Experimental Study on Concrete as a Partial Replacement of Steel Slag as Fine Aggregate

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Abstract

Steel slag is the residue of steel making industry and the emission amount is about 12 to 20 percent of rough steel production. Steel slag and slag has certain amount of important minerals of cement clinkers, such as C2S and C3S. So it can be used as cement and concrete admixtures. If the steel slag and slag occupies 15 percent of steel production (quality percentage), then the emission amount is 1.2 million tons. So if coarse aggregate can be replaced by steel slag and not only can the activity of slag be fully simulated but also the durability of concrete can be improved. Steel slag has higher strength characteristics than normal aggregate, which result in more strength differences between slag aggregate concrete and natural aggregate concrete. If the replacement of steel slag increases beyond 75%, to maintain the workability of concrete certain water reducing admixtures should be added. Four mixes were prepared by partially replacing steel slag as fine aggregate and tested for Mechanical Properties such as Compressive Strength, Splitting tensile strength, Flexural strength and durability properties such as Salt resistance, sulphate resistance and acid resistance and the results were discussed elaborately.

Keywords: Steel Slag, Compressive Strength, Admixtures, Durability

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I. INTRODUCTION

Sustainable construction is widely used concept now. It was introduced due to the growing concern about future of planet and it applies specifically for construction industry as, being a huge consumer of natural resource. Concrete is the material of area. Concrete is the most versatile construction material because it can be designed to withstand the harshest environment while taking on the most inspirational forms. Engineers are continually pushing the limits to improve its performance with the help of innovative chemical admixtures and supplementary cementitious material which forms part of the cementitious component. Materials are majority these by products from other processes. The use of these products not only helps to utilize these waste materials but also enhances the properties of concrete in fresh and hydrated states.

The steel industry slag having desirable qualities can be used as fine aggregates in concrete construction. Graf and Grube have reported that the Ground granulated blast furnace slag in concrete leads to many technical advantages. When two minerals admixtures are used together, better results can always achieve. The use of such industrial by product or waste material having desirable qualities can result in saving of energy and conventional materials. With increase in population, the demand of construction of residential and public buildings is also increasing. The iron and steel industry produce extremely large amounts of slag as by product of the iron making and steel making processes. As useful recycled materials, iron and steel making slag are mainly used in fields related to civil engineering, for example, in cement, roadbed material, and concrete aggregate.

Their recycling ratio is close to 100%, making an important contribution to the creation of a recycling-oriented society. However, public works projects, that is strongly related to recycled fields, tend to be reduced recently and, moreover, other recycled materials such as slag in the fields. The strength and performance of concrete and flexural behaviour such as deflection and load acting on slabs of size 1400 x 1200 x 100 mm, containing steel slag that is been used as partial replacement of natural fine aggregate of size 20mm, as opposed to that of normal concrete [1-3]. Steel slags are made at the temperatures up to 1600oC, utilization in concretes with improved properties after the exposure to high temperature is considered in this paper. An experimental program was designed

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and carried to study properties of four steel slag based concrete mixtures with different types of cement pastes prior and after heating up to 800oC [4]. The durability of steel slag aggregates concrete under freeze thaw environment was the main goal in this research, as there was a belief that the steel slag aggregates have expansive characteristics and would cause cracking in concrete [5-6]. Electric Arc Furnace (EAF) steel slag as by products from the steel production which could improve post fire properties due to the fact that it is the material that is made at the temperatures of up to 1650oC [7].

II. MATERIALS AND METHODS

A. Materials

1) Cement

Ordinary Portland Cement of 43 grade Confirming to IS12269-2013 was procured locally from market and Physical property results are presented in Table 1.

Table - 1
Physical Properties of Cement

Sl.no	*Tests conducted*	*Experimental results*	*Recommended values as per IS 12269-2013*
1	*Normal consistency (%)*	*34*	*-*
2	*Initial setting time (min)*	*48*	*Not less than 30*
3	*Final setting time (min)*	*240*	*Not greater than 600*
4	*Fineness (%)*	*3.5*	*<10*
5	*Specific gravity*	*3.07*	*-*

2) Fine Aggregate

The fine aggregate used was M- sand which is sieved through 4.75 sieves and proper care was taken to see that they were uniformly dry and clean. Table 2 represents physical property test results of fine aggregate (M-Sand).

Table - 2
Physical Properties of Cement

Sl.no	*Tests conducted*	*Experimental results*
1	*Specific gravity*	*2.54*
2	*Water absorption (%)*	*1.00*
3	*Moisture Content (%)*	*0.16*
4	*Net Water absorption (%)*	*0.86*
5	*Fineness modulus*	*3.05*

3) Coarse Aggregate

Crushed blue granite metal confirming to IS: 2386-1963 of size 20 mm was used.. Physical Property results of coarse aggregate are tabulated in table 3.

Table – 3
Physical Properties of Coarse Aggregate

Sl.no	*Test conducted*	*Experimental results*
1	*Specific gravity*	*2.68*
2	*Water absorption (%)*	*0.5*
3	*Moisture Content (%)*	*0.7*
4	*Fineness modulus*	*7.6*
5	*Impact value (%)*	*16.39*
6	*Crushing value (%)*	*24*
7	*Abrasion value (%)*	*22*

4) Water

Mixing water quality is required in accordance with the quality standards of drinking water and the Mixing Water used was taken from KPR Institute of Engineering and Technology, Coimbatore.

5) Steel Slag

Steel slag used in the present study was procured from Rambo industries, Coimbatore, Tamilnadu, India. Various Physical property tests were conducted to study the property of steel slag and presented in table 4.

Table – 4
Physical Properties of Steel Slag

Sl.no	*Test conducted*	*Experimental results*
1	*Density (kg/m3)*	*3.6*
2	*Water absorption (%)*	*2.5*
3	*Impact value (%)*	*28*

B. Mix Design

Five numbers of mixes were prepared with different combinations of waste plastics. Lime sludge is partially replaced with M-Sand for different mixes. Waste plastic and fine aggregate was used in ratio of 1:2. Table 5 represents mix proportion for various mixes.

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Furthermore, Mix M0 denotes the mix, with 0% steel slag (conventional control mix), M1 denotes mix, with 10% steel slag, M2 denotes mix with 20% steel slag and M3 indicates that mix with 30% steel slag.

Table - 5
Mix Proportion of Various Mixes

Mix id	*Cement (kg/m^3)*	*Fine aggregate (kg/m^3)*	*Coarse aggregate (kg/m^3)*	*Steel slag (kg/m^3)*	*W/C ratio*
M0	*372*	*661*	*1108.28*	*0*	*0.5*
M1	*372*	*601*	*997.48*	*110.8*	*0.5*
M2	*372*	*553*	*886.68*	*221.6*	*0.5*
M3	*372*	*502*	*775.78*	*664.8*	*0.5*

C. *Experimental Programme*

Cube specimens of size 150 x 150 x 150 mm, cylinder specimen of size 150 mm diameter and 300 mm height and beam specimen of size 100 mmx100 mmx500 mm were used to determine various mechanical properties such as compressive strength, spilt tensile strength, Flexural strength and cube specimens of size 150 x 150 x 150 mm was used to study the durability properties such as salt resistance, sulphate resistance and acid resistance strength properties are determined at the age of 28 days and durability properties are determined at the age of 56 days.

III. RESULTS AND DISCUSSIONS

A. *Mechanical Properties*

1) *COMPRESSIVE STRENGTH TEST*

Table 6 represents compressive strength test results of various mixes. The results showed that, Mix (M2) Shows higher compressive strength when compared with conventional control mix (M0) and M1, when the replacement percentage of steel slag increases it was noticed that there was a decrement in strength properties. Moreover Figure 1 graphically represents compressive strength test results of various mixes.

Table – 6
Compressive strength of various Mixes

Sl.no	*Mix ID*	*Compressive strength (N/mm^2)*	
		7 days	*28 days*
1	*M0*	*17*	*24.5*
2	*M1*	*16.5*	*25*
3	*M2*	*17.5*	*27.5*
4	*M3*	*15.5*	*24.3*

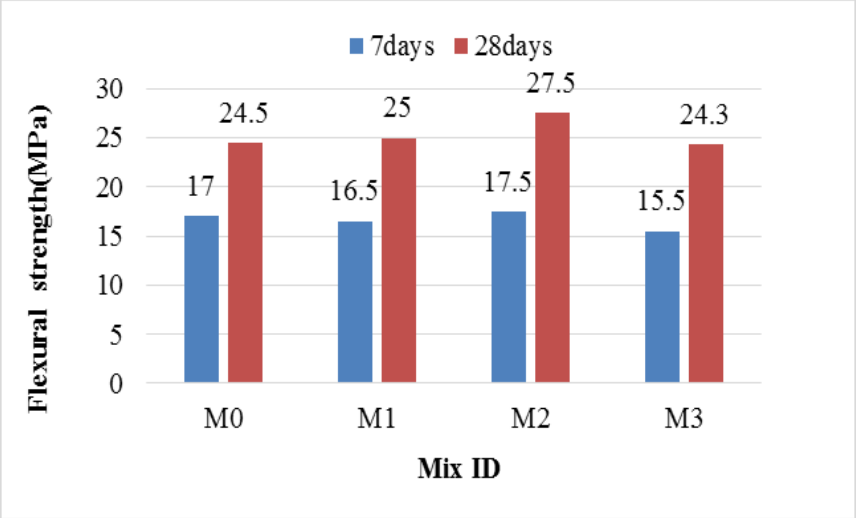

Fig. 1: Compressive strength of various Mixes

2) *Split Strength Test*

Table 7 shows the split tensile results of various mixes. The results showed that, Mix (M2) Shows higher Spilt tensile strength when compared with conventional control mix (M0) and M1, When the replacement percentage of steel slag increases it was noticed that there was a decrement in strength properties. Figure 2 graphically represents the Split tensile strength test results of various mixes.

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Table – 7
Spilt tensile strength of various Mixes

Sl.no	*Mix ID*	*Split tensile strength (N/mm²)*	
		7 days	*28 days*
1	*M0*	*1.45*	*2.45*
2	*M1*	*1.69*	*2.5*
3	*M2*	*1.99*	*2.75*
4	*M3*	*1.80*	*2.42*

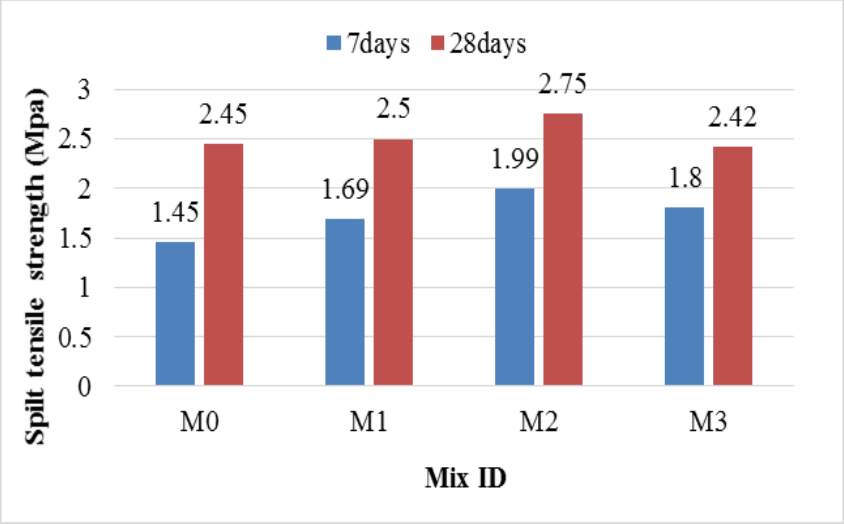

Fig. 2: Spilt tensile strength of various Mixes

3) Flexural Strength Test

Flexural strength test results of various mixes were tabulated in Table 8. The results showed that, Mix (M2) Shows higher Flexural strength when compared with conventional control mix (M0) and M1, when the replacement percentage of steel slag increases it was noticed that there was a decrement in strength properties. Figure 3 graphically represents Flexural strength test results of various mixes.

Table – 8
Flexural strength of various Mixes

Sl.no	*Mix ID*	*Flexural strength (N/mm2)*	
		7 days	*28 days*
1	*M0*	*1.30*	*3.46*
2	*M1*	*1.60*	*3.5*
3	*M2*	*1.88*	*3.67*
4	*M3*	*1.78*	*3.45*

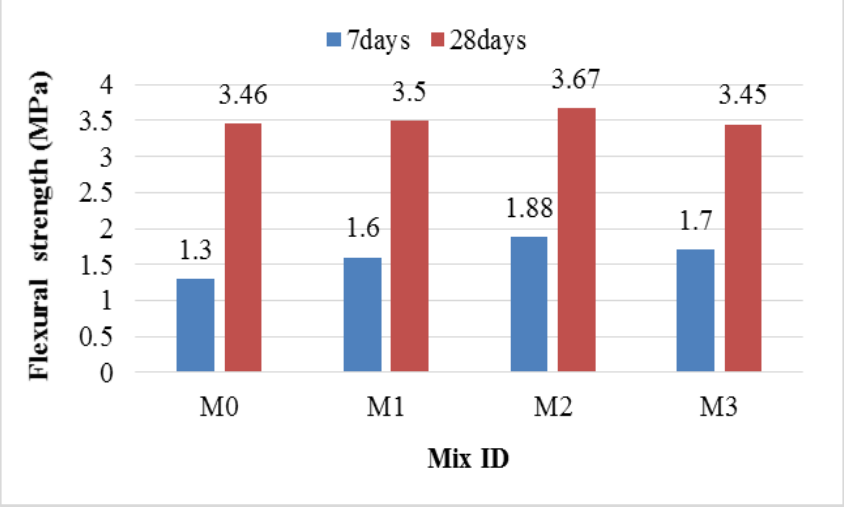

Fig. 3: Flexural Strength test of Various Mixes

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4) Durability Properties

Table 9 shows the effect of weight loss and loss in strength of M2 mix immersed in sodium chloride (NaCl), magnesium sulphate (MgSO4) and Hydrochloric acid (HCl) solution in at the age of 56 days. Test results shows that M2 mix concrete specimens shows better resistance against chemical attack. Furthermore, visual observation reveals that minor physical deterioration has occurred at the edges for the specimens immersed in MgSO4 and HCl solution. Regardless of colour change slight whitish formation was appeared on the surface of the specimens immersed in MgSO4 solution due to the displaced calcium precipitates mainly as gypsum. Specimens immersed in acid solution exhibits solution exhibits slight reddish colour formation on the surface due to the presence of iron content (Fe2O3) in fly ash and presence of free lime and iron content in the hydrated cement matrix. Specimens subjected to chemical attack are shown in Figure 4.

Table – 9
Durability Properties of various binders

Test conducted	*Weight loss (%)*	*Strength loss (%)*
Salt attack	*0.71*	*4.27*
Sulphate attack	*0.82*	*4.49*
Acid attack	*1.21*	*5.20*

Fig. 4: Specimens subjected to chemical attack

IV. CONCLUSION

Based on experimental study on steel slag Replacement the following conclusions can be drawn,

1) Mechanical properties such as compressive strength, split tensile strength, flexural strength and durability properties such as salt resistance, sulphate resistance, acid resistance were found and it satisfies the requirements.
2) It has been observed that 20% replacement of steel slag as a partial replacement of fine aggregate gives higher strength properties when compared to 10% and 30% replacement of steel slag.
3) Steel slag has higher strength characteristics than normal aggregate, which result in more strength difference between slag aggregate concrete and natural aggregate concrete.
4) The initial crack is delayed when compared with the beams without inclusion of steel slag.
5) Regardless of all the mixes mix M2 was considered as optimum mix and the same mix was considered to carry out durability tests.
6) Mix M2 demonstrates better resistance against salt, sulphate and acid attack. Moreover, slight physical deterioration at sharp edges was noticed in sulphate and acid attack specimens and colour change was noticed in acid attack specimens.
7) Hence forth, concrete made with partial replacement of fine aggregate by steel slag can be effectively used in sustainable construction.

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