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Original Research

Development of Eco Friendly Cement Concrete Using Ground Granulated Blast Furnace Slag

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Abstract

Cement is the most commonly used construction material. Now, cement production is increasing rapidly. In order to minimize the production and usage of cement, an alternative solution is to be implemented as either or partial replacement of cement. GGBS is the waste byproduct produced during the manufacturing of Steel. GGBS is used as a replacement for cement for every 5% and the optimum mix is found out by studying the mechanical properties. Replacement of GGBS was carried out up to 50% against cement. The presence of GGBS in the concrete mix exhibits notable achievement in the compressive strength of the concrete, however the presence of GGBS reduces the performance of concrete in split tensile stress and flexural stress due to increase in brittleness of the material. Modulus of elasticity of GGBS concrete shows prominent performance when compared with conventional concrete. From the above mixes, GGBS with 45% replacement against cement in concrete shows a better performance.

Keywords: GGBS, concrete, mechanical properties, steel slag

Introduction

India is the second largest producer of cement next to china. According to recent survey, it was found that cement requirement will rise 550 to 600 million tonnes per annum by the year 2025. Cement Production in cement industry is the major cause of global warming which liberates carbon dioxide [1, 2]. In order to reduce the global warming and to decrease the cement and aggregates in concrete, the alternatives are to be used like GGBS, Steel Slag, Fly ash etc., [3, 4] Granulated Blast Furnance Slag known as GGBS are the byproduct of blast furnace which is delivered during the manufacture process of iron. The iron is operated at 1500 deg Celsius and are quenched in large volume of water to form molten glassy materials and are further crushed to form powdered material known as GGBS. GGBS is used as a replacement for cement in concrete [5, 6]. Due to the usage of GGBS in cement, the production and usage of cement in concrete can be reduced to a considerable quantity [7]. Steel slag is the byproduct when lime is added to extract impurities during steel manufacturing process and it amounts about 15-20% of crude steel production [8, 9]. The application of steel slag includes producing metallurgical raw materials, road construction works, innovative building materials, environmental and also in agricultural fields. However, the application of steel slag in concrete is still

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Table 1. Chemical Composition of Cement.

%	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	Alkalines
Cement	63.71	22.3	4.51	3.39	1.77	2.59	1.73

minimum [10-13]. Steel slag is used as a replacement for aggregates. In our study, we are going to used GGBS as replacement for cement, finely grained steel slag as replacement for fine aggregate and coarsely grained steel slag as replacement for coarse aggregate in concrete.

Materials and Methods

Cement

OPC of 53 grade conforming to IS 12269 [14] was used in this study. The Chemical composition of Cement is shown in Table 1. River sand used as fine aggregate with specific gravity of 2.65 and 10 mm and 20 mm stone extracted from the quarry was used as a course aggregate with specific gravity of 2.8.

Ground Granulated Blast Furnace Slag

Ground Granulated Blast furnace Slag (GGBS) is a byproduct from the blast furnaces used to make iron. These operate at a temperature of about 1500 degrees centigrade and are fed with a cautiously controlled mixture of iron ore, coke and limestone. The iron ore is reduced to iron and the left over materials from a slag is floated on top of the iron. This slag is sometimes tapped off as a molten liquid and if it is to be used for the manufacture of GGBS it has to be rapidly satisfied in large volumes of water. The satisfying increases the cementitious properties and produces granules similar to coarse sand. This granulated slag is after that dried and ground to a powder.

Steel Slag

Steel slag is a by-product of the conversion of iron to steel process and it presents differences depending on the raw materials and process. Fifty million tons per year of steel slag are produced as a residue in the world. Owing to the intensive research work during the last 30 years, today about 65% of the produced steel slags are used on qualified fields of application. But the remaining 35% of these slags are still dumped. This Steel slag is crushed into pieces and used as a fine and coarse aggregate along with conventional fine and coarse aggregate [15].

Mix Proportions

Target mix strength of the concrete is M50 grade, Cement is replaced by GGBS from 5% to 45% by its weight. The different mix proportions used in this investigation is listed in Table 2.

Compressive Strength

Compressive strength is the capability of concrete material to take the compressive or flexural loads on its face without any deformation and cracks in the material. For this investigation 150 mm x 150 mm x 150 mm

Table 2. Mix Proportion of mixes developed with GGBS.

Mix ID	Cement (kg/m^3)	GGBS (kg/m^3)	Course Agg (kg/m^3)		Fine Agg (kg/m^3)	Silica Fume (kg/m^3)	Water/ Cement	Super Plasticizer (%)
			10 mm	20 mm				
CC	415	--	514	770	653	83	0.34	1.2
GGBSI	394.25	20.75	514	770	653	83	0.34	1.2
GGBSII	373.5	41.5	514	770	653	83	0.34	1.2
GGBSIII	352.75	62.25	514	770	653	83	0.34	1.2
GGBSIV	332	83	514	770	653	83	0.34	1.2
GGBSV	311.25	103.75	514	770	653	83	0.34	1.2
GGBSVI	290.5	124.5	514	770	653	83	0.34	1.2
GGBSVII	269.75	145.25	514	770	653	83	0.34	1.2
GGBSVIII	249	166	514	770	653	83	0.34	1.2
GGBSIX	228.25	186.75	514	770	653	83	0.34	1.2
GGBSX	207.5	207.5	514	770	653	83	0.34	1.2

size cubes were used to study the performance of different concrete mixes under compression after 28 days curing in a room temperature [16]. 100 Tonne compressive strength testing machine was used for this investigation and test was carried as per IS standards. For each mix three cubes were used for compression test.

Split Tensile Strength

Split tensile strength is one of the important properties of concrete material, since concrete is weak in tension owing to its brittle in nature. For this study cylindrical specimen of diameter 150 mm and 300 mm height is used for this investigation [17]. Cylinder is place horizontal on the compression testing machine and load was applied along the length to split the specimen. Formula given below was used to determine the split tensile stress of specimen, where P is the applied load, L is the length of the cylinder specimen, d is the diameter of cylinder.

Split Tensile Strength, $T = 2P/(\prod Ld)$

Flexural Strength

To evaluate the tensile strength of concrete indirectly flexural strength test setup was used. This is also called as modulus of rupture. Specimen of size 100 mm x 100 mm cross section and 500 mm length prism was used for this study. After 28 days curing specimen was subjected to investigation under flexural testing machine, clear span of the specimen is 450 mm and two point load was applied at every 150 mm [18].

Flexural Strength, $F = (P*L)/(bd^2)$

The formula is used to determine the flexural stress in the concrete, P is the applied load, L is the span between the support, b and d is the breadth and depth of the specimen respectively.

Modulus of Elasticity

Cylinder specimen of size 150 mm diameter and 300 mm length is used to determine the modulus of elasticity of concrete, this test provide the performance of hardened properties of cement paste with the coarse aggregate [19]. Compressometer is used to determine the strain in the concrete and it is placed in the center portion of length of the cylinder and dial gauge present in the compressometer provides the contraction of specimen under compressive load.

Sulphuric Acid Attack

The concrete cubes of size 150 mm x 150 mm x 150 mm are prepared for various percentage replacement of marble dust and quarry dust cured properly with mould for 24 hours, and the specimen are demoulded after 24 hours and kept in a curing tank for another 28 days and all the specimens are kept in an open atmosphere for 48 hours at a constant weight. Then specimens are weighed and immersed in sulphuric acid solution (H_2SO_4) of 5% concentration for 90 days. The pH value of the sulphuric acid media is 2.75 and checked periodically for constant maintenance of pH value. After 30 and 90 days of immersion in the acid solution, concrete specimen were taken out and washed in water and kept in atmosphere for 48 hours at a constant weight. Then the specimens were weighed. The loss in weight is calculated and after the measurement of weight, compressive strength of concrete is determined. Then the percentage of loss of weight and loss in strength were calculated.

Hydrochloric Acid Attack

The concrete cubes of size 150 mm x 150 mm x 150 mm are prepared for various percentage replacement of marble dust and quarry dust cured properly in a mould for 24 hours , and the specimen are demoulded after 24 hours in a curing tank for another 28 days and all the specimens are kept in atmosphere for 48 hours at a constant weight. Then specimens are weighed and immersed in hydrochloric acid solution (Hcl) of 5% concentration for 90 days. The pH value of the hydrochloric acid media is 3.01 and checked periodically for constant maintenance of pH valued. After 30 and 90 days of immersion in the acid solution concrete specimen were taken out and washed in water and kept in atmosphere for 48 hours at a constant weight. Then the specimens were weighed and the loss in weight is calculated and after measurement of weight compressive strength of concrete is determined. Then the percentage of loss of weight and loss in strength were calculated.

Results and Discussion

Compressive Strength

Compressive Strength GGBS based concrete mixes are shown in the Fig. 1. From the figure it was observed that the mix with 45% of GGBS performed better in compressive strength. Conventional concrete mix CC exhibit the compressive strength of 53.1 MPa, similarly mix GGBS9 exhibit 54.5 MPa. GGBS is replaced against the cement with the increment of 5% and stopped up to 50%, since the strength reduced after 45% replacement. 51.3 MPa, 52.1 MPa, 52.1 MPa, 52.4 MPa, 52.7 MPa, 52.9 MPa, 53.3 MPa, 53.9 MPa and 52.3 MPa are the compressive strength of concrete for GGBS1, GGBS2, GGBS3. GGBS4, GGBS5, GGBS6, GGBS7, GGBS8 and GGBS10 mixes respectively. The presence of GGBS improves the performance of the concrete under compressive strength, since 3.5%

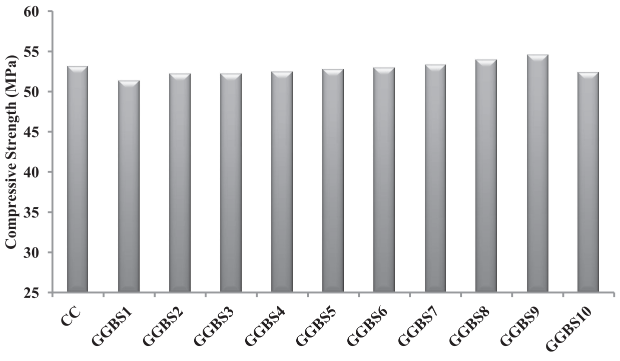

Fig. 1. Compressive Strength of GGBS based Concrete.

is the lowest strength of GGBS concrete from the conventional concrete strength [20].

Split Tensile Strength

Split tensile strength of concrete is show in the Fig. 2, from the results it was observed that presence of GGBS decrease the split tensile strength of the concrete. 5.21 MPa was the split tensile strength of conventional concrete, which is greater than 4.7%, 3.2%, 3.8%, 4.6%, 5.3%, 5.3%, 6.3%, 6.8%, 7.4% and 13.3% for the mixes for GGBSI, GGBSII, GGBSIII, GGBSIV, GGBSV, GGBSVI, GGBSVII, GGBSVIII, GGBSIX and GGBSX mixes respectively. In the results it is observed that the presence of GGBS reduces the split tensile strength of concrete having notable compressive strength, this shows that split tensile strength decreases with increases in GGBS content in the concrete. Brittleness of concrete was improved due to the presence of GGBS in the concrete mixes. [21].

Flexural Strength

Flexural Strength of the concrete is shown in Fig. 3. On analyzing the results, it is found that the GGBS influences the flexural strength of concrete. With the addition of GGBS, the strength of concrete decreases simultaneously. The flexural strength of conventional concrete is 4.87 MPa, however the flexural strength of GGBSI, GGBSII, GGBSIII. GGBSIV, GGBSV, GGBSVI, GGBSVII, GGBSVIII, GGBSIX and GGBSX mixes are 4.70 MPa, 4.78 MPa, 4.78 MPa, 4.74 MPa, 4.71 MPa, 4.66 MPa, 4.66 MPa, 4.63 MPa, 4.62 MPa, 4.6 MPa respectively [22]. Fig. 5 shows the regression analysis of flexural strength vs compression strength. From the regression analysis, it is found that experimental values are almost similar to the predicted values.

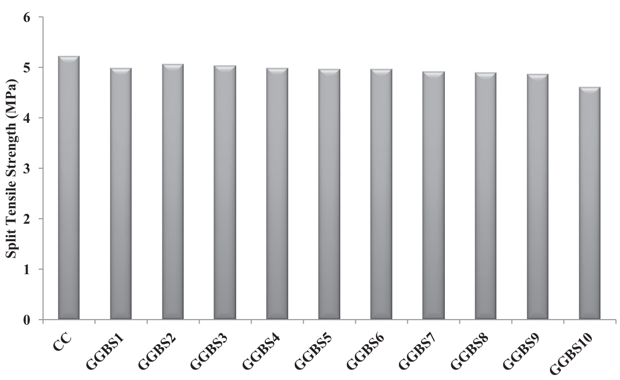

Fig. 2. Split Tensile Strength of GGBS based Concrete.

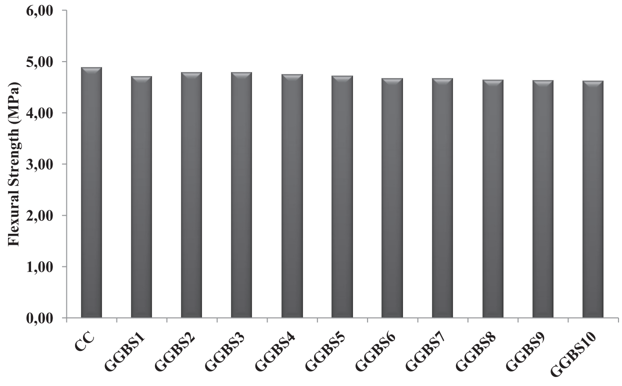

Fig. 3. Flexural Strength of GGBS based Concrete.

Modulus of Elasticity

Modulus of Elasticity of GGBS based concrete mixes are shown in the Fig. 4. From the figure it was observed that the mix with 45% of GGBS performed better in Modulus of Elasticity. Modulus of Elasticity of mix GGBSIX is 2.97% greater than conventional concrete. GGBS is replaced against the cement with the increment of 5% and stopped up to 50%, since the strength reduced after 45% replacement [23].

Sulphuric Acid Attack

The percentage of loss in strength, percentage of weight loss due to sulphuric acid attack for 30 days, 60 days and 90 days are represented in Fig. 5 and

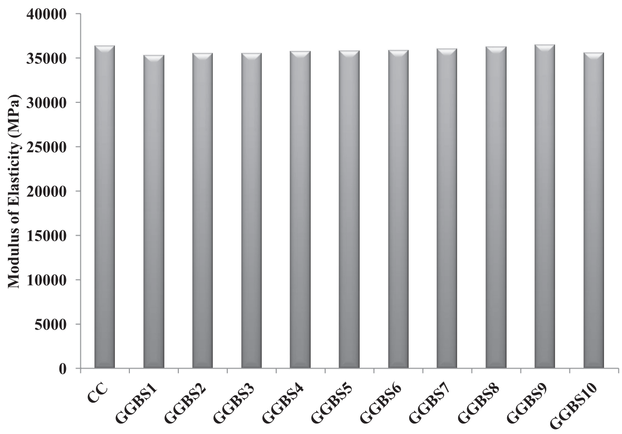

Fig. 4. Modulus of Elasticity of GGBS based Concrete.

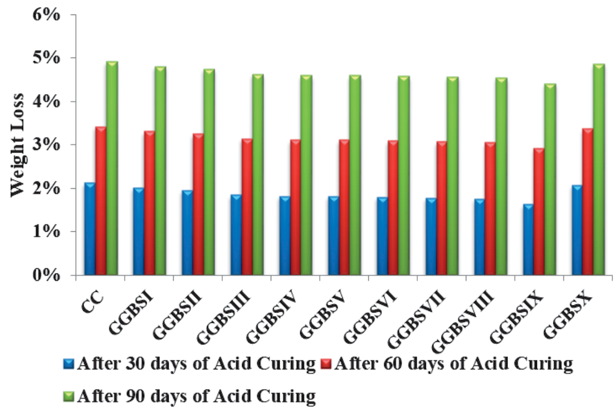

Fig. 5. Weight Loss of specimen under Sulphuric Acid Attack.

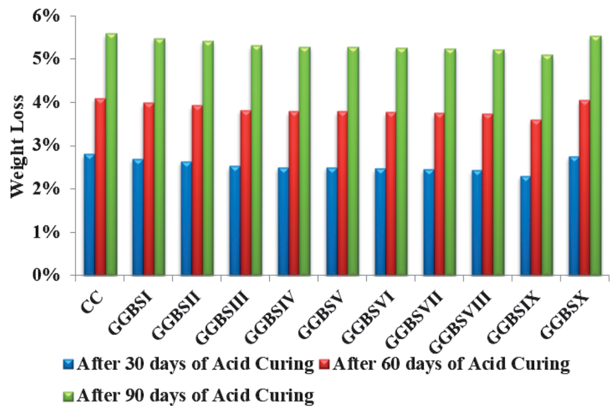

Fig. 7. Weight Loss of specimen under Hydrochloric Acid Attack.

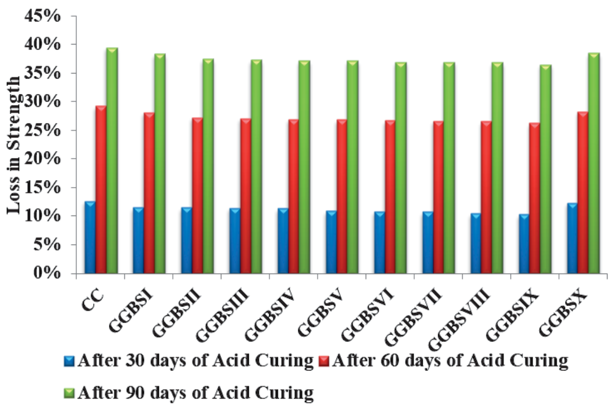

Fig. 6. Loss in Strength of specimen under Sulphuric Acid Attack.

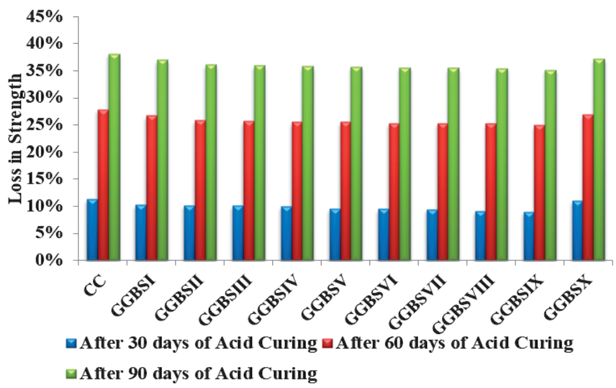

Fig. 8. Loss in Strength of specimen under Hydrochloric Acid Attack.

Fig. 6 respectively. The percentage change in compressive strength of various mixtures after 30 days of Sulphuric acid attacks were between 10.34% to 12.63%, after 60 days of Sulphuric acid attacks were between 26.29% to 29.24%, after 90 days of Sulphuric acid attacks were between 36.52% to 39.47%. Similarly for percentage of weight loss due to sulphuric acid of various mixtures after 30 days of Sulphuric acid attacks were between 1.63% to 2.13%, after 60 days of Sulphuric acid attacks were between 2.93% to 3.43%, after 90 days of Sulphuric acid attacks were between 4.42% to 4.92%. From the test results, it was observed that the mix developed with GGBSIX perform better than the other mixes. Presence of steel slag aggregates resists the sulphuric acid due to strong interfacial bond between cement paste and steel slag aggregate.

Hydrochloric Acid Attack

Percentage of loss in strength, percentage of weight loss due to hydrochloric acid attack for 30 days, 60 days and 90 days are represented in Fig. 7 and Fig. 8 respectively. The percentage change in compressive strength of various mixtures after 30 days of hydrochloric acid attacks were between 1.63% to 2.13%, after 60 days of hydrochloric acid attacks were between 2.93% to 3.43%, after 90 days of hydrochloric acid attacks were between 4.42% to 4.92%. Similarly for percentage of weight loss due to Hydrochloric acid of various mixtures after 30 days of hydrochloric acid attacks were between 1.63% to 2.13%, after 60 days of hydrochloric acid attacks were between 2.93% to 3.43%, after 90 days of hydrochloric acid attacks were between 4.42% to 4.92%. From the test results, it was observed that the mix developed with GGBSIX perform better than the other mixes. Presence of steel slag aggregates resists the hydrochloric acid due to strong interfacial bond between cement paste and steel slag aggregate.

Conclusion

An experimental study was carried out to investigate the effect of GGBS in split tensile strength, flexural strength, compressive strength and modulus of elasticity of concrete. The following conclusion is made

– Compressive strength of GGBS concrete performed better than the conventional concrete and 45% GGBS (Mix GGBS IX) replaced concrete exhibit more strength.

– The performance of GGBS concrete in split tensile strength and flexural strength is not at expected level. Presence of GGBS reduces the indirect tensile strength of concrete due to its brittleness nature.
– In the case of modulus of elasticity the harden gel formation of GGBS concrete was better than the conventional concrete, similar to the compressive strength concrete with 45% GGBS (Mix GGBS IX) exhibits better performance.
– The presence of steel slag aggregate increases the durability of concrete also increases due to the strong interfacial bond between cement paste and steel slag aggregate.

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Conflict of Interest

The authors declare no conflict of interest.

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