Effect of Steel Slag as a Replacement of Fine Aggregate in M40 Grade of Concrete

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Abstract - Steel Slag is a waste material obtained from steel and iron industry. In India, annual outcome of Steel Slag is about 10 Million Tonne. The increase in demand for the ingredients of concrete is met by replacement of materials by the waste materials which is obtained by means of various industries. Hence, here an attempt has been made to assess the possibility of using an industrial residue material viz. steel slag as a replacement of fine aggregate in concrete. Steel slag is used as a replacement of fine aggregate on criteria of particle size after performing sieve analysis using relevant Indian Standards and has been physically and chemically characterized, and replaced in the range of 0%, 20%, 40 %, 60%, 80% and 100% by weight of fine aggregate in concrete. Mix design has been carried out for M40 grade using relevant Indian Standard IS- 10262: 2009. The workability of concrete decreased as the replacement percentage increased. There is a considerable increase in compressive strength for 20% & 40% replacement; flexural strength and tensile strength had an increment of about 20% more than the required strength as prescribed in Indian Standards. The results for 80% & 100% replacement proportions were not that as expected as far as strength parameters are concerned, a reduction of about 10%-20% in compressive strength was noticed. Even if the results of strength parameters are same as that of conventional concrete at higher replacements, steel slag may be proved to be a major substitute of deficient fine aggregate or sand.

Keywords - Steel Slag, Workability, Compressive Strength, Flexural Strength, Spilt Tensile Strength, etc.

I. INTRODUCTION

1.1 General

Steel slag, one of the most common industrial wastes, is a by-product of steel production. One ton of steel implies the production of 130 – 200 kg of slag, depending on the composition of the steel and on the steel production process [13]. Slag often appears as granulated materials containing large clusters, coarse and very fine particles. Serious environmental problems formerly originated from unrestrained sand and gravel taken from rivers. Fortunately it has been considered for some decades the chance to use different recycled materials as concrete aggregates, even if just in partial replacement of natural counterparts. The steel slag sample was collected from Polaad Steel Company, Jalna, Maharashtra and the amount of presence of steel slag can be rectified from the figure 1 below.

Most of the volume of concrete is aggregates. Replacing all or some portion of natural aggregates with steel slag would lead to considerable environmental benefits. Concrete is a composite material composed of granular materials like coarse aggregates embedded in a matrix and bound together with cement or binder which fills the space between the particles and glues those together. Slag is a co-product of the iron and steel making process. When any new material is used as a concrete aggregate, three major considerations are relevant: (1) economy, (2) compatibility with other materials and (3) concrete properties. Steel slag has a high degree of internal friction and high shear strength [5].

Figure 1: Steel Slag Clusters at Polaad Steel

1.2 Objectives of Work

1.2.1 To study the effect of varying percentage of replacement of fine aggregate by steel slag on concrete.
1.2.2 To investigate the appropriate replacement percentage for steel slag based on the strength and workability parameters.
1.2.3 To study the degree of workability of concrete on all proposed replacement percentages.
1.2.4 To determine compressive strength, flexural strength and spilt tensile strength for various proportions.

1.3 Designation of Samples

Table 1 shows the designation given to the various replacement proportions.

Table 1- Designation used for samples

Sr. No.	Designation	Percentage Replacement of Fine Aggregate (%)
1.	S0	0
2.	S2	20
3.	S4	40
4.	S6	60
5.	S8	80
6.	S10	100

II. LITERATURE REVIEW

The authors, S. T. Borole et. al (2016) in their experimental investigation carried out on M30 grade concrete concluded that the compressive strength increases with increase in percentage of steel slag by 25% by weight of fine aggregate The compressive strength decreases after 25% replacement of steel slag. The split tensile strength increases with increase in percentage of steel slag by 25% by weight of fine aggregate. The flexural strength increases with increase in percentage of steel slag by 25% by weight of fine aggregate. From the results of compressive strength, split tensile strength and flexural strength of 7 days and 28 days curing, 25% replacement of fine aggregate by steel slag is the optimum percentage of replacement of M30 grade concrete and decreases considerably in further replacement of slag in concrete. Eco-friendly and Mass utilization of waste material is possible in construction by using steel slag as partial replacement material for partial replacement in concrete.

The authors, S. P. Palanisamy et. al (2015) concluded the use of steel slag, a waste cheap material used as fine aggregate in M55 grade concrete and recommends and approval of the materials for use in concrete as replacement material for fine aggregates .The partial substitution of natural aggregates permits a gain of compressive, tensile and flexural strength and modulus of elasticity of concrete up to an optimum value of replacement. It has been observed that up to 36% replacement of fine aggregate with steel slag to be good in Compression, as well as in Tension, whereas the concrete properties with equal proportion of steel slag and conventional fine aggregate confirmed to be inefficient. The benefits can also obtained by cost reduction, social benefits, mass utilization of waste material is possible in construction by using steel slag as a partial replacement material for fine in concrete.

The authors, Gozde Inan Sezer et. al (2015) performed their experimental investigation by replacing fine aggregate and/or coarse aggregate by steel slag. The authors concluded that the steel slag can be replaced by both fine and coarse aggregate in separate mixes, but cannot be replaced by fine as well as coarse aggregate in a same mix. They suggested the use of steel slag as a coarse aggregate more beneficial rather than using it as a replacement of fine aggregate. The increase in percentage replacement increased the mass of concrete. An increase in flexural strength of concrete was noticed as compared to the conventional concrete.

The experimental investigation carried out by Prof. Subathra Devi et al. (2014) was done on grade of concrete M20. On performing test on workability viz. Slump cone test, it has been concluded that the workability of concrete gradually decreases as the percentage of replacement of fine aggregate increases. Regarding strength parameters, author has mentioned test on compressive, tensile and flexural strength and the results indicated that the strength parameters increased in magnitude as compared to conventional concrete. In this study, durability tests such as acid resistance using HCl, H_2SO_4, etc were conducted. The mass loss in cubes after immersion in acids is found to be very low.

III. MATERIALS USED

3.1 Cement

Ordinary Portland cement of grade 53 was conforming to IS 12269: 1987 is used for this research work. The initial setting time of cement is 55 minutes and the specific gravity of cement is 3.15.

3.2 Fine and Coarse Aggregate

Fine aggregate used in this research work was locally available natural sand and conforming to IS 383-1970 and was clear sand passing through 4.75mm sieve with a specific gravity of 2.68. The grading zone of aggregate was zone II.
Coarse aggregate used in this research work was conforming to IS 383-1970 and was angular crushed aggregate with a specific gravity of 2.70.

3.3 Steel Slag

Steel slag has been sourced from Polaad Steel plant, Jalna. The sample obtained from the plant was black in color and granular in appearance. Chemical properties of steel slag sample collected from Polad Steel, Jalna is shown below in Table 2. The chemical composition was investigated at Shraddha Analytical Services, Ghatkopar, Mumbai by performing XRF test on the steel slag sample. The XRF graph is shown in Figure 2.

Table 2- Chemical Composition of Steel Slag

Symbol	Al	Si	K	Ca	Ti	V	Cr	Mn	Fe	Zn	Sr	Zr	Nb	Ba
Mass %	4.08	11.23	0.22	3.84	1.91	0.16	1.19	29.92	45.40	0.60	0.20	0.33	0.11	0.78

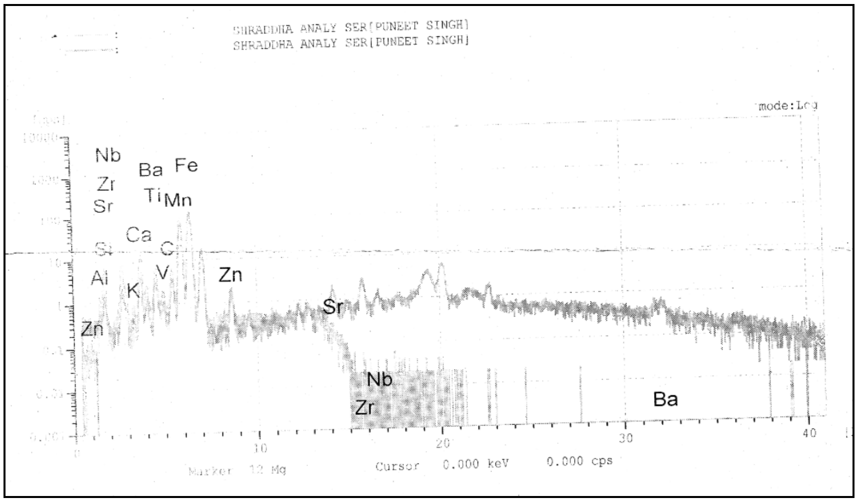

Figure 2- XRF Graph

3.4 Superplasticer

FOSROC Conplast SP430 is based on Sulphonated Napthalene Polymers and supplied as a brown liquid instantly dispersible in water. Conplast SP430 has been specially formulated to give high water reductions up to 25% without loss of workability or to produce high quality concrete of reduced permeability.

3.5 *Water*

Potable water available in the laboratory with the pH of 7.0 ± 1 and conforming to the requirement of IS: 456-2000 was used for mixing concrete and also for curing of specimens.

IV. RESULTS AND DISCUSSIONS

4.1 Workability (Slump Cone Test)

Slump Cone test was performed for investigation of workability of fresh concrete. Initially slump cone test was performed for 100% replacement of fine aggregate with different dosage trials of Superplasticer Fosroc Conplast SP430. Finally it was concluded that the trial dose of 3% satisfied the minimum criteria of workability with 20% reduction in water cement ratio and the same dosage was kept constant for all the six proportions in view to increase the workability as the replacement percentage decreases. Table 3 and Chart 1 shows the slump values for various proportions.

Table 3- Slump Value for All Proportions

Sr. No.	Designation	Slump Value (mm)
1	S0	65
2	S2	55
3	S4	47
4	S6	38
5	S8	35
6	S10	30

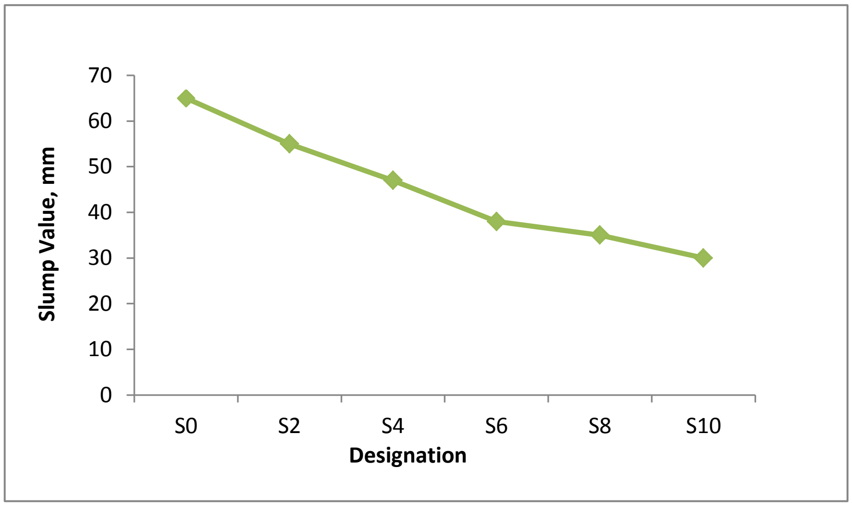

Chart 1- Slump Value for all proportions

4.2 Compressive Strength Test

Nine cube specimens of size 150 mm were casted to work out the 3 days, 7 days and 28 days compressive strength of all the six proportions.

Figure 3- Compressive Strength Test Setup

The results for compressive strength at 3 days, 7 days and 28 days durations are as shown in Table 4.

Table 4- Compressive Strength Test Results

Sr. No.	Designation	Compressive Strength (N/mm^2)			Mean 28th Day Compressive Strength (N/mm^2)
		3rd Day	7th Day	28th Day	
1	S0	20.44	32.00	44.89	44.89
		20.89	30.67	44.00	
		20.00	31.11	45.78	
2	S2	22.67	34.67	48.89	48.44
		23.56	34.22	48.00	
		23.11	33.78	48.44	
3	S4	22.67	32.89	46.67	46.37
		23.11	33.78	47.11	
		22.22	34.22	45.33	
4	S6	20.00	28.44	40.89	40.44
		20.44	29.33	41.33	
		20.44	28.89	39.11	
5	S8	18.67	27.56	36.44	37.48
		17.78	26.67	38.22	
		17.63	25.33	37.78	
6	S10	16.89	23.11	34.67	33.63
		15.56	23.56	33.33	
		17.33	24.00	32.89	

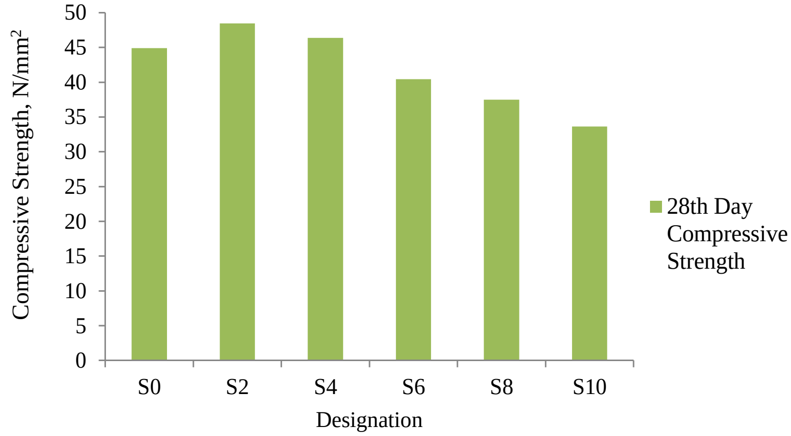

Chart 2- Compressive Strength Results

4.3 Spilt Tensile Strength Test

Three cylinder specimens of size 150mm diameter and 300mm height were casted to work out the spilt tensile strength at 28 days concrete age for all the six proportions. The results for 28th day spilt tensile strength are as shown in Table 5.

Figure 4 - Spilt Tensile Strength Test Setup

Table 5- Spilt Tensile Strength Test Results

Sr. No.	Designation	28th Day Tensile Strength (N/mm^2)	Mean Tensile Strength (N/mm^2)
1	S0	5.52	5.28
		5.09	
		5.23	
2	S2	5.38	5.38
		5.52	
		5.23	
3	S4	5.09	5.09
		5.23	
		4.95	
4	S6	4.95	4.90
		4.67	
		5.09	
5	S8	4.95	4.72
		4.67	
		4.53	
6	S10	4.24	4.48
		4.67	
		4.53	

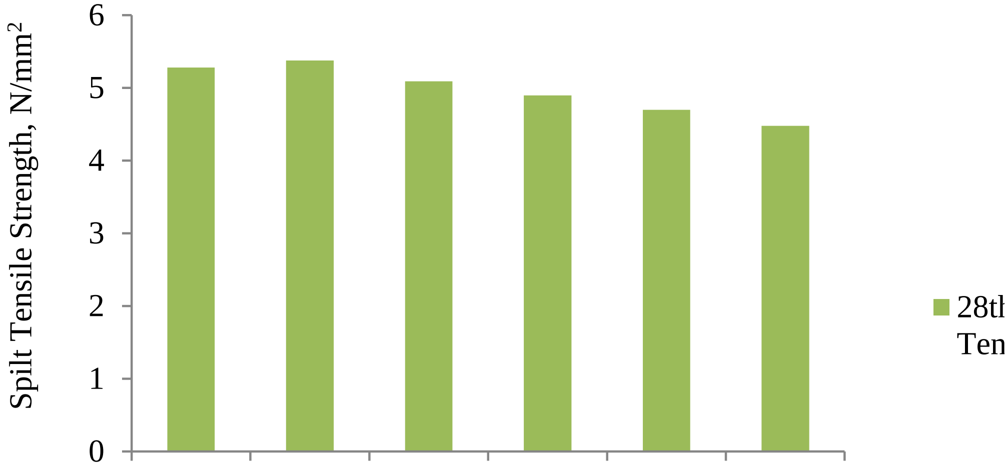

Chart 3- Spilt Tensile Strength Test Results

4.4 Flexural Strength Test

Three beams specimens of size 100x100x500 mm were casted to work out the flexural strength at 28 days age of concrete for all the six proportions.

Figure 5- Flexural Strength Test Setup

The results for 28th day flexural strength are as shown in Table 6.

Table 6- Flexural Strength Test Results

Sr. No.	Designation	28th Day Flexural Strength (N/mm^2)	Mean Flexural Strength (N/mm^2)
1	S0	5.68	5.44
		5.48	
		5.16	
2	S2	4.80	5.87
		6.00	
		6.80	
3	S4	5.12	5.77
		5.60	
		6.60	
4	S6	5.20	5.17
		5.32	
		5.00	
5	S8	5.12	4.87
		5.00	
		4.48	
6	S10	4.08	4.45
		4.60	
		4.68	

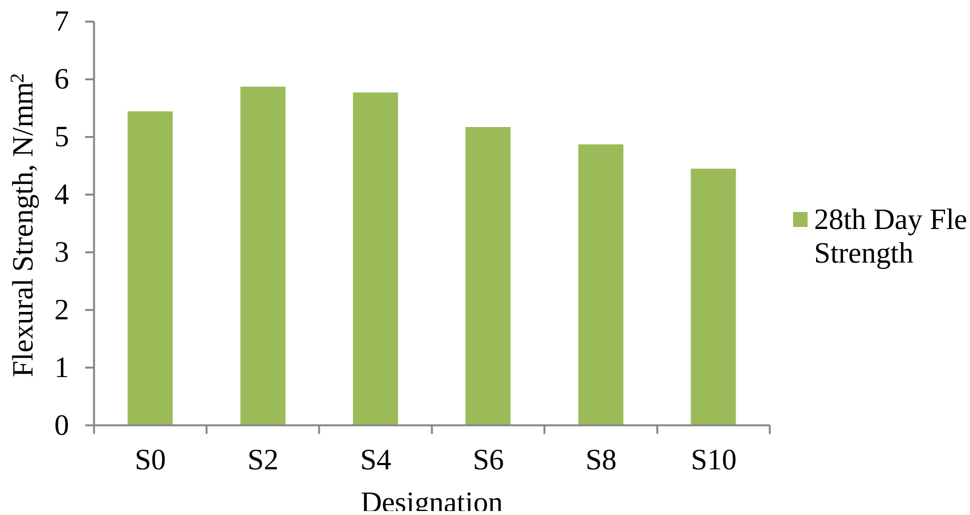

Chart 4- Flexural Strength Test Results

V. CONCLUSIONS

1. Workability decreases as the percentage replacement of fine aggregate by steel slag increases. This is due to the higher water absorption property of steel slag (3%) as compared to natural fine aggregate.
2. The compressive strength of concrete increased by 7.90% for 20% replacement of steel slag and nearly 3.29% rise for 40% replacement of steel slag as compared to the compressive strength obtained for 0% replacement of steel slag. For 60%, 80% & 100% replacement proportions, fall in compressive strength of about 9.91%, 16.50% and 25.08% respectively is noticed. The increase in strength is due to shape, size and surface texture of steel slag aggregate, which give better adhesion between the particles and cement paste. As the steel slag is porous, higher replacement of fine aggregate gives poor results.
3. For spilt tensile strength, all proportions satisfied the minimum criteria as per Indian standards, there was highest increment of about 21.52% in spilt tensile for 20% replacement proportion.
4. For flexural strength, all proportions satisfied the minimum criteria as per Indian standards, there was highest increment of about 32.59% in flexural strength for 20% replacement proportion.
5. The use of steel slag concrete on higher replacement percentage may lead to an efficient use of waste material and solve various environmental issues. As in this research work, if steel slag concrete of 60% replacement is used, it may solve the shortage issues of deficit natural sand and also lead to economical construction as steel slag is freely and readily available.
6. But the disadvantage is increase in the density of concrete at higher replacement as the specific gravity of natural sand is lower as compared to steel slag. At 60% replacement, the increase in density of concrete is 4.92% and the actual value obtained is 26.34 kN/m^3.
7. Further study is required to be carried out to sort this disadvantage of increment in density of concrete. May be the use of lighter coarse aggregate is the solution of this issue.

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