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Steel Slag ingredient for concrete pavement

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Abstract: Steel slag is an industrial by-product of steel industry. It possesses the problem of disposal as waste and is of environmental concern [9]. The demand for aggregate in construction industry is increasing rapidly and so is the demand for concrete. Thus it is becoming more important to seek suitable alternatives for aggregates in the future. In this study, the *natural coarse aggregates* (NCA) were replaced with *steel slag aggregate* (SSA) at various proportions of 20%, 40%, 60%, 80% and 100%. Experiments were conducted to determine the compressive strength, flexural strength and split tensile strength of concrete with various percentages of steel slag aggregate. The results were compared with conventional concrete.

Keywords: Natural coarse aggregate, partial coarse aggregate replacement, steel slag, steel slag aggregate.

I. INTRODUCTION

In many developed countries, concern over waste production, resource preservation and reduced material cost have focused attention on reusing solid waste materials. Waste materials when properly processed can meet various design specifications in the construction industry. So recovering useful materials from industrial wastes not only offers environmental gains, but also helps to preserve natural resources. It has therefore become necessary that the research efforts in using various types of solid wastes need greater attention [10].

Slag is a by-product of the iron and steel making process. Iron cannot be prepared in the blast furnace without the production of its by-product blast furnace slag. Similarly, steel cannot be prepared in the Basic Oxygen Furnace (BOF) or in an Electric Arc Furnace (EAF) without making its by-product, steel slag [7]. The use of steel slag aggregate in concrete by replacing natural aggregate is a most promising concept [4]. Steel slag aggregates are already being used as aggregates in asphalt paving road mixes due to their mechanical strength, stiffness, porosity, wear resistance and water absorption capacity [8], [11]. Studies and tests are being conducted on ways to use this steel slag as an aggregate in concrete. According to National Slag Association, steel slag is currently used in bituminous asphalt paving, in the manufacture of Portland cement and in road construction as a base coarse, along with some agricultural applications. The only potential problem with steel slag aggregate is its expansive characteristics and undesirable reactions between slag and components of concrete. This might be a perception, but most of the information is anecdotal in nature rather than documented in published research studies.

II. INVESTIGATION

A. Material Properties

The chemical and physical properties of steel slag were examined and are stated in Table I and II [3]. The specific gravity of SSA was found to be 2.58.

TABLE I
Chemical Composition of Steel Slag

Constituent	Composition %
CaO	Nil
SiO_2	11
FeO	76
MnO	5
MgO	Nil
Al_2O_3	1
P_2O_5	Nil
S	Nil
Metallic Fe	6

TABLE II
Physical Properties of Steel Slag

Properties	%-age
Water absorption	1.9
Crushing strength	29.3
Impact value	29
Los Angeles Abrasion	28

B. Mix Proportioning

A single batch of ordinary Portland cement (OPC), 53-grade, was used in this study. Steel slag was collected from the steel industry, Mannarkadu steels, Kanjikodu, Kerala, India. It was crushed down to 20 mm size for use as a coarse aggregate in concrete. The sand used in concrete was local river sand and the natural coarse aggregate was 20 mm crushed granite [4].

The study is for replacing natural coarse aggregate (NCA) with steel slag aggregate (SSA) for pavement concrete. The concrete mix selected is M40 and is proportioned as per Indian Roads Congress [5]. The quantity of materials per m^3 of concrete is shown in Table III. The obtained Mix proportion is 1:1.44:2.60:0.40 (Cement:FA:RCA:Water-cement ratio).

TABLE III
Concrete Ingredients

Ingredients	Quantity in kg/m^3
Ordinary Portland Cement	445
Sand	642
Coarse aggregate	1157
water	178

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C. Details of test Specimen
Concrete cubes of size 150 x150 x 150 mm, were cast for compressive strength tests and Cylinders, 100 x 300 mm, were cast for splitting tensile strength test and to determine the flexural strength, 100 x 100 x 500 mm prisms were cast. All specimens were demoulded 24 hrs after casting, and then cured for 28 days [6].

III. RESULTS

A. Slump Test
From the slump test it is found that the value increases with percentage increase of steel slag aggregate (SSA). The mixture ID is given based on the percentage replacement of natural coarse aggregate (NCA) by steel slag aggregate (SSA). C0 stands for 0% replacement, C20 – 20% replacement, C40 – 40% replacement, C60 – 60% replacement, C80 – 80% replacement, C100 – 100% replacement. Fig. 1 represents the slump values. It shows that slump value increases with increase in percentage of steel slag.

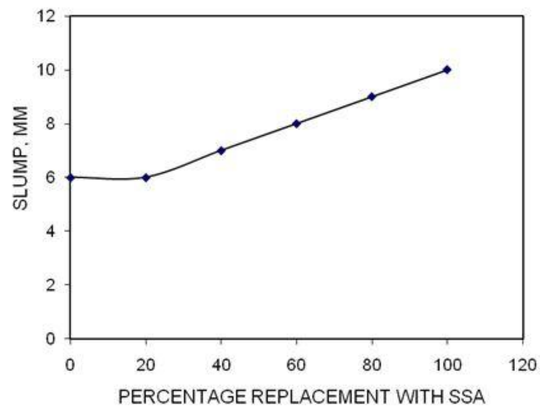

Fig.1 Slump Graph

B. Compressive Strength
The compressive strength of concrete cubes with 0%, 20%, 40%, 60%, 80%, 100% replacement with SSA were determined. Fig. 2 represents the 28 day compressive strength of different percentage of SSA replaced M40 concrete. It shows that the compressive strength decreases with increase in percentage of steel slag. Up to 20% replacement, it is at par with the conventional concrete. But for 40% replacement the strength decreases but satisfies with M40 concrete. Beyond that it has shown a reduction in compressive strength.

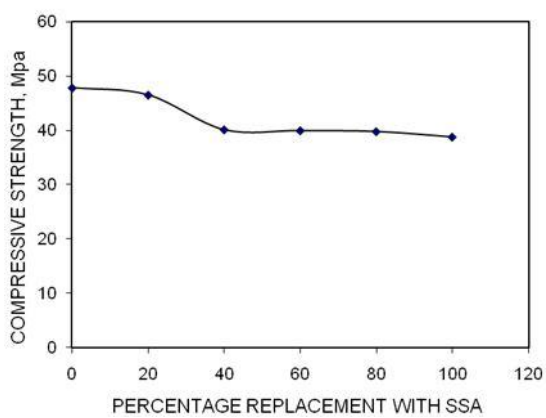

Fig. 2 Compressive Strength of SSA Replaced Concrete

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C. Split Tensile Strength

The tensile strength of concrete was obtained indirectly by split tensile test, where the compressive line loads were applied along the opposite generators of a concrete cylinder placed with its horizontal axis between the platens of compressive testing machine. Due to such applied line load, a fairly uniform tensile stress is induced over nearly two-third of the loaded diameter [2]. The stress induced will split the cylinder vertically into two halves. The magnitude of tensile strength was calculated using the Equation 1.

$$\sigma_{sp} = \frac{2P}{\pi DL} \qquad (1)$$

Where,

σ_{sp} = split tensile strength of concrete in N/mm^2

P = crushing load in N

D = diameter of the cylinder in mm

L = length of the cylinder in mm

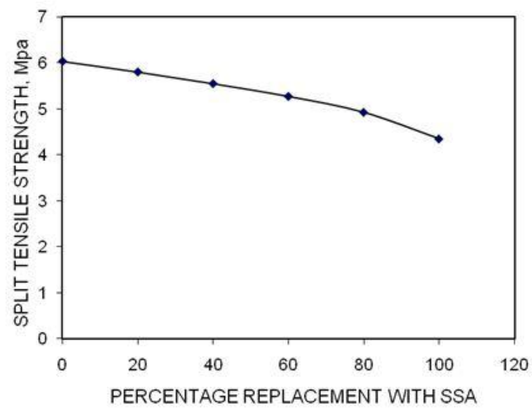

Fig. 3 Split Tensile Strength of SSA Replaced Concrete

Split tensile strength for various replacement percentages with SSA are shown in Fig. 3. Tensile strength, even though it decreases with increase in percentage of steel slag, it is more than the required characteristic value up to 40% replacement and is at par with the characteristic value at 60% replacement.

D. Flexural Strength

In this test, three specimens from each group were subjected to flexure using symmetrical two point loading until failure occurs.

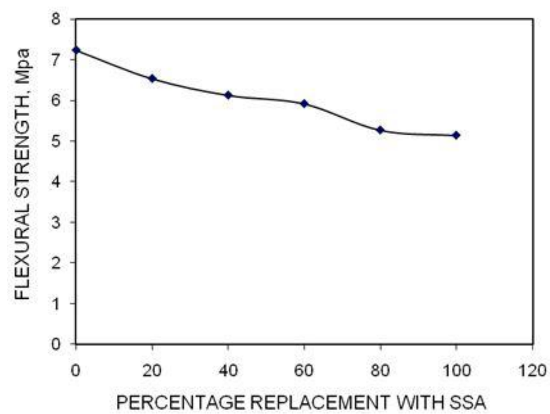

Fig. 4 Flexural Strength of SSA Replaced Concrete

Flexural strength of the conventional and SSA replaced concrete is given in Fig. 4. Flexural strength decreases with increase in percentage of steel slag. But all the batches of SSA replaced concrete have sufficiently good flexural strength [1].

From Fig. 4 it can be suggested that up to 20% natural coarse aggregate can be replaced with steel slag aggregate in pavement concrete. Increase in percentage of steel slag aggregate beyond this has shown a reduction in strength characteristics in comparison with conventional concrete.

IV. CONCLUSION

The following conclusions were drawn on the basis of experimental results.

- Slag aggregate having acceptable properties such as crushing value, impact strength and water absorption shall be used in concrete.
- Incorporating slag in coarse aggregate reduces compressive strength by 2% in 20% replacement, 16% for 40% replacement, 17% for 60% replacement and 19% for 100% replacement.
- The flexural strength of concrete decreases with increase in percentage of steel slag aggregate (SSA), but all the mixes satisfies the minimum required flexural strength of concrete (4 MPa as per IRC 58-2002) for rigid pavement.
- The split tensile strength decreases with increase in percentage of SSA by 3.8% for 20% replacement, 8% for 40% replacement, 12.6% for 60% replacement, 18% for 80% replacement and 30% for 100% replacement.

In view of the conclusions drawn above, it is proposed that steel slag if locally available and cheap, can be used for pavement concrete. Besides sustainability is now a high priority goal in the construction industry and so utilizing the waste product from steel industry is one of the ways to achieve this target.

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