Experimental Investigation on Strength and Durability Properties of High Performance Concrete Replacing Coarse Aggregate by Steel Slag

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***Abstract*: The main objective of this paper is to find out alternative materials for concrete to meet the demands of coarse aggregate for the upcoming years, to provide adequate strength at minimum cost, to make the eco-friendly structures. Use of steel slag a waste industrial by-product of iron and steel production provides great opportunity to utilize it as an alternative to normally available aggregates (coarse). In this study, blast furnace steel slag is used and concrete of M60 grade for W/C ratio of 0.28 respectively for the replacement of 0 to 100% coarse aggregate by steel slag aggregate for find out the optimum ratio of steel slag. In this study, a mix ratio of 1: 1.2: 2.4 is used in conventional mix. Initial optimization of steel slag aggregate for replacing the natural coarse aggregate was find with 7and 28 days strength. Test on compressive strength and non-destructive test at 7 and 28 days were conducted. It was concluded that possible optimum replacement of slag material was found to be 40%. Split Tensile Strength and Flexural Strength and durability characteristics were carried out for conventional and optimum concrete mix to study the properties of concrete with blast furnace steel slag.**

Keywords: Aggregates, Blast furnace steel slag, Compressive strength, Nondestructive test, Split Tensile Strength, Flexural Strength and durability characteristics.

1. INTRODUCTION:

Concrete is the largest production as construction materials. The increase in demand for the ingredients of concrete is met by partial replacement of materials by the waste materials which is obtained by means of various industries. The utilization of industrial waste or secondary materials has encouraged for the production of cement and concrete in construction field. New by-products and waste materials are being generated by various industries. For many years, by-products such as fly ash, silica fume and slag such as steel slag were considered as waste materials. Concrete prepared with such materials showed improvement in workability, strength and durability compared to normal concrete and has been used in the all type of construction. Nowadays, intensive research studies have been carried out to explore all possible reuse methods. Construction waste, electric arc steel slag, GGBS steel slag, coal fly ash and granite, marble powder have been accepted in many places as alternative aggregates in embankment, roads, pavements, foundation and building construction.

This study represents about the experimental investigation of the possibility of using steel slag in various percentage as coarse aggregate substitute in cement concrete. The attempt has made to investigate the characteristic of steel slag concrete for various parameters like compressive strength, quality of concrete and load carrying capacity. For thousands of years sand and gravel have been used in construction of roads and building. Today, demand for sand and gravel continues to increase in construction industries. Excessive in stream sand-and-gravel mining causes the degradation of sub surface and surface flow of rivers. In stream mining lowers the stream bottom, which may lead to bank erosion and the reduction of sub surface water.

Scarcity of good quality gravel due to depletion of resources and restriction due to environmental consideration has made concrete manufactures to look for suitable alternative coarse aggregate. One such alternative is “replacement of coarse aggregate by Steel slag aggregate”. Steel slag is unavoidable by-product in iron and steel making it is essentially a mixture of metal oxide and silicates. However iron and steel slag is non-metallic in nature and does not contain inorganic materials. Slag is an alternative coarse aggregate with superior environment friendly qualities and better product features.

2. EXPERIMENTAL INVESTIGATION:

2.1. Material Used

The following materials are used for producing the high strength concrete.

2.1.1 Water

Water is needed for the purpose of hydration of cement and to provide workability during mixing and placing of concrete. For this study portable water pH value 7 and conforming to the specifications of IS 456-2000 is used for concreting as well as curing of the specimen

2.1.2. Cement

Cement is a binder, a substance that sets and hardens as the cement dries and also reacts with carbon dioxide in the air dependently, and can bind other material together. In experiment ordinary Portland cement of 53 grade concrete used.

2.1.3. Fine aggregate

The fine aggregates serve the purpose of filling all the open spaces in between the coarse particles. Thus it reduces the porosity of the final mass and considerably increases its strength. Usually Natural river sand is used as a fine aggregate. The sand confirmed to grading zone II of IS 383-1970.

2.1.4. Coarse Aggregate

Optimum size of the coarse aggregate in most situations was about 20mm size was adopted. They generally possess all the essential qualities of a good building stone showing very high crushing strength, low absorption value and least porosity.

2.1.5. Blast Furnace Steel Slag

In this study blast furnace steel slag is used which is collected from JSW SISCOL plant, mecheri, Salem.

2.1.6. Super- Plasticizer

In this study conplast (430) is used. It is used to increase the workability of the concrete. The specific gravity of CONPLAST is 1.21.

Table 2.1: Properties of cement

S.No	Description	Values
1	Specific gravity	3.15
2	Fineness (by sieve analysis)	4.60%
3	Consistency	29%
4	Initial setting time	30 minutes

Table 2.2: Properties of coarse aggregate

S.No	Description	Values
1	Specific gravity	2.75
2	Bulk Density	1765.0 kg/m³
3	Water absorption	0.5%
4	Fineness modulus	6.45
5	Impact Value	13.33%
6	Cushing Value	17.3%
7	Abrasion Value	26.5

Table 2.3: Properties of Fine Aggregate

S.No	Description	Values
1	Specific gravity	2.64
2	Fineness modulus	2.76
3	Water absorption	1%
4	Bulk Density	1668.0 kg/m³

Table 2.4: Properties of Steel Slag

S.No	Description	Values
1	Specific gravity	2.93
2	Bulk Density	1682.0 kg/m³
3	Impact Value	14.5%
4	Cushing Value	23.3%

Table 2.1 shows the properties of cement are within the allowable limits. From Table 2.2 it was observed that the properties of coarse aggregate values satisfy the standards. Table 2.3 gives the properties of natural river sand. Table 2.4 is the properties of steel slag which has similar value of coarse aggregate. Super plasticizer is used in concrete mix to improve the workability of concrete.

3. CONCRETE MIX DETAILS

Two sets of mixes are prepared for M_{60} grade concrete. First Mix is ordinary conventional concrete. Second mix replacing steel slag for coarse aggregate. For each trial 3 cubes were cast, in which 3 cubes for testing the compressive strength at 7 and 28 days.

Table 3.1: Mix Ratio

Cement	Fine aggregate	coarse aggregate	water	Super plasticizer
1	1.2	2.4	0.28	1%

4. TESTING DETAILS:

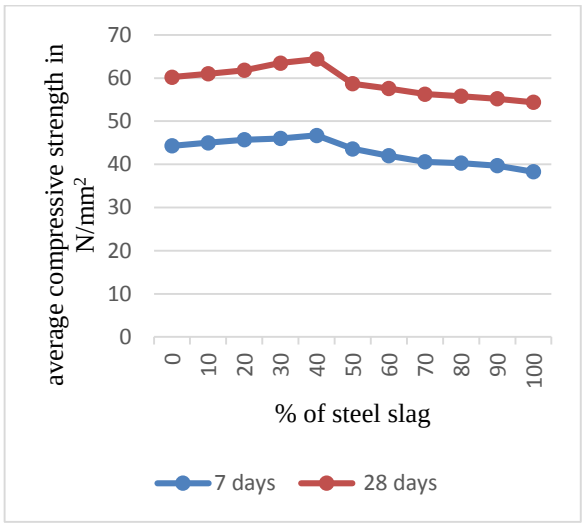
4.1. Nondestructive test

4.1.1. Rebound Hammer Test

Rebound hammer test was conducted for all the mixes for both 7 days and 28 days for M60 grade of concrete. 3 specimens were cast for each replacement of steel slag aggregate for coarse aggregate. The value for each trial increases the percentage of steel slag (0, 10%, 20….100%).

Figure 4.1.1: Rebound Hammer Test

From the following graph 4.1.1, shows the rebound hammer test results.



Graph 4.1.1: Rebound Hammer

4.1.2. Ultrasonic Pulse Velocity Test

In ultrasonic pulse velocity test, three methods are there. In this paper, direct method is used. The test was conducted for all the mixes for both 7 days and 28 days for M60 grade of concrete. Three specimens were cast for each replacement of blast furnace steel slag aggregate.

From the following table 4.1.2, the quality of concrete is determined with reference to the velocity obtained.

Table 4.1.2: Quality of concrete using UPV

Pulse velocity(km/sec)	Concrete quality (Grading)
Above 4.5	Excellent
3.5 to 4.5	Good
3 to 3.5	Medium
Below 3	Doubtful

Figure 4.1.2: Ultrasonic Pulse Velocity test

4.2. Compressive Strength Test:

To determine the compressive strength, six cubes (150mm x 150mm x 150mm) were cast for each trial mix of M60 concrete for each mix and three samples were tested after 7 days and next three samples were tested after 28 days of curing. 7 and 28 days cube compressive strength test was conducted. Compressive strength tests were carried out using 2000KN capacity compression testing machine.

Figure 4.2: Compressive Strength Test

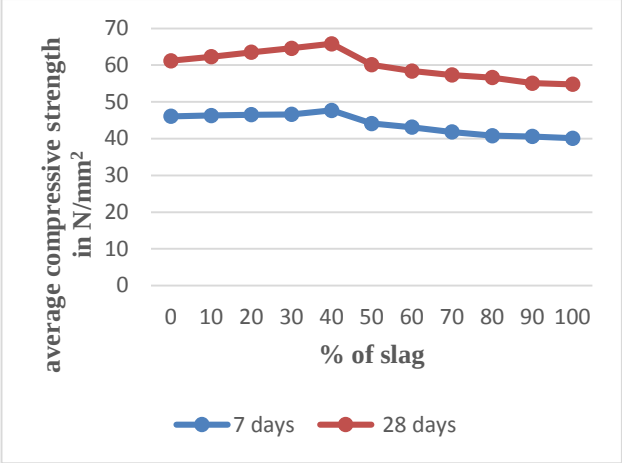


Figure 4.2.Compressive Strength test result

4.3. Split Tensile Strength Test

The test was conducted as per IS 5816:1999. For tensile strength test, cylindrical specimens of dimension 100 mm diameter and 300 mm length were cast. In each mix, three cylinders were cast and tested and their average value was taken. The split tension test was conducted by using digital compression machine having 2000 kN capacity.

Figure 4.3: Split tensile Test

Split tensile strength was calculated as follows:

Spilt Tensile strength (MPa) = $2P / \pi DL$
Where,
P = Failure Load (kN)
D = Diameter of Specimen (100 mm)
L = Length of Specimen (300 mm)

Test Results of splitting tensile strength for conventional and optimum percentage of steel slag concrete of M_{60} grade concrete as shown in table 4.3, below.

Table 4.3: Test Results of Split Tensile Strength

S.No	Mix ID	Average Split tensile strength in (Mpa)
1.	S0	5.44
2.	S40	6.97

4.4. Flexural strength test

For Flexural strength test, prism specimen of 100 mm X 100 mm X 500 mm was cast. For conventional and optimum mix, three prisms were cast and tested with two point load was applied and their average value was reported.

Figure 4.4. Flexural Strength test

A beam specimen is placed in the ultimate testing machine of 2000kN capacity for testing. The Flexural strength is calculated by using the formula,

$\sigma = P\ l / bh^2$

Where,
P = load in Newton shown in dial gauge
l = length of prism in mm i.e. 500 mm
b = breadth of prism i.e. 100 mm
h = height of prism i.e. 100 mm.

Table 4.4: Test Results of Flexural Strength

S.NO	Mix ID	Average flexural strength in (Mpa)
1.	S0	5.31
2.	S40	6.78

4.5. Water Absorption Test

To study the water absorption characteristics of steel slag aggregate concrete, 150mm x 150mm x 150mm size cubes were casted. After the curing period is completed, the specimen are immersed in the water tank and kept for 24 hours in water. The weight of the specimen is noted. The specimen is placed in an oven at 105°C temperature, and then the weight of the specimen is recorded. From these two values, the water absorbed by the entire specimen is calculated and tabulated.

Table 4.5: Water absorption test results

Mix ID	Wet weight of concrete in Kg (W_1)	Dry weight of concrete in kg (W_2)	Water absorption of the concrete (%)
S0	8.70	8.19	6.42
	8.72	8.20	6.53
	8.66	8.15	6.38
S40	8.71	8.32	4.69
	8.84	8.46	4.50
	8.78	8.41	4.40

% of Water absorption=[(W1-W2)/W2]×100

Where,

W1 = Weight of the wet specimen

W2 = Weight of the dry specimen

4.6. Chloride Attack

Chloride attack is primarily cause's corrosion of reinforcement. To test the effect of chloride on concrete, 150mm x 150mm x 150mm size conventional and steel slag aggregate concrete cubes were cast and kept at a room temperature. After 24 hours the specimens were cured in clean fresh water for 28 days. After curing the cubes were immersed in sodium chloride solution and tested for their compressive strength and there by durability were assessed.

Table 4.6: Loss of weight of specimen subjected to Chloride Attack

SI NO	Mix ID	Initial wt. in Kg	Wt. after 28days curing Kg	% of wt. loss
1	S0	8.80	8.70	1.11
		8.82	8.73	1.03
		8.90	8.81	1.02
2	S40	8.96	8.87	1.01
		8.74	8.66	0.92
		8.79	8.70	0.91

SI.NO	Mix ID	Compressive strength MPa
1	S0	**57.8**
2	S40	**62.6**

5. RESULTS & DISCUSSION:

From graph 4.2, it was noticed that the compressive strength gradually increases as the percentage of steel slag is increased up to 40% replacement. After replacement of 40% compressive strength is gradually decreased. Hence we can conclude that complete replacement of coarse aggregate with blast furnace steel slag has reduced the compressive strength in concrete.

From the UPV results, shows that the quality of concrete is come under excellent while increasing the steel slag up to 60%. While increasing the replacement of blast furnace steel slag above 60% quality of concrete is comes under good.

The compressive strength for M60 grade of concrete is shown in Graph 4.2, as above. As the curing days increases the strength also increases. This compressive strength test result also similar to the rebound hammer test.

From split tensile strength test, flexure strength test and also durability test results shows, the blast furnace steel slag aggregate concrete is better than the conventional concrete.

6. CONCLUSION:

1. In rebound hammer test, the compressive strength of the concrete was increased about 5 to 7% at 7 days curing and 7.5% is increased at 28 days curing, while replacement of 40% of steel slag compare to the conventional concrete.
2. In ultra-sonic pulse velocity test, the quality of concrete was excellent up to 60% replacement of steel slag aggregate.
3. The compressive strength of the concrete was increased about 3 to 8% at 7 days and 28 days curing, while replacement of 40% of steel slag compare to the conventional concrete.
4. From the result above 40% replacement of coarse aggregate with steel slag, the compressive strength of concrete decreases linearly.
5. Split tensile test results of cylinder at 28 days have been observed. S40 is 28.12% higher than the control mix.
6. Optimum steel slag replacement shows higher flexural strength results compare to the conventional mix at 28 days. S40 is 27.7% higher than the control mix.
7. The durability characteristics such as resistance to water penetration, resistance to chloride attacks of steel slag concrete are better than that of the controlled mix concrete
8. The chloride acid resistance of blast furnace steel slag concrete is significantly better than that of natural aggregate. Blast furnace Steel slag concrete is Eco-Friendly.

ACKNOWLEDGEMENT:

The authors express their gratitude to the staffs and friends for their work on this study.

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