Experimental Investigation on Steel Slag Concrete (SSC)

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***Abstract*— The aim of this research is to study the performance of steel slag as concrete as coarse aggregates compared to the conventional use of granites for the same purpose.To assess the performance of dense cement mix prepared using 100% steel slag (SSDA) and dense cement mix incorporating a combination of 50% granite and 50% steel slag (SSGDA).To evaluate the effect of moisture, temperature and aging on the performance of mixes incorporating steel slag.Test results shows that, for M30 grade 40% replacement of steel slag increases the compressive strength of 40.8 N/mm2 and for M40 grade 40% replacement of steel slag increases the compressive strength to a maximum of 46.3 N/mm2.For M30 grade above 40% replacement of steel slag reduces the compressive strength drastically, may be due to the water-cement ratio. Similarly for M40 grade more than 40% replacement of steel slag has reduces the compressive strength of concrete.Comparing SSC of M30 grade and M40 grade shows much good result for M30 grade of concrete. This may be due to the bond strength, aggregate interface and water-cement ratio.The split tensile strength of the SSC concrete for 40% replacement of coarse aggregate with steel slag was tested for 7 days and 28 days were given better results when compared to the concrete specimens.Similarly flexural strength of SSC at 40% replacement of coarse aggregate, performs very well than the control concrete. The results gives much increase strength for SSC better than the control concrete.These results encourage the use of steel slag for the partial replacement material for high strength concrete.The equation analysis for the determination of compressive strength of SSC for various replacement of steel slag for both M30 and M40 grade has been enhanced.**

Keywords— ***Steel Slag, Experimental analysis, Concrete.***

INTRODUCTION

Steel slag was existed as by-product during melting of steel scrap from the impurities and fluxing agents, which form the liquid slag floating over the liquid crude iron or steel in arc or induction electrical furnaces, or other melting units. The properties and chemical composition of the slag were stated by Clarkson University, the specific gravity ranges from (2.85-3.0) and bulk density varies from (1.0-1.4 gm/cm3. The active slag made from molten iron has to be water cooled. Chemical composition of typical slag consisted mainly SiO_2, Al_2O_3, CaO and Fe_2O_3. The slag may be further processed after cooling, mainly crushed and screened to desired size, prior to being used or sold. The main uses of steel slag were in road bases and surfaces concrete, asphaltic concrete and as aggregate in hydraulic cement concrete. In the past 20th century, slag was found to be excellent aggregate for asphalt road paving. Different forms of slag produced depend on cooling method used. It may be used as a mineral admixture for Portland cement concrete.

MATERIAL TEST RESULTS

CEMENT

1. Specific gravity = 3.15
2. Normal consistency = 32%
3. Initial setting time = 40 mins
4. Final setting time = 5hrs

FINE AGGREGATE

1. Specific gravity = 2.74
2. Bulk density in loose state = 1294.87 kg/m^3
3. Bulk density in compacted state = 1442.16 kg/m^3

The sieve analysis of fine aggregate result is given in Table 4.1.

COARSE AGGREGATE

1. Specific gravity of coarse aggregate = 2.75
2. Bulk density in state = 1346.7 kg/m^3
3. Bulk density in compacted state = 1480.07 kg/m^3
4. Crushing strength = 19.93%
5. Impact strength = 8.97%

STEEL SLAG

1. Specific gravity of Steel slag = 3.21
2. Crushing strength = 29%
3. Impact strength of steel slag = 14.32%
4. Loose density = 1483 kg/m^3
5. Compacted density = 1670 kg/m^3

MIX DESIGN AND MIX PROPORTION

Mix proportions are arrived for M30 & M40 grade of concrete based on the method of IS 10262, concrete mix design by replacing 0,10,20,30,40,50,60 percent of mass of aggregate by steel slag. Seven types of different mixtures were proportioned and designated as M1, M2, M3, M4, M5, M6, and M7 as shown in Table. M1 indicates controlled concrete specimens. Additionally, the other mixtures M2, M3, M4, M5, M6, M7 were proportioned to have aggregate replacement value of 10%, 20%, 30%, 40%, 50%, 60% by weight of coarse aggregate. These mixtures were proportioned for water-binder ratio of 0.5. Tables 6.1 and 6.3 shows the detailed mix proportion of M30 and M40 grade of concrete. Tables shows the detailed mix proportion of aggregate and steel slag for M30 and M40 grade of concrete.

Detailed Mix pro
portion for M30
Detailed Quantities of Aggregate and Steel slag for M30 grade

Materials	Cement	Water	Fine aggregat	Coarse aggregate
Weight Per m^3 of Concrete (Kg)	382	186	631.4	1147.58
Ratio	1	0.5	1.66	3.11

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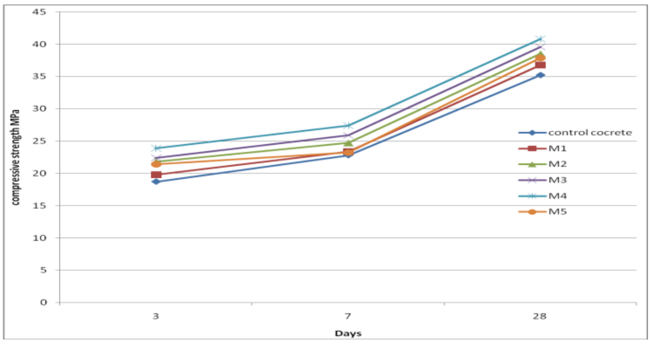
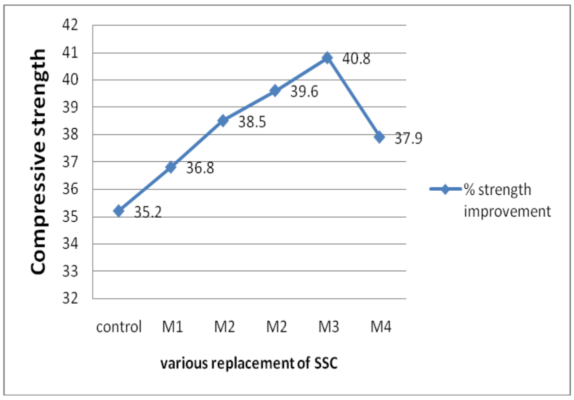
Compressive Strength Of Steel Slag

Concrete cubes of size 150x150x150mm were made using various percentage replacement of steel slag for coarse aggregate. Concrete cubes were made for M30 grade and M40 grade. The percentages of steel slag replacement for coarse aggregate were 10, 20, 30, 40, 50 and 60 and the cubes are represented as M2, M3, M4, M5, M6 and M7 respectively, while M1 refers to the control concrete. The cubes were tested for 3, 7 and 28 days compressive strength as per IS Standard and the results are given in the Table.



S.NO	Replacement level of steel slag in %	For 7 Days (N/mm^2)	For 28 days (N/mm^2)	% improvement at 28 days
1	0	22.8	35.2	
2	10	23.4	36.8	4.545
3	20	24.7	38.5	9.375
4	30	25.9	39.6	12.50
5	40	27.4	40.8	15.909
6	50	23.2	37.9	7.670
7	60	22.3	34.4	-0.023

Comparison between the Compressive strength of steel slag concrete for M30 grade



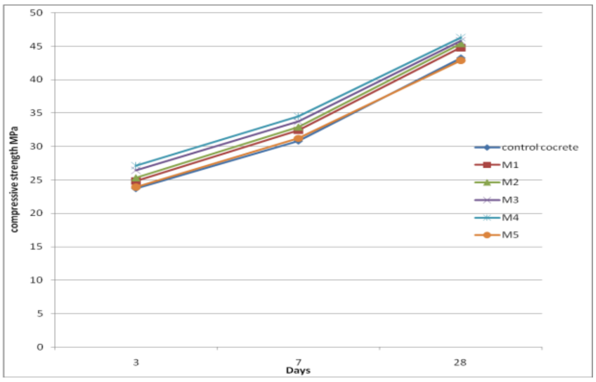
Mix	Steel slag(%)	Coarse aggregate(kg/m^3)	Steel slag(kg/m^3)
M1	0	1147.58	0.0
M2	10	1032.862	114.748
M3	20	942.027	226.642
M4	30	803.306	344.274
M5	40	714.962	461.752
M6	50	573.790	573.790
M7	60	459.032	688.548

Variation of percentage strength improvement with respect to percentage replacement of steel slag for M30 grade

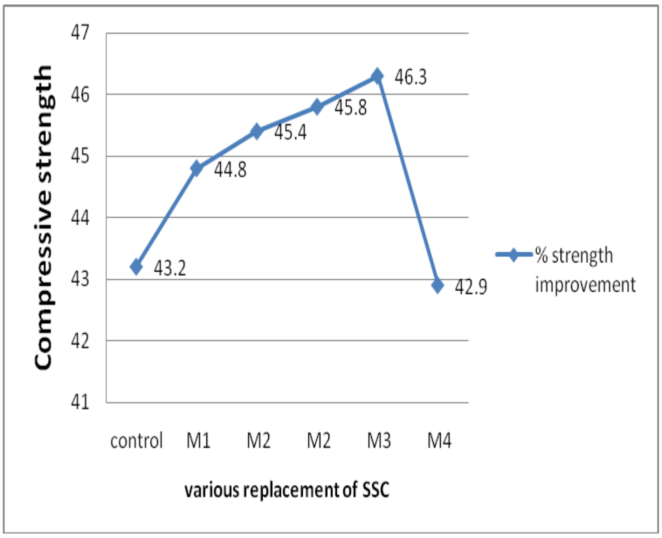
The above results shows the compressive strength of SSC for various replacements for M30 grade. The maximum percentage improvement attained 15.909% at 40% replacement which is shown in Table 7.1, above 40% resuts in the decrease in the compressive strength when compared with control concrete. Figure 7.1 shows the comparison of compressive strength of SSC. This line chart clearly indicates the variation of strength improvement at various replacements. Figure 7.2 shows that above 40% replacement, there is a decrease in the compressive strength. This may be due to aggregate interface, improper bonding and excess watercontent

Compressive strength of concrete with steel slag M40

S.NO	Replacement level of steel slag in %	For 7 days (N/mm^2)	For 28 days (N/mm^2)	% of improvement at 28 days
1	0	30.8	43.2	
2	10	32.4	44.8	3.703
3	20	32.9	45.4	5.092
4	30	33.7	45.8	6.018
5	40	34.5	46.3	7.175
6	50	31.2	42.9	-0.006
7	60	29.7	40.8	-0.058



Comparison between the compressive strength of steel slag concrete for M40grade



Variation of percentage strength improvement with respect to percentage replacement of steel slag for M40 grade

From Table, the compressive strength of SSC for various replacements of steel slag indicates that, till 40% of replacement of steel slag in coarse aggregate gives maximum strength improvement when compared with control concrete. Above 40% replacement results in decrease in compressive strength. It is clearly shown in the line chart in Fig. Variation of strength improvement is shown in fig. which indicates decrease in strength above 40% replacement. This may be due high cement content, bond strength and water cement ratio.

For M30 grade of concrete the 28 days strength is found to be 35.2N/mm^2. At the end of 28 days the concrete containing 40% steel slag shows the highest compressive strength as 40.8N/mm^2. The strength improvement is 15.909% than the control concrete at the 40% replacement level. The steel slag aggregate sample gave good strength than the rest, the reason might be the water-cement ratio and the bond strength at the paste-aggregate interface.

For M40 grade of concrete the 28 days strength is found to be 43.2N/mm^2. At the end of 28 days the concrete containing 40% steel slag shows the highest compressive strength as 46.3N/mm^2. The strength improvement is 7.175% than the control concrete at the 40% replacement level. Replacement level of above 40% gives less strength when compared with control concrete, reason might be the water-cement ratio.

SPLIT TENSILE STRENGTH

Concrete cylinders are tested for the split tensile strength after a period of 28 days curing period. The test was carried out by placing the cylindrical concrete specimen in a horizontal position between the loading surfaces of the compression testing machine between two plywood strips which was laid between the diametrical ends of the cylindrical concrete specimen. The plywood strips was placed between the loading faces so as to ensure uniform distribution of the load. The load was applied vertically along the diameter of the cylinder until failure at a uniform rate and the corresponding failure load was noted for each specimens. The split tensile strength of the cylindrical specimen was calculated using the following formula:

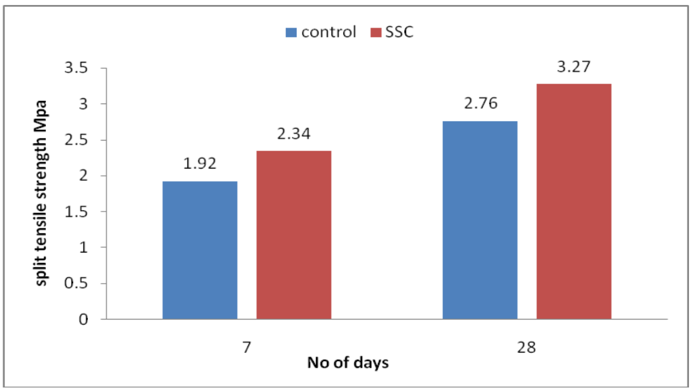
Split tensile strength (N/mm^2) =$2P/\pi LD$

where, P= ultimate load at failure, N
L= length of specimen, mm
D=diameter of cylindrical specimen, mm

The test results are tabulated in Table represented in Figure. The addition of steel slag contributes significant strength improvement and is evident from percentage improvement as shown in Figure. Similar to the compressive strength test, addition of steel slag shows higher split tensile strength.

Split tensile strength of concrete with steel slag for M30 grade

Specimen	Steel slag (%)	For 7 days (N/mm^2)	For 28 days(N/mm^2)	% of increment in strength
Control	0	1.92	2.76	16.88
Ssc	40	2.34	3.27	



Comparison between the Split tensile strength for M30

Split tensile strength of SCC was carried out for 40% replacement, since it results in the maximum compressive strength when it is compared with control concrete. The results were indicated in Table 7.3 and it is compared with control concrete. The result shows good improvement in 7 days and 28 days. Comparison of split tensile strength was also shown as bar chart in Fig.7.5. this shows the better result for SSC when compared with control concrete. This may be due to water content and aggregate interface. And also the mixture was very harsh with steel slag and the higher strength might be due to the cement paste and the bond strength at the paste- aggregates boundary. This shows SSC can perform well as a conventional concrete.

FLEXURAL STRENGTH

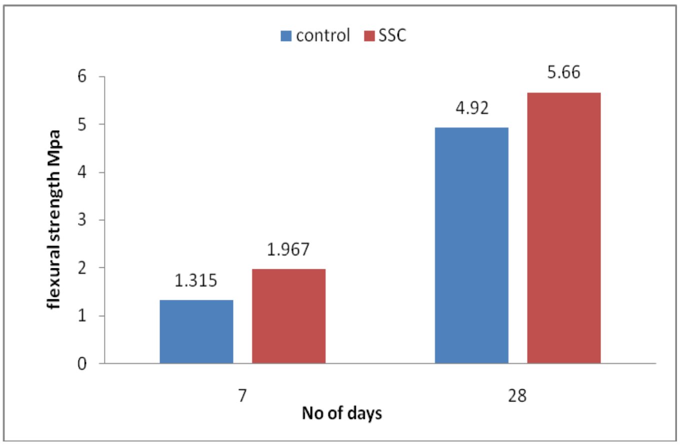
Beams are tested for 28 days strength. The beams are subjected to flexural loading in the universal testing machine in such a way that the load was applied at the uppermost surfaces cast in the mould along the centre point with an overhang of 50 mm along the supports. The axis of the specimen was carefully aligned with the axis of loading device. The load was applied gradually and the load was increased until the specimen was failed and the maximum load applied to the specimen during test was recorded.

The flexural strength is calculated using the formula,

Flexural strength=Pl/bd^2
where, P=maximum applied load, N
l=supported length of the beam, mm
b=width of the beam specimen, mm
d=depth of the beam specimen, mm

The test results are tabulated in Table and the comparison of flexural strength are shown in Figure,

Specimen	Steel slag (%)	For 7 days (N/mm^2)	For 28 days(N/mm^2)	% of increment in strength
Control	0	1.315	4.92	13.06
ssc	40	1.967	5.66	



For M30 and M40 grade SSC shows good improvement of strength when it is compared with control concrete which is shown in Fig. This shows SSC can be used for conventional concrete with its improved strength characteristics.

EQUATION ANALYSIS FOR COMPRESSIVE STRENGTH OF SSC

The compressive strength of the design mix for M30 grade is found to be 35.2 N/mm^2 and for M40 grade is 43.2 N/mm^2 and is taken as the base line strength for following equation analysis. Initially 10% of coarse aggregate is replaced by steel slag aggregates and 28 days compressive strength for that mix were tabulated. Similarly for various replacements like 20%, 30%, 40%, 50% and 60% were tabulated. The equations are determined for each of these percentage replacements. These equations are analysed to find out the approximate compressive strength of SSC for a particular percentage of replacement of steel slag.

M30 GRADE

(1) For replacement of 0%-10%,
Compressive strength of SSC = σM30 + 0.16 (x)
Where,
σM30 is 28 days compressive strength of control concrete for M30grade,
X is the no of percentage replacement required
0.16 is the constant derived from the average % increase of compressive strength.
The compressive strength from 0% to10% was shown in Table.
For example, to find out the compressive strength of SSC for replacement of 5%,
Compressive strength of SSC = σM30 + 0.162 (x)
= 35.2 + 0.162 (5) = 36.01N/mm^2.

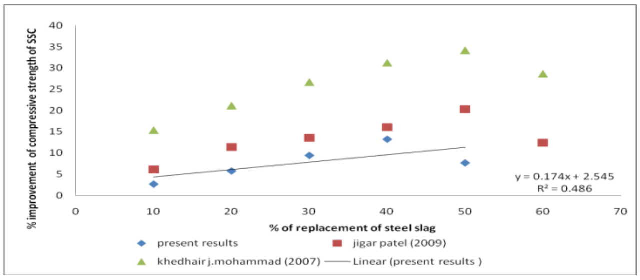
Compressive strength of SSC for 0%-10% replacement of steel slag

% replacement of steel slag	Compressive strength of SSC N/mm^2
1	35.362
2	35.524
3	35.686
4	35.848
5	36.010
6	36.172
7	36.334
8	36.496
9	36.658
10	36.820

For replacement of 11%-20%,
Compressive strength of SSC = σM30 + 0.165 (x)
Where,
σM30 is 28 days compressive strength of control concrete for M30grade,
X is the no of percentage replacement required
0.165 is the constant derived from the average % increase of compressive strength.
The compressive strength of SSC from 11% to 20% were shown in Table.

Generalized Equation

From the above equations and results, a generalized equation for both M30 and M40 grades can be formulated. This generalized equation can be initiated till 40% replacement of steel slag for compressive strength of SSC. From the above results the maximum compressive strength improvement attained at 40% replacement of steel slag for both M30 and M40 grade which is shown in Table 8.4 and table 8.8. Taking 40% improvement as a baseline in executing generalized equation,



From the Fig. Best fit line was drawn for present experiment results to derive the following generalized equation for percentage improvement of compressive strength of SSC.

Y = 0.174x + 2.545

$R^2 = 0.486$

Where, Y is the percentage improvement of compressive strength, X is the percentage replacement of steel slag.

CONCLUSIONS

Test results shows that, for M30 grade 40% replacement of steel slag increases the compressive strength of 40.8 N/mm^2 and for M40 grade 40% replacement of steel slag increases the compressive strength to a maximum of 46.3 N/mm^2.For M30 grade above 40% replacement of steel slag reduces the compressive strength drastically, may be due to the water-cement ratio. Similarly for M40 grade more than 40% replacement of steel slag has reduces the compressive strength of concrete. Comparing SSC of M30 grade and M40 grade shows much good result for M30 grade of concrete. This may be due to the bond strength, aggregate interface and water-cement ratio.The split tensile strength of the SSC concrete for 40% replacement of coarse aggregate with steel slag was tested for 7 days and 28 days were given better results when compared to the concrete specimens. Similarly flexural strength of SSC at 40% replacement of coarse aggregate, performs very well than the control concrete. The results gives much increase strength for SSC better than the control concrete. These results encourage the use of steel slag for the partial replacement material for high strength concrete. The equation analysis for the determination of compressive strength of SSC for various replacement of steel slag for both M30 and M40 grade has been enhanced. A generalized equation has been determined from the previous equation analysis which is suitable for both M30 and M40 grades of concrete. This equation gives results for compressive strength of SSC for a particular replacement percentage of steel slag.

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