Beneficial Effects of Steel Slag on Concrete

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Abstract- **Global warming and environmental destruction has come forward as a major issue in the recent years. Started alarming in engineers mind, especially in civil engineers mind. Looking forward for finding out the solution of these issues and also the use of more and more environmental- friendly materials in every Industry particularly construction industry is a paramount importance. Civil engineers start thinking about concrete, which is more dominant product to be used by civil engineers to make it environmental friendly. One of its part is natural aggregates which are becoming increasingly scarce, their production and shipment is becoming difficult for us. Concrete mixture contains supplementary cementitious material and admixtures which forms part of the cementitious component. These materials are majority byproducts from other processes, out of all these materials one of the useful byproduct material is Steel slag. Steel slag is previously used as aggregate in hot mix asphalt surface applications, but needs to update for additional work to determine the feasibility of utilizing this industrial by-product more wisely as a replacement for both fine and coarse aggregates in a conventional concrete mixture. The primary aim of study was to evaluate the Fresh, Hardened, Expansive and Durability properties of concrete made with steel slag aggregates. This study presents result of experimental investigations carried out to evaluate effects of replacing aggregate (coarse and fine) with that of slag on various concrete properties. In the present study M35 grade of concrete each having two types of concrete mixes C: S: A, C: S: SS, C: SS: SS (SS is steel slag), and the properties were determined adopting conventional testing procedure. From these results of the study we can say that as the percentage of steel slag as replacement is increased (0% to 55%) the strength of concrete increases. After 55% replacement of Coarse aggregate as steel slag slight decrease in strength is observe, but still it is higher than 0% replacement without any adverse effect on the strength of concrete.**

Keywords- Steel slag, compressive strength, flexural strength, Expansive properties and split tensile strength.

I. Introduction

Global warming and environmental destruction has come forward as a major issue in the recent years. Started alarming in engineers mind, especially in civil engineers mind. Looking forward for finding out the solution of these issues and also the use of more and more environmental- friendly materials in every Industry particularly construction industry is a paramount importance. Civil engineers start thinking about concrete, which is more dominant product to be used by civil engineers to make it environmental friendly. One of its part is natural aggregates which are becoming increasingly scarce, their production and shipment is becoming difficult for us. Concrete mixture contains supplementary cementitious material and admixtures which forms part of the cementitious component. These materials are majority byproducts from other processes, out of all these materials one of the useful byproduct material is Steel slag. Steel slag is previously used as aggregate in hot mix asphalt surface applications, but needs to update for additional work to determine the feasibility of utilizing this industrial by-product more wisely as a replacement for both fine and coarse aggregates in a conventional concrete mixture. The primary aim of study was to evaluate the Fresh, Hardened, Expansive and Durability properties of concrete made with steel slag aggregates. This study presents result of experimental investigations carried out to evaluate effects of replacing aggregate (coarse and fine) with that of slag on various concrete properties. In the present study M35 grade of concrete each having two types of concrete mixes C: S: A, C: S: SS, C: SS: SS (SS is steel slag), and the properties were determined adopting conventional testing procedure. From these results of the study we can say that as the percentage of steel slag as replacement is increased (0% to 55%) the strength of concrete increases. After 55% replacement of Coarse aggregate as steel slag slight decrease in strength is observe, but still it is higher than 0% replacement without any adverse effect on the strength of concrete.

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In today's sinario steel plants all most all producing 3-7 tonnes of waste which includes the solid, liquid and gas are generated for every ton of steel produced. Engineers are basically trying to focus on the principal of Recycling and Reuse of waste also trying to avoid the waste generation, so that the impact of waste can be minimized on environment. Steel slag is one of the wastes produced by steel making units in excess quantities, with the increment of these quantities disposal is big environment concern and a critical issue.

II. MATERIALS AND PROPERTIES

2.1 Steel Slag

Steel Slag is the main component of this study, which is locally available material. Steel Slag used in is work is collected from D.D Steel industry Ludhiana. Steel slag is a byproduct obtained either from conversion of iron to steel in a Basic Oxygen Furnace (BOF), or by the melting of scrap to make steel in the Electric Arc Furnace (EAF). The molten liquid is a complex solution of silicates and oxides that solidifies on cooling and forms steel slag. Steel slag is defined by the American Society for Testing and Materials (ASTM) as a non-metallic product, consisting essentially of calcium silicates and ferrites combined with fused oxides of iron, aluminum, manganese, calcium and magnesium that are developed simultaneously with steel in basic oxygen, electric arc, or open hearth furnaces. (Kalyoncu, 2001). The production of steel slag in nearby state is Punjab in area Mandi Gobindhgarh. The chemical composition and cooling of molten steel slag have a great effect on the physical and chemical properties of solidified steel slag.

Steel furnace slag is produced in a Basic Oxygen Furnace (BOF) or Electric Arc Furnace (EAF) as a byproduct of the production of steel. In the Basic Oxygen Furnace (BOF), the hot liquid metal from the blast furnace, scrap and fluxes, which contain lime (CaO) and dolomitic lime, are charged to a furnace (Shi, 2004). A lance is lowered into the converter and then oxygen in injected with high pressure. The oxygen then combines with and removes the impurities. These impurities consist mainly of carbon in the form of gaseous carbon monoxide, silicon, manganese, phosphorous and some iron as liquid oxides, which combine with lime and dolomitic lime to form steel slag. At the end of the refining stage, the steel in the liquid form is poured into the ladle while the slag is retained at the top in the vessel and is then subsequently removed in separate slag pot. This slag is in molten state and is then processed to remove all free metallic impurities with help of magnetic separation and then sized into construction aggregates.

Unlike the Basic Oxygen Furnace (BOF) process, the Electric Arc Furnace (EAF) does not use hot metal, but uses cold steel scraps. Charged material is heated to a liquid state by means of an electric current. The electricity has no electrochemical effect on the metal, making it perfectly suited for melting scrap. During the melting process, other metals are added to the steel to give the required chemical composition. Meanwhile oxygen is blown into the EAF to purify the steel. This slag which floats on the surface of molten steel is then poured off. The main constituents of iron and steel slags are silica, alumina, calcium, and magnesia, which together make about 95% of the total composition. Minor elements included are manganese, iron, sulfur compounds and traces of several other elements (Kalyoncu, 2001). Physical characteristics such as porosity, density, particle gradation, are affected by the cooling rate of the slag and its chemical composition.

Constituents	Composition provided By Steel Industry (%)	Composition provided by NSA (%)
Aluminum oxide (Al_2O_3)	4.84	1-5
Calcium oxide (CaO)	30.7	40-52
Chromium oxide (Cr_2O_3)	0.28	---
Iron oxide (FeO)	35.6	10 - 40 (70 - 80% FeO, 20 - 30% Fe2O3)
Magnesium oxide (MgO)	9.95	5-10
Manganese oxide (MnO)	3.99	5-8
Phosphorus oxide (P_2O_5)	0.61	0.5-1
Potassium oxide (K_2O)	0.05	--
Silicon oxide (SiO_2)	12.0	10-19
Sodium oxide (Na_2O)	0.09	--
Titanium oxide (TiO_2)	0.65	--
Vanadium oxide (V_2O_5)	0.21	--
Water Absorption	3.37	--
SSD Specific Gravity	3.09	--

Steel Slag is to be crushed into desired size of aggregate by mechanical means, steel slag obtained is greyish white in color. The final picture of steel slag, sometimes steel slag is allowed to go through weathering process due to their expensive properties, in this weathering process slag contacts with water to take place the hydration process between lime and water. Hydration of free lime (Cao) or free magnesia (MgO) is responsible for expensive nature of steel slag (Pajgede & Thakur, 2013).

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The physical, mechanical and chemical properties of steel slag are shown below.

Table 2.1 Physical Properties of Steel Slag

Property	Value
Specific Gravity	> 3.2 - 3.6
Unit Weight, kg/m3	1600 - 1920
Water Absorption	up to 3%

Table 2.2 Mechanical Properties of Steel Slag as Aggregate

Property	Value
Elongation Index	1.01 % (should not be more than 15 %)
Flakiness Index	4.48 % (should not be more than 15 %)
Specific Gravity of Steel Slag Aggregate	G = 2.91
Aggregate impact value	23.21 % (should not be more than 30 %)
Crushing value	36.55 % (should not be more than 45 %)
Dry Loose Bulk Density	1.12 Kg/lt
Water Absorption	2.5 % (should not be more than 2 %)
Abrasion Value	27 % (should not be more than 30 %)

Table 2.3 Chemical Properties of Steel Slag

1.2 CEMENT PROPERTIES

Cement Brand : Ultratech Cement
Cement Type : Ordinary Portland Cement
Specific Gravity of Cement: G = 3.13
Standard Consistency of cement:
Quantity of Cement: W1=400gms
Quantity of Water: W2= 33%= 132ml
Penetration of Plunger from Top = 33 mm (Desirable is 33 to 35 mm)
Initial Setting Time: Quantity of Cement: W1=400gms
Weight of Water as per Standard Consistency: P = 33 % = 132 ml
Initial Setting Time of the Cement : 28mins.
Final Setting Time of the Cement : 560 mins.
Fineness of Cement:W = 225m^2/kg
Compressive strength of Cement
3days : 23
7days : 37
28days : 43

1.3 SAND (Fine Aggregate)

The sand used for the work was locally procured and conformed to Indian Standard Specifications IS: 383-1970. The sand was sieved through 4.75 mm sieve to remove any particles greater than 4.75 mm. The various other tests conducted are specific density, bulk density, fineness modulus, water absorption and sieve analysis. The results are given below in Table 4.7 and 4.8. The fine aggregated belonged to grading zone II. This Aggregate has absorption of 1.23%. The Bulk Specific Gravity of the fine aggregate was 2.60 while its SSD Specific Gravity was 2.63.

Table 2.4: Physical Properties of fine aggregates

Characteristics	Value
Specific gravity	2.63
Bulk density	2.60
Fineness modulus	2.63
Water absorption	1.23%

Table 2.5: Sieve analysis of fine aggregate

Aggregate Size: Fine Type: Sand (Zone II)

Sieve size (mm)	Material retained in gms	% retained	%passing	Cumulative % retained
4.75	14.5	1.45	98.55	1.45
2.36	37	3.70	94.85	5.15
1.18	246.5	24.65	70.20	29.80
600	205.5	20.55	49.65	50.35
300	287.5	28.75	20.90	79.10
150	177	17.70	3.20	96.80
Pan	32	3.20		
Sum	**100**		**Sum**	**262.65**

F.M= 2.63

2.4 AGGREGATE (COARSE AGGREGATE)

The material which is retained on IS sieve no. 4.75 is termed as a coarse aggregate. The crushed stone is generally used as a coarse aggregate. The nature of work decides the maximum size of the coarse aggregate. Locally available coarse aggregate having the maximum size of 20 mm was used in this work. The aggregates were washed to remove dust and dirt and were dried to surface dry condition. The aggregates were tested as per IS: 383-1970. The results of various tests conducted on coarse aggregate are given in Table 2.6 and 2.7.

Table 2.6: Physical Properties of coarse aggregates

Characteristics	Value
Type	Crushed
Specific Gravity	2.884
Total Water Absorption	0.97%
Fineness Modulus	6.96

Table 2.7:Sieve Analysis of Coarse Aggregates (20mm)

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Sieve size (mm)	Material retained in gms	% retained	% passing	Cumulative % retained
80	0	0.00	100.00	0.00
40	0	0.00	100.00	0.00
20	68.5	2.28	97.72	2.28
10	2776.5	92.55	5.17	94.83
4.75	113.5	3.78	1.38	98.62
2.36	0	0.00	0.00	100
1.18	0	0.00	0.00	100
600	0	0.00	0.00	100
300	0	0.00	0.00	100
150	0	0.00	0.00	100
Pan	0	0.00	0.00	100
Sum	**3000**		**Sum**	**695.73**

F.M= 6.96

Table 2.8 Mechanical Properties of Aggragate

Property	Value
Elongation Index	13 % (should not be more than 15 %)
Flakiness Index	12 % (should not be more than 15 %)
Specific Gravity of Aggregate Slag Aggregate	G = 2.98
Aggregate impact value	4.5 % (should not be more than 30 %)
Crushing value	19.11 % (should not be more than 45 %)
Dry Loose Bulk Density	1.52 Kg/lt
Water Absorption	1.0 % (should not be more than 2 %)
Abrasion Value	14 % (should not be more than 30 %)

1.4 DESGIN MIX

Mass of Cement in kg/m^3 - 400
Mass of Water in kg/m^3 - 160
Mass of Fine Aggregate in kg/m^3 - 704
Mass of Coarse Aggregate in kg/m^3 - 1271
Mass of 20 mm in kg/m^3 - 915
Mass of 10 mm in kg/m^3 - 356
Mass of Admixture in kg/m^3 - 2.00
Water Cement Ratio - 0.40

III. RESULTS AND DISSCUSSION

Firstly, we will discuss the Fresh Concrete properties and then the Hardened Concrete properties.

3.1 Gradations.

The sieve analysis of the steel slag samples revealed that the material was a combination of both fine aggregates and coarse aggregates. Figure 3.1shows the results of sieve analysis of Steel slag, when compared with natural fine aggregates and coarse aggregates.

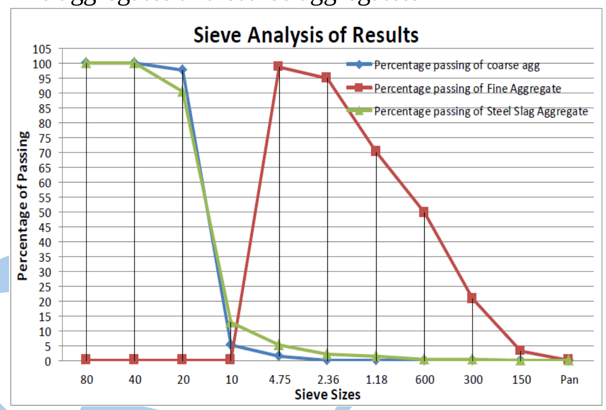

Figure-3.1 Sieve analysis results of Steel Slag compared with fine and coarse aggregates.

3.2 Slump Test

Slump test of various concrete mix specimens i.e C:S:A and C:SS:SS. are shown in table 3.1

Table-3.1 Slump Test Results of Fresh Concrete

Specimen	Mixture	Measured slump (mm)
Specimen 1 (C:S:A)	Steel Slag 0%	63
	Steel Slag 25%	60
	Steel Slag 50%	58
	Steel Slag 75%	53
	Steel Slag 100%	48
Specimen 2 (C:SS:SS)	Steel Slag 0%	62
	Steel Slag 25%	63
	Steel Slag 50%	56
	Steel Slag 75%	52
	Steel Slag 100%	46

It is observed from slump test (workability), workability of concrete increases with the increase in the steel slag with replacement by natural aggregates. But upto 50% limit after which there is decrement of slump is there not too much.

3.3 Unit Weight

Unit weight of concrete is measured, because the varying unit weight of steel slag due to moisture absorbing capacity. The unit weight of concrete mix specimens are shown in figure-3.2 and figure-3.3.

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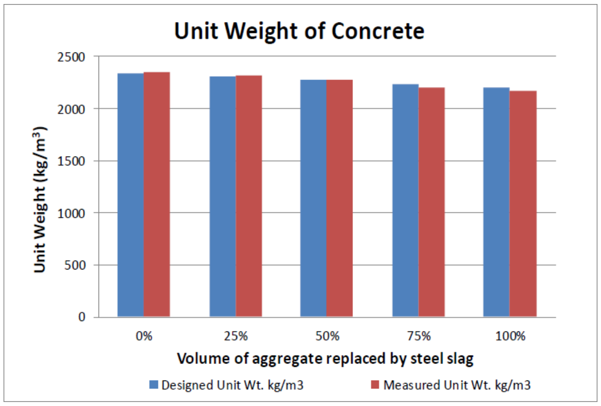

FIGURE 3.2: Graph showing Unit weight of aggregates replaced by steel slag (Specimen1)

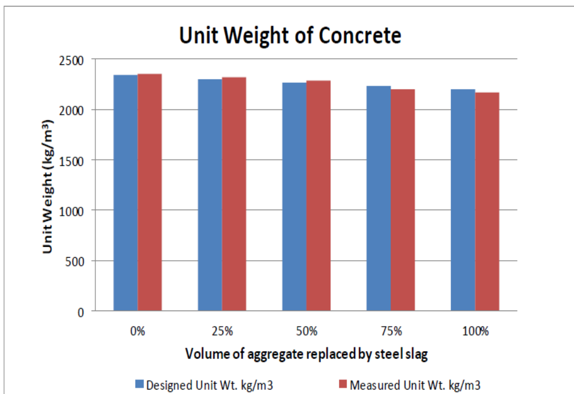

FIGURE 3.3: Graph showing Unit weight of aggregates replaced by steel slag (Specimen2)

% Replacement	7 days Flexural Strength (Mpa)		28 days Flexural Strength (Mpa)	
	(C:S:A)	(C:S.S:S.S)	(C:S:A)	(C:S.S:S.S)
0 %	0.5	0.4	3.9	3.85
25 %	0.9	0.8	4.36	4.4
50 %	1.3	1.2	4.6	4.6
75 %	1	0.9	4.2	4.2
100 %	0.7	0.7	3.9	3.8

From figures 3.2 & 3.3 it is observe that on addition of steel slag by replacement of natural aggregate for both specimens upto 50% there is almost constant unit weight, but further increase in steel slag there is 10% decrease unit weight of concrete mix in case of specimen1.

For specimen2 on increase of steel slag only upto 50% increment there is almost constant unit weight, but after 50% increment of aggregate almost 15% decrease of unit of concrete mix.

3.4 COMPRESSIVE STRENGTH OF CONCRETE

28 days compressive strength of various concrete mix i.e C:S:A, and C:SS:SS are tabulated in Table 3.2(a) and 3.2(b) compressive strength bar chart shown in Fig. 3.4

Table 3.3, 7 & 28-day Compressive Strength test result of M35 grade concrete

% replaced	7 days compressive strength (MPa)		28 days compressive strength(MPa)	
	Specimen 1 (C:S:A)	Specimen 1 (C:S.S:S.S)	Specimen 1 (C:S:A)	Specimen 1 (C:S.S:S.S)
0%	23.05	23.76	35.12	37.5
25%	23.75	24.12	39.94	41.23
50%	29.03	28.8	45.42	46.01
75%	25.15	26.04	41.33	42.64
100%	23.43	23.78	35.93	36.93

Graphical Representation

From observation we conclude that the strength of concrete increases as the quantity of steel slag is increases on replacement of fine and coarse aggregate. Only upto 50% of replacement of steel slag the compressive strength shows increment beyond it will show decrement in the strength is observed.
Characteristic strength increases maximum upto 50% replacement criterion for all the concrete mix.
The compressive strength of concrete mix increase upto 30% if 50% of aggregate is replaced by steel slag.
The compressive strength of concrete mix increase upto 23% if 50% of aggregate is replaced by steel slag and 10% sand is replaced by steel slag.

3.5 FLEXURAL STRENGTH OF CONCRETE

7 & 28-day flexural strength of various concrete mix i.e. C:S:A and C:SS:SS are tabulated in Table 3.4 and bar chart is shown in Fig. 3.5
Table 3.4, 7 & 28-day Flexural Strength test result of M35 grade concrete

Graphical Representation

From table 3.4 it is observed that flexural strength of concrete increases with the increase in the quantity of steel slag as replacement to natural aggregates only upto 50% of replacement by steel slag,but beyond 50% decrease in the strength is observed.
The flexural strength of concrete mix increase upto 18% if 50% of aggregate is replaced by steel slag.
The flexural strength of concrete mix increase upto 20% if 23% of aggregate is replaced by steel slag and 10% sand is replaced by steel slag.

3.5 SPLIT TENSILE STRENGTH OF CONCRETE

7 & 28-day Tensile strength of various concrete mix i.e. C:S:A and C:SS:SS are tabulated in Table 3.5 and bar chart is shown in Fig. 3.6

Table 3.5. 7 & 28-day Tensile Strength test result of M35 grade concrete

% Replacement	7 days Split Tensile Strength (Mpa) for Length of cylinder =300mm, diameter = 150mm		28 days Split Tensile Strength (Mpa) for Length of cylinder =300mm, diameter = 150mm	
	(C:S:A)	(C:S.S:S.S)	(C:S:A)	(C:S.S:S.S)
0 %	1.1	1.3	3.45	3.44
25 %	1.4	1.4	3.85	3.84
50 %	1.8	1.9	4.65	4.63
75 %	1.5	1.4	4.01	4.12
100 %	0.9	0.8	3.68	3.65

From observation we conclude that the Split Tensile strength of concrete increases as the quantity of steel slag is increases on replacement of fine and coarse aggregate. Only upto 50% of replacement of steel slag the Split tensile strength shows increment beyond it will show decrement in the strength is observed.

Split tensile strength increases maximum upto 50% replacement criterion for all the concrete mix.

The Split tensile strength of concrete mix increase upto 35% if 50% of aggregate is replaced by steel slag at 28 days.

The Split tensile strength of concrete mix increase upto 34% if 50% of aggregate is replaced by steel slag and 10% sand is replaced by steel slag at 28 days.

3.6 RESISTANCE TO SULPHATE

Durability test was conducted on 150 x 150 x 150mm cube specimens. The cubes were casted and cured in water for 28 days. Sodium sulphate ($NaSo_4$) solution of 50g/l is used to evaluate sulphate resistance of concrete. Cubes are immersed in solution after 28 days curing, and are tested for compressive strength at 7&28 days. Test results are given below in table 3.6. When this compressive strength is compare with the compressive strength of specimen cured in water at same ages also there is increase of steel slag aggregate with natural aggregate at 25%, 50%, 75%and 100% were also checked. When the replacement of natural aggregate with steel slag increase in the mix.

Table 5.7: Compressive strength of concrete mixes after immersion in Na_2So_4solution

MIX	7 Days Compressive strength (Mpa)		28 Days Compressive strength (Mpa)	
	Control (7 Days)	Immersed	Control (28 Days)	Immersed
0%	23.05	21.15	36.12	35.11
25%	23.75	21.1	39.94	36.78
50%	29.03	23.63	45.42	40.56
75%	25.15	21.48	41.33	37.82
100%	23.43	19.21	35.93	31.4

From observation we conclude that the Resistance to sulphate attack of concrete increases as the quantity of steel slag is increases on replacement of fine and coarse aggregate. Only upto 50% of replacement of steel slag the Resistance to sulphate attack of concrete shows increment beyond it will show decrement in the strength is observed.

Resistance to sulphate increases maximum upto 50% replacement criterion for all the concrete mix.

The Resistance to sulphate attack of concrete mix increase upto 16% if 50% of aggregate is replaced by steel slag at 28 days.

3.7 CHANGES IN LENGTH OF CONCRETE SPECIMENS

Table 5.8 shows the change of length of the concrete specimens and is compared to the initial length at the start of the test procedure. All the specimens were kept at the normal room temperature in the water basin. The result shows that the change in length of concrete specimens was negligible at the end of 90 days. The control specimens showed a sign of expansion but there was slight contraction in length in the specimens with 100% steel slag.

Table 5.8 shows the change of length of the concrete specimens

Specimen	Mixture	CD 7 Days	Length Change (%)	CD 28 Days	Length Change (%)
Specimen 1 (C:S:A)	0%	1	0	1.001	0.1
	25%	1.02	2	1.04	4
	50%	1.03	4	1.05	5
	75%	1.05	5	1.07	7
	100%	1.07	7	1.10	10
Specimen 2 (C:S.S:S.S)	0%	1.02	2	1.03	3
	25%	1.02	2	1.04	4
	50%	1.05	5	1.07	7
	75%	1.05	5	1.08	8
	100%	1.08	8	1.12	12

Specimen	Mixture	CD 56 Days	Length Change (%)
Specimen 1 (C:S:A)	0%	1.001	0.1
	25%	1.05	5
	50%	1.07	7
	75%	1.09	9
	100%	1.12	12

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Specimen 2 (C:S.S:S.S)	0%	1.06	6
	25%	1.07	7
	50%	1.10	10
	75%	1.12	12
	100%	1.15	15

From table 5.8 it is the major change in length of specimen is at 56 days from mixture of 75% replacement of aggregate with the natural aggregate in all concrete mixes.
The change in length of concrete mix increase upto 25% if 75% of aggregate is replaced by steel slag at 28 days.
The change in length of concrete mix increase upto 25% if 50% of aggregate is replaced by steel slag and 10% sand is replaced by steel slag at 28 days.

IV. CONCLUSIONS

- Hardened concrete properties (Compressive Strength, Flexural Strength and Split Tensile Strength) for use for steel slag as aggregate in concrete is higher as conventional concrete. The maximum strength is upto 50% replacement in all criterion.
- Strength of M35 grade of concrete increases with increases in steel slag quantity. The improvement in strength may be due to shape, size and surface texture of steel slag aggregate, which provide better adhesion between the particles and cement paste.
- Durability of steel slag aggregates concrete under freeze-thaw environment has pending in this research, as there was a belief that the steel slag aggregates have expansive characteristics and would cause cracking in concrete.
- The cost of slag is almost 50% of that of natural aggregate also it is economical to use the Steel Industrial waste product. Also it could be easily used as coarse and fine aggregate in all plain concrete applications.

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