

Utilization Of Steel Slag In Concrete As A Partial Replacement Material for Fine Aggregates

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Abstract: As a construction material, concrete is the largest production of all other materials. Aggregates are the important constituents in concrete. They give body to the concrete, reduce shrinkage and effect economy. 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. Slag is a byproduct of metal smelting and hundreds of tons of it are produced every year all over the world in the process of refining metals and making alloys. Like other industrial byproducts, slag actually has many uses, and rarely goes to waste. It appears in concrete, aggregate road materials, as ballast, and is sometimes used as a component of phosphate fertilizer. In appearance, slag looks like a loose collection of aggregate, with lumps of varying sizes. It is also sometimes referred to as cinder, in a reference to its sometimes dark and crumbly appearance. This substance is produced during the smelting process in several ways. Firstly, slag represents undesired impurities in the metals, which float to the top during the smelting process. Secondly, metals start to oxidize as they are smelted, and slag forms a protective crust of oxides on the top of the metal being smelted, protecting the liquid metal underneath. When the metal is smelted to satisfaction, the slag is skimmed from the top and disposed of in a slag heap to age. Aging material is an important part of the process, as it needs to be exposed to the weather and allowed to break down slightly before it can be used. In this experimental investigation an attempt is made to study the effect of partial replacement of fine aggregate by steel slag in the mechanical properties of M₂₀ grade concrete.

Key words: Concrete, Steel slag, Fine aggregate, Coarse aggregate, Portland cement

I. INTRODUCTION

Since aggregates occupy 70-80 percent of the volume of concrete, their impact on various characteristics and properties of concrete is undoubtedly considerable. All along in India, we have been using natural sand and gravel in concrete manufacturing. Availability of natural aggregates is getting depleted and also it becoming costly. Hence, there has to be an emphasis on the use of wastes and by-products in all areas including construction industry. As 75% of concrete is composed of aggregates it is imperative that we look to maximize the use of waste as aggregate input in concrete making. This research work determines the effect of partial substitution of fine aggregates by steel slag on the mechanical properties of concrete.

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II. LITERATURE REVIEW

A comprehensive study of the potential health risks associated with the environmental applications (e.g. fill, road base , landscaping) of iron and steel making slag was performed using characterization data for 73 samples of slag collected from blast furnaces, basic oxygen furnaces and electric arc furnaces. Characterization data were compared to regulatory health based “screening” bench marks to determine constituents of interest. Antimony, Beryllium, Cadmium, Trivalent & Hexavalent chromium, Manganese, Thallium and Vanadium were measured above screening levels and were assessed in an application–specific exposure assessment using standard U.S. Environmental Protection Agency risk assessment methods. A stochastic analysis was conducted to evaluate the variability and uncertainty in the inhalation exposure and risk estimates, and the oral bio accessibility of certain metals in the slag was quantified. The risk assessment found no significant hazards to human health as a result of the environmental applications of steel-industry slag.¹

The successful incorporation of steel slag as aggregates in construction products requires the consideration of certain issues. Firstly, as steel slag is an industrial byproduct until recently disposed in landfills, the question is whether it is suitable for use in construction. Then the technical characteristics of the material are examined because due to its physicochemical properties steel slag requires special care, but can also provide maximum value if used for specific applications. The utilization of a by-product in suitable applications mainly where it is advantageous compared to traditional materials, but also where it is most economical can give a higher added value to the product. Finally, there are a number of economy-related parameters that allow for a new product to enter the construction market like the situation of the local aggregate market or the need to communicate the efficiency of a new product through demonstration projects. Through all the above considerations and knowledge through practice we look at the way steel slag aggregates enter the construction market in Greece.²

There are three major steel-manufacturing factories in Jordan. All of their by-product, steel slag, is dumped randomly in open areas, causing many environmentally hazardous problems. This research was intended to study the effectiveness of using steel slag aggregate (SSA) in improving the engineering properties of locally produced asphalt concrete (AC) mixes. The research started by evaluating the toxicity and chemical and physical properties of the steel slag. Then 0%, 25%, 50%, 75%, and 100% of the limestone coarse aggregate in the AC mixes was replaced by SSA. The effectiveness of the SSA was judged by the improvement in indirect tensile strength, resilient modulus, rutting resistance, fatigue life, creep modulus, and stripping resistance of the AC samples. It was found that replacing up to 75% of the limestone coarse aggregate by SSA improved the mechanical properties of the AC mixes. The results also showed that the 25% replacement was the optimal replacement level.³

The durability performance of both steel slag and crushed limestone aggregate concretes was evaluated by assessing water permeability, pulse velocity, dimensional stability and reinforcement corrosion. The results indicated that the durability characteristics of steel slag cement concretes were better than those of crushed limestone aggregate concrete. Similarly, some of the physical properties of steel slag aggregate concrete were better than those of crushed limestone aggregate concrete, though the unit weight of the former was more than that of the later.⁴

EAF slag has been found to contain low sulphur and hence the potential to be used as concrete aggregate. The strength development of mortar made from EAF slag has been found to be better than equivalent mortar made with ‘inert’ sand. EAF slag has also been found to be stable in the presence of moisture. EAF slag are potentially suitable in road stabilization and controlled low-strength fill to reduce the cost of binder.⁵

The usage of steel slag in HMA improved the indirect tensile modulus and also improved the value of creep modulus than that of the limestone mixtures. Using steel slag in HMA facilitates the prevention environmental pollution.⁶

The highest and lowest compressive strength was obtained in the concrete specimens prepared with steel slag and calcareous limestone aggregates, respectively. Similarly, the split tensile strength of steel slag aggregate concrete was the highest, followed by that of dolomitic and quartzitic limestone aggregate concretes.⁷

Compressive and flexural strengths for slag concrete were similar or slightly higher than gravel concrete. The compressive strength for slag concrete cured under water

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may adversely be affected with time and requires further investigation. Splitting tensile strength for slag concrete was higher than gravel concrete.⁸

It was reported that the physical properties of steel slag aggregates were superior to those of crushed limestone. However, the bulk specific gravity of the former aggregates was more than that of the latter aggregates. The increase in unit weight of concrete, due to the incorporation of steel slag aggregate, in lieu of crushed limestone aggregate, was approximately 17 %. Though the compressive strength of SSA concrete was marginally better than that of crushed limestone aggregate concrete, no significant improvement in the flexural and split tensile strengths was noted in the SSA concrete compared to crushed limestone aggregate concrete.⁹

Steelmaking slag ~ specifically slag generated from EAFs, BOFs, and BF's during the iron/steel making process ~ has many important and environmentally safe uses. In many applications, due to its unique physical structure, slag outperforms the natural aggregate for which it is used as a replacement. Hence, not only does slag offer a superior material for many construction, industrial, agricultural, and residential applications, but the use of slag promotes the conservation of natural resources.¹⁰

III. MATERIAL PROPERTIES

Cement

Ordinary Portland cement of 43 grade conforming to IS: 8112 – 1989 and similar to ASTM type III (C150 – 95) was used. Its specific gravity was 3.15.

Fine aggregate

Natural river sand with fraction passing through the 4.75 mm sieve and retained on 600 µm sieve was used and tested as per IS: 2386. The fineness modulus of sand used was 2.81 with a specific gravity of 2.65

Coarse aggregate

Crushed granite coarse aggregates of 20mm size were used. The specific gravity was 2.75

Steel slag

Steel slag is obtained from Agni Steels Private Limited, Ingur, TamilNadu, India and its specific gravity in fine form was found to be 2.95. The chemical composition of slag is usually expressed in terms of simple oxides calculated from elemental analysis determined by x-ray fluorescence. Table 1. lists the range of compounds present in steel slag from a typical base oxygen furnace.

Constituent	CaO	SiO ₂	FeO	MnO	MgO	Al ₂ O ₃	P ₂ O ₅	S	Metallic Fe
Composition (%)	40 - 52	10 - 19	10 – 40	5 - 8	5 - 10	1 - 3	0.5 - 1	< 0.1	0.5 - 10

Table 1. Typical steel slag chemical composition

Virtually all steel slag fall within these chemical ranges but not all steel slags are suitable as aggregates. Of more importance is the mineralogical form of the slag, which is highly dependent on the rate of slag cooling in the steel-making process. The predominant compounds are dicalcium silicate, tricalcium silicate, dicalcium ferrite, merwinite, calcium aluminate, calcium-magnesium iron oxide, and some free lime and free magnesia (periclase). The relative proportions of these compounds depend on the steel-making practice and the steel slag cooling rate.

Water

Potable tap water available in the laboratory with pH value of 7.0±1 and conforming to the requirements of IS: 456 - 2000 was used for mixing concrete and also for curing the specimens.

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IV. EXPERIMENTAL PROGRAM

The experimental program was designed to study the mechanical properties of concrete with partial replacement of fine aggregate by steel slag for M₂₀ grade of concrete. The compressive, tensile and flexural strength of the specimens after replacing the fine aggregates by 10%, 20%, 30%, 40% and 50% with steel slag is studied after 28 days of curing. For the test specimens, 43 grade ordinary Portland cement, natural river sand and coarse aggregate, steel slag from steel plants is being utilized. The maximum size of the coarse aggregate was limited to 20mm. A sieve analysis conforming to IS 383 – 1970 was carried out for fine aggregate and for various proportions of sand replacement by slag. Figure 1 represents the particle size distribution for fine aggregate, slag and various replacement proportions.

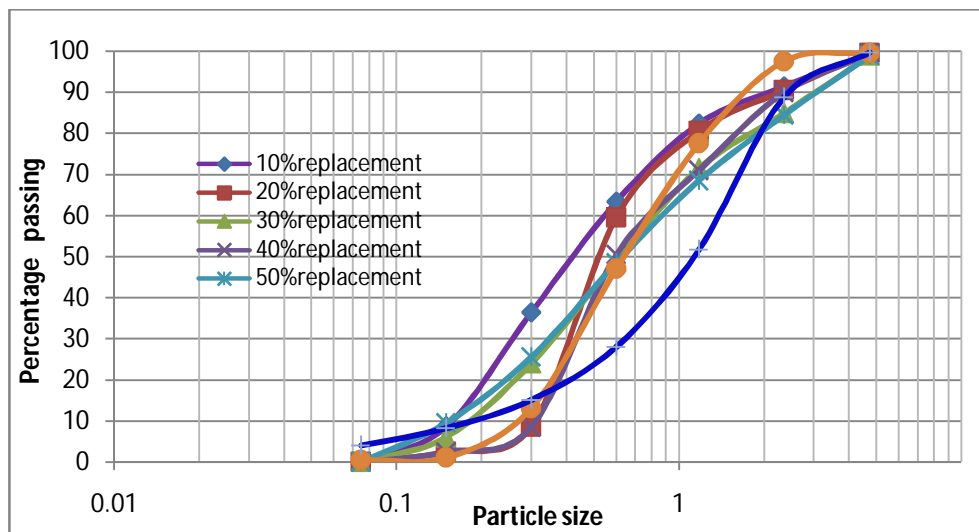


Figure 1. Particle size distribution curve

The concrete cubes (150mm X 150mm X 150mm), concrete beams (100mm X 100mm X 500mm) and concrete cylinders (150mm X 300mm) for conventional as well as other mixes were casted.

Mix Proportion

The concrete mix design was proposed to achieve the compressive strength of 20MPa after 28 days curing in case of cubes. The flexural strength and the split tensile strength of the specimens were also tested. The concrete mix proportions used, have been determined as per IS method of mix design. The mix proportion and designation for various concrete mixtures are tabulated and presented in Table 2. & Table 3.

% of replacement	0%	10%	20%	30%	40%	50%	w/c ratio
M20	1:1.595:3.348	1:1.546:3.425	1:1.667:3.348	1:1.715:3.348	1:1.799:3.348	1:1.835:3.348	0.5

Table 2. Mix proportion for fine aggregate replacement

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S.No	Mix	FA %	FINE SLAG %
1	CC	100%	-
2	CFP ₁	90%	10%
3	CFP ₂	80%	20%
4	CFP ₃	70%	30%
5	CFP ₄	60%	40%
6	CFP ₅	50%	50%

Table 3. Mix designation

V. EXPERIMENTAL PROCEDURE

Tests on Mechanical Properties

Fresh concrete properties such as slump test were conducted as per Indian standards. Cube specimens of 150 mm size for compressive strength, Cylinder specimens of 150 mm diameter x 300 mm height and prisms of size 500 mm x 100 mm x 100 mm were casted to study the mechanical strength properties such as compressive strength, split tensile strength and modulus of rupture according to Indian standards. Compressometer method on cylindrical specimens having 150 mm diameter and 300 mm length was conducted to find the modulus of elasticity as per California test procedure.

VI. RESULTS AND DISCUSSIONS

Slump value of conventional concrete is 100 and it lies between 85 to 105 for different mixes. Addition of steel slag both in the form of fine aggregate giving impact on workability slightly. In density point of view, there was no much difference among the values. Density of conventional concrete was 2.26. Other mixes it stands from 2.25 to 2.28. Air content is also an important fresh concrete property which produces minor deviations in all the mixes compared to conventional concrete mix. Heat liberated through hydration process gives 24.5°C for conventional concrete and it varies from 24.0°C to 24.9°C for other mixes. As a whole, addition of steel slag in both the forms did not make any major effects on fresh concrete properties. Fresh concrete properties of various mix proportions are represented in Figure 2 to Fig 5.

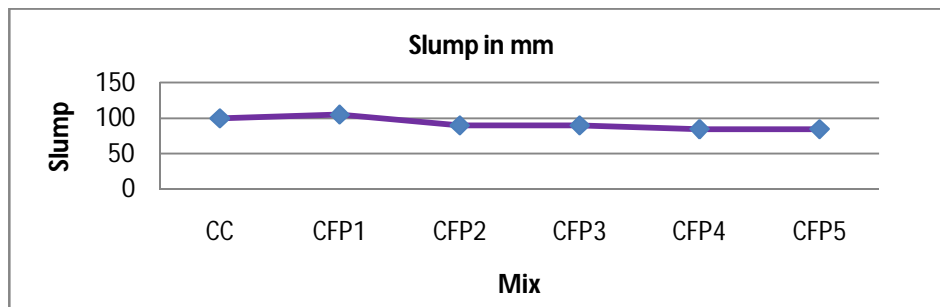


Figure 2. Slump value for various mix proportions

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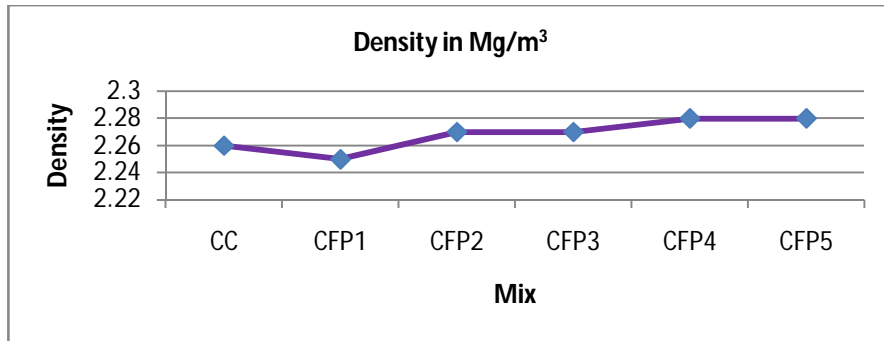


Figure 3. Density value for various mix proportions

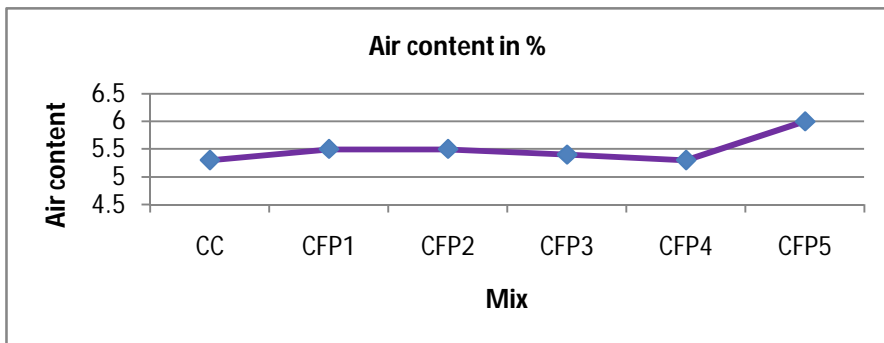


Figure 4. Value of air content for various mix proportions

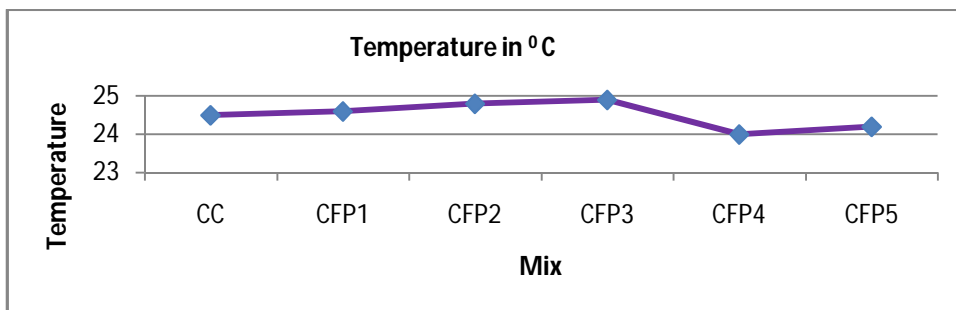


Figure 5. Temperature value for various mix proportions

The results of mechanical properties are represented in Figure 6 to Figure 9. Test results shows that the compressive strength of the concrete increases and the optimum value was found at a slag replacement proportion of 30% for fine aggregate and after that any further replacement of slag decreases the compressive strength. The tensile strength and

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flexural strength and Modulus of Elasticity values follow the same for all the replacement proportions. The results are represented in Figure 6 to Figure 9.

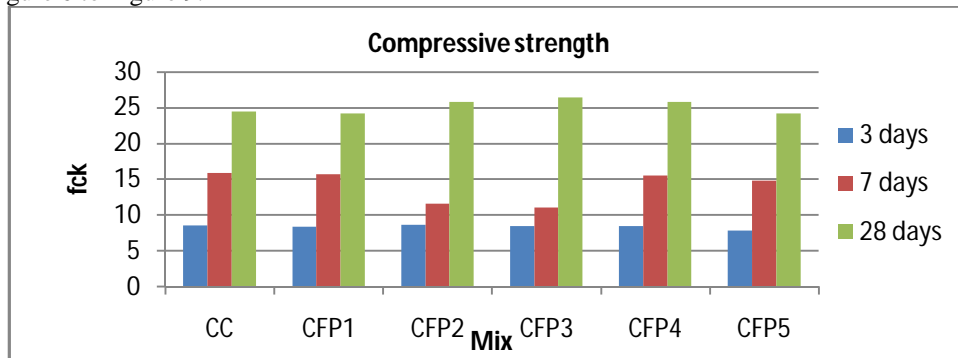


Fig.6 Comparison of 3,7 & 28 days compressive strength

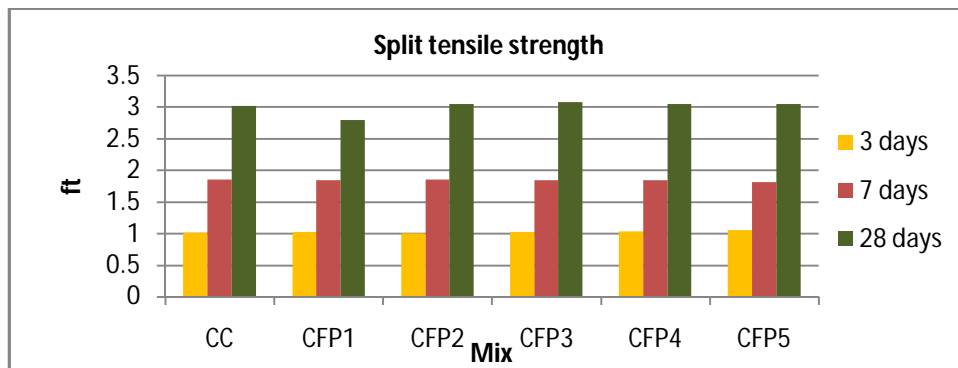


Fig.7 Comparison of 3,7 & 28 days split tensile strength

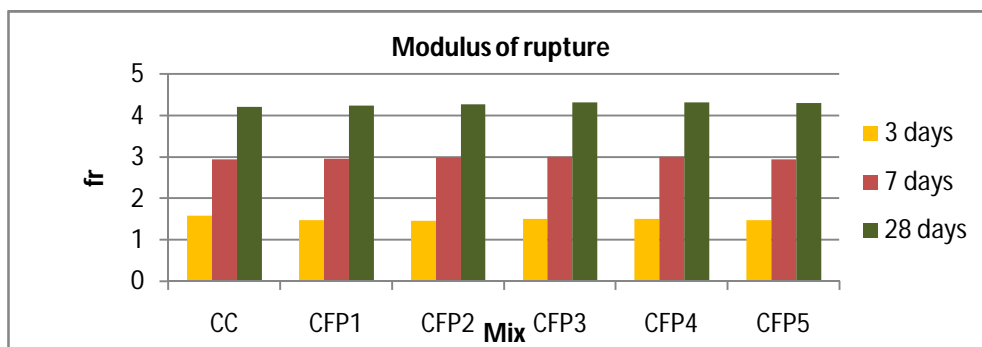


Fig.8 Comparison of 3,7 & 28 days modulus of rupture

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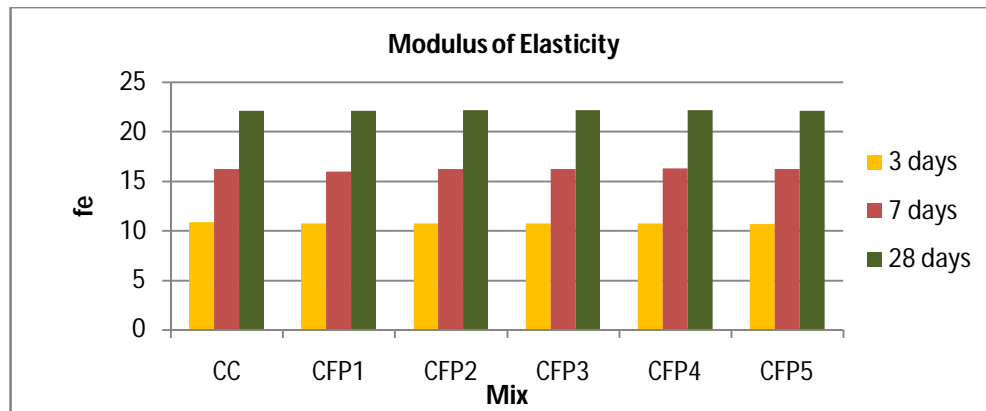


Fig.9 Comparison of 3,7 & 28 days modulus of elasticity

VII. CONCLUSIONS

This work relates the use of steel slag, a waste cheap material used as fine aggregates in M₂₀ grade of concrete and recommends the approval of the material for use in concrete as a replacement material for fine aggregates. The partial substitution of natural aggregates with steel slag aggregates permits a gain of compressive, tensile and flexural strength and modulus of elasticity of concrete up to an optimum value of replacement. The following benefits can also be obtained:

- Cost reduction
- Social benefits &
- Mass utilization of waste material is possible in construction by using steel slag as a partial replacement material for fine aggregates in concrete.

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