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Strength and Durability Study on Concrete with GGBS and Steel Slag

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***Abstract*—Preventing the exhaustion of natural resources and enhancing the usage of waste materials has become a significant problem of the modern world. Million tons of waste materials come into being as a result of within a year. A limited number of studies have been done concerning the protection of natural resources, prevention of environmental pollution and contribution to the economy by using this waste material. Fortunately we have just such a material - concrete, and most of the essential research has been done to enable concrete to fill this role. This chapter deals with the studies on research works and investigations done using GGBS and steel slag as a replacement for cement and fine aggregate. This chapter gives an overview of studies done in different parts of the world in the field of concrete construction by finding alternatives to cement and fine aggregate.**

Keywords—Concrete, GGBS, Steel Slag, durability.

I. INTRODUCTION

Global warming and environmental destruction have become the major issue in recent years. Emission of host of greenhouse gases from industrial processes and its adverse impact on climate has changed the mind set of people from the mass-production, mass-consumption, mass-waste society of the past to a zero-emission society, utilization of industrial wastes and conservation of natural resources. We can reduce the pollution effect on environment, by increasing the usage of industrial by-products in our construction industry. In the present study to produce the concrete the Portland cement is replaced with GGBS (Ground granulated blast furnace slag) used as the binding of materials and steel slag as fine aggregate. 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 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 quartzite limestone aggregate concretes.[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]

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.[4]

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. [5]

Compressive and flexural strengths for slag concrete were similar or slightly higher than gravel concrete. The compressive strength for slag concrete cured under water may adversely be affected with time and requires further investigation. Splitting tensile strength for slag concrete was higher than gravel concrete.[6]

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.[7]

A comprehensive study on GGBS& PFA on Early age engineering properties of Portland cement. It has been found that partially replacing pc PFA or GGBS resulted in longer setting time but better workability with PFA exhibiting more prominent effect than GGBS. At the replacement level up to 30% by mass GGBS concrete exhibited higher splitting tensile strength than PC concrete. Both PFA &GGBS can reduce drying shrinkage and reduction effects become more significance as replacement level measured with GGBS performing better than PFA. [8]

The optimum percentage levels of 7.5% GGBS and 0.3% Glass fibre replacement to the weight of the cement is taken with the HPC M75 mix ratio of 1:1.03:1.973:0.26 which gave the better results. The Compressive strength of 76.96 N/mm2 is achieved in the HPC mix due to the presence of GGBS which exhibits more filler effect. Figure no. 1, 3, and 5 represents the compressive strength, split tensile strength and flexural strength of various mixes with different replacement level of GGBS and glass fibre at the age of 28 days. The compressive strength and splitting tensile strength of concrete is increase as the Percentage of GGBS increases with 0.3% of glass fibre when compared to control mix.[9]

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 flexural strength and Modulus of Elasticity values follow the same for all the replacement proportions.[10]

Steelmaking slag ~ specifically slag generated from EAFs. BOFs, and BFs 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. [11]

II. EXPERIMENTAL INVESTIGATION

The aim of the experimental investigation is to ascertain and compare the improvement in the performance of concrete by partial replacement of fine aggregate with steel slag and cement with GGBS thereby to assure at the optimum percentage of steel slag and study the durability of concrete mix.

A. Material

a) Cement

Ordinary Portland cement-53 grade (Ramco Cement) have used in investigation. The cement was tested according to IS 4031:1988. It confirmed to IS 12269:1987.

b) Ground Granulated Blast-furnace Slag (GGBS]

Ground granulated blast-furnace slag is the granular material formed when molten iron blast furnace slag is rapidly chilled (quenched) by immersion in water. It is a granular product with very limited crystal formation and is highly cementitious in nature. It is ground to cement fineness and hydrates like Portland cement. The specific gravity of GGBS is 2.85.

c) Fine Aggregate

Good quality M sand was used as a fine aggregate conforming to Zone- II of IS: 383- 1970 have fineness modulus of 2.79, specific gravity of 2.65

d) Steel slag

Steel slag is obtained from KEY PEE Steels Private Limited, Kollam Kerala, India and its specific gravity in fine form was found to be 2.65.

e) Coarse aggregate: Coarse aggregate are the crushed stone used for making concrete. The commercial stone is quarried, crushed and graded. Much of the crushed stone used is granite, limestone and trap rock. Crushed angular granite metal of 10 mm size from a local source was used as coarse aggregate. The specific gravity of 2.6 and fineness modulus 6.05 was used.

B. Mix design

The concrete mix design is a process of selecting suitable ingredients and determine their relative proportions with the object of producing concrete of certain minimum strength and durability as economical as possible. The design of concrete mix required complete knowledge of the various properties of these constituent materials.M20 was designed as per IS 10262:2009 and the mix proportion was obtained 1:1.75:3.19. Water cement ratio was 0.50. Seven mixes were made were SS0, SS10, SS30, SS40, SS50, SS60, SS60.

SS0 was the control mix with 20% GGBS and 0% steel slag. the other mixes SS10,SS30,SS40,SS50,SS60,SS60 contained 20% GGBS by weight of cement and varying steel slag content (10%,20%,30%,40%,50%,60%) by weight of M sand

TABLE 1 MIX DESIGNATION FOR DIFFERENT MIXES

Sl.No.	Mix Designation	M sand (%)	Steel slag (%)	GGBS (%)
1	SS 0	100	0	20
2	SS 20	90	10	20
3	SS 20	80	30	20
4	SS 30	70	30	20
5	SS 40	60	40	20
6	SS 50	50	50	20
7	SS 60	40	60	20

C. Specimen details

TABLE 2 SPECIMEN DETAILS

Sl. No.	Properties	Specimen	Size	Numbers
1	Compressive strength	Cube	150mm ×150mm× 150mm	63
		Cylinder	150mm diameter 300mm height	21
2	Splitting tensile strength	Cylinder	150mm diameter 300mm height	21
3	Flexure tensile strength	Beam	500mm × 100mm× 100mm	21
4	Durability	Small cube	100mm × 100mm ×100mm	210
		Disc	50 mm diameter 150 mm height	9

D. Test on specimens

Testing of specimens plays an important role in controlling and conforming the quality of concrete. All the specimens cast were subjected to the testing to study the effect of partial replacement of steel slag with respect to M sand (20% constant GGBS.) on workability, strength and durability thus the experiential investigations carried out was divided into three main headings .they are as follows

1. Study on workability
   1. Slump test
   2. Compacting factor test
2 Study on strength
   1. Compressive Strength
   2. Flexure Strength
   3. Splitting Tensile Strength
3 Study on durability

III. RESULT AND DISCUSSIONS

A. Properties of fresh concrete

Studies conducted on fresh concrete properties are given in table 4. From the results obtained, it can be conducted that the slump and compacting factors increase with replacement of cement with GGBS and fine aggregate with steel slag

TABLE 3. PROPERTIES OF FRESH CONCRETE

Sl.No.	Mix designation	Workability	
		Slump (mm)	Compacting factor
1	SS 0	28	0.84
2	SS 10	29	0.85
3	SS 20	30	0.88
4	SS 30	33	0.90
5	SS 40	36	0.91
6	SS 50	40	0.93
7	SS 60	41	0.94

B Properties of hardened concrete

i Cube compressive strength: When we refer to concrete strength, we generally talk about compressive strength of concrete. Because, concrete is strong in compression but relatively weak in tension and bending. Compressive strength mostly depends upon amount and type of cement used in concrete mix. Compressive strengths of specimens with various percentage replacement of cement with GGBS and fine aggregate by steel slag is determined by casting concrete cubes of size 150 mm X 150mm X 150mm and testing them after 7,28 &56 days of curing.Comparing with the control mix compressive strength increases up to 30% and then decreased. From this study 30% replaces of fine aggregate with the steel slag was taken as the optimum percentage.

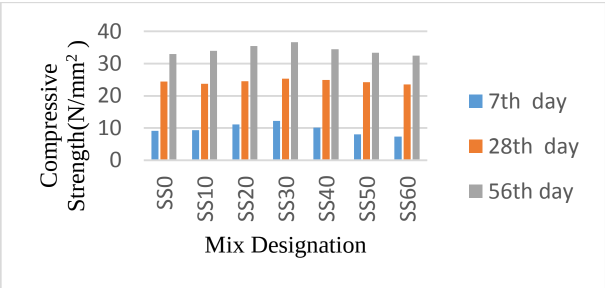

Fig 1 Cube compressive strength

ii. cylinder strength; It is difficult to say whether cube test gives more realistic strength properties of concrete or cylinder gives a better picture about the strength properties of concrete. However, I can be said that the cylinder is less affected by the end restrains caused by platens and hence it seems to give more uniforms results than cube. Cylinders are cast and tested in the same position, whereas cubes are cast in one direction and tested from the other direction. In actual in the field, the casting and loading in similar to that of the cylinder and not like that.as such, cylinder simulates the condition of the actual structural member in the field in respect of direction of load. From the result it can be seen that SS30 HAS higher compressive strength than SS 0,SS 10, SS 20, SS 40, SS 50, and SS 60.

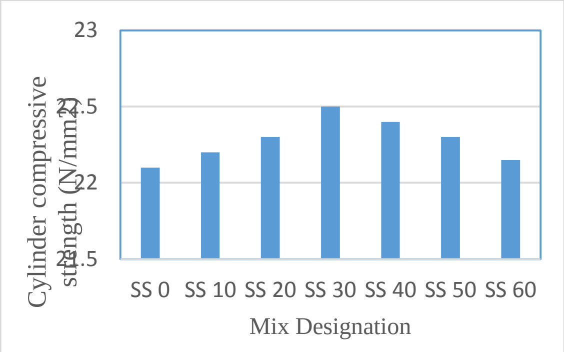

Fig2 Cylinder compressive strength

iii. Splitting tensile strength: The splitting tensile strength of concrete cylinder was determined based on 516-1959. The load shall be applied nominal rate within the range 1.2 N/ (mm^2/min) to 2.4 N/ (mm^2/min). Load is applied until the specimen fails, along the vertical diameter. Tensile strength of the concrete design mix was check by casting and testing of 150 mm diameter & 300 mm depth size Cylinders after curing period of, 28 days .From the results of splitting tensile strength of cylinder for SS 0, SS 10, SS 20, SS30, SS 40, SS 50, SS 60 ,The SS30 has higher strength than others

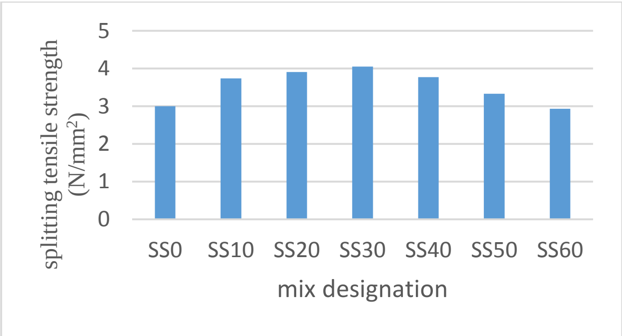

Fig 3 Splitting tensile strength

iv. Flexural strength of concrete: The flexural strength of concrete prism was determined based on IS: 516 –1959. Place the specimen in the machine in such a manner that the load is applied to the upper most surface as cast in the mould along two lines spaced 13.3cm a part. The flexural test was conducted on prisms of size 500 mm x 100 mm x 100 mm over a span of 400 mm, under symmetrical two point loading, at the age of 28 days and conforming to IS: 516-1959. .from the results of flexural strength of concrete SS30 has higher strength than SS 0, SS 10, SS 20, SS 40, SS 50, SS 60.

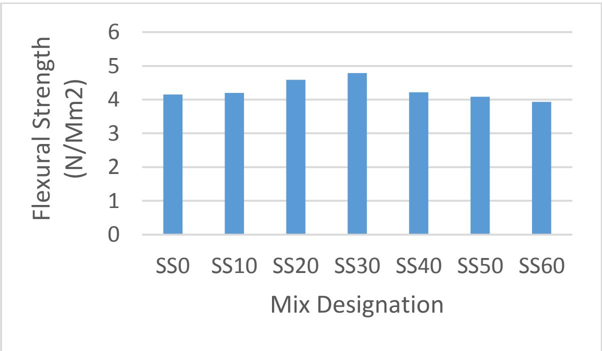

Fig 4 flexural strength

C. Durability of concrete

Durability of concrete is defined as its ability to withstand weathering action, chemical attack or any other process of deterioration. A durable concrete requires little or no maintenance and retains its original form, quality and serviceability when exposed to its environment expect harsh or highly aggressive environment. With increasing pollution level it has become necessary to check the durability of concrete. Concrete Mix design procedure considers only the compressive strength of concrete. Although compressive strength is a measure of durability of concrete to a great extent but it is not always true that a strong concrete is a durable concrete.

1 Acid Resistance:

Concrete is not fully resistant to acid. Most acid solutions will slowly or rapidly disintegrates Portland cement concrete depending upon the type and concentration of acid the acid resistance tests were carried out on 100 mm size cube specimens.The cube specimens were weighed and immersed in water diluted with one percent by weight of sulphuric acid for 56 days and 90 days continuously. Then the specimens were taken out from the acid water and the surfaces of the cubes were cleaned. Next the weight and the compressive strengths of the specimens were found out and the average percentage of loss of weight and compressive strengths were calculated.

Sulfuric acid test :The specimens were exposed to 5% sulphuric acid solution.The specimens were immersed in the solution after removing from the mould. Then the specimens were taken out from the acid water and the surfaces of the cubes were cleaned

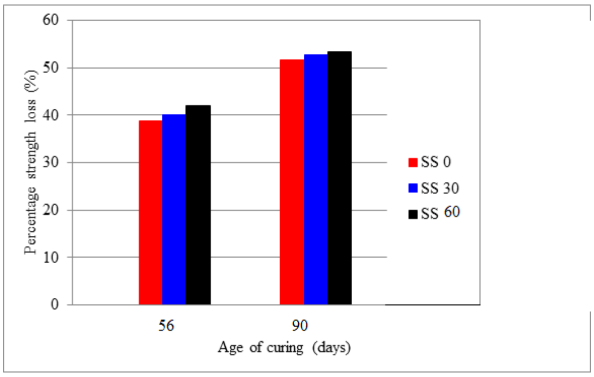

Fig 6 Percentage strength loss in acid solution

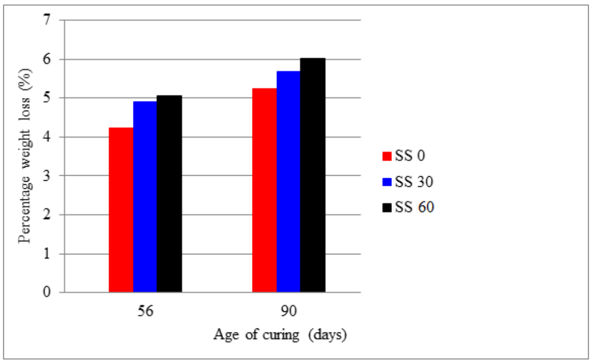

Fig 7 Percentage weight loss in acid solution

2. Sodium Hydroxide Attack Test

Alkalinity Test is one of the important tests to study the durability of concrete. For this test cube of 100mm×100mm×100mm were used, and kept in NaOH solution after demoulding. The solution was prepared by mixing 1% sodium hydroxide pellets with tap water. Then the compressive strength and weight of specimen at 56 days, 90 days were compared with normal water cured specimens.

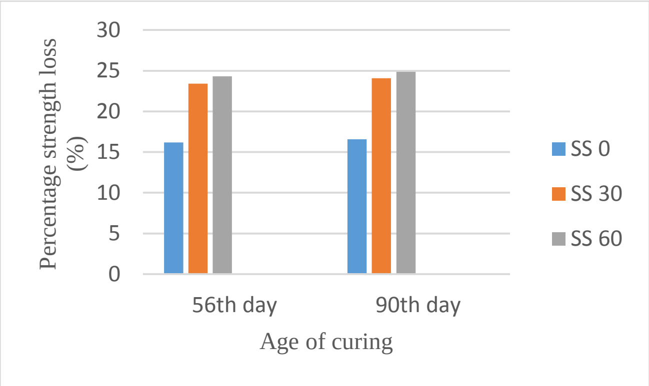

Fig 8 Percentage strength loss in alkaline solution

From the result obtained, it is observed that, percentage strength loss was more for SS 30 and SS 100 in alkaline. The percentage of strength loss for SS 60 was about 24.86% and the strength loss for SS 0 was

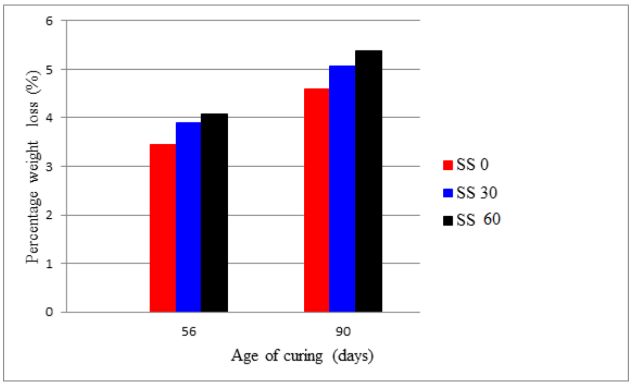

Fig 9 percentage weight loss in alkaline solution

only 16.58% on90 days of curing in alkaline solution. The weight loss was also much higher for the steel slag concrete compared to control mix. This indicates that SS 60 shows less resistance than SS 0.

3. Sulphate attack

To study the sulphate attack on concrete, the cubes were tested after 56 days 90 days of exposure to sulphate solution. The effect of sulphate attack on concrete specimen was assessed by measuring the compressive strength and weight loss at respective ages compared them with water cured specimen.

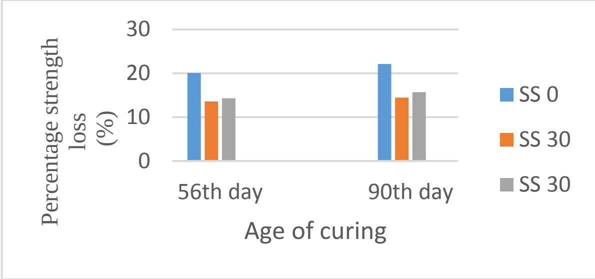

Fig 10 Percentage strength loss in sulphate solution

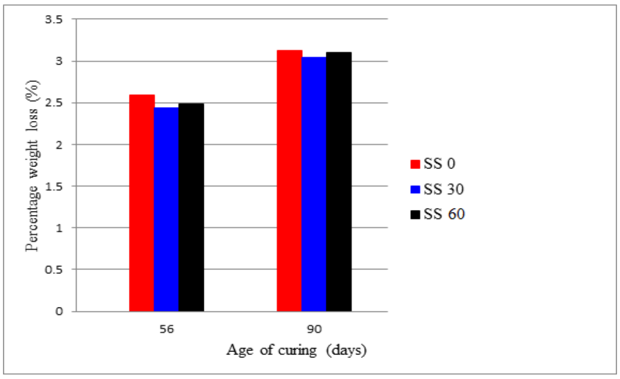

Fig 11 Percentage weight loss in sulphate solution

The result indicates that the steel concrete which contains GGBS reduces the sulphate attack compared with the control mix .when compared to acid and alkali attack, steel concrete shows better durability properties. this may be due to the presence of steel slag in concrete mix, steel slag present in the mix reduce concrete permeability and make it harder for sulphate to penetrate.

4. Sea water attack

Large number of concrete structures are exposed to sea water either directly or indirectly. For several reasons, effects of sea water on concrete deserves special attention. The coastal and offshore structures are exposed to simultaneous action of a number of physical and chemical deterioration process. To study the seawater on concrete, the cubes were tested after 56 days 90 days of exposure to seawater. The effect of sulphate attack on concrete specimen was assessed by measuring the compressive strength and weight loss at respective ages compared them with water cured specimen.

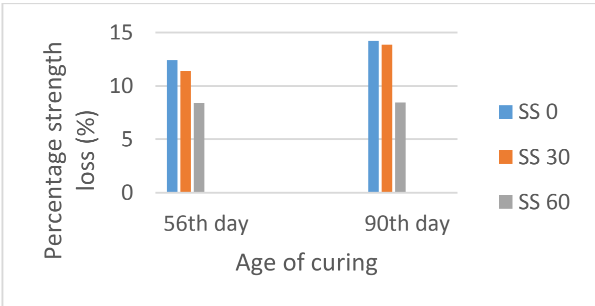

Fig 12 Percentage strength loss in seawater

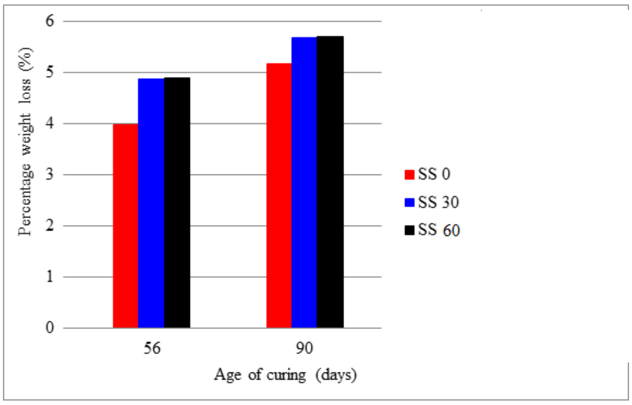

Fig 13 Percentage weight loss in seawater

GGBS present in the concrete has higher potential to improve durability in coastal environment. Due to presence of GGBS the percentage of strength loss is lesser. The weight loss obtained for the ss0 ss30 were almost similar from my research it is clear that GGBS steel slag concrete has higher resistance power against sea water attack

IV. 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 splitting tensile strength of concrete up to an optimum value of replacement .The following benefits can also be obtained:

- Compressive strength and the other tests show that steel slag is superior to the natural aggregates.
- Addition of mild steel slag as a fine aggregate improves good interlocking and eventually improved the mechanical properties of the mixes.
- Protection of environment from the pollution effects of huge quantities of slag rejected from steel melting in India or in all over the world.
- High strength and durable concrete blocks at low cost.

From the above results we can insure the improvements of the concrete mixture properties due to addition of mild steel slag. Accordingly we could state that many advantages were achieved by using mild steel slag instead of natural aggregates, however the last was available, and also this will encourage other investigations to find another filed of using slag

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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