FLEXURAL BEHAVIOUR OF RC BEAMS WITH PARTIAL REPLACEMENTS OF SLAG SAND WITH RIVER SAND AND FLY ASH WITH CEMENT

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Abstract: In the present study the experimental investigations carried out to evaluate the effects of replacing the fly ash with cement and slag sand with river sand, on various concrete properties. The main objective of this study was to identify alternative source of good quality fine aggregates which is depleting very fast due to the fast pace of construction activities in India. Use of slag sand is a waste industrial by-product of iron and steel production and fly ash is a by product of power plants provides great opportunity to utilize it as an alternative to normally available aggregates and cement. In this study, M40 grades Concrete was considered for a water content (w/c) 0.39 and fly ash replaced 30% with cement and slag sand replacements of 0%,10%,20%,30%,40%,50% with river sand. To investigate the properties of compressive strength, split tensile strength, flexural strength of concrete mix. The strength of cube specimens varied from 40.11 N/mm^2 to 46.51 N/mm^2. The marginal strength of slag sand (41.71N/mm^2) 40% replacement was considered to cast the reinforced concrete beams. The beam casted with 40% replace of slag sand mix was tested for flexure, under two point loading condition. Different structural parameters were investigated.

Keywords- steel slag sand, Fly ash, compressive strength, flexural strength of prisms, split tensile strength and flexural strength of beams.
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1. Introduction:

Concrete is the most preferred and the single largest building material used by the construction industry. Concrete is basically made of aggregates, both fine and coarse, glued by a cement paste which is made of cement and water. In fact, many by-products and solid wastes can be used in concrete mixes as aggregates or cement replacement, depending on their chemical and physical characterization, if adequately treated. The incorporation of fly ash and granular slag sand in concrete leads to many technical advantages. The present work aims at developing a cementation material that can replace the conventional cement in concrete work using the waste product like fly ash, granulated slag sand used as fine aggregate. This will solve the problem of waste disposal side by side preserving our natural resources. Isa yuksela [1], Durability of concrete incorporating non-ground blast furnace slag and bottom ash as fine aggregate. 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. 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. Singh S.P. [3] eco-friendly concrete using by-products of steel industry. He outlines the method of preparation, testing procedure and salient results on the eco-friendly concrete that is manufactured using the waste products of steel industries and hydraulic lime.

2. Experimental program:

2.1 Materials used:

The materials used in the experimental program are:
Cement, Fly ash, Fine aggregates, Slag sand, Coarse aggregates, Water, Super plasticizer

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.

Fly ash: Fly ash used in this experimental work is brought from Raichur thermal power station (RTPS) Karnataka. It is a class F fly ash (the fly ash which contains less than 10 % of the Calcium), fly ash is tested for its physical and chemical properties.

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 = 3.276.

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=2.512.

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 = 5.82

Water: Clean potable water is used for Mixing and Curing operation for the work. The Water supplied in the campus is of the potable standard of PH value 7 is used.

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, 1.4% (max 2%) dosages was used to increase the workability of concrete.

2.2 SELECTION OF SUITABLE MIX PROPORTION:

Concrete mix design of M40 grade was designed conforming to IS: 10262-2009 is given in Appendix-A. 4 trial mixes were attempted and the best suited workable mix was adopted for further casting of specimens. Cubes of standard size 150x150x150mm, Prisms of size 500x100x100mm and cylinders of diameter 150mm and height 300mm were casted and pond cured at room temperature and were tested at 7, 14 and 28 days of curing.

Table1: Design parameters per cubic metre:

Cement	300kg
Fly ash	120kg
Fine aggregate	702kg
Coarse aggregate	1065kg
W/C ratio	0.39
Super plasticizer	1.4%

2.3 PROPERTIES OF FRESH CONCRETE:

Concrete mixes were checked for workability through slump test. Adequate workability or slump value of control mix achieved decreased as the percentage of slag sand increased. The slump values obtained for different percentages of slag sand mixes are tabulated below.

Table 2: Slump values

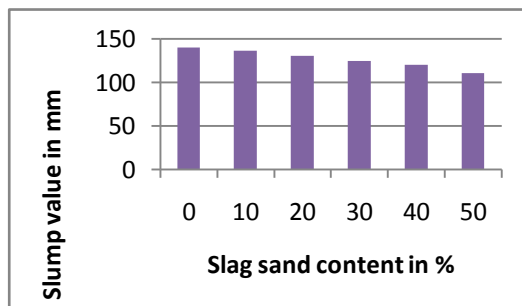| Mix Designation	Slump in mm
CM	140
SS-10%	136
SS-20%	130
SS-30%	124
SS-40%	120
SS-50%	110

Fig1: Slump values for various proportion   Fig 2: Slump test on Fresh Concrete

2.4 COMPRESSIVE STRENGTH:

Compressive strength test is carried out on the various mixes by varying percentage of slag sand and keeping all other parameters as constant. The main objective of conducting the tests on various mixes is to find out the most suitable mix of having higher compressive strength with better workability. For each mix 9 cube specimens were cast in moulds. After 7, 14 and 28 days of curing the cubes were removed from the curing tank, weighed and tested for compressive strength in a 2000 KN compression testing machine according to IS: 516-1959. The cast face parallel to the axis of loading at the rate of 14N/mm2/minute as per IS: 516. 3 cubes were tested at 7 days, 3 cubes were tested at 14 days and the remaining 3 cubes were tested at 28 days of curing. Each compressive strength result is the average of 3 test results the experimental compressive strength was obtained by dividing the maximum load applied on the specimen during the test by its cross sectional area.

Mix designation	Avg compressive strength(N/mm^{2}compressive strength(N/mm^2)
CM	48.83
SS-10	46.51
SS-20	45.05
SS-30	40.84
SS-40	41.71
SS-50	40.11

COMPRESSION STRENGTH OF CUBES

	CM	SS-10	SS-20	SS-30	SS-40	SS-50
fck (N/mm^2)	48.83	46.51	45.05	40.84	41.71	40.11

28-Day Compression Strength of cubes (N/mm^2)

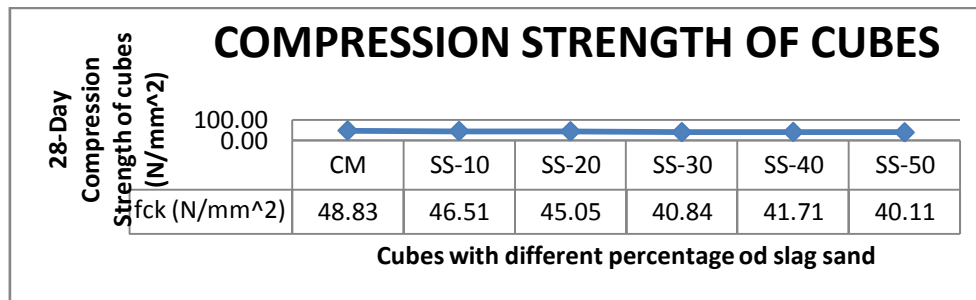Cubes with different percentage od slag sand

Fig 3: Compressive strength of cubes at 28 days

The test results of compression test of cubes after 28 days shows that there is a decrease in the strength value after the 5th mix i.e. the strength increase was shown up to 40% slag sand replacement and the strength decreased for the next percentage replacement. The 10% and 20% replacement test results are approximately equal to the test results of control mix.

2.5 FLEXURAL STRENGTH TEST:

The flexural strength is determined by testing standard test specimens (Prisms) of size 500 x 100 x 100 mm over a span of 400mm, Under symmetrical two-point loading according to IS: 516-1959. For each mix three beams (prisms) of size 100 x 100 x 500 mm were cast, de-moulded after 24 hours and then cured for 28 days. After 28 days of curing the prisms were taken out from the curing tank, weighed and tested for flexural strength under two point loading in a flexure testing machine according to IS: 516 – 1959. The maximum load "P" and the distance of the crack from the nearer support "a" measured on the centre line of the tensile face of the specimen are recorded. The flexural strength was calculated according to the clause 8.4 of IS: 516 – 1959.
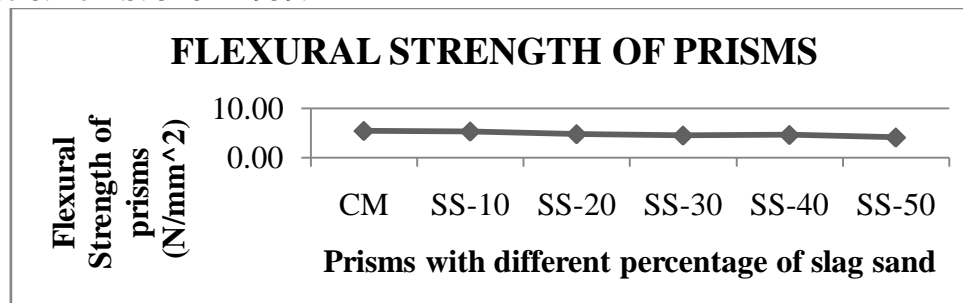
FLEXURAL STRENGTH OF PRISMS

Flexural Strength of prisms (N/mm^2)

CM   SS-10   SS-20   SS-30   SS-40   SS-50

Prisms with different percentage of slag sand

Fig 4: Flexural strength of prisms

The flexural strength of prisms when compared to control beams shows a gradual decrease up to 30% replacement and shows an increase in strength for 40% replacement of slag sand. Based on the results obtained from the compression test and flexure tensile test, 40% slag sand replacement is chosen as the optimum strength giving percentage versus all the other percentages included in this study.

2.6 Split tensile strength:

The test consists of applying compressive line loads along the opposite generators of a concrete cylinder placed with its axis horizontal between the platens of a compression testing machine. Due to the applied line loading a fairly uniform tensile stress is induced over nearly two-third of the loaded diameter. The magnitude of this splitting tensile stress (acting in a direction perpendicular to the line of action of applied compression) is given by $fct = 2P/\pi dl$, Where P = the applied compressive load at failure, d = Diameter of the cylinder, l = Length of the cylinder. Due to this tensile stress, the specimen fails finally, by splitting along the loaded diameter. Immediately under the load, a high compressive stress is induced. For each

mix three cylinders of size 150 mm in diameter and 300mm in length were cast and cured for 28 days. After 28 days of curing the cylinders were removed from the curing tank, weighed and tested for splitting tensile strength in a 2000kN compression testing machine as per IS: 516-1959. Each splitting tensile strength results is the average of 3 test results. The experimental splitting tensile stress was calculated according to the above equation.
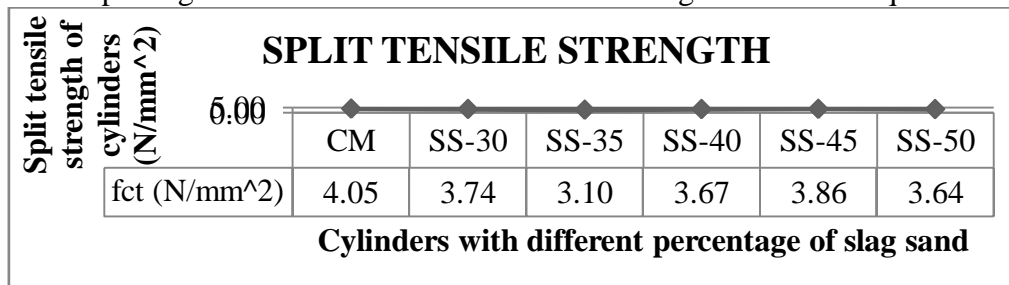
SPLIT TENSILE STRENGTH						
	CM	SS-30	SS-35	SS-40	SS-45	SS-50
fct (N/mm^2)	4.05	3.74	3.10	3.67	3.86	3.64

Split tensile strength of cylinders (N/mm^2)

Cylinders with different percentage of slag sand

Figure 5: Split tensile strength of cylindrical specimens

The results of the above test shows that there is an increase in the strength up to 30% and decrease in the strength for the next replacement compared to the control mix.

3. Casting and Testing of Beams:
3.1 Dimensions of beam specimens:

The dimensions of a member is selected based on the, practical limitations, such as size of the loading frame and its capacity, capacity of the hydraulic jack used for loading the beams, applicable distance between supports in the loading frame, available measurement equipments capability, and capacity of the proving ring, should be considered in defining the Size of beam specimens. Accordingly, dimensions of the beam elements are explained below:
Overall Length L=1700mm
Effective Length l_e=1500mm
Overall Depth D=200mm
Breadth B=150mm
Effective depth d=166mm

3.2 GEOMETRY AND REINFORCEMENT ARRANGEMENT:
All 12 beams were 150 mm wide and 200mm deep in cross-section, they were 1700mm in length and simply-supported over a span of 1500mm. Two different tensile reinforcement ratios were used. The clear cover to reinforcement was 20 mm on all faces. The geometry and reinforcement arrangement of beams were presented in table below.

Table3: Beam details

Beams	Mix used	Beam Dimension In mm	Reinforcement		Tensile Reinforcement ratio (%)
			Compression	Tension	
B1,B2,B3	CM	150X200X1700	2 # 8	2 # 10	0.63%
B4,B5,B6	SS-40%	150X200X1700	2 # 8	2 # 10	0.63%
B7,B8,B9	CM	150X200X1700	2 # 8	2 # 12	0.91%
B10,B11,B12	SS-40%	150X200X1700	2 # 8	2 # 12	0.91%

3.3 TEST SETUP AND INSTRUMENTATION:

All the beams are simply supported over the span 1500mm and tested by using 500 kN capacity loading frame. All the beams were tested by two point load method, three dial gauge of least count 0.001 mm 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, crack width was measured using the Brinnel microscope with least count of 0.01 mm. The testing arrangement of the beam specimens are shown below.
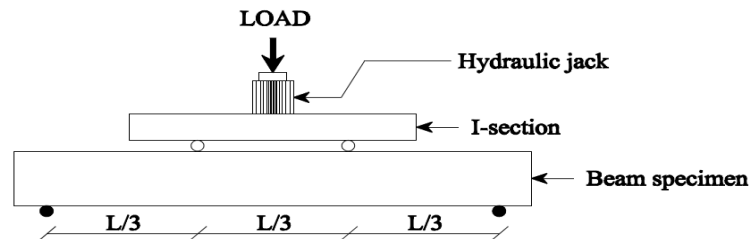

Fig 6: Schematic diagram for flexure test on beam

3.4 TEST PROCEDURE:

Before placing the beam specimens on the loading frame, all the specimens were white washed in order to facilitate marking of cracks. After white wash the beam specimens were placed on the loading frame with all the arrangement shown in, load is applied in an interval of 2kN using hydraulic jack at the same time deflection is noted down with the help of digital dial gauges, and also Demec gauge reading is also noted. Crack load, crack width, crack length, ultimate load is recorded also the cracking patterns are marked to study the crack patterns of the specimens. The loading is continued until the failure of beam specimens.

Fig7: marking and test setup of beam.

4. Result and discussion:

4.1 Crack pattern:

The 12 beam specimens were failed in same 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. The cracks almost found in bending zone. The shear cracks were not observed. The cracks are almost straight and propagating towards compression zone. The failure mode was typical of that of an under reinforced.
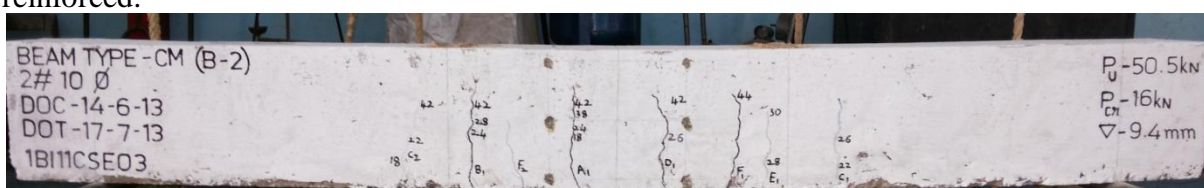

Fig 8: Crack patterns

4.2 DEFLECTIONS:

Totally 6 control beams and 6 slag sand specimens were casted and tested for flexure the specimens are designated as B1, B2, B3, B4, B5, B6,B7,B8,B9,B10,B11 and B12, three dial gauges were used to measure the deflections at 1/3rd span, mid span and at 1/6th span. Demec gauge were used to measure the top and bottom strain at mid span. The deflections were recorded up to failure load and compared with test values. The Load versus mid-span deflection curves of the test beams are presented below.
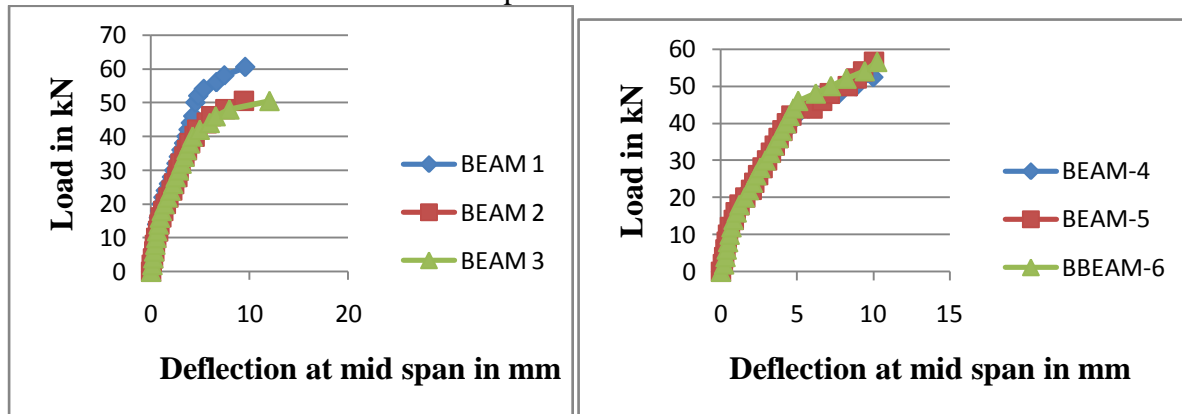

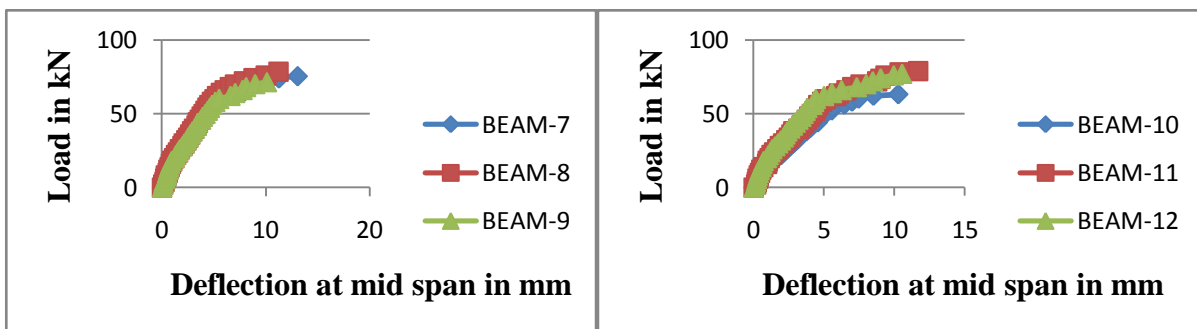**Fig 9: Load v/s mid span deflections of control beams –B1, B2, B3 and B4, B5, B6**

Fig 10: Load v/s mid span deflections of control beams –B7, B8, B9 and B10, B11, B12

4.3 EXPERIMENTAL RESULTS:

All the reinforced concrete beam specimens were tested in a 500 KN capacity loading frame. As the load is increased the beam starts to deflect. Typical cracking, service and ultimate load to which the beam is subjected and the deflection at those load value is also recorded.

p_{cr} = load at 1st crack, δ_{cr} = deflection at 1st crack, W_{cr} = width of 1st crack, P_s = service load δ_s = deflection at service load, W_s = crack width of service load, P_u = ultimate load δ_u = deflection at ultimate load, W_u = crack width of ultimate load

Here, two categories of beams are been compared by the results obtained from the flexural test. In the first category control beam and 40% slag sand beam with 10mm diameter longitudinal bars as tension reinforcements are compared and in the second category beams with 12mm diameter tension reinforcements are compared. The comparison shows that there is a slight increase in the strength of later beam in the first category by 2.8%. Similarly in second category the later beam shows about 1.3% increase in the strength compared to the later one.

Table 4: Experimental values of cracking, service and ultimate load with deflections

Beam number	A_{st} %	Slag sang	Experiment values								
			P_{cr} (kN)	δ_{cr}	W_{cr} mm	P_s (kN)	δ_s	W_s mm	P_u (kN)	δ_u mm	W_u mm
B-1	0.63%	0%	20	1.071	0.03	40	3.596	1	60.5	9.560	1.6
B-2	0.63%	0%	18	1.235	0.04	34	3.393	0.9	50.5	9.420	1.5
B-3	0.63%	0%	20	1.365	0.03	34	3.370	1.3	50.5	11.990	2.5
B-4	0.63%	40%	20	1.455	0.05	36	3.930	0.9	52.5	9.980	1.5
B-5	0.63%	40%	16	0.970	0.04	38	4.015	1.4	56.5	10.35	2.5
B-6	0.63%	40%	18	1.210	0.04	38	3.990	1.1	57	10.240	2.2
B-7	0.91%	0%	20	1.010	0.05	50	4.1	1.3	75.5	13.040	2.5
B-8	0.91%	0%	20	1.150	0.04	52	4.2	1.4	78.5	11.195	2.5
B-9	0.91%	0%	18	0.935	0.03	48	3.950	1.2	71.3	10.131	2.5
B-10	0.91%	40%	16	1.239	0.04	42	4.195	1.1	63	10.290	2.2
B-11	0.91%	40%	18	1.007	0.05	54	4.462	1.3	79	11.675	2.3
B-12	0.91%	40%	18	0.708	0.04	52	3.683	1	77	10.531	2.2

4.4 SURFACE STRAIN:

Surface strains were measured using demec gauges. The strains were measured at every 2 KN load increments and are tabulated below.

Table 5: Surface strains at service load of RC beams

Beam designation	% of tensile Reinforcement	Slag sand	Working Load (KN)	Surface Strain	
				Compression	Tension
B-1	0.63%	0%	40	-0.000083	0.000105
B-2	0.63%	0%	34	-0.00012	0.000255
B-3	0.63%	0%	34	-0.00012	0.000187
B-4	0.63%	40%	36	-0.00015	0.000125
B-5	0.63%	40%	38	-0.0002	0.000249
B-6	0.63%	40%	38	-0.00019	0.000285
B-7	0.91%	0%	50	-0.00021	0.000233
B-8	0.91%	0%	52	-0.00019	0.000236
B-9	0.91%	0%	48	-0.00017	0.000233
B-10	0.91%	40%	42	-0.0002	0.000212
B-11	0.91%	40%	54	-0.00023	0.000235
B-12	0.91%	40%	52	-0.00017	0.000254

4.5 CRACKING MOMENT:

The load at which the first flexural crack was visibly observed was recorded. From the available test data theoretical cracking moments were determined according to the IS: 456-2000. Both the experimental and theoretical test results were compared, the test result shows the experimental first crack moment is higher than the theoretical cracking moment. The results are given in below Table shows the variation of moment at first crack with % of tensile reinforcement.

Table 6: Cracking moment of test Beam

Beam	% of tensile Reinforcement	Slag sand	compressive strength fck (N/mm^2)	Modulus of rupture (N/mm^2) fcr= 0.7√fck	Moment at first crack Mc (kN-m)	Theoretical Cracking moment Mr=(fcr xIgr/Yt) (kN-m)	Ratio M$_c$/M$_r$
B1, B2,B3	0.63%	0%	41.71	4.52	4.83	4.52	1.06
B4,B5,B6	0.63%	40%	41.71	4.52	4.5	4.52	1.0
B7,B8,B9	0.91%	0%	41.71	4.52	4.83	4.52	1.06
B10,B11,B12	0.91%	40%	41.71	4.52	4.33	4.52	0.96

From the above table it is evident that moment at first crack is same with increase in % of tensile reinforcement as the percentage of tensile reinforcement.

4.6 FLEXURE CAPACITY:

The theoretical ultimate moment and load are calculated using IS 456:2000 codes and compared with experimental ultimate moment and loads. The test results show that the experimental values are higher than the theoretical, which shows that the design is conservative.

Table 7: Flexural capacity of test Beams

Beam	% of tensile Reinforcement	Slag sand	compressive strength fck (N/mm2)	Average Mid span deflection at failure(mm)	Theoretical ultimate moment M$_{uc}$ kN-m	Tested ultimate moment M$_{ut}$ kN-m
B1,B2,B3	0.63%	0%	41.71	10.32	8.83	13.45
B4,B5,B6	0.63%	40%	41.71	10.085	8.83	13.83
B7,B8,B9,	0.91%	0%	41.71	11.46	12.33	18.78
B10,B11,B12	0.91%	40%	41.71	10.832	12.33	18.25

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 35.79%.

5.0 CONCLUSION:

Based on the experimental results following conclusion were made:

1. The results of M40 grade control mix concrete cubes tested for compressive strength after 28 days minimum strength of 47.08N/mm^2 and maximum strength of 50.58N/mm^2.

2. The compressive strength of cubes casted with 10% and 20 % slag sand are equal to the minimum strength of 43.6N/mm^2 and maximum strength of 50.14N/mm^2.

3. The compressive strength values of cubes with 30% and 40% slag sand are equal to the minimum strength of 40.12N/mm^2 and maximum strength of 43.16N/mm^2. And shows a decrease in compressive strength as the percentage of slag sand increased 50% with minimum strength of 37.06N/mm^2 and maximum strength of 40.54N/mm^2.

4. The split tensile strength value of 40% slag sand is 2.96N/mm^2 and control mix specimen value is 2.98N/mm^2. Whereas it shows an increase in the value for 10%, 20% and 30% replacements of minimum value of 3.13N/mm^2 and maximum value of 3.45N/mm^2. Further the value decreased for 50% replacement of value of 2.83N/mm^2

5. Flexural test results of prisms shows that there is a continues decrease in the values for increments in the percentages of slag sand up to 30% replacement and thereby increase for 40% replacement and again a decremented value for 50% replacement of slag sand.

6. 40% slag sand shows up as an optimum replacement in aspects regarding the optimum strength of 40N/mm^2, up to maximum extent it can be replaced so that the material could be used to its maximum, the tests on physical properties of slag sand shows an approximate.

7. The flexural strength of control beam with 10mm diameter tension reinforcement tested under two point loads shows the result with minimum value of 12.63N/mm^2 and maximum value of 15.13N/mm^2 and 12mm diameter tension reinforcement the minimum value of 17.83 N/mm^2 and maximum value of 19.63 N/mm^2.

8. The flexural strength of Slag sand beam with 10mm diameter tension reinforcement with minimum value 13.13N/mm^2 of and maximum value of 14.25N/mm^2

9. The flexural strength of Slag sand beam with 12mm diameter tension reinforcement with minimum value of 15.75 N/mm^2 and maximum value of 19.75N/mm^2.

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