Effect of Replacement of Natural Sand by Iron Slag on Fresh and Hardened Concrete

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Abstract-Due to growing environmental awareness, as well as stricter regulations on managing industrial waste, the world is increasingly turning to use it as secondary raw material in other industrial branches. Iron slag is still considered as industrial waste in most countries in the world but by its physical and chemical properties and data on its use as valuable material for different purposes, it is definitely not a waste. Considering the specificity of physical and chemical properties of metallurgical slag and a series of possibilities for their use in other industrial branches and in the field of civil constructions

These days, due to depletion of natural aggregates and continuous use in concrete construction works, iron slag, creating environment problems, has to be used. Also, we have to conserve the natural aggregates for future generation. On the other hand, enormous byproducts are produced due to industrialization and its disposing off is the main challenge being faced in India. Therefore, it is a challenging task for scientific/engineering fraternity to utilize these byproducts economically and effectively.

This experimental study demonstrates the possibilities of using iron slag as partial replacement of sand in concrete. To date, these types of slag have been widely used in cement and as aggregate for civil works. The study presents an investigation of physical and durability properties of concrete by adding iron slag as replacement of sand in various percentages. The results show that the strength properties of concrete can be significantly achieved when sand is partially replaced by iron slag up to fifty percent. Beyond fifty percent, there is a reduction in strength gain than target strength.

Key words: River sand, Iron slag, mix design, replacement of slag, compressive strength

I. INTRODUCTION

Iron slag is a by-product obtained in the manufacture of pig iron in the blast furnace and is produced by the blend of down-to-earth constituents of iron ore with limestone flux. Mostly, the slag consists of magnesium, aluminium silicates, calcium and manganese in various arrangements. Even though the chemical compositions of slag are same but the physical properties of the slags vary with the varying method of cooling. The slags can be used as cement major constituents as they have greater pozzolanic properties. As slag is an industrial by- product, its productive use grant an chance to relocate utilization of limited natural resources on a large scale.

In the recent past, the application of steel slag was not noticeable because enormous volumes of blast furnace slag were available and creating disposal problem day by day. The use of slags became a common practice in Europe at the turn of the 19th century, where the incentive to make all possible use of industrial by-products was strong and lack of storage space for by-products. Shortly after, many markets for slags opened in Europe, the United States, and elsewhere in the World.

The American Society of Testing and Materials (ASTM) (1999) define blast furnace slag as “the non-metallic product consisting essentially of calcium silicates and other bases that is developed in a molten condition at the same time with iron in a blast furnace”.

Through awareness of environmental considerations and more recently the concept of sustainable development, extensive research and development has transformed slag into modern industrial product which is effective and beneficial.

II. MATERIALS AND METHODAOLGY

In order to achieve the objectives of present study, an experimental program was planned to investigate the effect of iron slag on compressive strength, workability and density of concrete.

The properties of concrete mostly depend on the properties of its ingredients used for making concrete mixture. The locally available materials were used in this study. Other materials used in present study were cement, coarse aggregates, fine aggregates, iron slag and admixtures. The stocks of materials were preserved to get the uniform results throughout the investigation process. The properties of materials were determined in laboratory as per relevant codes of practice.

2.1 Portland Cement

Generally, use of high grade cement offers many advantages for making stronger concrete. Although it is little costlier than low grade cement, it offers 10-20% saving in cement consumption and also, it offers many hidden benefits. One of the most important benefits is the faster rate of strength development. Ordinary Portland Cement (OPC) of 43 Grade from a single lot was used throughout the course of the investigation. Utmost care has been taken to keep the cement free from moisture and any damage. The physical and chemical properties of the cement as determined from various tests conforming to IS: 269-2015 & IS: 8112: 2013 are presented in Table I.

Table I: Physical and Chemical Properties of Cement

Sl. No.	Test Conducted	Results	Requirement as per IS: 269-2015 & IS:8112-2013
Physical Properties			
1.	Normal Consistency (%)	32.0	Not Specified
2.	Specific Gravity	3.13	Not Specified
3.	Soundness (by Lechatlier) (in mm)	4.0	Expansion shall not be more than 10 mm
4.	Initial setting time (in minutes)	105	Shall not be less than 30 min.
5.	Final setting time (in minutes)	239	Shall not be more than 600 min.
6.	Compressive Strength (Average of three results)		
	3 days (in MPa)	28.96	Shall not be less than 23.0 MPa
	7 days (in MPa)	37.20	Shall not be less than 33.0 MPa
	28 days (in MPa)	46.91	Shall not be less than 43.0 MPa
Chemical Properties			
1.	Loss on Ignition, % by Wt.	2.52	5 % Max.
2.	Silica (as SiO_2), % by Wt.	15.95	-
3	Insoluble Residue (as IR), % by Wt.	3.79	4 % Max.
4	Iron Oxide (as Fe_2O_3), % by Wt.	3.47	-
5	Aluminum Oxide (as Al_2O_3), % by Wt.	8.73	-
6	Calcium Oxide (as CaO), % by Wt.	60.09	-
7	Magnesium Oxide (as MgO), % by Wt.	1.42	6 % Max.
8	Total Sulphur content calculated as Sulphuric anhydride (as SO_3), % by wt.	3.06	3.5 % Max.
9	Na (Na_2O), % by Wt.	0.13	For reactive aggregate, the use of cement with total alkali content below 0.6% expressed as equivalent Sodium Oxide is recommended.
10	K (Na_2O), % by Wt.	0.59	
11	Total Alkalies (Na_2O)	0.72	
12	Ratio of percentage of lime to percentage of Silica, alumina and iron oxide, when calculated by formula: $\frac{CaO-0.7SO_3}{2.8\ SiO_2+1.2\ Al_2O_3+0.65\ Fe_2O_3}$	1.01	0.66 < value < 1.02
13	Ratio of percentage of Alumina to that of Iron Oxide	2.52	Not less than 0.66
14	Tri Calcium Aluminate $C3A=2.65(Al_2O_3)-1.69(Fe_2O_3)$	17.27	

2.2 Aggregates

The aggregates provide about 75% of the concrete and hence its influence is extremely important. It should, therefore, meet certain requirements, if the concrete is to be workable, strong, durable and economical. The aggregates must be of proper shape, clean, hard, strong and well graded.

2.2.1 Coarse Aggregates

The aggregate which is retained over IS Sieve 4.75 mm is termed as coarse aggregate. The crushed quartzite aggregates having maximum size of 20 mm was used in this study. The physical properties of coarse aggregates were conforming to IS: 383-2016. The alkali silica reactivity was tested by accelerated mortar bar method in 1N NaOH solution at 80° C as per ASTM C 1260. The test results are presented in Table-2 and graphical representation of alkali silica reactivity test is presented in Figure-1.

Table 2: Test Results of Coarse Aggregates

Sl. No.	Details of Test	Test Values	Limits as per IS: 383-2016
1	Specific gravity	2.67	No specified limit
2	Water absorption, (%)	0.38	No specified limit
3	Aggregate impact value, (%)	15.8	≤30% for wearing & ≤ 45% for non-wearing surfaces.
4	Aggregate crushing value, (%)	20.0	
5	Aggregate abrasion value, (%)	28.3	≤30% for wearing & ≤ 50% for non-wearing surfaces
6	Soundness loss,(%) (in $Na_2\ SO_4$ solution)	3.19	≤12 % when tested with Sodium Sulphate solution

7	Flakiness Index	12.05	Flakiness & Elongation Index shall not exceed 40%
8	Elongation Index	20.59	
9	Alkali Silica Reactivity, Maximum Expansion Observed	0.052	As per ASTM C 1260, Expansion of less than 0.10% at 16 days after casting is indicative of innocuous behavior.

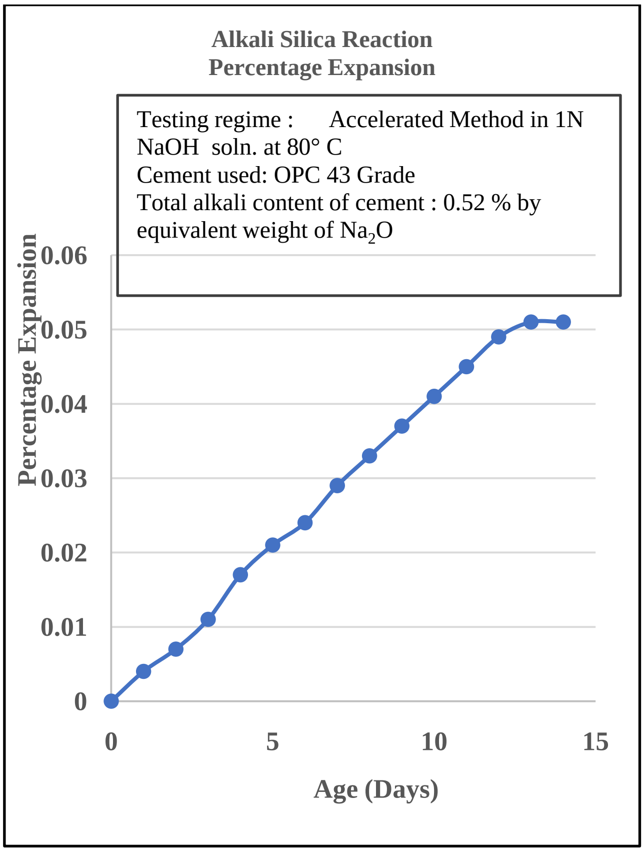

Figure-1: Alkali Silica Reactivity Test on Coarse Aggregates

2.2.2 Fine Aggregates

The most important function of the fine aggregate is to assist in producing workability and uniformity in mixture. The fine aggregate assists the cement paste to hold the coarse aggregate particles in suspension.

In this experimental program, fine aggregate was locally procured and it was coarse sand light brown in color. The physical properties and sieve analysis of fine aggregate are conforming to IS: 383-2016. The sand was conforming to grading zone I as per IS:383-2016. The physical properties of sand are presented in Table-3 and the graphical representation of sieve analysis is presented in Figure -2.

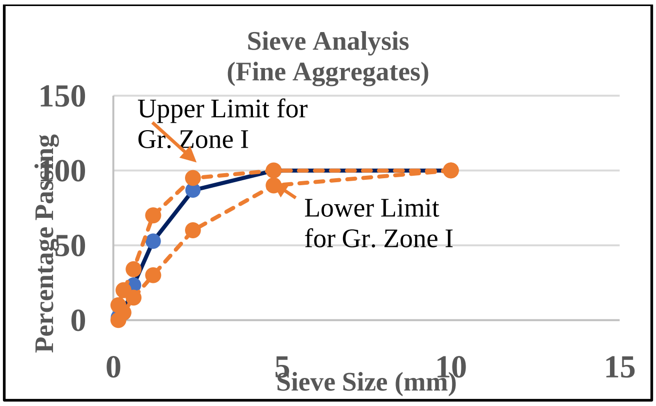

Figure -2: Sieve Analysis of Fine Aggregates

Table-3: Physical properties of Fine Aggregates

Sl. No.	Name of Test	Test Results
1.	Sieve Analysis	Falls under Grading Zone-I as per IS:383-2016
2.	FM	3.30
3.	Specific Gravity	2.68
4.	Water Absorption %	0.5
5.	Soundness Loss (5 Cycles in Sodium Sulphate Solution)	2.9
6.	Silt & Clay %	0.35
7.	Organic Impurities	Passes in colour test

2.3 Iron Slag

In this experimental program, the Iron Slag is taken from a private steel company. It is gray in color. The physical properties and sieve analysis of iron slag were conforming to IS: 383-2016. The chemical properties of iron slag were tested as per IS 4032:1985, Method of chemical analysis of hydraulic cement. The physical properties of iron slag are presented Table-4 and the graphical representation of sieve analysis is presented in Figure -3.

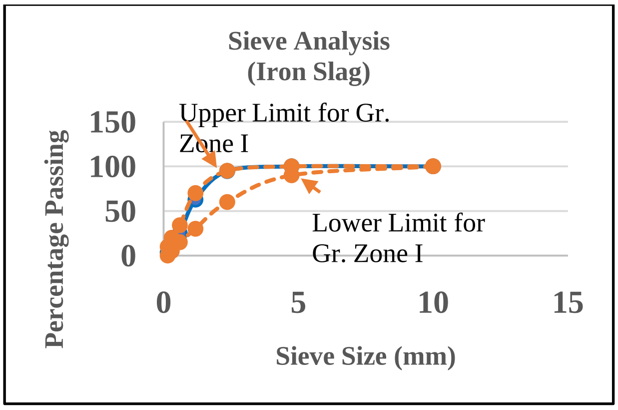

Figure -3: Sieve Analysis of Iron Slag

Table 4: Physical and Chemical analysis of Iron slag sample

Sl. No.	Sample Parameter	Test Results
Physical Properties		
1.	Sieve Analysis	Falls under Grading Zone-I as per IS:383-2016
2.	Fineness Modulus	3.05
3.	Specific Gravity	2.47
Chemical Properties		
1.	Silica (as SiO_2), % by wt.	18.22
2.	Al (as $Al_2O_{3)}$, % by wt.	3.10
3.	Fe as Fe_2O_3, % by wt.	20.85
4.	Calcium Oxide (as CaO), % by wt.	40.46
5.	Magnesium oxide (as MgO), % by wt.	9.52
6.	Sulphuric anhydride (as $SO_{3)}$, % by wt.	0.79

2.4 Admixture

The chemical admixture is generally used in concrete to reduce the water content and achieve the desired workability. In this experiment, water reducing admixture has been used. The dosages of admixture were fixed from 0.5 to 0.66 to achieve the designed workability. The admixture sample was tested for complete uniformity requirement in accordance with IS: 9103-1999 (Amendment 2007). The test results are presented in Table-5.

Table-5: Test results of water reducing admixture

Sl. No.	Parameters	Test Results	Limit as per IS: 9103-1999 (Amendment 2007)	Manufactures Data
1	Colour	Light Amber		Light Amber Liquid
2	pH	6.73	Min. 6	6.42
3	% Dry Material content	44.36	0.95 T≤ DMC<1.05T Where, T=Manufactures stated value, % by mass DMC= Test Result, % by mass	43.35
4	% Ash content	19.01	0.95T ≤ AC< 1.05T Where, T= Manufactures stated value, % by mass AC= Test results, % by mass	-
5	% Chloride	0.024	Within 10% of the value or within 0.2 % whichever is greater as stated by the manufacturer	0.0018
Remarks: The manufacturers data in respect of ash content of the above sample is not given, therefore, conformity remark for uniformity tests & requirements as per IS: 9103-1999 (Amendment 2007) cannot be given.				

2.5 Water

Generally, water suitable for drinking, is satisfactory for use in concrete. When water is obtained from above source, no sampling is necessary. When it is suspected that water may contain sewage, mine water, or wastes from industrial plants or canneries, it should not be used in concrete unless tests indicate that it is satisfactory. The potable water is generally considered satisfactory for mixing and curing of concrete as per IS: 456-2000. Accordingly potable water was used for making concrete in this experiment.

III. EXPERIMENTAL STUDIES

The properties of concrete were evaluated in two stages, fresh concrete and hardened concrete. The durability of concrete depends upon the mix design and quality of aggregates. The water-cement ratio and addition of admixtures greatly affect the durability of concrete.

In this study M25A20 grade of concrete has been taken. The mix design was carried out as per procedure given in IS:10262-2009. The mixes were designed for workability of 100±25mm, moderate exposure condition and good degree of supervision. The target strength for M25 grade of concrete considering the other conditions has been calculated as 31.6 MPa.

3.1 Fresh Concrete Properties

Fresh concrete properties include slump, unit weight and air content test. The slump of the concrete was tested as per IS:1199-1959. The slump test is used to ensure the uniformity between the different concrete batches for a given job (Mindess et al. 2003). The unit weight test is a more reliable test and provides more valuable information than the slump test. The unit weight of the mixture was also tested according to IS:1199-1959.

3.2 Hardened Concrete Properties

To determine the properties of hardened concrete, the Compression test was conducted as per IS: 516-1959. Concrete is much stronger in compression than in tension and so the compressive strength of concrete is an important property of the concrete (Mindess et al. 2003).

3.3 Mixture Proportioning

The four types of mixture were prepared in this investigation. One reference/controlled mix and three mixtures with the iron slag replacing 30%, 50 % and 60 % of fine aggregates. The reference concrete mixture composed of cement (357 kg/m^3), fine aggregate (836.90 kg/m^3), coarse aggregates (1041.30 kg/m^3) and water to cement ratio is 0.46. The other concrete mixtures were prepared with the iron slag replacing 30%, 50 % and 60 % of fine aggregates with the same amount of cement, coarse aggregates and water cement ratio. The water reducing admixture from the dosages of 0.5 to 0.66% of cement to achieve the designed workability (slump) of 100±25mm was used. The curing period of all the concrete mixes was 7, 28, 90 and 180 days.

3.4 Test Procedure and Discussion of Results

Test specimens of size 150 × 150 × 150 mm were prepared for testing the compressive strength concrete. The concrete mixes with varying percentages (0%, 30%, 50 % and 60 %) of iron slag as partial replacement of fine aggregate (sand) were cast into cubes for testing. In this study, to make concrete, cement and fine aggregate were first mixed dry to uniform colour and then coarse aggregate was added and mixed with the mixture of cement and fine aggregates. Water was then added and the whole mass mixed. The interior surface of the moulds and the base plate were oiled before concrete was placed. After 24 hours the specimens were removed from the moulds and placed in clean fresh water at a temperature of 27^0 ± 2^{0}C. The specimens so cast were tested after 7, 28, 90 and 180 days of curing measured from the time water is added to the dry mix. The specimens were placed in the platens of compression testing machine. The load was applied axially without shock till the specimen was crushed. The cube strength results of concrete mix are presented graphically in Figure-4 with graphical representation of percent change in compressive strength compared to controlled mix is presented in Figure -5.

The compressive strength decreases as compared to control mix as the percentage of iron slag was increased. Compressive strength decreases from 6 to 15% after 7days, 5 to 15% after 28 days, 4 to 16% after 90 days and 7 to 20% after 180 days as the sand replacement increases from 30 to 60% with iron slag.

However, comparing with the required target strength (TS), the 180 days compressive strength (CS) in case of controlled mix is 44% more than TS, in case of 30% replacement CS is 34% more than TS, in case of 50% replacement CS is 19% more than TS and in case of 60% replacement CS is 4% less than TS.

The unit weight of the mixture was tested as per IS: 1199-1959 and found that there was minimum decrease in unit weight (up to 2.5 to 3%) when sand replacement increased from 0 to 60% with iron slag.

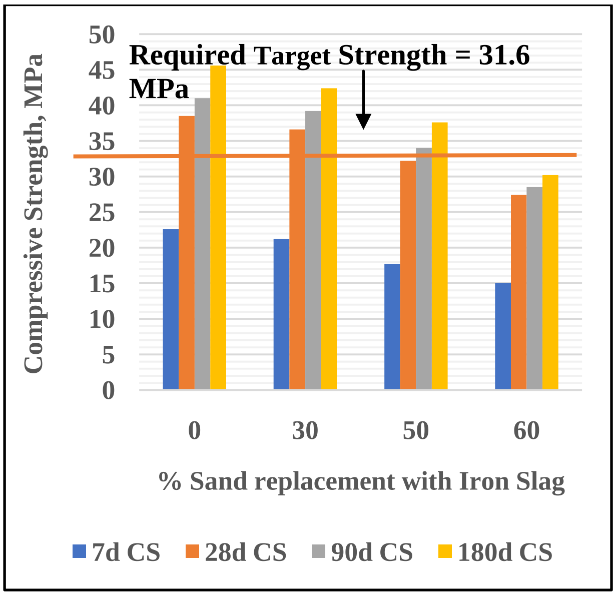

Figure- 4: Compressive Strength of Concrete with varying % of Iron Slag

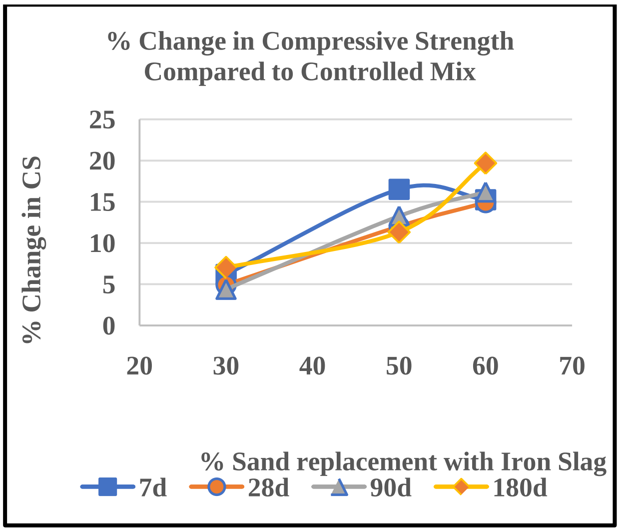

Figure- 5: Percent Change in Compressive Strength compared to Controlled Mix

IV. CONCLUSIONS

The strength characteristics of concrete mixtures has been computed in the present work by replacing 30%, 50 % and 60 % iron slag with the sand. On the basis of recent testing, subsequent conclusions were drawn.

The compressive strength decreases as compared to control mix as the percentage of iron slag was increased. The literature shows that in replacement of any concrete making material, the later age strength is more reliable than early age strength. Therefore, in this study, the conclusions were drawn based on 180 days strength.

Compressive strength decreases from 7 to 20% after 180 days as the sand replacement increases from 30 to 60% with iron slag.

Comparing with the required target strength (TS), the 180 days compressive strength (CS) in case of controlled mix is 44% more than TS, in case of 30% replacement CS is 34% more than TS, in case of 50% replacement CS is 19% more than TS and in case of 60% replacement CS is 4% less than TS.

From these experimental results, it can be concluded that sand replacement up to 50% with iron slag in concrete may be used without any problem.

ACKNOWLEDGMENT

The authors extend their sincere thanks to the Director, CSMRS who has been constant source of inspiration throughout this work. The authors also extend their thanks to Mr. M. A. Ansari and Mr. Vivek Kumar Vaidh and one & all in Concrete Discipline for the timely help extended by them during experimental works. Sincere gratitude is extended to all the authors whose publications provided us directional information from time to time.

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