Concrete with steel Slag

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Abstract

In the entire construction project we as engineers try to use the materials which lead to save time, cost, and encountered the problems which we often faced at Sites.Steel slag aggregate for concrete construction has solved some of the different problems and gives early strength.Using steel slag instead of sand we can enhance the properties of the concrete mix. In all mixes, three ratios of slag-sand replacement (15, 30, and 45%) have been used, also three mixes of concrete with 25 MPa strength has been used in the study. The results showed that steel slag improves the strength of concrete without affecting workability. The ratio 30% has shown more benefit regard to strength of concrete.

Keywords: steel slag, concrete compressive strength, workability, density

1. Introduction

Steel slag, a by-product of steel making, is produced during the separation of the molten steel from impurities in steel-making furnaces. The slag occurs as a molten liquid melt and is a complex solution of silicates and oxides that solidifies upon cooling. Virtually all steel is now made in integrated steel plants using a version of the basic oxygen process. The open-heart furnaces process is no longer used. In the basic oxygen process, hot liquid blast furnace metal, scrap, and fluxes, which consist of lime (CaO) and dolomitic lime (CaO.MgO or dolime), are charged to a converter (furnace). A lance is lowered into the converter and high-pressure oxygen is injected. The oxygen combines with and removes the impurities in the charge.

These impurities consist of carbon as gaseous carbon monoxide, and silicon, manganese, phosphorus and some iron as liquid oxides, which combine with lime and dolime to from the steel slag. At the end of the refining operation, the liquid steel is tapped (poured) into a ladle while the steel slag is retained in the vessel and subsequently tapped into aseparate slag pot. There are many grades of steel that can be produced, and properties of the steel slag can change significantly with each grade. Grades of steel can be classified as high, medium the steel slag produced during the primary stage of steel production is referred to as furnace slag or tap slag. This is the major source of steel slag aggregate.

After being tapped from the furnace the molten steel is transferred in a ladle for further refining to remove additional impurities still contained within the steel. This operation is called ladle refining because it is completed within the transfer ladle. During ladle refining, additional steel slags are generated by again adding fluxes to the ladle to melt. These slags are combined with any carryover of furnace slag and assist in absorbing deoxidation products (inclusions), heat insulation, and protection of ladle refractories. The steel slags produced at this stage of steel making are generally referred to as raker and ladle slags,m, and low, depending on the carbon content of the steel. High-grade steels have high carbon content. To reduce the amount of carbon in the steel, greater oxygen levels are required in the steel-making process. This also requires the addition of increased levels of lime and dolime (flux) for the removal of impurities from the steel and increased slag formation.

Types of slag

There are several different types of steel slag produced during the steel-making process. These different types are referred to as furnace or tap slag, synthetic or ladle slags, and pit or cleanout slag. The most commonly known types of steel slag are: Blast Furnace slag, air-Cooled slag, palletized of expanded slag, steel furnace slag and granulated slag.

Slag in History

While widespread use of slag in its many contemporary applications is a fairly recent development, the material itself is an old as the smelting process which produces it. As early as 1589, the Germans were making cannon balls cast from iron slag. And record is available which indicate that cast iron slag stones were used for masonry work in Europe of the 18^{th} century.

Roads made from slag were first built in England in 1813 and just seventeen years later, the first slag road was laid in this country. By the year 1880, blocks cast of slag were in general use for street paving in both Europe and the United States. Amajor city under the American flag with a long history of slag-paved streets is San Juan, Puerto Rico. Perhaps the earliest appearance of slag in American history came with the Pilgrims. Since slag was commonly used as ship ballast in that era, it seems likely that the Mayflower itself carried a load of Even though slag was demonstrating its versatility well before the 20^{th} century, for a long time, its principle use in this country was as track ballast for the nation's railroad. As production grew, so did the need to find new applications. One that proved immediately valuable was in the building of military roads during World War I.

By 1918, the year the national slag Association was formed, the nation was producing 40 million tons of pig iron a year, with a concomitant output of 20 million tons of slag. The time had come for full recognition of slags potentialities. This is what the Association has tried to achieve. Today, millions of tons of slag aggregates are produced annually in the United States. Its future is limited only by the imagination of its users. Technical personnel of member companies, acting through the National slag Association, are working constantly to job that imagination.

Slag Production

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Pit slag and clean out slag are other types of slag commonly found in steel-making operations. They usually consist of the steel slag that falls on the floor of the plant at various stages of operation, or slag that is removed from the ladle after tapping.

Because the ladle refining stage usually involves comparatively high flux additions, the properties of these synthetic slags are quite different from those of the furnace slag and are generally unsuitable for processing as steel slag aggregates. These different slags must be segregated from furnace slag to avoid contamination of the slag aggregate produced.

In addition to slag recovery, the liquid furnace slag and ladle slags are generally processed to recover the ferrous metals. This metals recovery operation (using magnetic separator on convey or and/or crane electromagnet) is important to the steelmaker as the metals can then be reused within the steel plant as blast furnace feed material for the production of iron.

Material (steel slag) processing requirements are: quality control, washing and, crushing and screening.

Applications of steel slag

The use of steel slag as an aggregated is considered a standard practice in many jurisdictions, with applications that include its use in concrete, granular base, embankments, engineered fill, highway shoulders, and hot mix asphalt pavement.

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Prior to its use as a construction aggregate material, steel slag must be crushed and screened to meet the specified gradation requirement for the particular application.

The slag processor may also be required to satisfy moisture content criteria and to adopt material handling (processing and stockpiling) practices similar to those used in the conventional aggregates industry to avoid potential segregation. Common uses of different types of slag are given in Table 1.

Table1: Common uses of different types of slag

Air-Cooled slag	Expanded slag	Granulated slag	Steel Slag
Asphalt aggregate	Concrete masonry	GGBS cement	Asphalt aggregate
Concrete aggregate	Lightweight concrete	Soil cement	Fill
Insulation/mineral wool	Lightweight fill	Roller Compacted concrete	Cement raw feed
Cement raw feed	Insulation		Agriculture

Agriculture			Environmental App.
Fill			Railroad ballast

Chemical, Physical and Mechanical Properties of Steel Slag

The chemical composition of slag is usually expressed in terms of simple oxides calculated from elemental analysis determined by x-ray fluorescence. Table 2 lists the range of compounds present in steel slag from a typical base oxygen furnace. Virtually all steel slags fall within these chemical ranges but not all steel slags are suitable as aggregates. Of more importance is the mineralogical from of the slag, which is highly dependent on rate of slag cooling in the steel-making process.

Table (2): Typical chemical composition of steel slag

Constituent	Composition (%)
CaO	40-52
SiO_2	10-19
FeO	10-40 (70-80%FeO,30%Fe_2O_3)
MnO	5-8
MgO	5-10
Al_2O_3	1-3
P_2O_5	0.5-1
S	<0.1
Metallic Fe	0.5-10

Physical properties: Steel slag aggregates are highly angular in shape and have rough surface texture. They have high bulk specific gravity and moderate water absorption (less than 3 percent). Physical properties of steel slag are given in Table 3.

Table (3): Typical physical properties of steel slag.

Property	Value
Specific Gravity	3.2-3.6
Unit Weight, kg/m^3	1600-2000
Absorption	Up to 3%

Mechanical properties**:** Processed steel slag has favorable mechanical properties for aggregate use, including good abrasion resistance, good soundness characteristics, and bearing strength.Typical mechanical properties of steel slagare given in Table 4**.**

Table4: Typical mechanical properties of steel slag

Property	Value
Lose Angeles Abrasion (ASTM C131),%	20-25
Sodium Sulfate Soundness Loss (ASTM C88), %	<12
Angle of Internal Friction	40^o-50^o
Hardness (measured by Moh's scale of mineral hardness)*	6-7
California Bearing Ratio (CBR), % top size 19mm (3/4 inch)**	Up to 300
*Hardness of dolomite measured on same scale is 3 to 4. ** Typical CBR value for crushed limestone is 100%.	

Experimental program:

In order to study the use of steel slag obtained from local sources, a comprehensive experimental program has been designed, the experimental program included the following:

1- Study of local basic aggregate.
2- Study of local steel slag basic properties.
3- Preparation of special mixes using ACI method of mix design.
4- Study of the effect of steel slag on the workability of concrete.
5- Study of the effect of steel slag on the density of concrete at various ages.
6- Study of the effect of slag on the comprehensive and tensile strength of concrete at various ages.

In all mixes, three ratios of slag-sand replacement (15, 30, and 45%) have been used, also three mixes of concrete with25 MPa strength have been used in the study.All materials used have been tested according to ASTM specifications; the following are the results of testing. Chemical analysis of steel slag taken from Natural Resources Authority laboratories directorate in Jordan are shown in Table 5.

Table (5): Chemical analysis of steel slag.

Oxides	%
Fe_2O_3	97.05
MnO	1.07
TiO_2	0.01
SiO_2	0.8
MgO	0.4
CaO	0.4
C	0.23
S	0.21
Water solubility% = 0.009	

Sieve analysis of coarse aggregate, fine aggregate, and steel slag has been performed according to ASTM C 136-84a, (7). The results are shown in Tables 6to9.Two types of course aggregate are used called medium and course, in this study; the two types were combined in order to obtain a grading within ASTM limits.

Table (6): Sieve analysis of steel slag

Sieve size (mm)	Trial#1 passing%	Trial#2 passing%	Trial#3 passing%	Average Passing
9.5	100	100	100	100
4.75	99	99	99	99
2.36	95.6	95.5	95.6	95.6
1.18	85.5	85.4	85.4	85.4
600	72.2	72.1	72	72.1
300	56.1	56.2	56.2	56.2
150	40	39.8	40	40
75	20.5	20.6	20.4	20.5
Pan	0	0	0	0

*The fines modules is 1.5

Table (7): Sieve analysis of fine aggregate

Sieve size (mm)	Trial#1 passing%	Trial#2 passing%	Trial#3 passing%	Average Passing
9.5	100	100	100	100
4.75	99.7	99.9	100	99.9
2.36	99.4	99.6	99.8	99.6
1.18	98.7	98.9	99.2	98.9
600	90.7	91.1	92.1	91.3
300	38.2	47.2	49.8	45.1
150	7.7	8.3	9.8	8.6
75	0.9	0.9	1.1	1
Pan	0	0	0	0

*The fines modules is 1.66

Table (8): Sieve analysis of medium aggregate

Sieve size (mm)	Trial# 1 passing%	Trial# 2 passing%	Trial# 3 passing%	Average Passing%
37.5	100	100	100	100
25	100	100	100	100
19	100	100	100	100
12.5	82.3	80.7	82	81.6
9.5	48	46.6	50.6	56.4

4.75	1.7	2	2.2	1.9
2.36	0.4	0.6	0.7	0.6
Pan	0	0	0	0

Table (9): Sieve analysis of course aggregate

Sieve size (mm)	Trial #1 passing%	Trial# 2 passing%	Trial# 3 passing%	Average Passing%
37.5	100	100	100	100
25	97	97.4	100	98
19	54.3	55.8	57.4	55.7
12.5	1.9	1.5	1.4	1.7
9.5	0.3	0.3	0.3	0.3
4.75	0.3	0.3	0.3	0.3
2.36	0.3	0.3	0.3	0.3
Pan	0	0	0	0

Specific gravity and absorption has been performed for aggregate, and steel slag according to ASTM C127-88,while for fine aggregate the test was performed according to ASTM C128-88 . Resultsare shown in Tables 10 to13.

Table (10): Specific gravity and absorption of fine aggregate

Trial No.	A	B	C	S	Bulk specific gravity (dry) A/ (B+S-C)	Bulk specific gravity(SSD) S/(B+S-C)	Apparent Specific gravity A/(B+A-C)	Absorption S-A/A *100%
1	500	1280	1586	502	2.551	2.561	2.577	0.4
2	500	1280	1589	504	2.564	2.585	2.618	0.8
			Average =		2.558	2.573	2.598	0.6

Where:

A=weight of oven-dry specimen in air, g.

B=weight of pycnometer filled with water, g.

C=weight of pycnometer with specimen and water to calibration mark, g.

S=weight of saturated surface-dry specimen, g.

Table (11): Specific gravity and absorption of course aggregate.

Trial No.	A	B	C	Bulk specific gravity(dry) A/(B-C)	Apparent Specific gravity A/(B-C)	Apparent Sp gr A/(B-C)	Absorption B-A/A *100%
1	3000	3045	1885.4	2.587	2.626	2.692	1.5
2	3000	3055	1887.8	2.570	2.617	2.697	1.83
Average =				2.579	2.622	2.695	1.667

Table (12): Specific gravity and absorption of medium aggregate.

Trial No.	A	B	C	Bulk sp gr(dry) A/(B-C)	Apparent Sp gr A/(B-C)	Apparent Sp gr A/(B-C)	Absorption B-A/A *100%
1	3000	3045	1885.4	2.587	2.626	2.692	1.5
2	3000	3055	1887.8	2.570	2.617	2.697	1.83
Average =				2.579	2.622	2.695	1.667

Table (13): Specific gravity(sp.) and absorption of steel slag.

Trial No.	A	B	C	S	Bulk sp gr (dry) A/(B+S-C)	Bulk sp gr(SSD) S/(B+S-C)	Apparent Sp gr A/(B+A-C)	Absorption S-A/A *100%
1	500	1586	1930	516	2.907	3	3.205	3.2
2	500	1579	1927	516	2.976	3.071	3.289	3.2

Mix design:

All mixes design has been performed according to ACI211.1-81, (1) medium workability concrete of 80 to 100mm slump was assessed to suit local market requirements. The results are shown in Tables 14-20.

Table (14): Normal concrete mixes

Compressive strength	Cement (kg)	Water (kg)	Coarse Aggregate (kg)	Medium Aggregate (kg)	Fine Aggregate (kg)	Silica Sand (kg)	Total weight (kg)
25 MPa	300	175	458	686	191	572	2382

Table (15): Mixes with 15% steel slag sand replacement:

Compressive strength	Cement (kg)	Water (kg)	Coarse Aggregate (kg)	Medium Aggregate (kg)	Fine Aggregate (kg)	Silica Sand (kg)	Steel slag (kg)	Total weight kg

25 MPa	300	175	458	686	191	486.2	85.8	2382

Table (16): Mixes with 30% steel slag sand replacement:

Compressive Strength	Cement (kg)	Water (kg)	Coarse Aggregate (kg)	Medium Aggregate (kg)	Fine Aggregate (kg)	Silica Sand (kg)	Steel slag (kg)	Total weight (kg)
25 MPa	300	175	458	686	191	400.4	171.6	2382

Table (17): Mixes with 45% steel slag sand replacement

Compressive strength	Cement (kg)	Water (kg)	Coarse Aggregate (kg)	Medium Aggregate (kg)	Fine Aggregate (kg)	Silica Sand	Steel slag (kg)	Total weight (kg)
25 MPa	300	175	458	686	191	314.6	257.4	2382

Workability:

Workability has been assessed according to the ASTM C143-90 a (Slump test), (8). The results are shown in Table 18.

Table (18): Slump of concrete for all mixes

% of steel slag	Slump (cm)
0	11
15	10
30	10
45	10

Density of concrete

The experimental results for density of concrete are given in Tables19 and 20.

Table (19): Density of concrete with different Slag ratios at of 3,7 and 28 days age .

Slag ratio	Density (kg/m3) At 3 days age	Density (kg/m3)At 7 days age	Density (kg/m3)At 28 days age
0	2429.63	2444.444	2456.3
15	2474.97	2503.7	2518.52
30	2503.7	2533.33	2548.15
45	2511.11	2540.74	2555.56

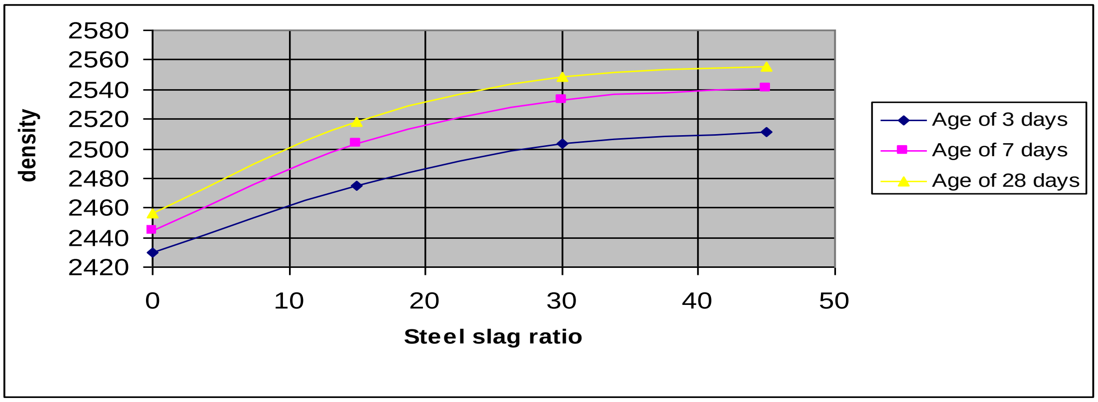

Figure (1) : Relationship between density and steel slag ratio at different ages

Table (20):Results of density for 25 MPa concrete mixes.

Age(Days)	Ratio 0%	Ratio 15%	Ratio 30%	Ratio 45%
3	2429.63	2474.97	2503.7	2511.11
7	2444.444	2503.7	2533.33	2540.74
28	2456.3	2518.52	2548.15	2555.56

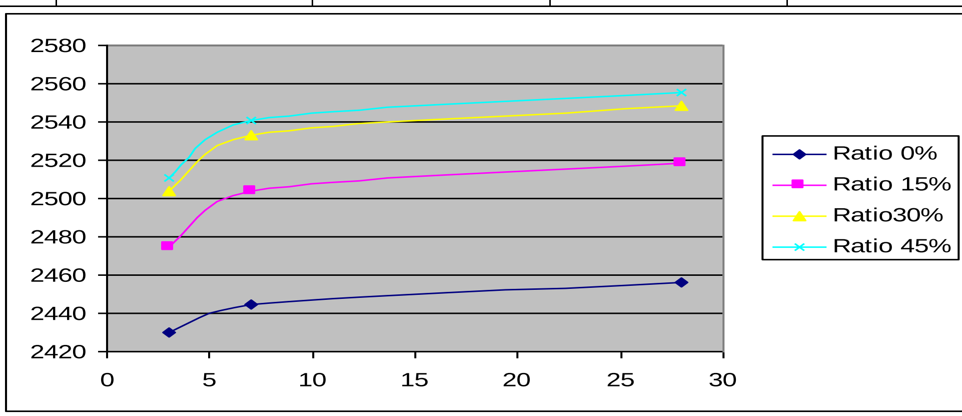

Figure (2) : Relationship between density and steel slag ratio at different ages

Compressive and Tensile Strengths of Concrete

150*150*150 mm concrete cubes have been prepared and tested for compressive strength at the age of 3,7, and 28 days. The results are shown in Tables 21and 23 and also in Figure3.While, the results of tensile strength of concrete with different steel slag ratios are given in Table 22 and also in Figure 4.

Table (21) : results of compression strength for 25 MPa a concrete mixes.

Age	Ratio 0%	Ratio 15%	Ratio 30%	Ratio 45%
3	17.84	23.7	26.73	18.89
7	18.15	28.74	30.37	22.52
28	36.96	37.33	37.6	36.1

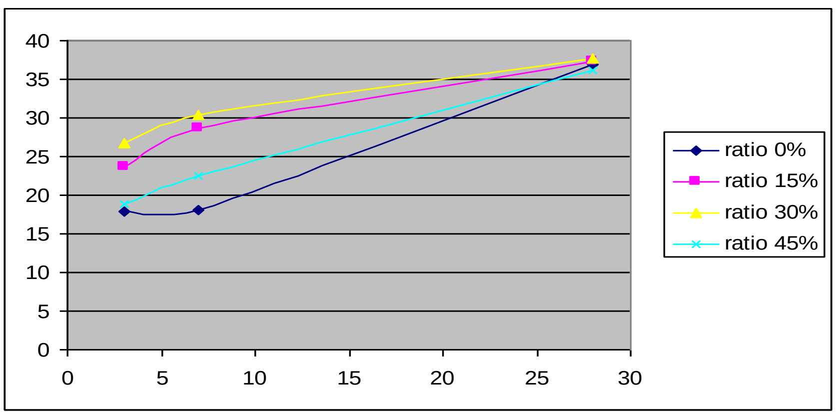

Figure (3) : Relationship between steel slag ratio and compressive strength of concrete

Table (22) : Tensile strength for 25 MPa concrete mixes.

Age	Ratio 0%	Ratio 15%	Ratio 30%	Ratio 45%
28	3.63	3.76	3.88	3.95

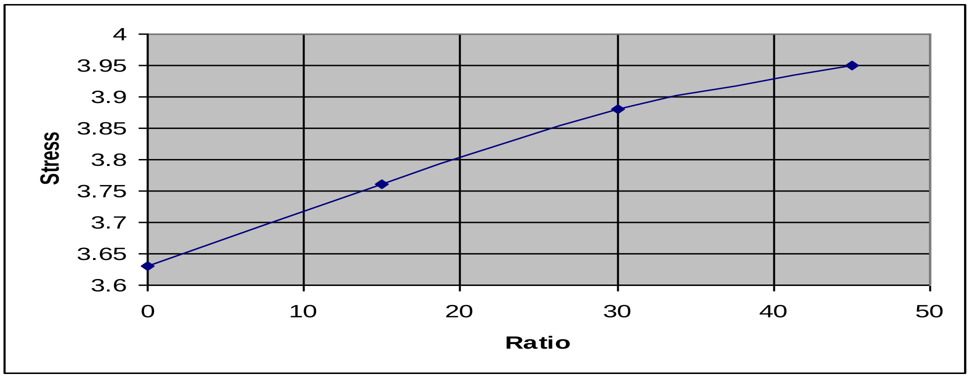

Figure (4) : Relationship between steel slag ratio and tensile strength of concrete

Table (23) : Compressive strength for different concrete mixes at ages of 3,7,and 28 days.

Slag ratio%	Compressive Strength at 3days age (MPa)	Compressive Strength at 7 days age (MPa)	Compressive Strength at 28 days age (MPa)
0	17.84	18.15	36.96
15	23.7	28.74	37.33
30	26.73	30.37	37.6
45	18.89	22.52	36.1

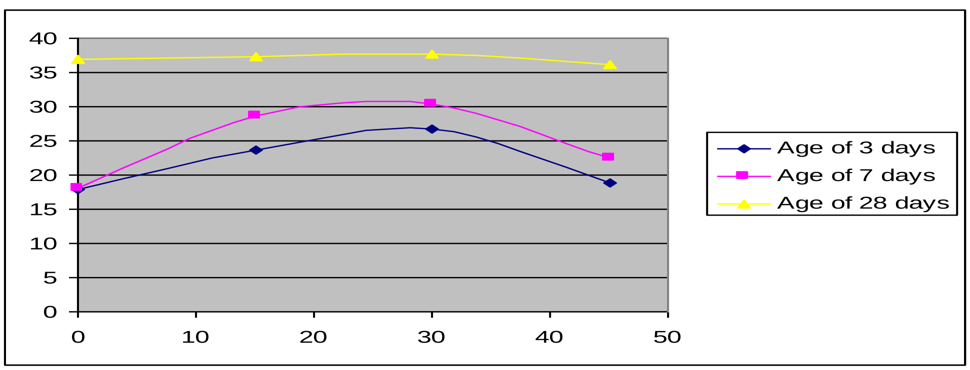

Figure (5): Relationship between steel slag ratio and compressive strength of concreteat different ages

Discussion of Result

1- The obtained results show that steel slag is not effective in workability of concrete because that steel slag decreasing the slump of concrete not more than 1-2 cm.
2- It is clear that steel slag increases the density of concrete, that refer to the nature of this material which have higher specific gravity than the materials which replace, so by

increasing the steel slag ratio the density of concrete will increases, and that is clear in the tables.

3- Also, steel slag is useful in increasing the compressive strength of concrete. However, the results for 30% ratio give good benefit, workability, compressive and tensile strength, which lead to the conclusion that the ratio for 30% is the best one with regard to other mixes. the steel slag is useful to reach the compressive strength design in short time, and that lead to saving time and costs which is the mainly important terms in construction industry.
4- Finally, the tensile strength of concrete is increased as the ratio of steel slagincreased for all strength designed, so the steel slag could be considered as a useful material to improve performance of concrete in both tensile and compressive strength.

Conclusions and Recommendations:

1- The use of steel slag obtained from local sources is beneficial for concrete. Therefore, it can be considered as a useful waste material and is recommended.
2- In all concrete mixes, steel slag has practically no effect on the workability of concrete. All mixes showed medium workability of slump 10cm.
3- Concrete strength improves when slag is added to concrete, and both compressive and tensile strength are better.
4- Density of concrete increases with the addition of slag, the higher the percentage the higher the strength.
5- Practically, the best benefit is obtained by using 30% steel slag as sand replacement.
6- Further study is recommended for various ages of concrete.
7- Study of concrete durability is recommended.

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