compression zone, crack width was measured using the Brinnel microscope with the least count of 0.01mm. The loading was done with the hydraulic jack that is placed centrally over the channel section ISMC 250 and this channel transfer's load on the beam by the help of two steel rollers of 30mm diameter placed at L/3 span from either side of support. The testing arrangements of the beam specimens are shown figure 7.

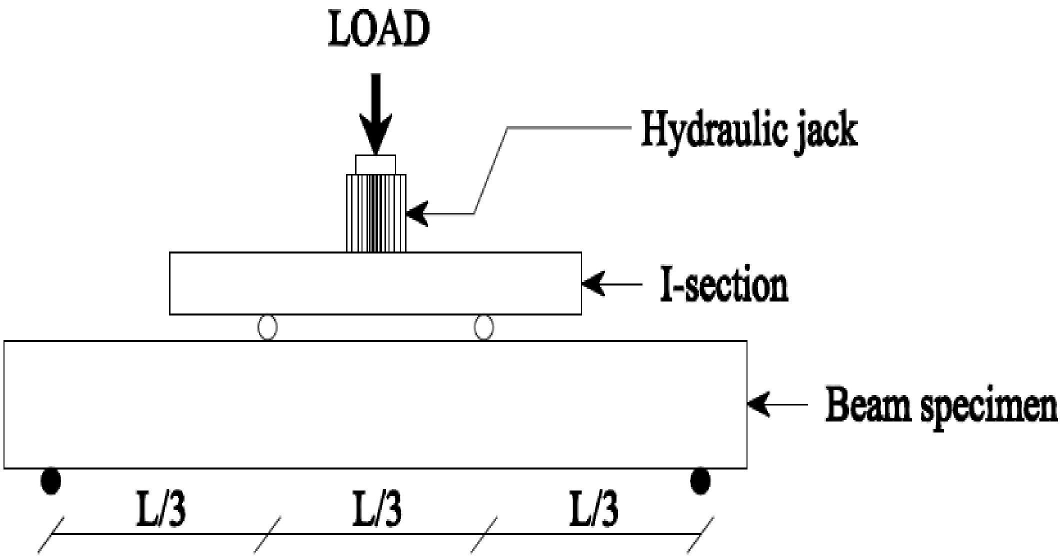


FIG 7: TEST SET UP FOR FLEXURAL TEST OF REINFORCED BEAMS

III. RESULTS AND DICUSSIONS

3.1 Crack Patterns: All 8 beams were failed in flexural mode, as the load increases the flexure cracks initiates in the pure bending zone and the first cracks appears almost in the mid span. As the load increases, existing cracks propagated and new cracks developed along the span. The cracks at the mid-span opened widely near failure, the beams deflected significantly, thus indicating that the tensile steel must have yielded at failure.

FIG 8: CRACK PATTERN OF TEST BEAMS

3.2 Experimental Results: All the test beams were studied for pure bending case. Structural parameters like cracking load, service load and ultimate load with their respective deflections are investigated. Also, the experimental values mentioned above are compared with the theoretical values conforming to IS: 456- 2000. The results are tabulated in table3

TABLE 3: AVERAGE EXPERIMENTAL RESULTS OF TEST BEAMS

Beam designation	A_{st} (%)	Experimental results								
		P_{cr} (kN)	Δ_{cr} (mm)	W_{cr} (mm)	P_s (kN)	Δ_s (mm)	W_s (mm)	P_u (kN)	Δ_u (mm)	W_u (mm)
TB- 1, TB- 2	0.72	25	1.186	0.01	55.5	4.302	0.202	82.67	10.303	0.318
TB- 3, TB- 4	0.72	26	1.291	0.01	57.5	4.435	0.210	86	10.397	0.322
TB- 5, TB- 6	1.03	29	0.901	0.01	77	3.490	0.176	115.34	10.128	0.418
TB- 7, TB- 8	1.03	30	1.023	0.01	76.5	3.656	0.178	114.67	10.334	0.4

3.3 Cracking Moment: The load at which the first crack was observed was calculated as the cracking moment. As the tensile reinforcement is increased the cracking moment also increases as shown. The theoretical cracking moment was calculated as per the test data available and the IS: 456- 2000 recommendations. Also, the theoretical values are compared with the experimental values for the varying tensile reinforcement and are tabulated in table 4.

TABLE 4: EXPERIMENTAL RESULTS AND THEORETICAL RESULTS OF CRACKING MOMENT

Beam designation	A_{st} (%)	Experimental cracking moment, M_c (kNm)	Theoretical cracking moment, M_r (kNm) (IS:456-2000)	Ratio M_c/M_r (IS:456-2000)
TB- 1, TB- 2	0.72	5.0	3.837	1.25
TB- 3, TB- 4	0.72	5.2	3.837	1.30
TB- 5, TB- 6	1.03	5.8	3.837	1.45
TB- 7, TB- 8	1.03	6.0	3.837	1.50

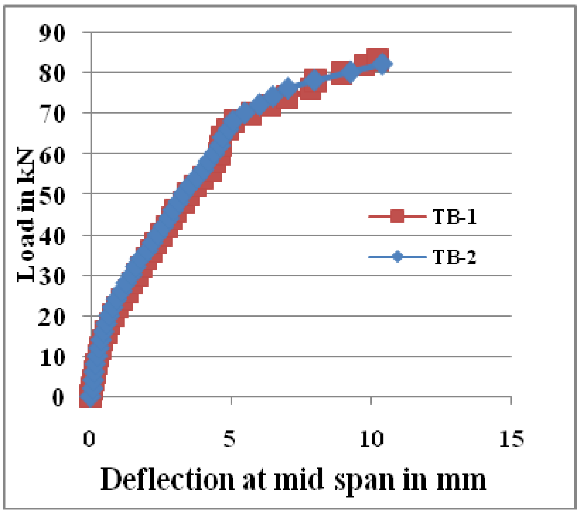
3.4 Flexural Capacity: The ultimate moment carrying capacities of the beams are calculated theoretically conforming to IS: 456- 2000 and compared it with the experimental results. The experimental and theoretical results are tabulated in the table 5.

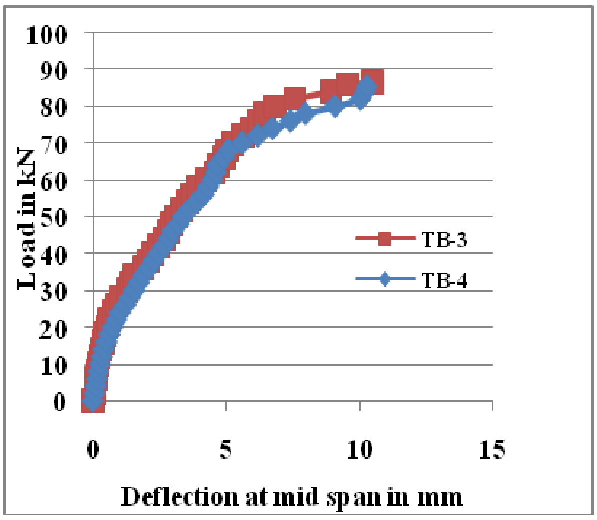
TABLE 5: EXPERIMENTAL RESULTS AND THEORETICAL RESULTS OF ULTIMATE MOMENT

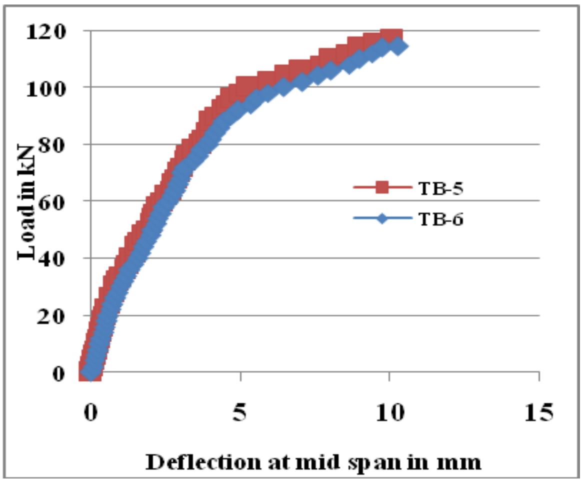
Beam designation	A_{st} (%)	Experimental ultimate moment, $M_{u,e}$ (kNm)	Theoretical cracking moment, $M_{u,t}$ (kNm) (IS:456-2000)	Ratio $M_{u,e}/M_{u,t}$ (IS:456-2000)
TB- 1, TB- 2	0.72	16.54	10.60	1.56
TB- 3, TB- 4	0.72	17.2	10.60	1.62
TB- 5, TB- 6	1.03	23.07	14.58	1.60
TB- 7, TB- 8	1.03	22.94	14.58	1.59

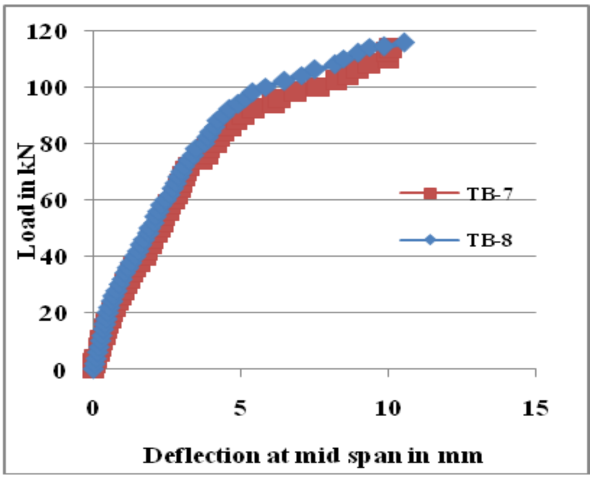
From above table we can see that there increase in the tested flexural capacity compared to the theoretical ultimate moment of beams. Also we can see that ultimate moment increases with increase in tensile reinforcement ratio. When the ratio of tensile reinforcement increases from 0.63 to 0.91 the increase in ultimate moment is 36.97%.

3.5 Deflection: The deflection of the beam were measured at an interval of 2kN at mid span and $1/3^{rd}$ span from both the sides of support till the failure of the beams. The deflections recorded are compared with the theoretical values conforming to IS: 456- 2000 at the all the loads.









3.6 Crack Width: Crack width is an important factor from the durability point of view and IS: 456-2000 specifies that the width of surface cracks should not exceed 0.3mm. The cracks formed propagated towards the compression zone from the tension zone and the observations were made.

TABLE 6: TEST RESULTS OF CRACK WIDTH

Beam Designation	Service Load (kN)	Experimental Crack width, $W_{cr,e}$ (mm)	Theoretical Crack width, $W_{cr,t}$ (mm)	Permissible Crack Width (mm)
TB- 1, TB- 2	56	0.202	0.1212	0.3
TB- 3, TB-4	58	0.2143	0.1212	0.3
TB- 5, TB- 6	78	0.178	0.1270	0.3
TB- 7, TB-8	76	0.174	0.1270	0.3

3.7 Surface Strain: Surface strains were measured using demec gauges. The strains were measured at every 2kN load increments are tabulated in table 7.

TABLE 7: SURFACE STRAIN

Beam Designation	Service Load (kN)	Surface Strain	
		Compression	Tension
TB- 1, TB- 2	56	-0.00012	0.00021
TB- 3, TB-4	58	0.00011	0.00024
TB- 5, TB- 6	78	-0.00017	0.00031
TB- 7, TB-8	76	-0.00019	0.00033

IV. CONCLUSION

Based on the experimental results following conclusion were made:

1. The fresh concrete property (slump) varied from 100mm to 140mm and all the concrete mixes were homogeneous and cohesive in nature with no segregation and bleeding in any of the mixes. Also, the slump is improved as the GGBS content is increased with shear type of failure compared to the control mix.
2. The results of the hardened concrete properties such as Compressive strength, split tensile strength and the flexural tensile strength of all the concrete mixes concluded that the mix having 40% GGBS (i.e. MIX- 2) was optimum and equal to the control mix for 28 days of curing period.
3. However the MIX-3 showed decrease in strength compared to the control mix due to higher level of glass content present and slow strength gain in the early periods of curing. Hence, MIX- 2 was incorporated in beams to study the flexural behavior of singly reinforced RC beams.
4. All the beams were designed as an under reinforced section such that it fails in the flexural zone and evidently all the beams were failed as such. The flexural crack propagated from the tension fiber to the compression fiber with crushing of concrete at the top surface with no horizontal cracks at the level of the reinforcement, indicating no bonding failure.
5. The flexural results show that there is increase in cracking moment by 23.38% for 0.72% tensile reinforcement and 34.90% for 1.03% tensile reinforcement.
6. The experimental ultimate moment of the test beams are greater than the theoretical ultimate moment by 36.82%. Also, as the tensile reinforcement is increased by 0.72% to 1.03% the ultimate moment carrying capacity is increased by 26.70% and 20.51% respectively. However, there is a variation of 26.67% when compared to the control beam and the beam containing GGBS and Slag Sand.
7. The deflection is increased as the tensile reinforcement is increased by 0.72% to 1.03% due to increase in load carrying capacity of beams. The deflection is increased for the beams containing GGBS and Slag sand by 3.74% % compared to the control beams. Also, the deflections at mid span at service load obtained during the testing of beams are within the prescribed limits as per codal provisions.
8. According to the IS 456:200 provisions, the maximum strain at working load should not exceed 0.0035 and the experimental results show that the maximum strain in all the beams is well within the limit.
9. Crack width at service load calculated as per IS: 456-2000 is 0.1212mm and 0.1270mm and the average experimental crack width of beams are 0.2081mm and 0.176mm. Also, the crack width of the test beams are well within the permissible limits (i.e. 0.3mm).

10. The CO_2 emission caused due to heat of hydration of the OPC is reduced immensely by replacing GGBS as a mineral admixture. Also, the strength and durability is increased more than 50% when 50% GGBS is replaced as compared to the OPC at age of 1 year.

11. The slag sand improves the density making it lighter compared to the conventional concrete. Also, the slag sand saves the natural resource i.e. natural river sand by 50% making a sustainable concrete.

12. The use of 40% GGBS and 40% Slag Sand in the present research work reduces the cost by 29% making a concrete sustainable, economical, eco-friendly pertaining to the CO_2 emission due to heat of hydration by OPC and saving the natural resource i.e. natural river sand which is at scares forever.

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