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A STUDY ON FLEXURAL BEHAVIOUR OF REINFORCED CONCRETE BEAM BY REPLACEMENT OF LINZ-DONAWITZ (LD) SLAG AS FINE AGGREGATE

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Abstract: **Sustainability and resource efficiency are becoming increasing important issues within today's construction industry. This paper is mainly focused on making an effort to use LD Slag which is an industrial waste by-product of Steel industry. An experimental investigation was carried out to evaluate the effect of replacing fine aggregate by LD Slag on mechanical properties of concrete and on flexural behaviour of RCC beams. Fine aggregate (sand) was replaced with six percentages (15%, 30%, 45%, 60%, 80% and 100%) of LD Slag by volume in M40 grade of concrete with water-cement ratio (w/c) 0.4. The test results indicated that fine aggregate replacement using 45 percent LD Slag showed a better performance compared to control mix. The concrete mix with 45% of LD Slag 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.**

Keyword: **LD Slag, Mechanical properties and Flexural behavior of RCC beams.**

I. INTRODUCTION

The rapid rate of growth in population in India as forced the construction industry to use the building materials at rapid rate and resulting in depletion of natural resources and also has a severe impact on the environment causing many hazards either directly or indirectly such as depletion of river due to sand mining being done at alarming rate etc. On the other hand industrialization, rapid growth of industries in India gave birth to numerous kinds of waste products. The steady increase in demands due to population growth as also resulted in increase in production and as the production rate increases to match the consumption rate the waste produced by the process during production also increases proportionality. But the waste products generated by these industries is causing environmental hazards as their disposal being a major problem, due to this over the period of time waste management has become one of the most complex and challenging problems in India. Hisham Qasrawi et al [1], conducted a research on the utilization of steel slag as fine aggregate. Compressive strength and 28-day tensile strength tests were performed based on different slag ratios. The results indicated the improvement of compressive strength for replacement slag ratios of 15-30% and tensile strength for replacement slag ratios of 30-50%. D. Brindha et al [2], evaluated the potential use of granulated copper slag from Sterlite Industries as a replacement for sand in concrete mixes. They concluded that the percentage replacement of sand by copper slag shall be up to 40% and compressive strength was increased by about 35-40% and split tensile strength by 30-35%. Ansu John et al [3], studied on the utilization of induction furnace slag as an alternative for conventional fine aggregate. They concluded that the fine aggregate replacement using 30 percent induction furnace showed a better performance compared to control mix. Ramadevi.K et al [4], investigated the possibility of replacing Granulated Blast Furnace Slag (GBFS) as a sand substitute in concrete. They concluded that the compressive strength of concrete increased with increase in percentage of GBFS up to 50%. Beyond 50% there was a marginal decrease in strength of concrete. Hemanth V et al [5], 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 behaviour of beams.

II. EXPERIMENTAL PROGRAMME

2.1 Materials Used

In present work various materials is used with their respective properties namely: OPC 53 Grade, Fine aggregates: River sand and LD Slag, Coarse aggregate, Super-plasticizer, Water.

1. 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. .

2. 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= 2.60 and loose and compacted bulk density was found to be 1.47 g/cc and 1.51 g/cc respectively.

3. LD Slag: Slag used in the present investigation was collected from JSW steel plant, district of Bellary. The tests on LD Slag were carried out as per IS: 383-1970. Slag was of Zone I. Fineness Modulus=3.97, Specific gravity= 3.43, loose and compacted bulk density was found to be 1.89 g/cc and 2.013 g/cc respectively.

4. 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= 2.65.

5. 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.

6. 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.

7. 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 were casted and cured at room temperature and tested at 7 and 28 days. Prisms of size 500x100x100mm and cylinders of diameter 150mm and height 300mm were casted and cured at room temperature and tested at 28 days.

TABLE 1: CONCRETE MIX DESIGN

Unit of batch	Water (Liters)	Cement (Kgs)	Fine aggregates (Kgs)	Coarse Aggregates (Kgs)	Super-plasticizer
Cubic meter content	168	420	766	1061	5.04
Ratio of ingredients	0.40	1	1.82	2.52	1.2%

2.2 Fresh Concrete Properties

The test results show that the slump value decreases with increase in LD Slag content and when the LD Slag content increases the care should be taken as the mix is likely to segregate.

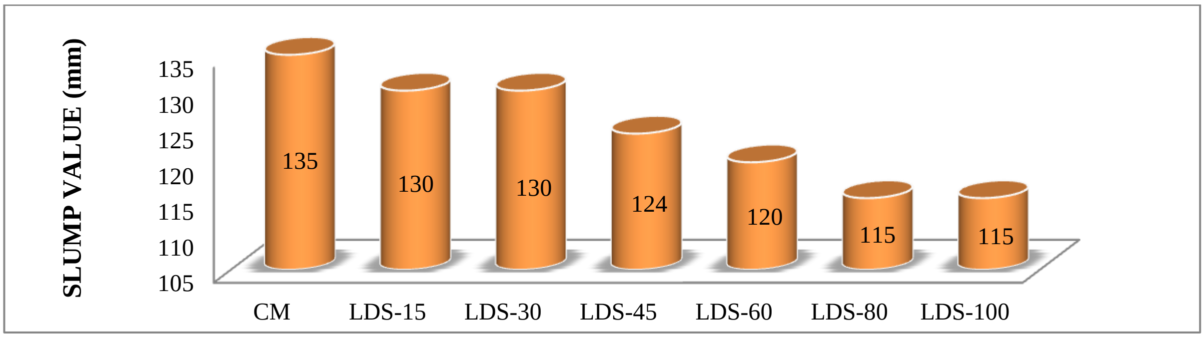


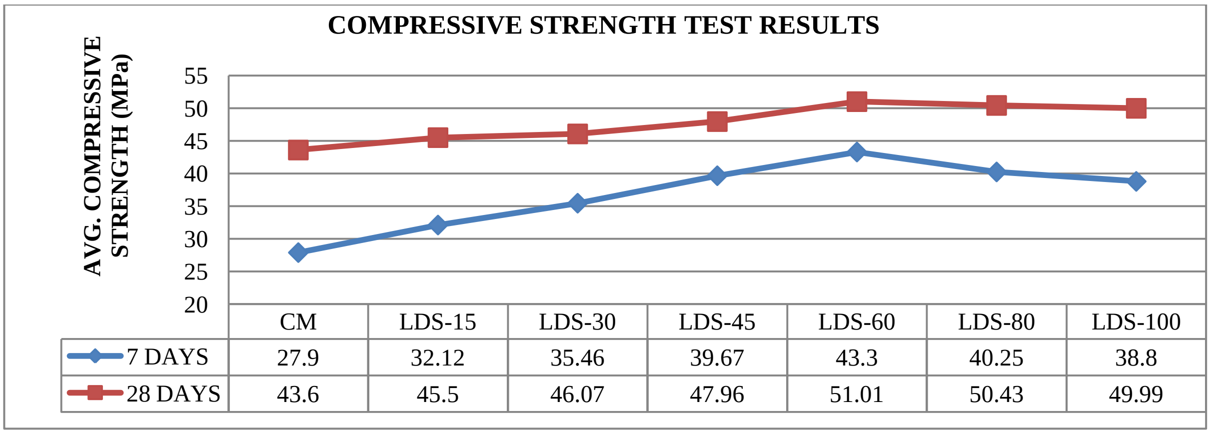
Fig 1: Effect of Ld Slag Content In Concrete On Slump

2.3 Hardened Concrete Properties

Compressive strength, splitting tensile strength and modulus of rupture of different mixes were determined.

2.4 Compressive Strength

The cubes of size 150mm×150mm×150mm are casted for various percentages of LD Slag (0%, 15%, 30%, 45%, 60%, 80% and 100%). The cubes are cured and tested for 7 and 28 days. Testing was made in 2000kN testing machine with loading rate of 140kg/cm^2/min. The average of 3 cubes for each curing and each replacement is noted down to get the compressive strength of concrete.

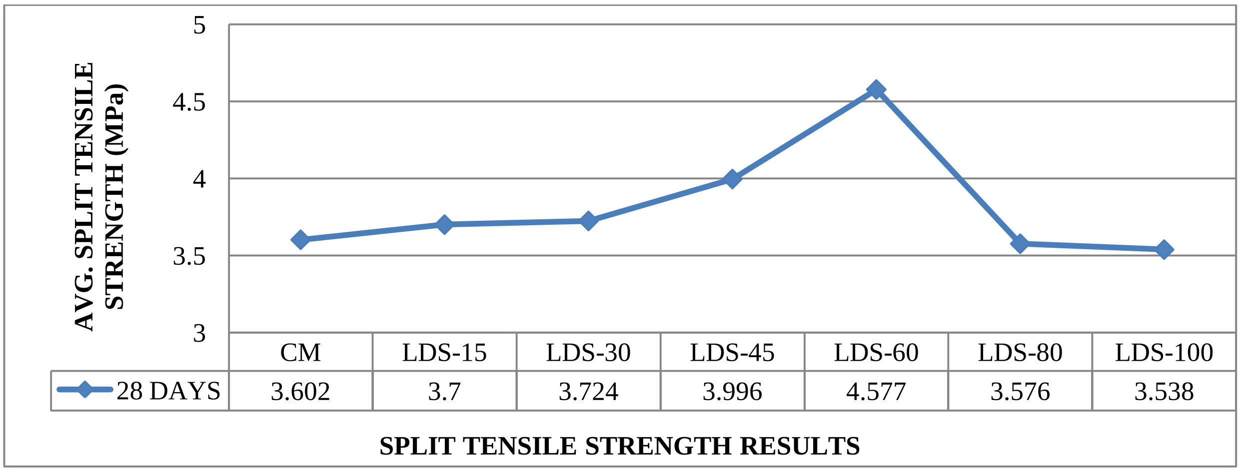


	CM	LDS-15	LDS-30	LDS-45	LDS-60	LDS-80	LDS-100
7 DAYS	27.9	32.12	35.46	39.67	43.3	40.25	38.8
28 DAYS	43.6	45.5	46.07	47.96	51.01	50.43	49.99

Fig 2: Compressive Strength Variation Of All Mixes At 7 And 28 Days Of Curing

2.5 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 LD Slag (0%, 15%, 30%, 45%, 60%, 80% and 100%) and cured for 28 days for each replacement of LD Slag. 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.



	CM	LDS-15	LDS-30	LDS-45	LDS-60	LDS-80	LDS-100
28 DAYS	3.602	3.7	3.724	3.996	4.577	3.576	3.538

Fig 3: Split Tensile Strength Variation of All Mixes at 28 Days of Curing

2.6 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 LD Slag (0%, 15%, 30%, 45%, 60%, 80% and 100%) and cured for 28 days for each replacement of LD Slag. 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.

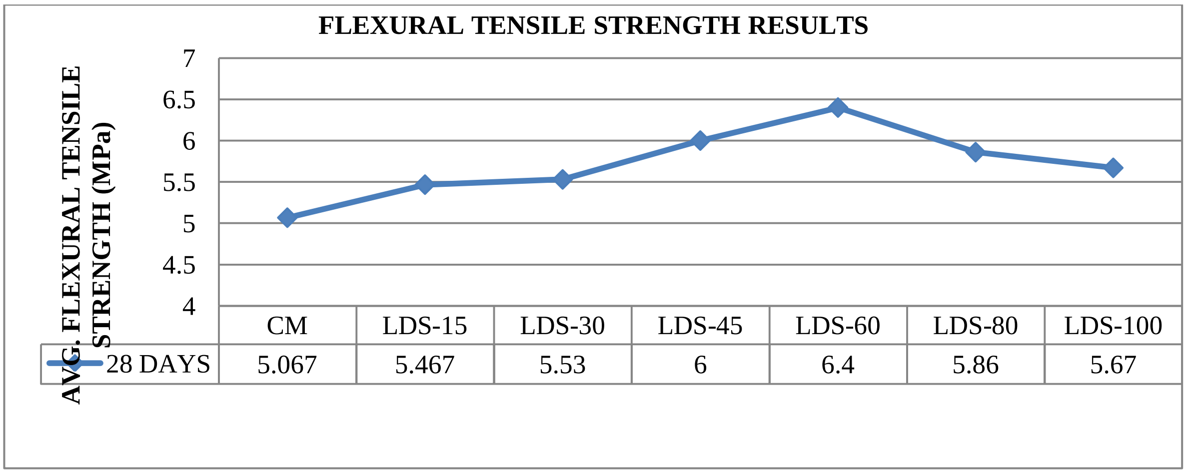


Fig 4: Flexural Tensile Strength Variation Of All Mixes At 28 Days Of Curing

2.7 Flexural Behaviour of RCC Beams with LD Slag as Fine Aggregate

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	LD-45	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	LD-45	130×200×1400	2 # 8	2 # 12	1.03

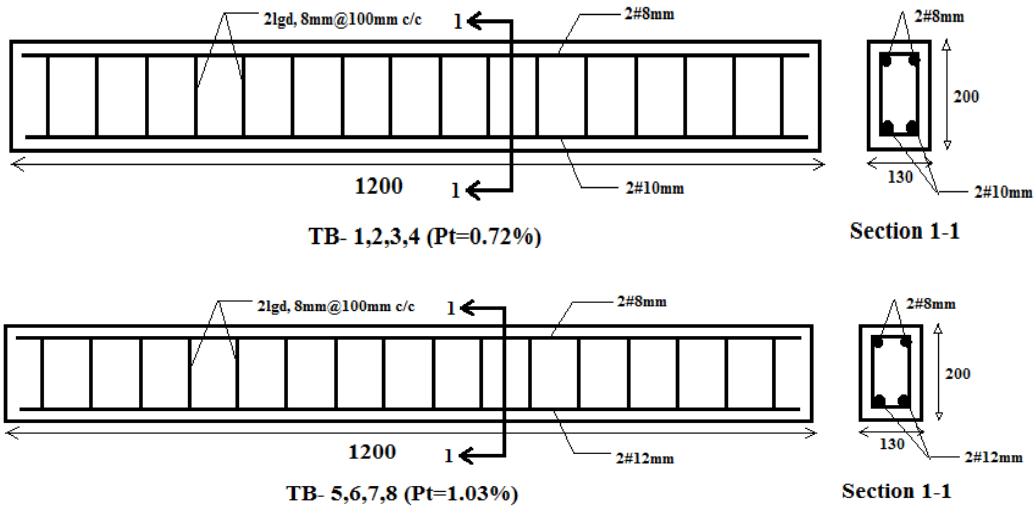


Fig 5: Detailing Of All Test Beams

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.

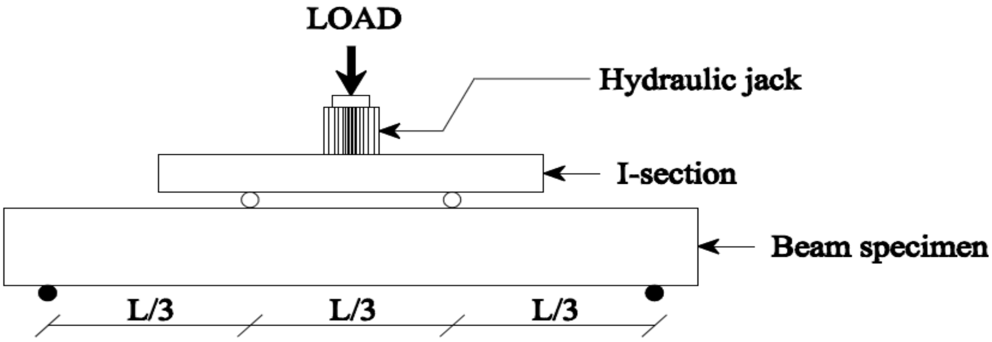


Fig 6: Test Set Up For Flexural Test Of Reinforced Beams

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 7: 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	27	1.083	0.01	55	3.623	0.17	84.17	10.535	0.56
TB- 3, TB- 4	0.72	28	1.209	0.015	55	3.414	0.175	83.84	10.337	0.585
TB- 5, TB- 6	1.03	29	0.957	0.01	77	3.880	0.18	117.00	10.678	0.625
TB- 7, TB- 8	1.03	32	1.018	0.02	78	3.616	0.195	118.34	11.191	0.57

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 (KN-m)	Theoretical cracking moment, M_r (KN-m) (IS:456-2000)	Ratio M_c/M_r (IS:456-2000)
TB- 1, TB- 2	0.72	5.4	3.837	1.40
TB- 3, TB- 4	0.72	5.6	3.837	1.45
TB- 5, TB- 6	1.03	5.8	3.837	1.51
TB- 7, TB- 8	1.03	6.4	3.837	1.67

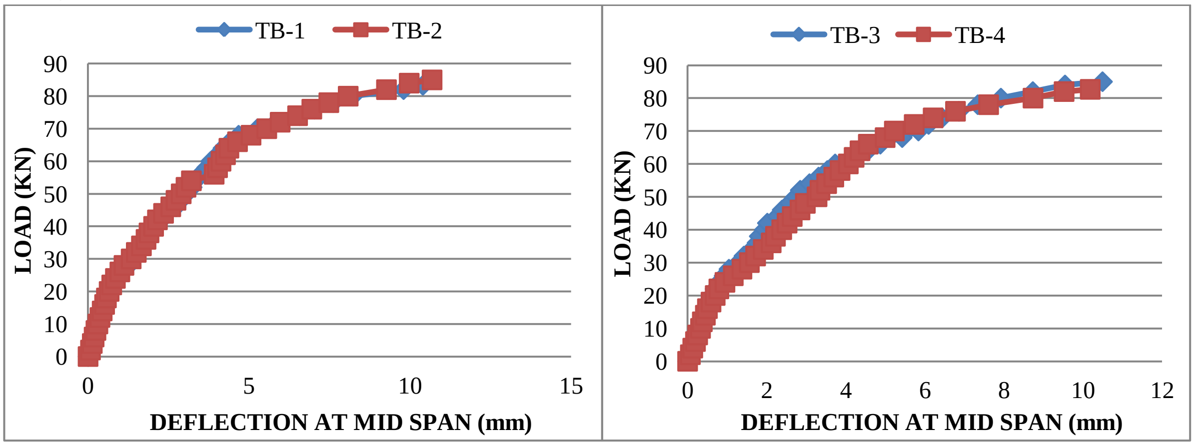
3.4 Flexural Capacity: The ultimate moment carrying capacities of the beams are calculated theoretically conforming to IS: 456- 2000 and compared it with the experimental results. The experimental and theoretical results are tabulated in the table 5.

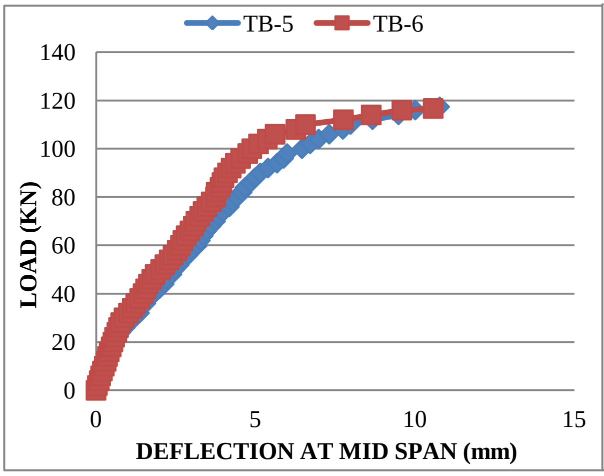
TABLE 5: EXPERIMENTAL RESULTS AND THEORETICAL RESULTS OF ULTIMATE MOMENT

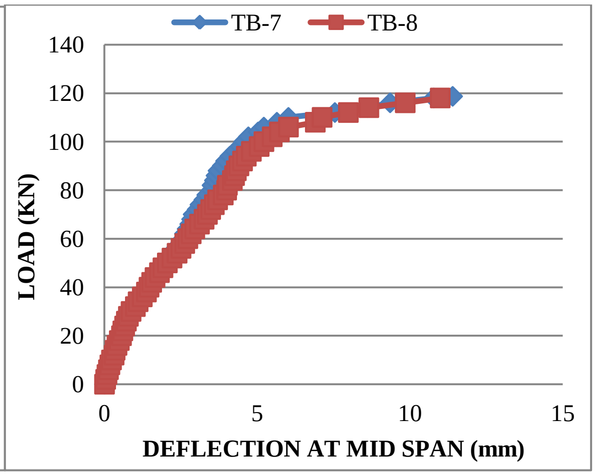
Beam designation	A_{st} (%)	Experimental ultimate moment, $M_{u,e}$ (KN-m)	Theoretical cracking moment, $M_{u,t}$ (KN-m) (IS:456-2000)	Ratio $M_{u,e}/M_{u,t}$ (IS:456-2000)
TB- 1, TB- 2	0.72	16.84	10.60	1.588
TB- 3, TB- 4	0.72	16.77	10.60	1.582
TB- 5, TB- 6	1.03	23.40	14.58	1.60
TB- 7, TB- 8	1.03	23.67	14.58	1.62

From above table we can see that that the ultimate moment increases with increase in percentage of tensile reinforcement in flexure zone. The experimental ultimate moment of the test beams are greater than the theoretical ultimate moment by 58.20% for 0.72% of tensile reinforcement and 62.34% for 1.03% of tensile reinforcement.

3.5 Deflection: The deflection of the beam were measured at an interval of 2kN at mid span and 1/3rd 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	55	0.17	0.1212	0.3
TB- 3, TB-4	55	0.175	0.1212	0.3
TB- 5, TB- 6	77	0.18	0.1270	0.3
TB- 7, TB-8	78	0.195	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	55	-0.000101	0.000240
TB- 3, TB-4	55	0.000113	0.000297
TB- 5, TB- 6	77	-0.000201	0.000235
TB- 7, TB-8	78	-0.000220	0.000246

IV. CONCLUSION

Based on the experimental results following conclusion were made:

The test results for the fresh concrete properties showed that the slump value decreases with increase in LD Slag content and when the LD Slag content increases the care should be taken as the mix is likely to segregate.

The results for hardened concrete indicated that the fine aggregate replacement using 60% of LD Slag showed a maximum compressive strength, split tensile strength and flexural tensile strength and these strengths goes on decreasing marginally beyond this value.

However, it was observed that the density of hardened concrete increases with increase in LD Slag. Hence, the optimum percentage replacement was taken as 45% so as to categorize it as a normal density concrete (i.e. <2600kg/m^3). Also, as the LD Slag was increased beyond 45% the density of concrete was categorized as High density concrete (i.e. >2600kg/m^3).

Hence 45% replacement of LD Slag for river sand in concrete is used in production of RCC beams to study the flexural behaviour.

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 fibre to the compression fibre with crushing of concrete at the top surface with no horizontal cracks at the level of the reinforcement, indicating no bonding failure.

The flexural results shows that there is increase in cracking moment by 3.7% for 0.72% of tensile reinforcement and 10.35% for 1.03% of tensile reinforcement. The moment at first crack increases with increase in percentage of tensile reinforcement in flexure zone.

The experimental ultimate moment of the test beams increases with increase in percentage of tensile reinforcement in flexure zone. The experimental ultimate moment of the test beams are greater than the theoretical ultimate moment by 58.20% for 0.72% of tensile reinforcement and 62.34% for 1.03% of tensile reinforcement.

The deflection increases with increase in percentage of tensile reinforcement in flexure zone. The deflection is increased by 4.8% for the beams containing LD Slag when compared to the control beams for 1.03% of tensile reinforcement and the deflection is decreased marginally for the beams containing LD Slag when compared to the control beams for 0.72% of tensile reinforcement. Also, the experimental deflections at service load were well within the permissible limits as per IS: 456-2000.

The maximum strain at service load should not exceed 0.0035 and the experimental results show that the maximum strain in all the beams is well within the limits per IS: 456-2000.

The theoretical crack width at service load calculates was 0.1212mm for 0.72% and 0.1270mm for 1.03% of tensile reinforcement. Also, the experimental crack width at service load was well within the permissible limits as per IS: 456-2000 (i.e. 0.3mm) for moderate type of exposure.

The LD slag can be used for both normal and high density concrete as mentioned in this research work, which can be advantageous as it is easily available material that can replace natural sand up to 100%.

Also, the LD Slag can be used both as fine and coarse aggregates in concrete making it sustainable, economical and eco-friendly preventing the usage of natural resources that is depleting and are at scares.

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