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The Effect of Using Iron Slag as a Replacement for Fine Aggregates for Green Concrete Mixes

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Abstract
Green concrete is defined as a concrete which uses waste material as at least one of its components, or its production process does not lead to environmental destruction. The goal of sustainability is to maintain balance among economy, environment, and society, and to ensure that today's needs are met without compromising the needs of future generations. This research studies the possibilities of using iron slag as total or partial replacement of fine aggregates to make green concrete. Compressive, tensile and flexural strength tests were conducted in by adding iron slag as replacement of sand in green concrete mixes in various percentages (10%, 20%, 40%, 60% , 80% ,100 at 7, 28 and 56 days. The results showed that the optimum percentage of Iron slag replacement is 60%.
Keywords: Green Concrete; Sustainability; Iron Slag; Flexural Strength; Compressive Strength.

1. Introduction

Recycling or reuse of industrial by-products and wastes is economically and/or ecologically very important. The use of different waste materials shows prospective application in construction industry as an alternative to conventional materials. Blast furnace slag is a non-metallic material consisting of silicates and aluminosilicates of calcium and magnesium together with other compounds of sulphur, iron, manganese and other trace elements. Air-cooled slag, which is allowed to solidify slowly in ladles or pits, is by far the most abundant and is a rock-like material which is almost wholly crystalline. Many researchers concluded that using iron slag as a replacement for fine aggregates for green concrete mixes could be effective. It was observed an increase in strength than normal concrete at all curing periods of 3 days, 7 days, 14 days, 28 days and 56 days was observed.

It is well known that the extraction of Steel from iron ore by quenching and smelting process results in 35 to 40% of slag as a by-product which is cost effective and eco-friendly (Karanji D. (2018)).

Nataraj et al, (2015) replaced river sand by slag sand at various replacements of 0%, 25%, 50%, 75% and 100% in the production of mortar of 1:3 proportions for various water cement ratio of 0.4%, 0.5% and 0.6%.

They found that the higher strength than control concrete is achieved at 70% of replacement of river sand by slag sand beyond which a reduction in strength is observed.

Rafat Siddique, et.al, (2016) The environment problems are very common in India due to generation of industrial by-products. Due to industrialization enormous by-products are produced and to utilize these by-products is the main challenge faced in India. Iron slag is one of the industrial by-product from the iron and steel making industries. In this paper, the compressive strength of the iron slag concrete was studied. The results confirm that the use of iron slag overcome the pollution problems in the environment. The results shows that the iron slag added to the concrete had greater strength than the plain concrete.

Ramesh et al. (2013) in this investigation entitled use of furnace slag (FS) and welding slag (WS) as a replacement of fine aggregates in concrete. The aim of this study is to examine the behaviour of the WSA in HPC. For mixtures containing WS, the 7 d compressive strength of concrete cubes increased from 10 to 15% and 28 d compressive strength increased from 5 to 15%. It was concluded that 5% of WS and 10% FS replacement with fine aggregates is effective for practical purpose.

2. Material

Various materials were used in the present experimental program; natural fine aggregates (NFA), coarse aggregates, cement, crushed bricks (CB), and crushed recycled concrete.

Cement: ASTM Type I normal Portland cement was used with a specific gravity of 3.16 and a specific surface area (Blaine fineness) of 374 m^2/kg.

Natural Fine Aggregates: Natural siliceous river sand (NS) with a fineness modulus of 2.7, a saturated surface dry specific gravity of 2.6 and absorption of 2.0 percent.

Coarse Aggregates: Crushed dolomite (CD) with specific gravity of 2.7 and absorption of 1.8% was incorporated in the concrete mixtures.

Iron Slag: The iron slag is a waste/by-product which remains after iron ore smelting process. When the blast furnace is operating at a temperature more than 15000C, the molten slag is obtained from the bottom of the furnace, which is later cooled by a jet of water and quenched. As the ore materials are heated above 15000C, at this temperature the slag constituents become inert. So, there will be no reactive silica or alkali in the granular iron slag. The Fineness of Slag is 3.83, density is 1595(kg/m3), water absorption % is 0.95, and Specific gravity is 2.66. Table 1 shows the chemical composition of Iron Slag and Table 2 shows its physical properties.

Table 1: Chemical Composition of Iron Slag

Particulars	Proportions
SiO2	28.23%
Al_2O_3	3.25%
Fe_2O_3	62.45%
MnO	1.13%
MgO	1.83%
P_2O_5	1.45%
SO_3	0.89%

Table 2: Physical Properties of Iron Slag

Particulars	Proportions
Fineness	3.83
Density (Kg/m^3)	1595
Water absorption %	0.95%
Specific Gravity	2.66

Figure 1. Patches of iron slag for mixing

The physical properties tests of the aggregates were conducted according to ASTM standards and their results are shown in Table 1.

Table 3: Physical properties of aggregates

Properties		Volume Weight (t/m^3)	Specific Gravity	Void Ratio %	% Absorption	Fineness modulus
Fine aggregate	**NS**	1.73	2.6	33.46	2	2.7
Coarse aggregate	**CD**	1.6	2.7	40.6	1.8	6.2

Water: ordinary tap water was used in the present research.

3. Methods

3.1 Mix Design and Preparation

The mix design was done in accordance with ACI standards using the absolute volume method. The W/C ratio was kept constant at 0.45 for all mixes. Seven concrete mixes were used in the current research The replacement ratios of 0% (control mix) ,10%, 20%, and 40%, 60%, 80 %, and 100% by weight of either fine aggregate were used. Table 4 shows the details of the mix for each of the seven mixes.

Table 4: Composition of the concrete mixes / M^3

Mix Designation	NS Kg/M^3	CD Kg/M^3	Cement Kg/M^3	W/C Ratio	Water Kg/M^3	Iron Slag Kg/M3
(M_c)	624	1248	400	0.45	180	0
$M_{(10\%)}$	561.5	1248	400	0.45	180	62.5
$M_{(20\%)}$	499	1248	400	0.45	180	125
$M_{(40\%)}$	374	1248	400	0.45	180	250
$M_{(60\%)}$	249	1248	400	0.45	180	375
$M_{(80\%)}$	124	1248	400	0.45	180	500
$M_{(100\%)}$	0	1248	400	0.45	180	624

3.2 Experimental Program

Th experimental program of the present research consisted of testing Eight concrete mixes with different percentages of replacement materials namely: 0% (control mix), 10%, 50%, and 100%. A total of 168 specimens were cast and tested for compressive, splitting tensile as well as, flexural strength.

3.3 Test Specimens

Cubes of dimensions 100 mm were used to determine the compressive strength, cylinders of dimensions 100 x 200 mm were used to determine indirect tensile strength (splitting test), and beams of dimensions 100x100 x500 mm were used to determine the flexural strength. The concrete mechanical properties were determined at 7, 28, ad 56 days after cast of the test specimens. Figure 1. Shows the test specimen during casting.

The specimens were de-molded 24 hours after the casting, and then were cured in water for 7, 28 or 56 days till the time of testing. Three samples were cast for every single test parameter and the average of obtained test results has been recorded. A total of 147 test specimens were casted and tested in the present research. Figure 1. Shows the test specimen during casting.

Figure 2. Shapes of test molds: cubes, cylinders, and beams.

4. Results and Discussion

4.1 Compressive Strength Tests Results

The standard cubic specimens were tested at the ages of 7-day and 28-day, three replicates of each specimen configuration were tested to obtain more reliable results based on the average of three results.

For the cubes where fine aggregate is replaced with a percentage of iron slag, the results of compressive strength of concrete cubes after 7, 28 and 56 days summarized in Table 11 and Figure 36.

Table 5. Results of compressive strength of concrete cubes after 7 days and 28 days

Iron Slag %	7 Days	28 Days	56 Days
	Average Compressive Strength (N/mm²)	**Average Compressive Strength (N/mm²)**	**Average Compressive Strength (N/mm²)**
0	31	25	42
10%	20.5	20	23.50
20%	27	22.50	33
40%	13.50	18	29.50
60%	21	30.50	38
80%	19	16.50	37
100%	8.50	23.50	30

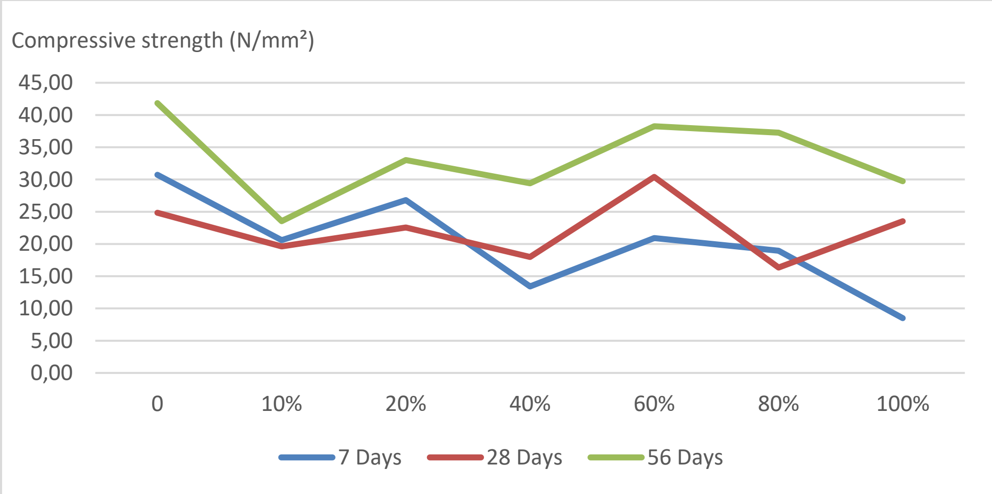

Figure 3.1 Results of compressive strength of concrete cubes after 7, 28 and 56 days.

It is observed that when fine aggregate is replaced by 20% with iron slag, the compressive strength at 7 days is found to be the highest on average. However, it is evident that overall highest strength is at 56 days with 60% of fine aggregate replaced with iron slag.

4.2 Splitting tensile strength test results

The splitting tension test was carried out on cylindrical specimens to get a bit of information about the effect of iron slag on the tensile strength of concrete in order to check whether it will improve its resistance to tension forces or not. The results of splitting tensile strength of concrete cylinders after 7 ,28 and 56 days summarized in Table 12 and Figure 37.

Table 6. Results of splitting tensile strength of concrete cylinders after 7, 28 and 56 days.

Iron Slag %	7 Days	28 Days	56 Days
	Average Splitting Tensile Strength (N/mm²)	Average Splitting Tensile Strength (N/mm²)	Average Splitting Tensile Strength (N/mm²)
0		30	39
10%	23.5	20	38
20%	20	26.50	30
40%	19	29	31
60%	19	25.50	40.50
80%	14	32	33
100%	15	41.50	33

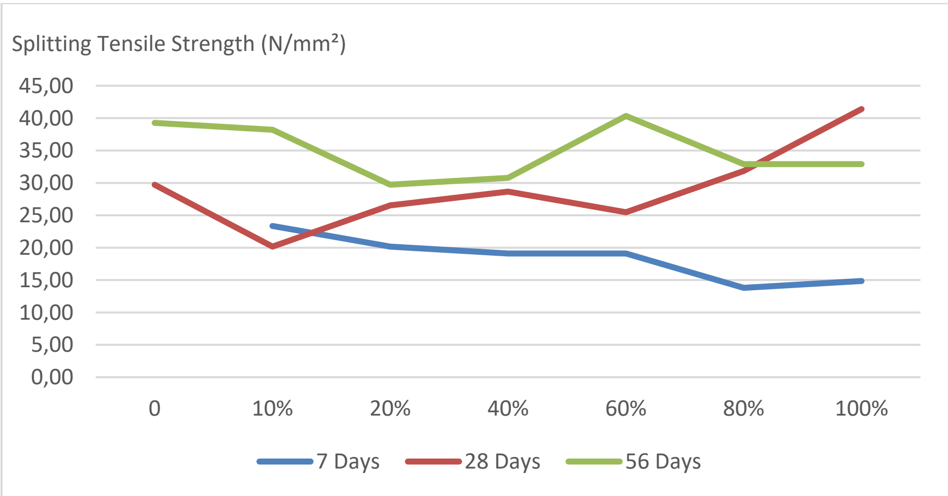

Figure 4. Results of splitting tensile strength of concrete cylinders after 7, 28 and 56 days

It was observed that when fine aggregate is replaced by 60% iron slag, the tensile splitting strength at 56 days is found to be the greatest and that any further replacement would, on average, reduce the tensile splitting strength at both 7 and 28 days.

4.3 Flexural strength test results

For the flexure test, the specimens used were prisms with dimensions of 100*100*500 mm in accordance with the code specifications. Table 13 shows the results obtained from flexure test. While figure 38 shows a comparison for the average values of flexural strength of specimens with different percentages of brick-fine aggregate replacements.

Table 7. Results of flexural strength of concrete Prisms after 28 and 56 days

Iron Slag %	28 Days		56 Days	
	Average load (KN)	Flexural Strength (N/mm²)	Average load (KN)	Flexural Strength (N/mm²)
0%	17	13	20	15
10%	14	11	17	12.5
20%	16	12	18	13.5
40%	15	11.5	15.5	11.5
60%	17.5	13	19	14
80%	20	15	22	16.5
100%	19.5	14.5	19	14.5

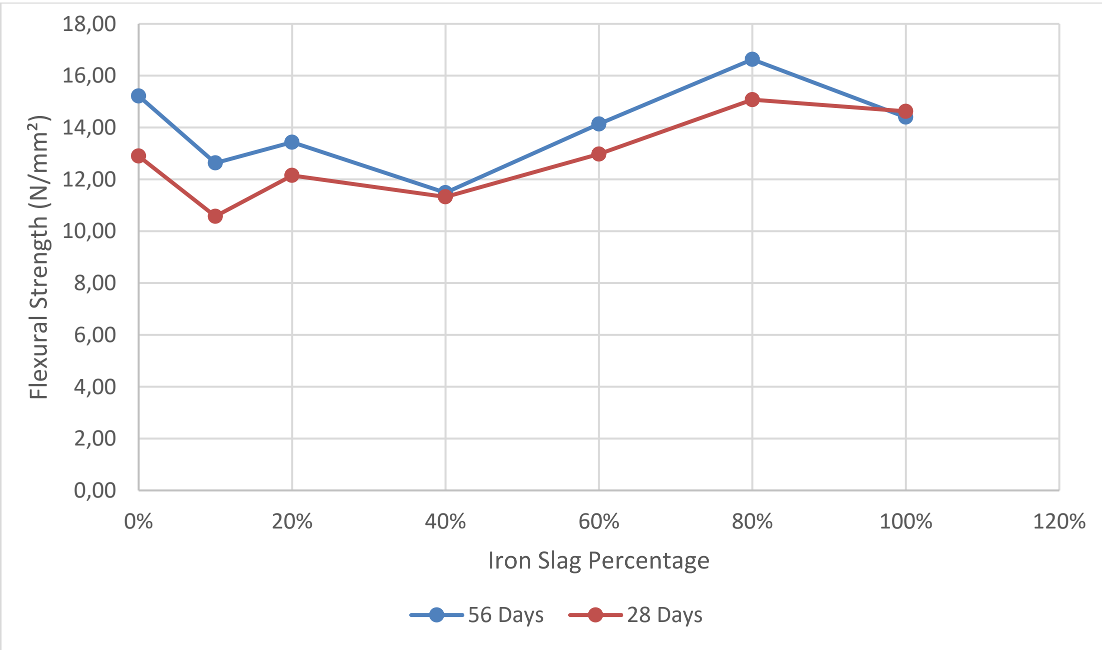

Figure 5. Results of flexural strength of concrete Prisms after 28 and 56 days.

5. Conclusions

The possibility of using wastes such as iron slag as a partial replacement for fine aggregates in green concrete mixes was investigated. The research consisted of testing concrete mixes with different iron slag percentages as partial replacement of fine aggregates. The replacement ratios used were 10%, 20%, 40%, 60%, 80% and 100%. The specimens were tested into three different types of tests, compression test, split tension test and flexure test. Based on the results of the current research the following conclusions could be drawn:

- Wastes such as iron slag can be used as a partial replacement of fine and coarse aggregates in concrete as there was an overall improvement in compressive, tensile and flexural strengths.

- There is an optimum percentage of replacement that gives the highest effect when substituting fine aggregate with iron slag which was found to be 60 % in concrete.
- At this optimum ratio (60% replacement ratio of fine aggregate with iron slag) the percentage increase in compressive strength was 23% and the percentage increase in indirect tensile strength was 28%.

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Conflict of Interests
The author declares no conflict of interest.

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