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Original Research Paper

Effective Utilization of Wastes from Steel Industries in Concrete

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ABSTRACT

Steel slag, a by-product of steel making, is produced during the separation of the molten steel from impurities in steel-making furnaces. The slag occurs as a molten liquid melt and is a complex solution of silicates and oxides that solidifies upon cooling. It is estimated that 115-180Mt of steel slag is poured out annually worldwide and in addition to this previous accumulation of the material has created mountains of steel slag. In India, steel slag output is approximately 20% by mass, of the crude steel output. The slag in India is used mainly in the cement manufacture and in other unorganized work, such as landfills and railway ballast. In order to reduce the pollution load on landfill for the disposal of steel slag at steel industries, it can be effectively utilized in construction as aggregates in concrete. Use of waste materials can solve problems of lack of aggregate in various construction sites and reduce environmental problems related to aggregate mining and waste disposal. The use of waste aggregates can also reduce the cost of the concrete production. In this research work an attempt is made to utilize the steel slag as partial replacement material for natural aggregates in concrete. 10% to 100% replacement was done in 10% increment and fresh and hardened concrete properties were studied.

INTRODUCTION

Steel slag, a by-product of steel making, is produced during the separation of the molten steel from impurities in steel-making furnaces. The slag occurs as a molten liquid melt and is a complex solution of silicates and oxides that solidifies upon cooling. Slags are named based on the furnaces from which they are generated. In this research work, steel slag was obtained from the open stocking yard of Agni Steels Private Limited, Ingur, Erode, Tamilnadu, India where steel slag was stockpiled over a period of 2.5 years. Basic oxygen furnace process of steel making is used in the industry and the slag produced is known as BOF slag.

Shetty (1982) has reported that aggregates are the important constituents in concrete. They give body to the concrete, reduce shrinkage and effect economy. The mere fact that the aggregates occupy 70-80 percent of the volume of concrete, their impact on various characteristics and properties of concrete is undoubtedly considerable. Mindness et al. (2003a) states that aggregates provide dimensional stability and wear resistance for concrete. Not only do they provide strength and durability to concrete, they also influence the mechanical and physical properties of concrete. Aggregates act as a filler material and lower the cost of concrete. Aggregates should be hard, strong, free from undesirable impurities and chemically stable. They should not interfere with the cement or any of the materials incorporated into concrete. They should be free from impurities and organic matters which may affect the hydration process of cement. Mindness et al. (2003b) identified a wide range of materials, which can be used as an alternative to natural aggregates. When any new material is used as a concrete aggregate, three major considerations are relevant: (1) economy, (2) compatibility with other materials and (3) concrete properties. Kalyoncu (2001) reported that steel slag is a by-product obtained either from conversion of iron to steel in a basic oxygen furnace (BOF), or by the melting of scrap to make steel in the electric arc furnace (EAF). The molten liquid is a complex solution of silicates and oxides that solidifies on cooling and forms steel slag. Zeghichi (2006) explained that when the slag is allowed to cool slowly, it solidifies into a grey, crystalline, stony material, know as air cooled, or dense slag. This forms the material used as a concrete aggregate, it is a real silico calcareous rock, similar to the basalt, of angular aspect, rugous and of micro alveolar structure. NSA (1998) reported the results of the risk assessment, which demonstrate that BF, BOF, and EAF slags are safe for use in a broad variety of applications and pose no significant risks to human health or the environment. Pajgade & Thakur (2013) reported that the steel slag must be allowed to undergo the weathering process before using as an aggregate in construction because of its expansive nature. This is done in order to reduce the quantity of free lime to acceptable limits. The steel slag is allowed to stand in stockpiles for a period of at least 4 months and exposed to weather. Chinnaraju et al. (2013) discussed

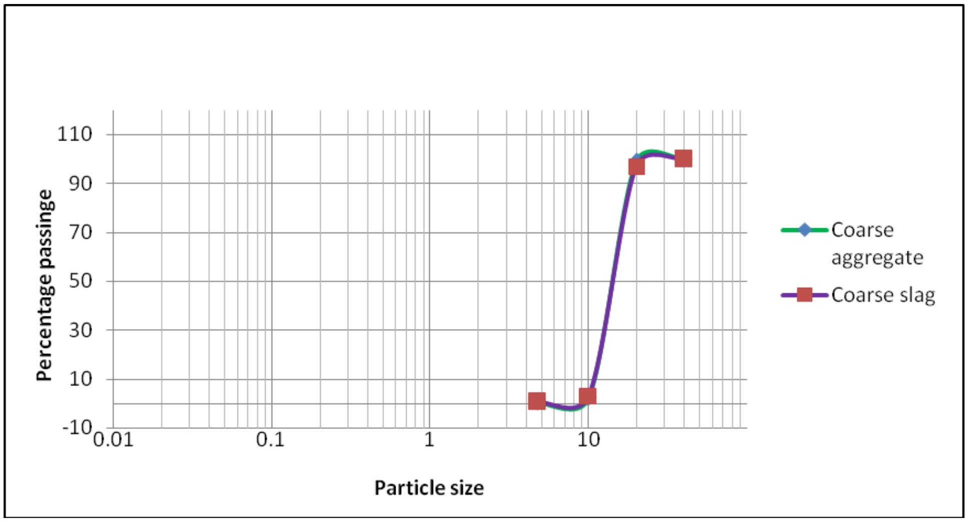

Fig. 1: Particle size distribution curve.

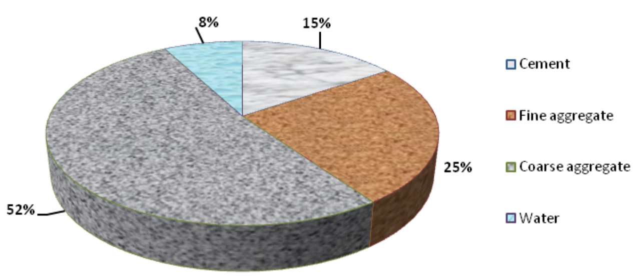

Fig. 2: Mix proportion of M20 grade concrete.

the effect of steel slag as replacement for coarse aggregate in concrete and eco sand, which is a commercial by-product of cement manufacturing process. Tests on compressive strength, flexural strength, split tensile strength at 7 days and 28 days, and water absorption at 28 days were conducted on the specimens. It was concluded that replacing some percentage of coarse aggregate with steel slag enhances the strength.

MATERIALS AND METHODS

Properties of steel slag: The specific gravity of steel slag in coarse form was 3.1. The chemical composition of steel slag is expressed in terms of simple oxides calculated from elemental analysis determined by Le Chatlier method (IS 228, 1987). Table 1 lists the chemical compounds present in steel slag from a typical basic oxygen furnace and the chemical composition satisfies ACI 233 R-03, 2003. Table 2 lists the physical properties. Sieve analysis of coarse aggregate and coarse slag was done and found that there is no significant variation in the particle size distribution of the coarse aggregate and coarse slag. Particle size distribution curve is given in Fig. 1.

Experimental programme: The mix proportion of the concrete is represented in Fig. 2. The reference mixture (CC) was completely prepared with natural aggregates like granite jelly and river sand, while the other mixtures were prepared from the slag from steel plant. For the entire test, M20 designed mix was taken with the w/c ratio 0.5. Table 3 gives the mix designation for various mixes of concrete for coarse aggregate replacement with coarse form of slag. Other materials used are given below:

***Cement*:** Ordinary Portland cement of 43 grade conforming to IS: 8112-1989 and similar to ASTM type III (C150-95) was used.

***Fine aggregate*:** Natural river sand with fraction passing through the 4.75mm sieve and retained on 600µm sieve was used. The specific gravity of fine aggregate is 2.62, fineness modulus is 2.83 and density is 1654kg/m^3.

***Coarse aggregate*:** Crushed granite stone aggregates of 20mm maximum size having specific gravity of 2.70, fineness modulus of 2.73 and density of 1590kg/m^3 is used.

***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.

Experiment: Fresh concrete properties such as slump value, density and air content were found out as per IS: 1199-1959, ASTM C 231 specifications and ASTM C 138 guidelines respectively. Hardened concrete properties such as compressive strength, tensile strength and flexural strength

Table 1: Chemical composition of steel slag.

Constituent	Composition (%)	Composition (%) as per ACI 233 R-03
Cao	32.5	32 to 45
SiO_2	34	32 to 42
Fe_2O_3	0.3	0.1 to 0.5
MgO	9	5 to 15
Al_2O_3	22	7 to 16
P_2O_5	0.56	-
SO_3	0.7	-

Table 2: Physical and mechanical properties of steel slag.

Test particulars	Results
Specific gravity	Coarse form - 3.1; Fine form - 2.95
Bulk density (kg/m^3)	1650
Aggregate impact value	13.2
Aggregate crushing value	26.70
Water absorption (%)	2.7

Table 3: Mix designation for various replacement proportions.

S.No	Mix	Coarse aggregate, %	Coarse slag, %	Fine aggregate, %
1.	CC	100%	-	100%
2.	CS1	90%	10%	100%
3.	CS2	80%	20%	100%
4.	CS3	70%	30%	100%
5.	CS4	60%	40%	100%
6.	CS5	50%	50%	100%
7.	CS6	40%	60%	100%
8.	CS7	30%	70%	100%
9.	CS8	20%	80%	100%
10.	CS9	10%	90%	100%
11.	CS10	-	100%	100%

were determined as per IS: 516-1959, IS: 5816-1970 and IS: 516-1959 respectively. Tests were conducted for all the replacement proportions (10% to 100% in 10% increment) of coarse aggregate by coarse slag for M20 grade concrete.

RESULTS AND DISCUSSION

Fresh concrete properties such as slump value, density and air content of the various replacement proportions are graphically represented in Figs. 3, 4 and 5. Slump value of conventional concrete is 100mm and increase in the proportion of steel slag decreases the workability of concrete. The density values of all the replacement proportions were higher than conventional concrete density of $2.25 kN/m^3$. All the mixes show a density value between $2.26 kN/m^3$ to $2.285 kN/m^3$. Regarding air content value, all the mixes shows a decreased percentage of air content when compared with the value of conventional concrete which is 5.3%. Hence following conclusions were drawn:

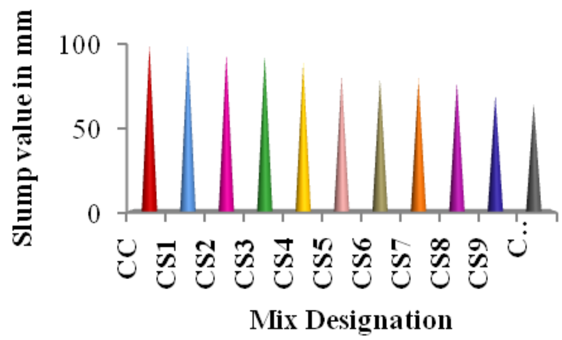

Fig. 3: Slump value.

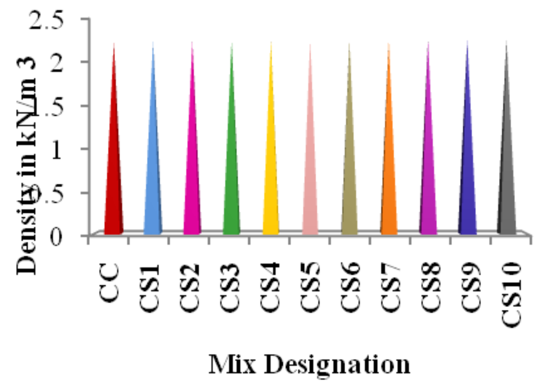

Fig. 4: Density.

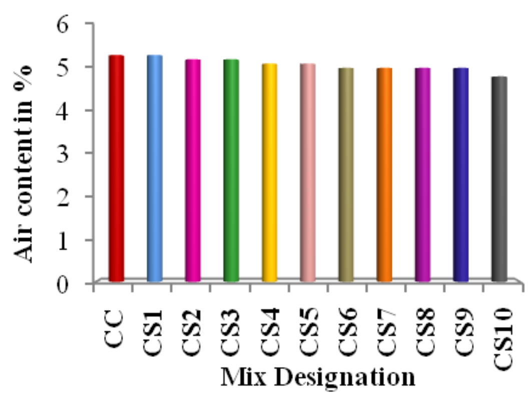

Fig. 5: Air content.

More angularity and rough texture of the steel slag aggregates affect the workability of the concrete. The rough texture and angular particles of steel slag aggregates create better interlocking between the particles and the cement paste which helps in improving the density of concrete. The air content in steel slag aggregate is comparatively lower and hence workability was reduced.

Results of the mechanical properties such as compressive strength, tensile strength and flexural strength are graphically represented in Figs. 5, 6 and 7. In case of M20

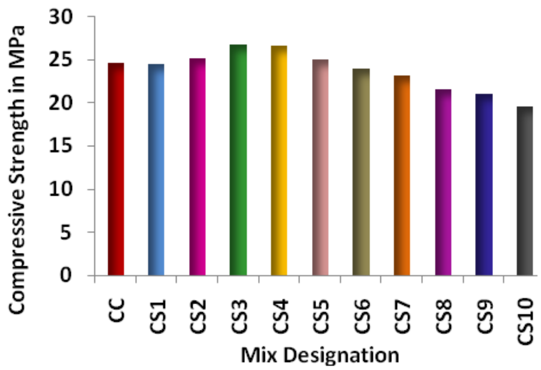

Fig. 6: Compressive strength.

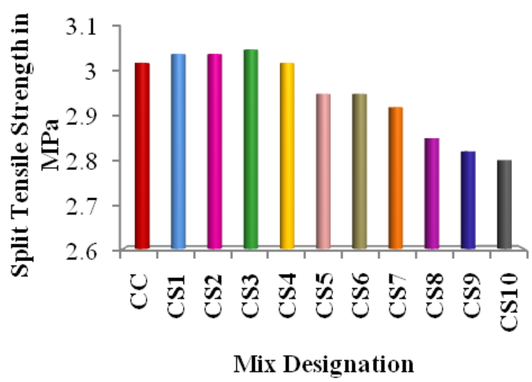

Fig. 7: Split tensile strength.

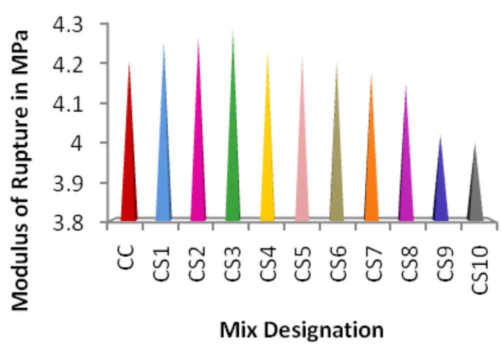

Fig. 8: Modulus of rupture.

grade concrete, the compressive strength of conventional concrete is 24.5MPa. For coarse aggregate replacement by coarse slag, maximum compressive strength is achieved in the mix CS3 and its strength is 26.7MPa. At 28 days there is an increase in compressive strength of 8.98% achieved when compared with conventional concrete. At lower replacement levels of 10% and 20%, there is a slight decrease in strength at 28 days when compared with conventional concrete. At replacement levels of 40% and 50% there is an increase in strength of 26.6MPa and 25MPa at 28 days for the mixes CS4 and CS5. Higher replacement proportions show decrease in strength when compared with conventional concrete.

In case of M20 grade concrete, the split tensile strength of conventional concrete is 3.02MPa. For coarse aggregate replacement by coarse slag, maximum split tensile strength is achieved in the mix CS3 and its split tensile strength is 3.05MPa at 28 days At lower replacement levels of 10% and 20% there is a slight increase (0.02MPa) in split tensile strength observed when compared with conventional concrete. 40% replacement level shows the same strength of 3.02MPa at 28 days but beyond that proportion split tensile strength starts decreasing.

CONCLUSIONS

From the results obtained from the experimental investigation, following conclusions are derived:

- No major difficulty in handling concrete incorporating steel slag aggregate was encountered.
- More angularity and rough texture of the steel slag aggregates affect the workability of the concrete but increases the density of fresh concrete and improves the hardened concrete properties.
- An optimum strength is achieved at the replacement proportion of 30% of coarse aggregate by coarse slag in the hardened concrete.

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