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EXPERIMENTAL STUDY ON STEEL SLAG AS COARSE AGGREGATE IN CONCRETE

RA.B.DEPAA[1], Dr. T. FELIX KALA[2]

[1]Assistant Professor, Dept of Civil Engineering, Dr.MGR Educational and Research Institute University, Chennai, Tamilnadu, India
depaabalachandran@gmail.com

[2]Additional Dean (Engineering & Technology), Dr.MGR Educational and Research Institute University, Chennai, Tamilnadu, India
kalastrut@yahoo.co.in

Abstract - Steel slag is an industrial waste product from steel manufacturing industries. It is produced in large quantities during steel manufacturing operations which utilize Electric Arc Furnaces (EAF). It is also produced by smelting iron ore in the Basic Oxygen Furnaces (BOF). Steel slag can be widely used in construction industry as aggregate in concrete as natural aggregate. Natural aggregates are becoming scarce and their production is difficult. So there arises a need for alternate material as coarse aggregate. In this study, it is proposed to utilize steel slag as replacement of coarse aggregate in concrete. Concrete cube, cylinders and prisms were cast with steel slag as coarse aggregate replacement materials up to 100% and the compressive strength characteristic has been studied. Based on the compressive strength results it was concluded that the optimum replacement of coarse aggregate by steel slag is 80%.

Keywords - Steel slag aggregate, flexural strength, water absorption.

1. Introduction

Steel slag is a by-product formed during the steel manufacturing process. It is a non metallic ceramic material formed from the reaction of flux such as calcium oxide with the inorganic non-metallic components present in the steel scrap. The use of steel slag reduces the need of natural rock as constructional material, hence preserving our natural rock resources, maximum utilization and recycling of by-products and recovered waste materials for economic and environmental reasons has led to rapid development of slag utilization.

2. Experimental study

In this study, it is proposed to utilize steel slag as full replacement of coarse aggregate in the production of concrete. Concrete blocks were cast with Steel slag with 0 to 100% replacement of coarse aggregate.

3. Selection of materials

A. Cement

In this study OPC 53 grade has been used. For OPC 53 grade Cement, the following tests has been carried out as per IS 456-2000 and conforming to IS 4031 (part1): 1996 as shown in table 1.

Table 1 Physical Properties of cement

Specific gravity	3.15
Fineness of cement by dry sieving	1%

B. Steel slag

Steel slag is the by-product of steel industries, which form during reduction process of iron melting. The chemical composition changes depending on the melting procedure. Its mineralogical composition also varies based on the cooling procedure. Air cooled Steel slag contains significantly higher calcium oxide and iron oxide compared to granite rock. Granite rock contains high silica and alumina content and is generally hydrophilic. Physical, mechanical and chemical compositions are studied as given in table 1, table 2 and table 3 respectively.

Fig 1 Steel Aggregate which were retained in 10mm sieve

Table 2 Physical properties of steel slag aggregate

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

Table 3 Mechanical Properties of steel aggregate

Property	**Value**
Los Angeles Abrasion	20 – 25
Sodium Sulfate Soundness Loss	<12
Angle of Internal Friction	40° - 50°
Hardness	6 – 7

Table 4 Chemical composition given from lab

Constituent	**Composition (%)**
Aluminum oxide (Al2O3)	1-3
Calcium oxide (CaO)	40-52
Chromium oxide (Cr2O3)	-
Iron oxide (FeO)	10-14
Magnesium oxide (MgO	5-10
Manganese oxide (MnO)	5-8
Phosphorus oxide (P2O5)	0.5-1
Potassium oxide (K2O)	-
Silicon oxide (SiO2)	30-35
Sodium oxide (Na2O)	-
Titanium oxide (TiO2)	-
Water Absorption	0- 3
SSD Specific Gravity	3.2-3.6

C. Fine aggregate (Natural river sand)

River sand having density of 1460 kg/m^3 and fineness Modulus (FM) of 2.51 was used. The specific gravity was found to be 2.6

D. Coarse aggregate

Natural granite aggregate having density of $1700 kg/m^3$ and Fineness Modules (FM) of 6.80 was used. The specific gravity was found to be 2.60 and water absorption as 0.45%.

E. Water

The water used for mixing concrete should be portable drinking water having pH value of 7 and the water is free from organic matter and the solid contents should be within the permissible limits as per IS 456-2000 and conforming to IS 3025.1964.

4. Mix combinations

For the present study, eleven combinations were selected as shown in Table 5.

Table 5 Mix Combinations (Note: St- Steel slag)

S.No	Mix combination	Steel slag (%)
1	St0	0
2	St10	10
3	St20	20
4	St30	30
5	St40	40
6	St50	50
7	St60	60
8	St70	70
9	St80	80
10	St90	90
11	St100	100

5. Testing of specimens

A. Compressive strength test

Cube specimens of size 100 mm ×100 mm × 100 mm were cast for each mix proportion. After curing for required period the specimens were tested using compressive testing machine. Figure 2 shows the typical compressive testing setup.
Compressive strength is determined using the following formula
Compressive strength (MPa) = Maximum load (N) /cross sectional area (mm^2)

Fig 2 Compressive strength testing

B. Split tensile strength test

Cylindrical specimens of diameter 150 mm and length 300 mm were cast for required mix proportion. After curing for required period the specimens were tested. Fig 3 shows split tensile strength test setup. The split tensile strength is calculated using the following formula
Split tensile strength (MPa) = $2P/\pi LD$
Where,
P is the compressive load on the cylinder
L is the length of the cylinder
D is the diameter of the cylinder

Fig 3 Split tensile strength testing

Fig 4 Flexural strength testing

C. Flexural strength test

Prisms of size 100 mm x 100 mm x 500 mm were cast for required mix proportion. After curing for required period the specimens were tested. Fig 4 shows the flexural strength test setup. The modulus of rupture is calculated using the following formula

Modulus of rupture, $f_b = PL/bd^2$

Where,

f_b = modulus of rupture in MPa

P = maximum load applied on the specimen

L = length of the span on which Specimen is supported (400 mm)

b = width of the specimen

d = depth of the specimen at the point of failure

D. Water absorption test

The saturated water absorption test was performed on cube specimens of size 100 mm after 28 days of curing as per ASTM C 642-81.The specimens were dried out in a hot air oven at a temperature of 105°C. The dried specimens were cooled at room temperature, weighed accurately and noted as dry weight. Then the specimens were immersed in water. The immersed specimens were taken out at regular intervals of time, surface dried using a clean cloth and weighed. This process was continued till the weights became constant (fully saturated). The difference between the measured water saturated mass and oven dried mass expressed as a percentage of oven dry mass gives the saturated water absorption. Fig 5 shows dry and wet specimen. Water absorption is calculated using the following formula

Water absorption % = $(W_w – W_d) / W_d$ x 100

W_w = Saturation weight of the specimen (kg)

W_d = Dry weight of the specimen (kg)

Fig 5 Water absorption testing

E. Rapid chloride penetration test

The rapid chloride penetration test (RCPT) was performed as per ASTM C 1202 to determine the electrical conductance of the specimens at the age of 28 days curing and to provide a rapid indication of its resistance to the penetration of chloride ions.

$$Q = 900\ (I_0 + 2\ I_{30} + 2\ I_{60} + \ldots\ldots + 2\ I_{330} + I_{360})$$

Where

Q = charge passed (coulombs)

I_0 = current (amperes) immediately after voltage is applied, and

I_t = current (amperes) at't' minutes after voltage is applied.

The concrete quality (degree of chloride ion penetrability) can be assessed based on the limits as shown in table 6 as per ASTM C 1202.

Table 5 Chloride Ion Penetrability based on Charge Passed

Charge passed (coulombs)	Chloride ion penetrability
> 4000	High
2000 – 4000	Moderate
1000 – 2000	Low
100 – 1000	Very Low
< 100	Negligible

6. Results and discussion

A. Compressive strength test

The variation of compressive strength at 7 days and 28 days of the concrete blocks with various replacement level of slag up to 100% are shown in table 6.

Table 6 7 and 28 days compressive strength

S.No	M.C	7 day Com Strength (MPa)	28 day Comp Strength (MPa)
1	St 0	28.7	49.9
2	St 10	29.5	48.25
3	St 20	30.25	49.75
4	St 30	30.6	51.1
5	St 40	31.55	52.2
6	St 50	32	52.7
7	St 60	32.75	54
8	St 70	33.5	54.4
9	St 80	33.95	58.9
10	St 90	32.4	42.1
11	St 100	31	39.1

7 and 28 days compressive strength results are indicated graphically as shown in figure 6.

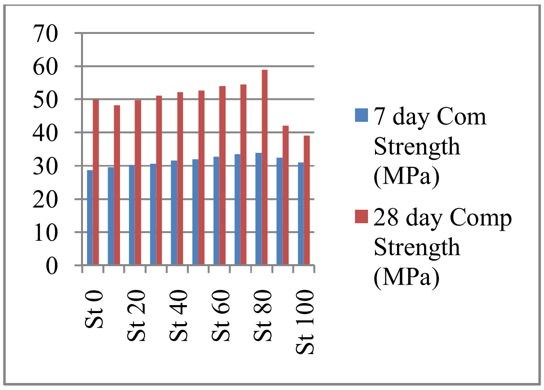

Fig 6 7 and 28 days compressive strength

B. Flexural strength test

The variation of flexural strength at 28 days and breaking load of the concrete blocks are shown in table 7.

Table 7 Flexural Strength Results

S.No	Mix Combination	Breaking Load (kN)	Flexural Strength (MPa)
1	St 0	13.03	7.818
2	St 10	14.5	8.7
3	St 20	13.7	8.22
4	St 30	14.8	8.88
5	St 40	15.8	9.48
6	St 50	19.2	11.52
7	St 60	20.76	12.45
8	St 70	23.5	14.67
9	St 80	24.0	15.35
10	St 90	16.9	10.14
11	St 100	18.9	11.34

The flexural strength results are indicated graphically as shown in figure 7.

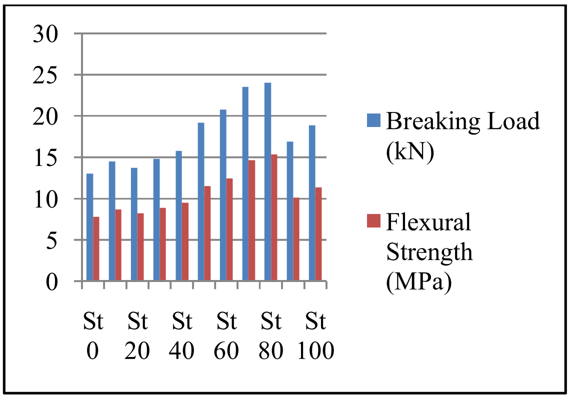

Fig 7 Flexural Strength Results

C. Water absorption

The variation of water absorption at 28 days of the concrete blocks is shown in Table 8.

Table 8 Water Absorption Results

S.No	Mix combination	Water absorption (%)
1	St 0	2.5
2	St 10	3.8
3	St 20	1.07
4	St 30	2.89
5	St 40	2.8
6	St 50	2.78
7	St 60	2.9
8	St 70	3.1
9	St 80	4.2
10	St 90	5.1
11	St 100	5.8

Figure 8 shows the graphical form of water absorption test. The water absorption of the concrete blocks shall not be more than 6 percent by mass in individual samples. Hence from the test results obtained all the combinations can be used for production of concrete blocks.

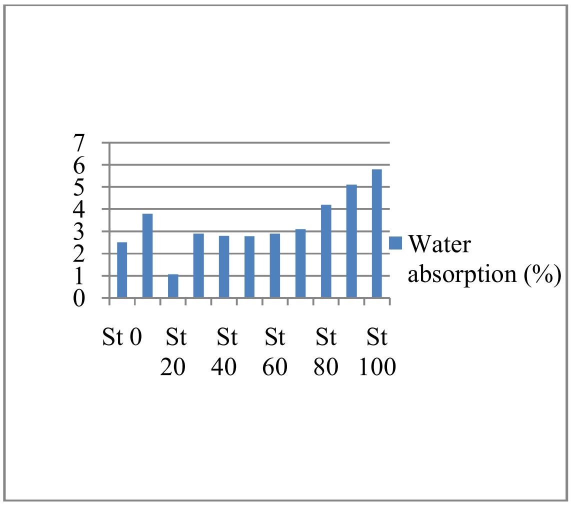

Fig 8 Water Absorption test results

D. Rapid chloride ion penetration

The Rapid chloride ion penetration tests were conducted on the specimen and results are shown in the Table 9. This clearly shows that the chloride penetration is very low up to 80 % of steel slag replacement and for 100% we obtain low chloride penetration value. This proves the paver blocks are durable enough if we use steel slag as aggregate as per IS 15658:2006

Table 9 Chloride ion test

S.No	Mix Comb	Charge passed (coulombs)	Chloride ion penetrability
1	St 0	54	Negligible
2	St 10	48	Negligible
3	St 20	63	Negligible
4	St 30	51.1	Negligible
5	St 40	90	Negligible
6	St 50	663	Very Low
7	St 60	709	Very Low
8	St 70	846	Very Low
9	St 80	950	Very Low
10	St 90	1499	Low
11	St 100	1874	Low

E. Split tensile strength results

The variation of split tensile strength at 7 and 28 days of the concrete blocks are shown in table 10.

Table 10 Split tensile test results

S.No	Mix Comb	7 day tensile strength	28 day tensile strength
1	St 0	4.6	7.4
2	St 10	4.8	7.9
3	St 20	5.6	8.7
4	St 30	5.9	8.9
5	St 40	6.7	9.9
6	St 50	6.8	10.5
7	St 60	6.9	10.9
8	St 70	7.9	11.1
9	St 80	8.8	12.7
10	St 90	8.7	12.7
11	St 100	8.7	12.3

The split tensile strength results are indicated graphically as shown in figure 9.

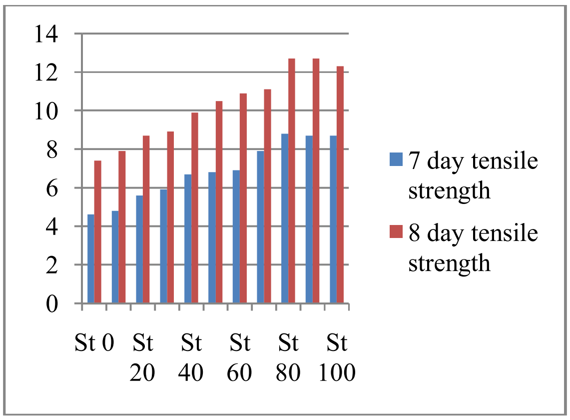

Figure 9 Split tensile strength test

7. Conclusions

Based on the test results and analysis, the following conclusions were made:

- Replacing the conventional granite coarse aggregate by steel slag aggregate in concrete enhances the compressive strength when the replacement level is up to 80 percent, for further replacements compressive strength decreases but gives the minimum compressive strength.
- Based on the flexural strength and breaking load results, it was found that all the combinations were satisfied the codal requirements.
- Considering Compressive strength, water absorption, flexural strength tests and cost analysis, it was found that St 60, St 70, and St 80 as optimum combination for M50 and S 10 to St 80 as optimum combination for M40.
- The Rapid chloride ion penetration tests were conducted on the specimen and results are shown in the Table 9. This clearly shows that the chloride penetration very low up to 80 % of steel slag replacement and for 100% we obtain low chloride penetration value.

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