INFLUENCE OF SLAG AGGREGATES ON THE FUNCTIONAL PROPERTIES OF CONCRETE

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ABSTRACT. In recent years, studies have been made to replace the conventional coarse aggregate of concrete with green materials. In this work, an attempt was made to replace the coarse aggregate with steel slag aggregates. M30 grade concrete was prepared with complete replacement of slag aggregates obtained from steel industry. Casted specimens were tested as per pertaining standards. Chemical curing has been adopted throughout the study. Engineering properties viz. Compressive strength and split tensile strength and the functional properties namely Sorptivity, water permeability, rapid chloride penetration test, test on sulphate resistance, chloride attack test and test on acid resistance were carried out and reported for 180 days. The results have shown the desirable strength compared to conventional concrete of the same grade. Also, Concrete with slag aggregate proved to be durable from the durability indexes obtained through various tests as mentioned.

Keywords: Coarse steel slag, Functional properties, Compressive strength, Chemical curing.

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INTRODUCTION

Concrete is the most widely used product all over the world as most of the construction is dependent upon concrete in its variable forms. The concrete as we know is an amalgamation of different products viz. cement, aggregates, admixtures and water. These products in different ratios contribute to variants of concrete. In recent years, we are facing much problem in sand and aggregates. Aggregate such as gravel and granite drastically reduce the natural stone deposits and this has damaged the environment thereby causing ecological imbalance. Therefore, there is a need to explore and to find out suitable replacement material to substitute the natural stone. Hence, we use Slag, an industrial waste as coarse aggregates and to study the durability properties of the concrete.

The increase in volume fraction of MP fiber results in increasing modulus of elasticity and split tensile strength. In low volume fractions, PP fibers have a greater influence on the compressive strength of high-strength concrete in comparison with that of MP fibers (Fallah et al., 2017). The mechanical and durability properties of concrete under different curing conditions were examined. The porosity in initial water curing is lower than the other curing conditions. So, it is resistant to chemical attacks (Sallehan et al., 2017). Compressive strength was not dependent on fines content of crushed limestone sand for low water-cement ratio concrete mixes. A significant positive relationship between resistivity values and fines content was observed for both series of concretes with different water-cement ratios (Gokce et al., 2016). Geopolymer binder is produced with sustainable cementitious materials. This study confirmed that the geopolymer concrete contains low electric resistance properties and higher negative corrosion potential values. It shows geopolymer concrete contains lower durability performance comparing to OPC concrete (Pasupathy et al., 2016). All lightweight self-consolidating Concrete (LWSCC) mixtures exhibited good performance when subjected high temperature. All LWSCC mixtures behaved reasonably well after 2 weeks of exposure to sulfuric acid fresh, hardened and durability properties are affected by the changes in the coarse to fine aggregate ratio. (Lotfy et al., 2016). The increase of silica fume affects the resistance to chloride penetration for all mixtures. The freeze-thaw tests proved that water absorption ratio of lightweight aggregate affects the frost resistance of Light Weight Aggregate Concrete. (Youm et al., 2016).

Investigations of mechanical properties of concretes show that the substitution of cement by zeolite resulted in some reduction of strength. Increase of resistance to freezing and thawing damage, decrease of drying shrinkage, water penetration depth and results in the improved durability of concretes. (Markiv et al.,2016). Durability studies of mixes with and without steel slag coarse aggregates were studied. Replacement of natural aggregates with steel slag aggregates, the sulphate resistance of alkali activated concrete mixes decreases. Steel slag aggregates provide good strength and durability performance in those mixes. (Palankar et al., 2016). The compressive strength, split tensile strength, and flexural strength decrease with increasing aluminium dross content. RCPT, sorptivity and permeability are found to increase with the percentage levels of ASD and are significant for larger Replacements. (Reddy et al., 2016). Replacing 10% cement by micro-silica reduced durability of concretes in magnesium sulphate environment. Replacing cement with slag in concretes subjected to the magnesium sulphate environment increased the durability from the strength viewpoint. Utilizing 15% limestone powder as cement replacement increased durability of concretes. (Mostofinejad et al., 2016). The durability of high early strength concrete was studied. They evaluated the durability properties by exposing the cubes in severe exposure conditions like sea water exposure, acid exposure and fire exposure. It is concluded that for acid exposure, fire exposure and sea water exposure, the compressive strength of the high early strength concrete is 25%, 75%and 25% more than control concrete respectively (Patel et al., 2016). The durability properties of geo polymer concrete were studied. The durability properties were evaluated by conducting tests like Sulphate resistance, acid resistance, water absorption, sorptivity and chloride attack. The concrete was resistant to chloride attack with longer time to corrosion cracking than control concrete (Salmabanu et al., 2016). Metakaolin governs the mechanical performance for the mixes containing both silica fume and metakaolin. The compressive strength is increased with increased in metakaolin. Combined use of silica fume and metakaolin did not result in better performance in compressive strength (Adorján Borosnyói 2016).

MATERIALS AND METHODOLOGY

The materials used for Steel slag aggregate concrete are given below. The properties of materials used will affect the engineering and durability properties of concrete.

Cement

Ordinary Portland cement of 53- grade cement was used conforming to IS 12269.

Aggregates

Fine Aggregates: Fine aggregates such as sand should be obtained from a reliable supplier. Fine aggregates conforming to grading zone II are suitable.

Steel Slag Coarse Aggregates

Slag coarse aggregates are used with fully replacement of conventional coarse aggregate. Slag aggregate is an industrial waste obtained from steel industry. Also, Slag is eco-friendly to the environment.

Water

Water used in the mixing should be free from any organic and harmful solutions. Salt water is not to be used. By the process of hydration, cement reacts with water and form a paste. This cement paste fills the voids and makes the aggregate together. Low water cement ratio makes a durable, strong concrete. High water cement ratio makes high slump concrete.

Admixtures

In this work, super plasticizer is used as admixtures by 0.6% weight of the cement.

Curing

Chemical curing has been adopted throughout the study. CERA POLYCURE-R is the chemical used for curing the concrete which prevents the evaporation of water from the capillaries of concrete to ensure proper hydration process.

Mixture Proportions

The mix proportioning for M30 grade concrete has been done as per IS10262. Conventional aggregates are replaced by steel slag aggregates and the water absorption is taken care in the calculation. As a result of various trial mixes, the ratio of ingredients obtained as 1: 2.62: 3.08. The steel slag aggregate concrete quantities for various materials are given in Table 1.

Table 1 Quantities of SSAC per cubic meter

S.NO	MATERIALS	QUANTITY
1	Cement content	350 kg/m^3
2	Fine Aggregates	920 kg/m^3
3	Coarse Aggregates	1080 kg/m^3
4	Water cement ratio	0.45

EXPERIMENTAL INVESTIGATIONS

This chapter describes about the engineering properties and the durability properties in detail. The engineering properties include the compressive strength test. The durability of the concrete is tested by conducting the following tests sorptivity test, rapid chloride penetration test, acid attack, Sulphate resistance and chloride attack. Procedures for the above tests are given below.

Hardened Concrete Test

The compressive strength of the cylindrical concrete test specimens was measured according to IS516-1959. A calibrated compression test apparatus was used to perform the compressive strength test on each cylindrical specimen. The density of the concrete is the ratio of weight of the concrete per unit volume of the specimen= 2380 kg/m^3.Load at the failure divided by area of specimen gives the compressive strength of concrete

Functional Properties

The Functional properties of the concrete is tested by conducting the following tests like sorptivity test, rapid chloride penetration test, acid attack, Sulphate resistance and chloride attack

Rapid Chloride Penetration Test

In this test, the chloride ion penetration is tested by passing current. The procedure for the RCPT test is given in ASTM C 1202. It indicates the resistance of concrete to chloride ion penetration. The cylinder is cut into the disc cylinders of 50 mm thickness and 100 mm thickness diameter using cutting machine. Then the samples lateral side is coated with epoxy resin and rests it for dry. Specimens are kept in vacuum chamber for 3 hours and then saturated it with water. After that, the specimens are inserted into the cells and seal it tight using epoxy resin so that it will be water tight and keep it for one day for drying. One cell is connected to cathode terminal that is filed with 3% of sodium chloride solution. Other cell is connected to anode filled with 0.3N of sodium hydroxide solution. Specimens are subjected to 60V potential continuously for 6 hours. Current and temperature readings being measured in every 15 minutes, from which total charge passed is calculated.

Average current flowing through one cell is calculated by,

$I = 900* [I0 + 2*[I30 + I60 + I90 + I120 + I150 + I180 + I210 + I240 + I270 + I300 + I330 + I360]]$

Where I0, I30, I60, I90, I120, I150, I180, I210, I270, I300, I360 are the current reading at 0, 30, 60, 90,120,150,180,210, 240,270,300, 330, 360 minutes in mA.

Sorptivity Test

Sorptivity test determines the absorption of water in concrete over time. The samples were cut into disc cylinders of 25mm thick using concrete cutter. Except the bottom side of the samples, apply epoxy resin to avoid absorption and leave it for 1 day for drying. Weigh the specimens in dry condition to an accuracy of 0.01g. After that, place two sticks in the tray leaving gaps between them and the edges of tray. Keep the specimens on top of the sticks. Prepare the solution of 5% of calcium hydroxide that is for 5 grams of calcium hydroxide for 1liter of water. Pour the calcium hydroxide solution in to the tray; level of solution should be such that it will be slightly above the bottom edge of the specimen. Start the stop watch after placing the specimen. Weight the specimen at 3, 5, 7, 9,12,16,20 and 25 minutes, after wiping the solution of the specimen with a piece of cloth. Specimens should be dry while weighing the specimen. After weighing the specimen, start the stop watch again and it should only take 5-10 seconds. Below equation is used for finding sorptivity value for the specimens.

M (t) =c* t1/2

where,,M is the mass change in grams,c is the sorptivity value, t is time in minutes.

Acid Attack Test

Some chemical environments can deteriorate the concrete even if it is a high quality concrete. Sulphuric acid can be formed by sulphurous gases which forms during combustion react with moisture and forms sulphuric acid. Also, the bacteria present in the sewage converts in to sulphuric acid. During the reaction of sulphuric acid with concrete, calcium sulpho-aluminate will forms and it crystallise and causes expansion and disruption of concrete. For the acid attack test, three specimens of cubes 150mm x150mm x150 mm after curing were taken. Note the initial weights of the cubes before immersing in the solution. Specimens were immersed in the solution of 5% of sulphuric acid. The pH of 3 was maintained throughout the test. After 28, 56 and 90 days, specimens have to keep for 1 day for drying. After drying, check the weight of the specimens and also, the compressive strength of the specimens by testing it in compressive testing machine..

Sulphate Attack

Sulphate attack can happen in two ways-internal and external attacks. External sulphate attack can happen through environments like soil, water which penetrates to concrete structures. Internal sulphate attack can happen either by high sulphate content or from aggregates contaminated with gypsum. The specimens after curing were weighed and noted as the initial weight of the specimens. Then, the specimens were immersed in the 5% of sodium sulphate solution. After 28, 56 and 90 days, specimens were taken out from the solution and allow it to dry. Check the weight of the specimen as final values of specimens. Also, the compressive strength and compare it with initial compressive strength.

Chloride Attack

Chloride attack is the primarily cause of corrosion of reinforcement. Calcium chloride and sodium chloride leaches calcium hydroxide and cause concrete disintegration. For the chloride attack, specimens were immersed in 5% of sodium chloride solution. Before immersing, dry weights of the specimens are to be noted. After particular days, take out the specimens and keep it for drying. Weigh the specimens and check the variation in the weights. Also check the compressive strength and find the percentage change in the Compressive strength of the specimen.

RESULTS AND DISCUSSIONS

Properties of Aggregates

The Specific gravity and Water absorption results have been tested using pycnometer apparatus and the results are shown in Table 2.

Table 2 Steel slag aggregate Properties

S.NO	PROPERTIES	VALUES
1	Specific Gravity	2.3
2	Water Absorption	2.8%
3	Shape	Angular
4	Size	20mm

Test on Fresh Concrete

Slump cone test measures the consistency of fresh concrete before the concrete sets. It is mainly used to find the workability of the concrete by IS 7320. Hence, Slump cone is used for testing Fresh concrete and the slump cone test values are shown in table 3**.**

Table 3 Slump Test Value

S.NO	TEST	MINIMUM VALUE TO BE OBTAINED	VALUE OBTAINED	REMARKS
1	Slump Test	More than 75 mm according to IS 7320:1974	90 mm	Desirable

Test on Hardened concrete

Compressive strength of the specimens was checked by compressive strength machine after curing. The compressive strength values obtained for steel slag aggregate concrete and conventional concrete is given in Table 4.

Table 4 Compressive Strength values

S.NO	CONCRETE	SPECIMEN ID	28 DAYS COMP. STRENGTH (N/mm^2)
1	Steel Slag aggregate concrete	SSAC	38
2	Conventional concrete	CC	39.5

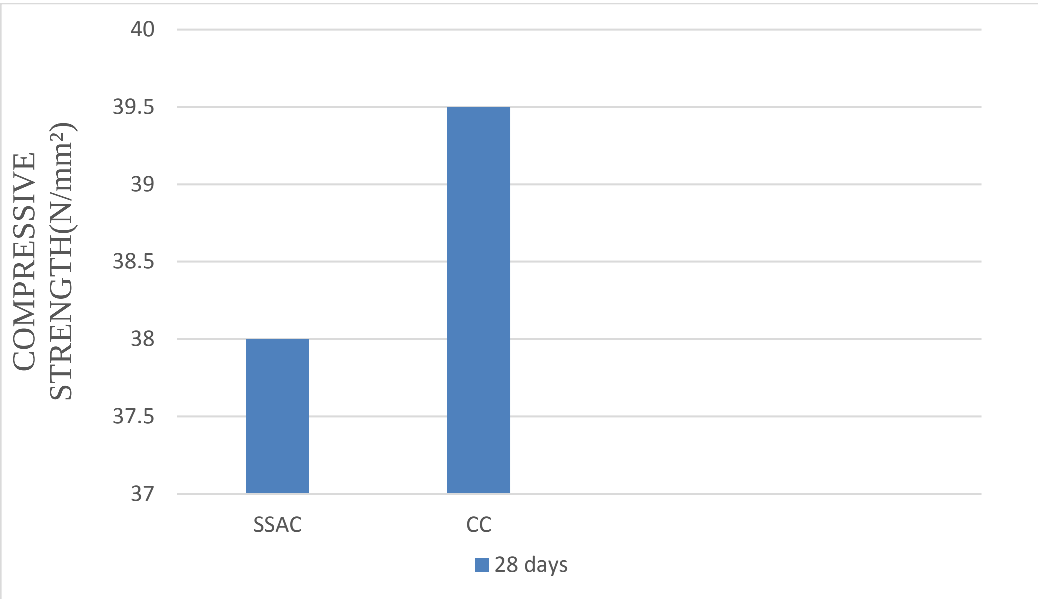

Figure 1 Compressive strength of the concrete specimens

TEST RESULTS ON FUNCTIONAL PROPERTIES

Water Sorptivity test

The samples where cut using concrete cutter into 2.5 cm thick cylinders. The samples where coated with epoxy resin on all sides except the bottom. Weights of the specimen after sealing were taken as initial weight. The initial mass of the sample was taken and at time 0 it was immersed to a depth of 5-10 mm in the water. Since the values for SSAC is below 6, the quality of concrete is good.

Table 5 water sorptivity resluts

NO OF DAYS	SORPTIVITY VALUE(10^-4) (MM/√MIN)	
	SSAC	CONVENTIONAL CONCRETE
28 days	5.31	5.42
56 days	4.91	5.11
90 days	4.36	5.03
180 days	4.12	4.89

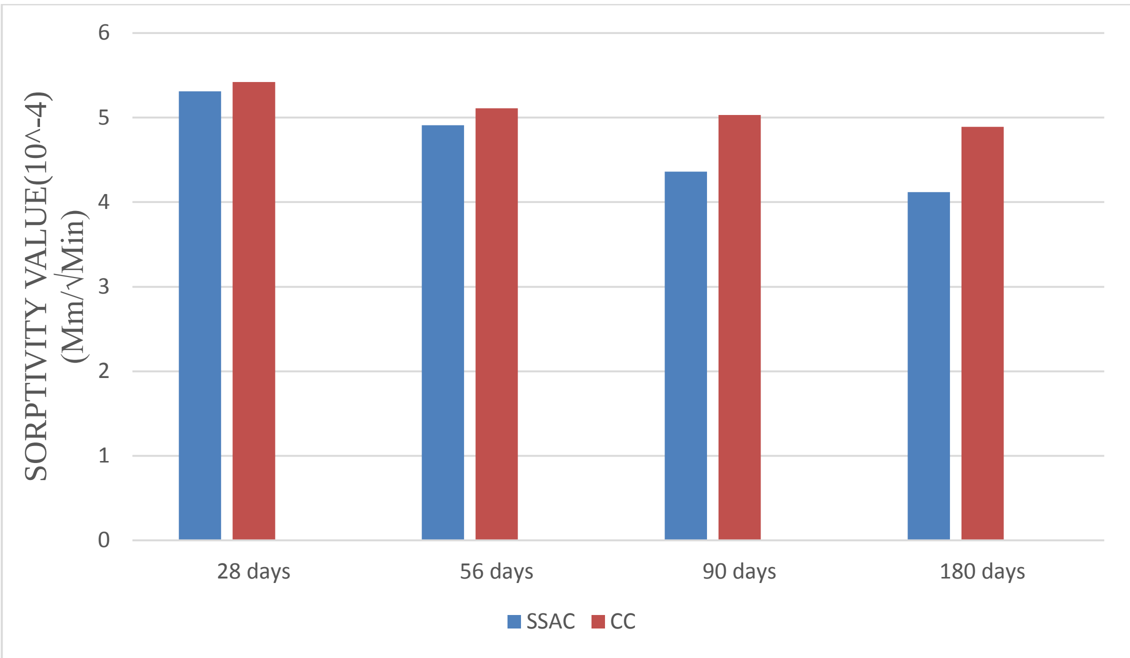

Figure 2 Change in sorptivity coefficient over time

Rapid Chloride Permeability Test

In RCPT test, two cells will be there and one connected to the cathode terminal filled with 3% Nacl and the other is filled with 0.3N NaOH connected to the anode. The readings are recorded for 6 hours with 15min interval and a potential of 60V direct current is applied between the opposite sides of the concrete.

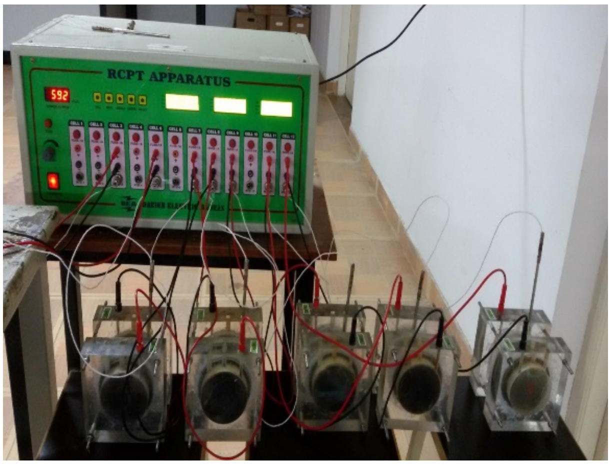

Figure 3 RCPT apparatus

Table 6 RCPT test values

TYPE	CHARGES PASSED	CHLORIDE ION PERMEABILITY
	28 days	
SSAC	1195	low
CC	895	very low
	56 days	
SSAC	1167	low
CC	820	very low
	90 days	
SSAC	1121	low
CC	762	very low
	180 days	
SSAC	1092	low
CC	741	very low

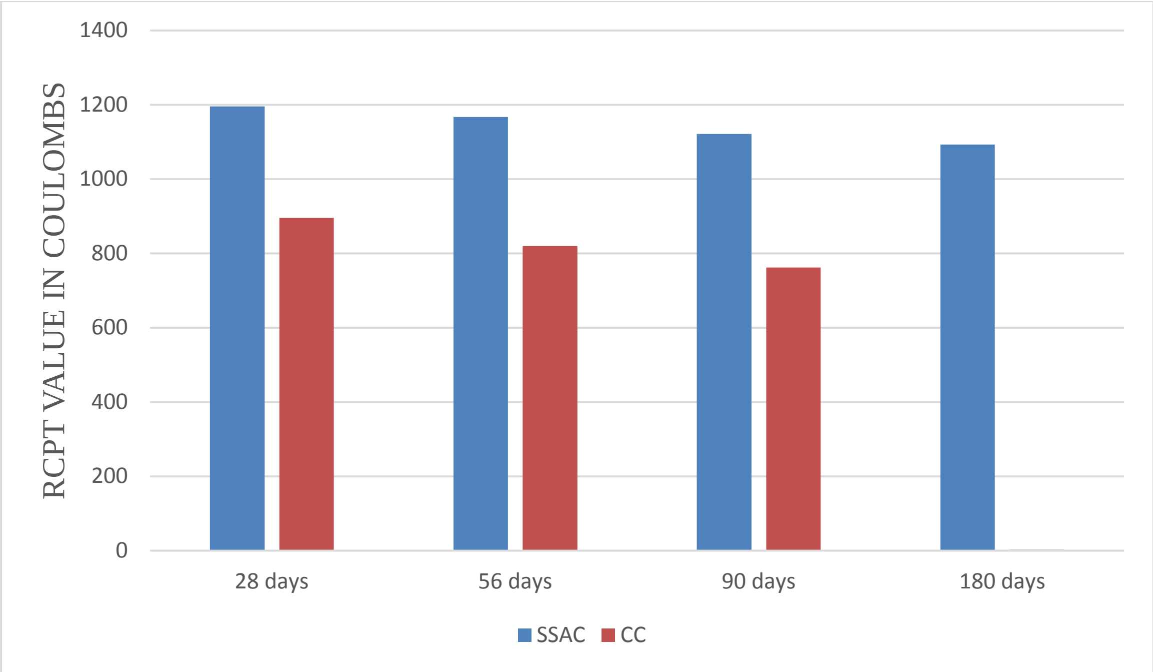

Figure 4 Comparison of RCPT results

Acid Attack Test

The samples kept in acid attack were checked for weight and compressive strength. It's noticed that there is a change in weight as the outer layer gets degraded.

Table 7 Compressive strength values

NO OF DAYS	COMPRESSIVE STRENGTH(N/MM²)		% CHANGE IN WEIGHT	
	SSAC	CONVENTIONAL CONCRETE	SSAC	CONVENTIONAL CONCRETE
28 days	33.1	35.5	2.66	2.3
56 days	29.5	33.2	5.64	5.21
90 days	27.6	29.1	8.71	8.16
180 days	26.9	28.5	12.6	11.16

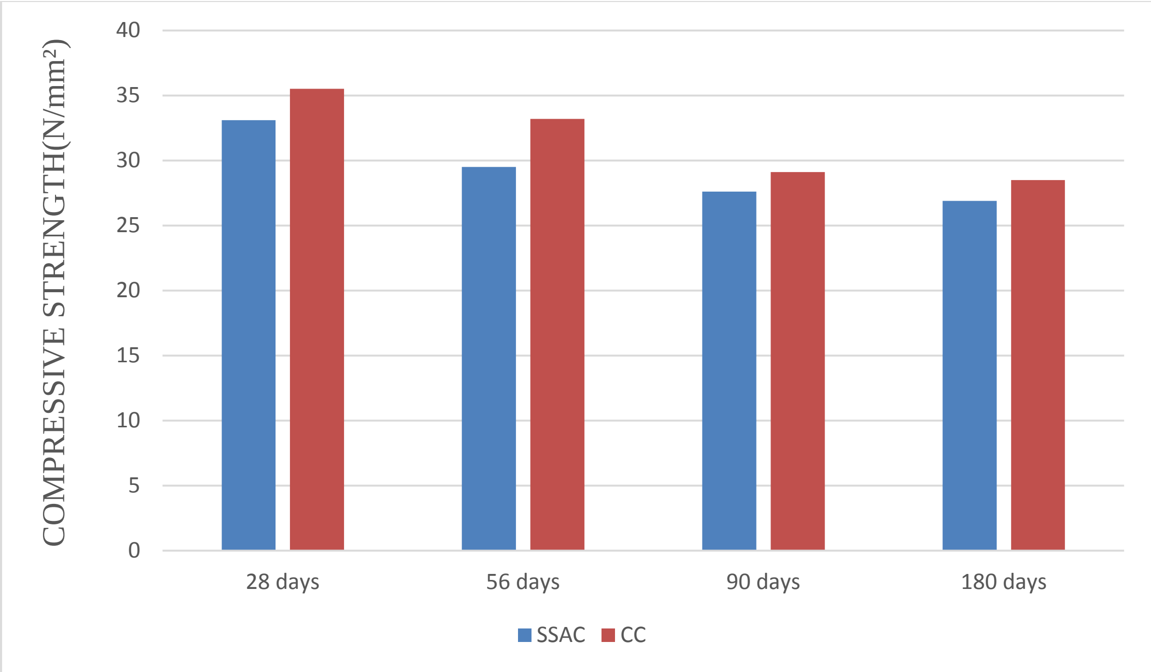

Figure 5 Compressive strength of the concrete by acid attack

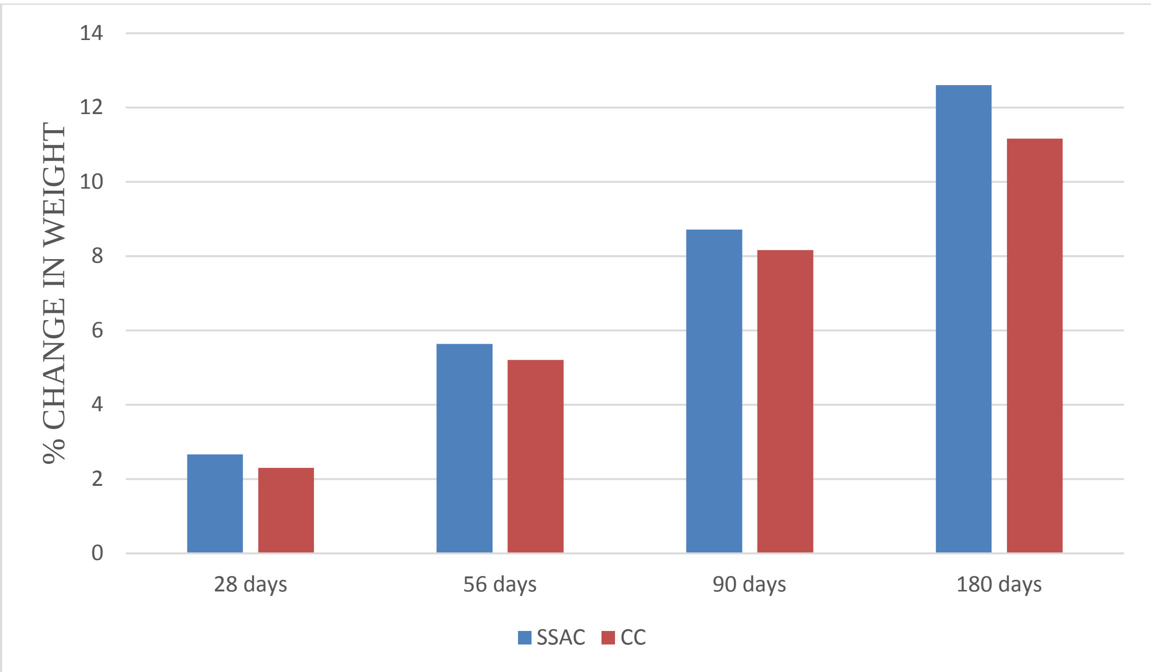

Figure 6 Change in percentage weight due to acid attack test

Sulphate Attack Test

The samples were weighed and immersed in 5% sulphate solution after curing. Table 8 shows the percentage of change in weights and compressive strength values.

Table 8 Compressive strength values

NO OF DAYS	COMPRESSIVE STRENGTH(N/MM^2)		% CHANGE IN WEIGHT	
	SSAC	CONVENTIONAL CONCRETE	SSAC	CONVENTIONAL CONCRETE
28 days	36	38.2	0.727	0.515
56 days	35.1	37.6	1.54	0.926
90 days	33.8	35.9	2.15	1.51
180 days	31.9	34.1	2.69	2.22

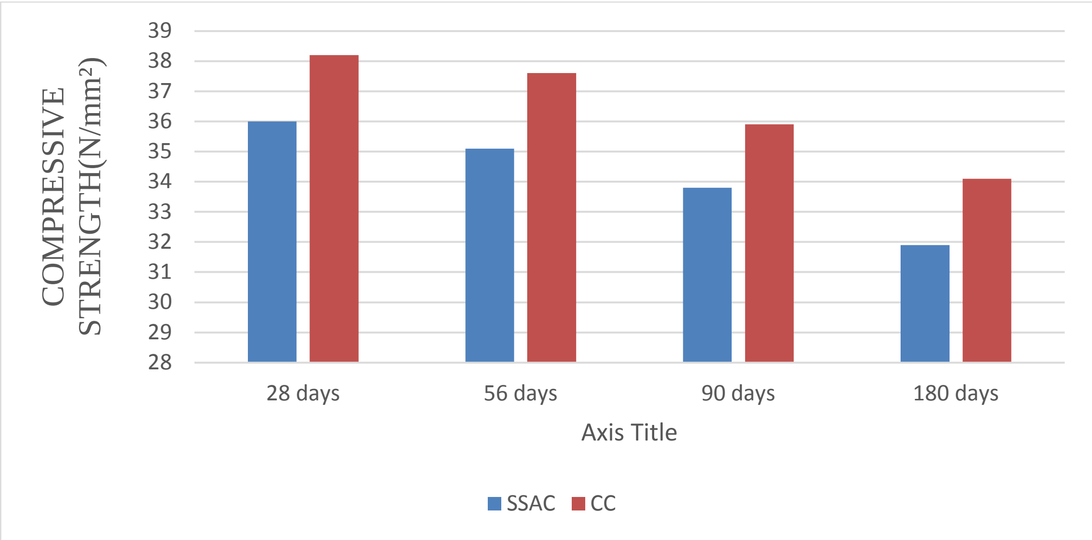

Figure 7 Compressive strength of the concrete by sulphate attack

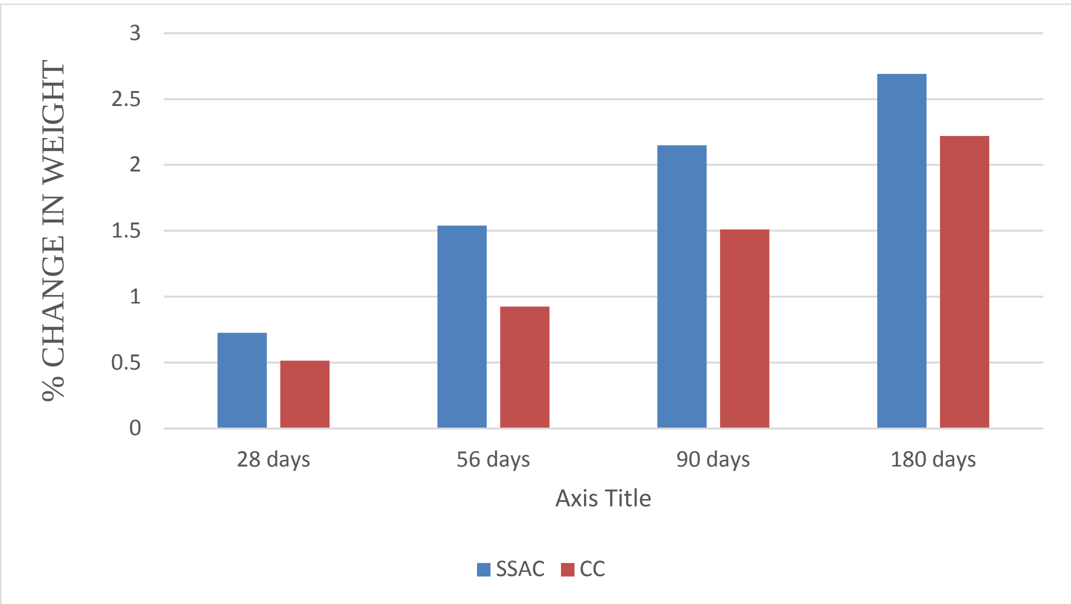

Figure 8 Change in percentage weight due to sulphate attack test

Chloride Attack Test

The specimens are kept immersed in sodium chloride solution and the insertion of chloride could be calculated by comparing the decrement in the strength of the concrete in sufficient amount of days.

Table 9 Compressive strength values

NO OF DAYS	COMPRESSIVE STRENGTH(N/MM^2)		% CHANGE IN WEIGHT	
	SSAC	CONVENTIONAL CONCRETE	SSAC	CONVENTIONAL CONCRETE
28 days	37.4	38.1	0.607	0.52
56 days	35.15	37.5	1.42	1.16
90 days	33.9	36.1	1.96	1.49
180 days	32.2	34.9	2.56	1.98

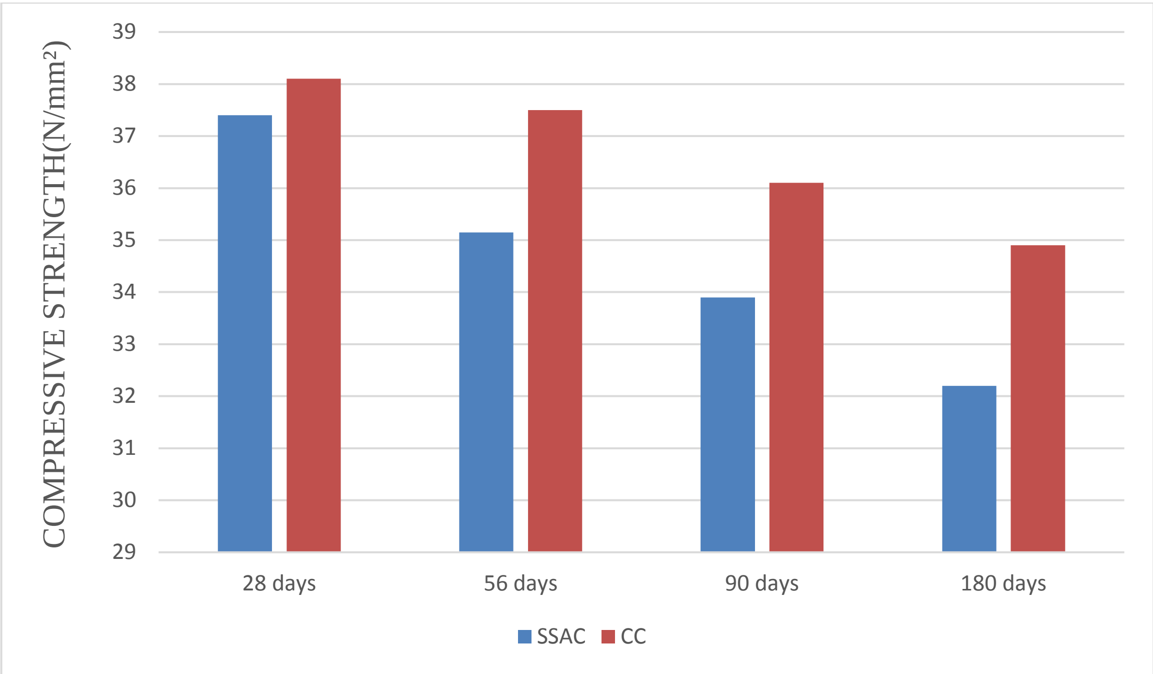

Figure 9 Compressive strength of the concrete specimens by chloride attack

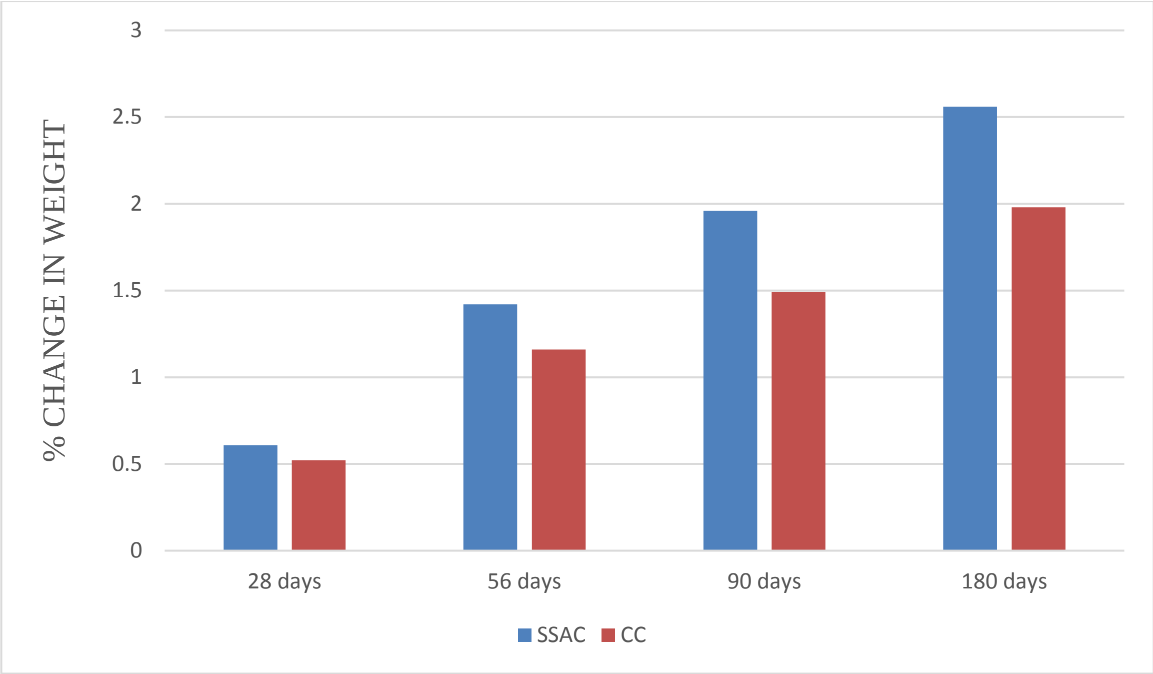

Figure 10 Change in percentage weight due to chloride attack test

CONCLUDING REMARKS

Based on the data obtained from the experiments the following conclusions can be derived regarding the performance of the concrete.

- The 28 days compressive strength of SSAC (steel slag aggregate concrete) is almost same when compared to conventional concrete.
- Since the water sorptivity value for SSAC (steel slag aggregate concrete) is below 6, the quality of concrete is good.
- The chloride ion penetration for SSAC (steel slag aggregate concrete) is low.
- It is observed that during acid attack there is a considerable decrease in both strength and weight compared to sulphate attack and chloride attack.
- SSAC (steel slag aggregate concrete) gives better results and since Steel slag is an industrial waste, we can use steel slag aggregate concrete for low constructions.

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