EXPERIMENTAL STUDIES ON USE OF GGBS AND STEEL SLAG IN CONCRETE MIXTURE

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ABSTRACT: The increasing demand of use of industrial wastes in construction industry puts forwards the question of its effect on mechanical and rheological properties of concrete. The principal objective of this experimental investigation is to establish that the use of pozzolanic materials in concrete structures does not affect the behavior of concrete significantly. To test the mechanical properties, cube, beam and cylinder specimens were cast and tested up to failure. The size of all the samples and testing were as per IS 516:1959.With reference to the literature, 40% fine aggregate was replaced by granular steel slag. However cement was replaced by GGBS, with replacement ratios of 0%, 10%, 20%, 30% and 40%.The comparison of samples with and without GGBS indicates that there is an increase in compressive, flexural and split tensile strength of concrete up to 30% replacement of GGBS. This may be associated with the denser matrix and greater water absorption offered by GGBS.

Keywords: GGBS, steel slag,HSBFC, chemical composition,coarse and fine aggregate.

INTRODUCTION

1.1 GENERAL

India is a developing country and since independence, the Government of India has launched six-year plans for industry, agriculture, transport etc. These plans envisage the construction of road and bridges. Industrialization demands the construction of factories and houses. The spread of education involves the construction of schools, colleges, and universities. Urbanization demands public health engineering schemes and slum clearance schemes. Agriculture presupposes in irrigation facilities and flood control measures, which need construction of dams, barrages, weirs, and spillways. All these construction activities demand the efficient and economical use of construction materials. Concrete is one of the important basic construction materials for all above type of construction projects.

Concrete is used over a wide area as construction materials in the world. In order to promote sustainability and reduce stress on the environment due to the extraction of natural sources in the production of cement and concrete, there is growing emphasis on identification of alternate sources of these materials. Direct substitution of the waste products from various industries is one of the effective steps towards sustainable development, as a result, the study on the use of alternate materials in concrete gained momentum.

GGBS is used to make durable concrete structures in combination with ordinary Portland cement and/or other pozzolanic materials. GGBS has been widely used in Europe, and increasingly in the United States and in Asia for its superiority in concrete durability, extending the lifespan of buildings from fifty years to a hundred years.

Two major uses of GGBS are in the production of quality-improved slag cement, namely Portland Blast furnace cement (PBFC) and high-slag blast-furnace cement (HSBFC), with GGBS content ranging typically from 30 to 70%; and in the production of ready-mixed or site-batched durable concrete.

Concrete made with GGBS cement sets more slowly than concrete made with ordinary Portland cement, depending on the amount of GGBS in the cementitious material, but also continues to gain strength over a longer period in production conditions. This results in lower heat of hydration and lower temperature rises, and makes avoiding cold joints easier, but may also affect construction schedules where quick setting is required.

1.2NECESSITY OF GGBS IN CONSTRUCTION FIELD

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1.3 USEFUL OF STEEL SLAG IN THE CONSTRUCTION INDUSTRY

Slag is usually a mixture of metal oxides and silicon dioxide. However, it can contain metal sulfides and elemental metals.

Slag is the glass-like by-product left over after the desired metal has been separated (i.e., smelted) from its raw ore. Slag is usually a mixture of metal oxides and silicon dioxide. Slag, aka ground granulated blast furnace slag (GGBFS) is used as a supplementary cementitious material. It can be used ot replace some of the Portland cement in concrete. It can help to make economical concrete of exceptional quality. It can decrease the exothermically produced temperature rise in large sections. It can markedly help reduce the permeability of chloride ions. It can mean a significant economical benefit.

1.6 OBJECTIVES

1. Selected mix is of proportions 1:1.5:3 by weight.

2. Tests on rheological properties of concrete.

3. Tests on hardened properties uses of compressive strength, split tensile strength, flexural strength and bond strength.

4. Tests on durability properties will be carried out by exposing the specimens to 2% Na_2SO_4 and 5% $MgSO_4$ solution for certain duration.

1.7 SCOPE OF WORK

1. To study rheological properties of concrete mixes having GGBS and Steel Slag.
2. The hardened properties of said concrete mixes when compare both.

3. Replace the percentage of cement by slag to reduce the CO_2 emissions and reducing the global warming effect in overall.
4. To know the performance of said mixes from durability point of view.

1.8 METHODOLOGY

1. Nominal mix of 1:1.5:3 was considered.

2. The gradation of aggregate was conforming to Table 4 of IS 383 (1970).

3. In order to achieve consistency in hardened properties of concrete the coarse aggregates sieved and stored separately in fraction size of 20-16 mm, 16-12.5 mm, 12.5-1 mm and 10- 4.75 mm and used subsequently in concrete mixtures with predefined percentage of respective fraction size.

4. The control specimens were tested in compression, split tension and flexural in accordance to IS 516:1959.

5. The specimens were also tested for loss in weight after exposure to 2% Na_2SO_4 and 5% $MgSO_4$ solutions.

6. Results were logged, compared and analyzed.

2. LITERATURE REVIEW

Reshma Rughooputh and Jaylina Rana[1] studied the effects of partial replacement of OPC by GGBFS on various properties of concrete including compressive strength, tensile strength, splitting strength, flexure strength, modulus of elasticity, drying shrinkage and initial surface absorption. Cement was partially replaced by 30 % and 50 % of GGBFS by weight and test was performed at 7 and 28 days. It was found that GGBFS in concrete leads to lower early compressive strength gain but higher later compressive strength gain. Flexural strength of test specimens is creased by 22% and 24%, tensile strength increased by 12% and 17% for 30% and 50% replacement respectively. Drying shrinkage increased by 3% and 4%. Static modulus of elasticity increases by 5% and 13%. She also observed that the initial surface absorption decreases as the GGBFS content increases because GGBFS decreases the permeability of concrete. Based on the results the optimum mix was the one with 50% GGBFS.

Vijaya Gowri et. al.[2] In this literature review they compare the effect of partial replacement of cement with GGBS on compressive strength and flexural strength of concrete at 28,90,180,and 360 days. From all investigation they used 50% GGBS as replacement material of cement of various water/binder ratio i,e.0.55,0.50,0.45,0.40,0.36,0.32,,0.30 and 0.27.After completion they observed that the high volume of slag concrete gains enough amount of strength in 90 days .It increase along with decrease in water /binder ratio. He found out that the strength of high volume of slag concrete.

Sabeer Alavi.C et. al.[3] In this research paper studied about the effect of partial replacement of cement with 10-50% of GGBS and found that 30% GGBS replacement is good but after that they conclude that the compressive strength started decrease. when they increase GGBS after that they concluded the split tensile strength and flexural strength conducted at 7 and 28 days also increases

Magandeep et. al.[4] Replacement of GGBFS increase from 10 to 40% ,when they observed the slump value of various mix proportion of GGBFS concrete increase.
When the percentage of GGBFS increases at the age of 7 to 28 days decrease the value of compressive strength and flexural strength, but in this case percentage of GGBFS increase the age of 56 days. from the research paper when he used 20% and 30% cement replace then give a better performance than control mix at 56 days, whereas 40% cement replacement looked like decreases in strength at 56 days.
He also observed that the split tensile strength of the mix with 20% and 30% cement replacement better performed than control mix at 56 days where as the mix with 40% cement replacement showed a decrease in strength at 56 day.

Santosh Kumar Karri et. al.[5] selected 30%, 40% and 50% as cement replacement levels and cured the specimens of M20 and M40 grade of concrete for 28 and 90 days. He found out that the workability of concrete increases with the increase in GGBS replacement level. He observed that the maximum compressive strength, split tensile strength and flexural strength is achieved at 40% cement replacement for both M20 and M40 grade concrete, beyond which the strength decreases slightly. Concrete cubes were also exposed to H2SO4 and HCl of 1% and 5% concentration and were tested for compressive strength at 90 days and 28 days respectively. It was observed that the resistance power increases up to 40% replacement beyond which it decreases but the compressive strength values of acid affected concrete decreases on comparison with normal concrete. It was also seen that the compressive strength of GGBS concrete affected to HCl was greater than that of H2SO4.
Devi, V. Subathra and B. K. Gnanavel[6] have examined experimentally the effect of partial replacement of coarse and fine aggregates by steel slag on the mechanical and durability properties of concrete by using the mix design of M20 grade. The optimum percentage of replacement of fine and coarse aggregate by steel slag is found. Workability of concrete gradually decreases as the percentage of replacement 8 increases, which is found using slump test. Compressive strength, tensile strength, flexural strength and durability tests such as acid resistance, using HCl, H2S04 and Rapid chloride penetration are experimentally investigated. The results indicate that for conventional concrete, the partial replacement of fine and coarse aggregates by steel slag improves the compressive, tensile and flexural strength. The mass loss in cubes after immersion in acids is found to be very low.

3. EXPERIMENTAL PROGRAM

3.1 GENERAL

This chapter presents the properties of various constituent materials used in this investigation, details of concrete mixture, and the characteristics of the test specimens together with the relevant procedures. The following part deals with the experiments conducted on specimens and related design details, instruments have been presented and discussed in detail. It is believed that the results of this investigation will serve to add value to the state-of-the-art on the application of slag in concrete use in structural members and to the design procedures in current codes.

3.2 MATERIALS

The test specimens used in this investigation were made using locally available Ordinary Portland Cement (OPC), Ground Granulated Blast Furnace Slag (GGBS), Fine Aggregates (FA), Coarse Aggregates (CA), Granular Steel Slag (SS), potable water. All the materials compiled with requirements of the relevant Indian Standards and their characteristics are presented in the following subsections.

3.2.1 CEMENT

Ordinary Portland Cement (OPC) of grade 53 from a single source and conforming to the requirements of IS 12269-1987 was used throughout the investigation. The physical analysis of cement was carried out in accordance to the requirements of IS 8112: 2013 and the measured values are presented below.Following tests were performed on the cement samples

- Fineness of cement
- Soundness test
- Standard Consistency
- Initial and final Setting Time
- Compressive strength of mortar cube

FINENESS TEST

To find the fineness of cement used in the investigation, weight of cement sample taken was 100 grams.

It is found that weight retained on IS 90 micron sieve after 15 minute hand shaking was 9grams.Thus percentage residue by weight of the sample was 9%.

As per IS:4031-1968, the residue should not exceed 10 % by weight of the cement sample. Thus the test result is below the limiting value of the IS code.

SOUNDNESS TEST

Apparatus used for the test was Le Chatelier apparatus (conforming to IS: 4031-1988)

Weight of cement sample considered was 100 gms

According to IS: 4031-1988 water added to cement should be = 0.78*standard consistency. Thus, Water: 0.78x31.5 = 24.57 ml It was observed that distance between the indicator points before boiling of water was 22 mm Also, distance between the indicator points after boiling of water (i.e. after 3 hours) was 26 mm.

Thus, expansion of apparatus due to cement expansion = 4 mm

As per IS standards0(IS:4031-1988), difference between the two pointers should not exceed 10 m). Thus the results fall within the limit.

Table 3.1 : Results of standard consistency test

Sr No	% Water added	Penetration from bottom (mm)
1	25	32
2	27	19.5
3	30	12
4	31	8.5
5	31.5	7

It was observed that for 31.5% of water added, the penetration of the plunger was 7mm From the bottom of the vicat's mould. As per IS:4031-1968, the penetration of plunger should lie between 5-7 mm for standard consistency. Thus, standard consistency of cement considered is 31.5%.

Table 3.2 : Results of setting time test

Time (minutes)	Penetration from bottom (mm)
0	0
30	2
40	3
50	4
60	4.5
65	5

It is observed from Table3.2 that the Vicat's needle failed to penetrate less than 5 mm from the bottom of the mould fter 65 minutes.It is also observed that after 215 minutes into the test, the annular attachment of the needle failed to make an impression.

Thus,Initial Setting Time = 65 min.
Final setting time = 215 minutes

SPECIFIC GRAVITY AND WATER CONTENT TEST

For this test, the sample of fine aggregate was taken as 500 gm. Pycnometer test was performed on the sample for determination of specific gravity and water content.

Table 3.4 : Results of pycnometer test

Description	Sample
Weight A : weight of jar + water +Sample	1.711
Weight B : weight of jar + water	1.38
Weight C: Surface dry weight (after 24 hours)	0.538
Weight D : Oven dry Weight (100 to 105 ^{o}C for 24 hours)	0.498
Specific gravity [C /(B-A +C)]	2.601
Water content [{(C-D) / D} x 100]	8.03%

COMPRESSIVE STRENGTH TEST OF CEMENT MORTAR CUBES

According to IS 4031-1988, for the test of compressive strength of cement, a cement mortar of cement to sand proportion0as 1:3 should be considered.

Here, we have taken weight of cement as 200gm.

And weight of standard sand is taken as 600 gm.

Also the water added should be,

($_4$ + 3) % of combined mass = (31.5/4 + 3)*800/100 = 87 ml

BULK DENSITY TEST

For determination of bulk density of sand considered for the project, the sample of fine aggregate was taken as 5.98 kg.

Weight of sample + weight of container = 11.46 kg

Volume of container = 3 litres

FINENESS MODULUS TEST

For this test, weight of fine aggregate considered was 2000 gm From the table 3.5, fineness modulus of sand = 328/100 = 3.28

- Particle size distribution curve of the sand sample is drawn below,

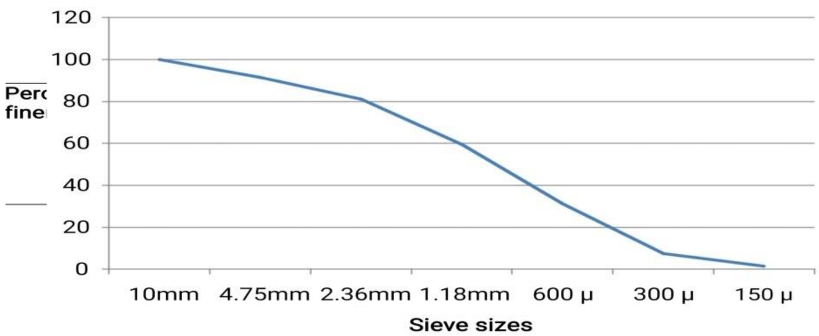

Figure 3.2: Particle size distribution curve of the sand

GRANULAR STEEL SLAG FINENESS MODULUS TEST

For this test, weight of fine aggregate considered was 2000 gm , fineness modulus of sand = 367/100 = 3.67

CHEMICAL COMPOSITION

Chemical composition of steel was obtained after conducting various chemical tests in the lab. Following are the results obtained.

Table 3.7 : Composition of steel slag

Characteristics	Values
Magnesia content	8.06%
Sulphide sulphur	0.53%
Manganese content	0.23%
Chloride content	0.001%
Moisture content	0.03%
Glass content	89%
CaO+MgO+SiO2	82
CaO+MgO/SiO2	1.3
CaO/SiO2	1.03

4. COARSE AGGREGATES

Locally available crushed stone aggregates of nominal maximum size 20 mm procured from a single source were used as the coarse aggregates in this investigation. Before being used in concrete, the coarse aggregates were successively screened through 20 mm, 10 mm and 4.75 mm sieves, washed clean with water, sun dried and then stored in bags in sufficient quantities in the casting laboratory. An additional 12.5 mm sieve and 16 mm sieve was also placed in between the 20 mm and the 10mm sieve so that the percentage of various fractions could be adjusted in order to achieve consistency and uniformity in grading of aggregates. The particle size distribution of the coarse aggregates (fineness modulus = 6.275)

3.2.5 WATER

To be suitable for mixing and curing of concrete, water shall be clean and free from injurious amounts of oils, acids, alkalis, salts, sugar, organic materials or other substances that may be deleterious to concrete or steel. According to the IS 456:2000 (2000), potable water is satisfactory for the purpose of mixing and curing of concrete. Hence, potable tap water conforming to IS 456:2000 (2000) was used for both mixing and curing of concrete.

3.2.6 GGBS

The waste was collected from one of the local steel making industry from Hazira, Surat. It was in granular form which was converted in powder form with the help of ball mill situated in Hazira, Surat. GGBS is primarily made up of silica, alumina, calcium oxide and magnesia. The chemical composition of GGBS, as determined from lab, is given below:

Table 3.8: Chemical composition

Compounds	Percentage by weight
CaO	32.60
SiO_2	39.86
Fe_2O_3	1.46
Al_2O_3	23.13
Sulphide	1.96
MnO	0.09

EQUIPMENTS USED

The experimental work includes different types of equipment and instruments to carry out the work.

- The universal testing machine of 40 tones capacity was used for testing of flexural strength of concrete.
- Digital Standard Testing Machine and Compressive Strength Testing Machine of 200 tones capacity was used for compressive strength.
- Digital Standard Testing Machine was used for split tensile strength.
- Slump test apparatus of size bottom diameter 200 mm, top diameter 100 mm and height 300 mm was used to measure the workability of concrete.

MIX CONSIDERED AND SAMPLE PREPARATION

A nominal mix of 1:1.5:3 by weight is taken for the experiment purposes. Water cement ratio was taken as 0.48. Emphasis is on the comparison of performances of concrete with varying proportions of GGBS and its interaction with steel slag.This project required preparation of several specimens of various proportions for testing. The samples were prepared in accordance with the IS standard relevant to each test. Cubes samples were used for compression testing, rectangular prismatic moulds were used to prepare samples for flexural testing and cylindrical moulds were used for split tensile strength testing.

Table 3.9: Samples considered for testing

Type of Test	Sample Type	Sample Size
Compression Test	Cube	150×150×150 mm
Flexural Test	Rectangular Prismatic	500×100×100 mm
Split Tensile	Cylindrical	L=300mm, D=150mm

DURABILITY OF CONCRETE CUBES

The durability of concrete cubes (150*150*150 mm) at 56 days and 90 days hydration time was studied by using the exposure of 10% solution of $MgSO_4$ and 10% solution of
Na_2SO_4 separately. These cubes were put into the solutions of these chemicals after 28 days of water curing for 28 days and 62 days exposure of the same. After the exposure period of 28 days (56 days hydration time) and 62 days (90 days hydration time) these cube were tested for weight and strength deterioration. The weight and strength results are compared with the results of water curing of the same hydration age. A total of 30 cubes of dimensions 150*150*150 mm were cast as given in the table below

Table 3.11 No. of Cubes for durability of concrete

% Replacement by GGBS	No. of concrete cubes		Total
	MgSO4 Exposure	Na2SO4 Exposure	
	56 & 90 days	56 & 90 days	
0	3	3	6
10	3	3	6
20	3	3	6
30	3	3	6
40	3	3	6
			30

4.RESULT AND DISCUSSIONS : The aim of this study is to be accomplishing by conducting the experimental work on four mixes. It consists mixing of concrete in the laboratory by replacing fine aggregate with steel slag by 40% (by weight). Cement is also replaced by GGBS by 0% (for the control mix), 10%, 20%, 30% and 40%. Concrete samples were prepared and cured in the laboratory, and are tested, to evaluate the fresh and harden properties of concrete viz. slump test, compressive strength, split tensile strength and flexural strength requirements.

Table 4.1: Slump values of different mixes

Mix	Slump (mm)
0% GGBS	35
10% GGBS	36
20% GGBS	36
30% GGBS	38
40% GGBS	40

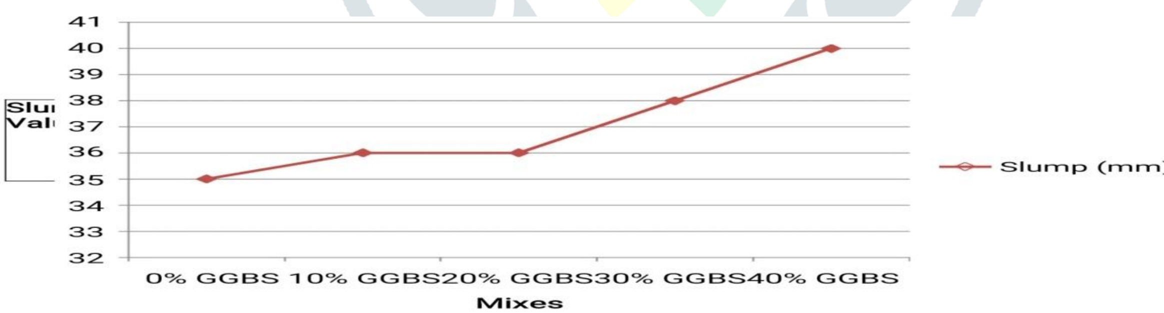

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Figure 4.1: Slump values variation

4.2 HARDENED CONCRETE PROPERTIES

Table 4.2: Compression strength values (MPa) of different

Mixes	7 Days	28 Days
0% GGBS	23.93	34.5
10% GGBS	30.03	41.8
20% GGBS	32.00	43.33
30% GGBS	35.13	44.26
40% GGBS	31.42	40.23

From the test results, it can be seen that the compressive strength of GGBS concrete mixes with 10%, 20%, 30% and 40% replacement of cement were higher than the control mix at all ages. It is evident from Table 4.2 and that compressive strength of all mixes continued to increase with the increase in age.

4.2.2 FLEXURAL STRENGTH

Samples of size 500 x 100 x 100 mm, were prepared and tested for flexural strength at 7 days and 28 days of curing. At least 3 samples were tested at each curing age. The average flexural strengths of the concrete composites measured during this phase of the project are presented in Table 4.3

Table 4.3: Flexural strength values (MPa) of different mixes

Mixes	7 Days	28 Days
0% GGBS	2.97	4.38
10% GGBS	3.50	5.06
20% GGBS	3.62	5.20
30% GGBS	3.94	5.34
40% GGBS	3.48	4.5

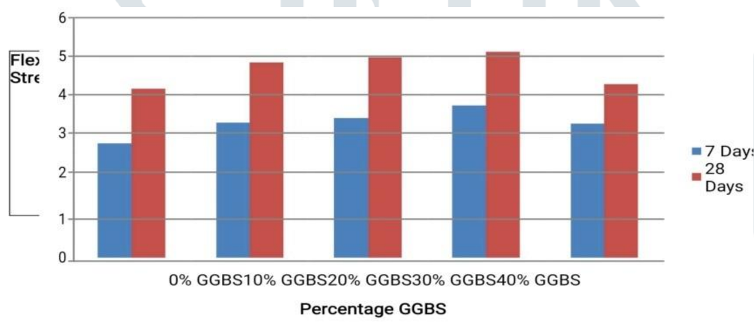

Figure 4.3: Flexural strength variation

The flexural strength test results of concrete mixes are given in Table 4.3 and shown in Figure 4.3 shows the flexural strength development with age, shows the variation of flexural strength with various percentages of GGBS.

It is evident from Table 4.3 and Fig. 4.3 that flexural strength continued to increase with the increase in GGBS percentages at 28 days, and there is significant increase in strength with that of strength of control mix. The highest compressive strength was achieved by 30% replacement of cement by GGBS, which was found about 5.35 MPa compared with 4.39 MPa for the control mixture. This means that there is an increase in the strength of almost 22% compared to the control mix at 28 days. However the value of flexural strength decreased when replacement was increased to 40%.

4.2.3 SPLIT TENSILE STRENGTH

Cylindrical samples of L=300mm and D=150mm were prepared an tested for split tensile strength at 7 days and 28 days of curing. At least 3 samples were tested at each curing age. The average split tensile strength of the concrete composites measured during this phase of the project are presented in Table 4.4 and graphically on Figure 4.4. The split tensile strength test results of concrete mixes are given in Table 4.4 and shown in Fig. 4.4 shows the split tensile strength development with age, shows the variation of flexural strength with various percentages of GGBS.

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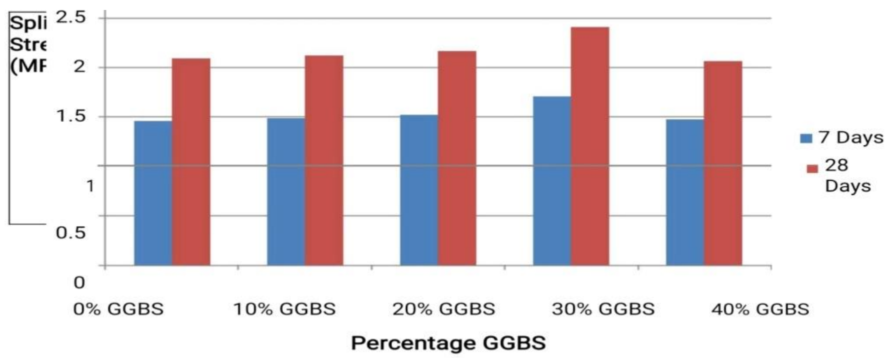

Figure 4.4: Split tensile strength variation

It is evident from Table 4.4 and Fig. 4.4 that flexural strength continued to increasewith the increase in GGBS percentages at 28 days, and there is significant increase in strength with that of strength of control mix. The highest compressive strength was achieved by 30% replacement of cement by GGBS, which was found about 2.4 MPa compared with 2.09 MPa for the control mixture. This means that there is an increase in the strength of almost 15% compared to the control mix at 28 days. However the value of flexural strength decreased when replacement was increased to 40%. achieved by 30% replacement of cement by GGBS, which was found about 2.4 MPa compared with 2.09 MPa for the control mixture. This means that there is an increase in the strength of almost 15% compared to the control mix at 28 days. However the value of flexural strength decreased when replacement was increased to 40%.

4.2.4 RATIO OF SPLIT TENSILE STRENGTH TO COMPRESSIVE STRENGTH

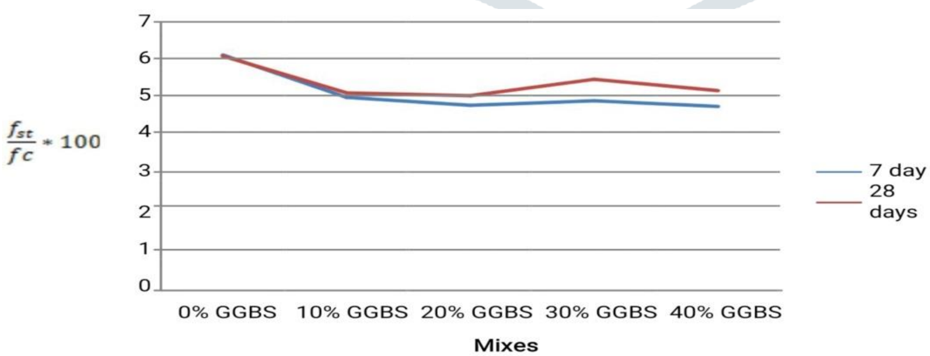

Figure 4.5: Ratio of split tensile strength to compressive strength

Ratio of the Split Tensile Strength to the Compressive strength for 28 days samples having 0%, 10%, 20%, 30% and 40% were 6.1, 4.9, 4.73, 4.85, 4.7. It means the split tensile strength of concrete samples were 4.5 to 6% of its Compressive strength. Using this graph, we can anticipate split tensile behavior of concrete containing GGBS and steel slag as partial replacements of cement and fine aggregate respectively.

4.2.5 RATIO OF FLEXURAL STRENGTH TO COMPRESSIVE STRENGTH

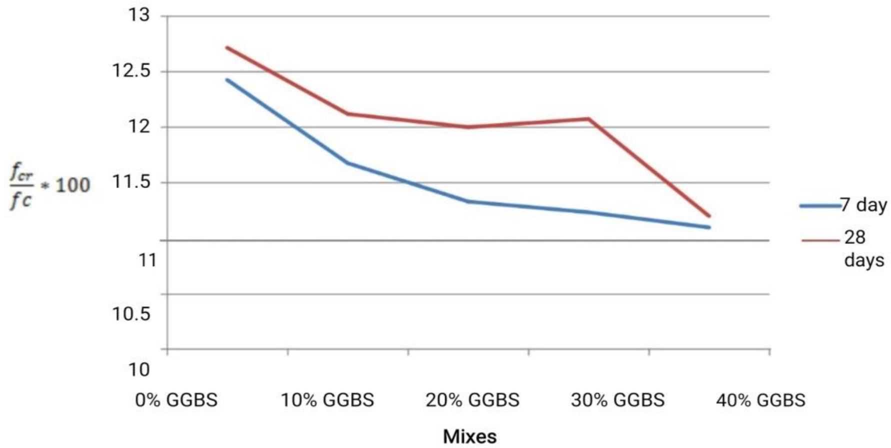

Figure 4.6: Ratio of flexural strength to compressive strength

Using this graph, we can anticipate split tensile behavior of concrete containing GGBS and steel slag as partial replacements of cement and fine aggregate respectively.

4.2.6 WEIGHT DETERIORATION FACTOR (WDF)

WDF at 90 days hydration age at different percentages of GGBS replacements resulted as 3.87%, 3.584%, 2.664%, 2.511% and 1.94%. In Na_2SO_4 exposure condition, the WDF at 56 days hydration age at different percentages of GGBS replacements i.e. 0%, 10%, 20%, 30%, and 40% resulted as 1.15%, 1.05%, 0.95%, 0.70% and 0.68%. Similarly, WDF at 90 days0hydration age at different percentages of GGBS replacements resulted as 2.41%, 2.08%, 1.76%, 1.41% and 0.97%. The overall WDF under Na_2SO_4 exposure condition results were larger as compared with $MgSO_4$ exposure condition. In Na_2SO_4 exposure condition, the WDF at 56 days hydration age at different percentages of GGBS replacements i.e. 0%, 10%, 20%, 30%, and 40% resulted as 1.15%, 1.05%0.95%, 0.70% and 0.68%. Similarly, WDF at 90 days0hydration age at different percentages of GGBS replacements resulted as 2.41%, 2.08%, 1.76%, 1.41% and 0.97%. The overall WDF under Na_2SO_4 exposure condition results were larger as compared with $MgSO_4$ exposure condition. The degradation of C-S-H phase in the presence of $MgSO_4$ is significantly faster and more than with Na_2SO_4. The reason is the extremely low solubility of $Mg(OH)_2$ and low pH of solution in equilibrium with the phase

4.2.7 STRENGTH REDUCTION FACTOR (SDF)

From figures 4.9 and 4.10, it is also observed that the effect of $MgSO_4$ is greater than that of Na_2SO_4 in reducing the compressive strength of samples.

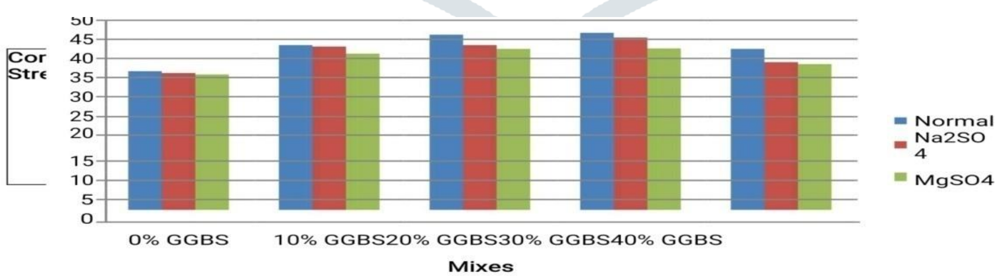

Figure 4.9: Compressive strength values after 56 days

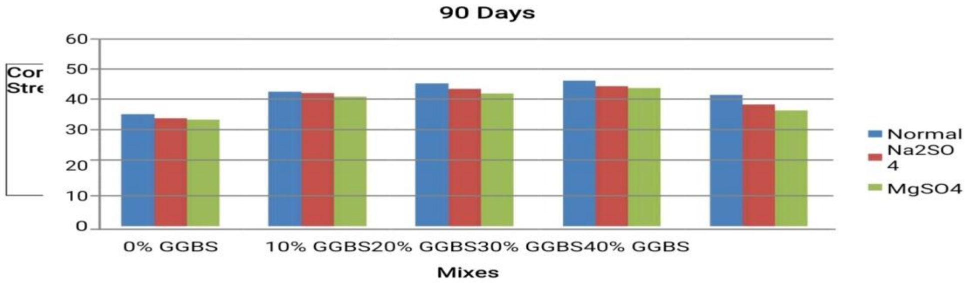

Figure 4.10: Compressive strength values after 90 days

There is reduction in strength if compared with water cured mortar cube of the same age for each percentage replacement. Under $MgSO_4$ exposure at 56 days SRF increases as percentage replacement of GGBS increases. But at 90 days exposure0SRF variation is not continuously increasing. Initially SRF decreases from 4.76 % at 0% replacement to 3.94% at 10% replacement of GGBS. Afterwards SRF increases at 20% to 7.2% & after a small decrease to 5.14% at 30% replacements, a high SRF of 12.11% at 40% replacement of GGBS occurred.

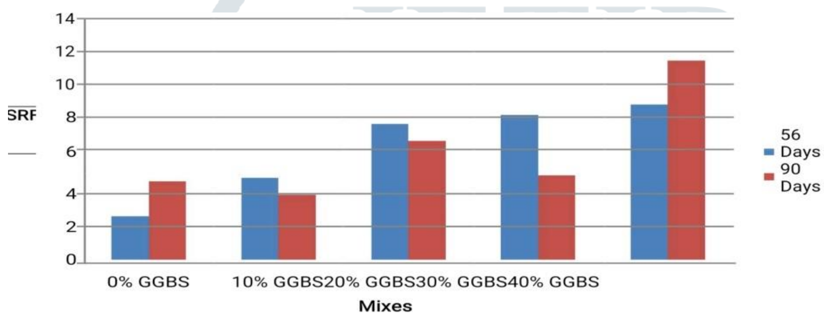

Figure 4.11: SRF of concrete with exposure to MgSO4

For Na2SO4 also, there is reduction in strength if compared with water cured mortar cube of the same age for each percentage replacement. . Initially SRF decreases from 3.8% at 0% replacement to 1.1% at 10% replacement of GGBS. Afterwards SRF becomes approximately constant at 20% & 30% replacements as 4% and 3.8%. At 40% replacement of GGBS gave a high SRF of 7.3%.

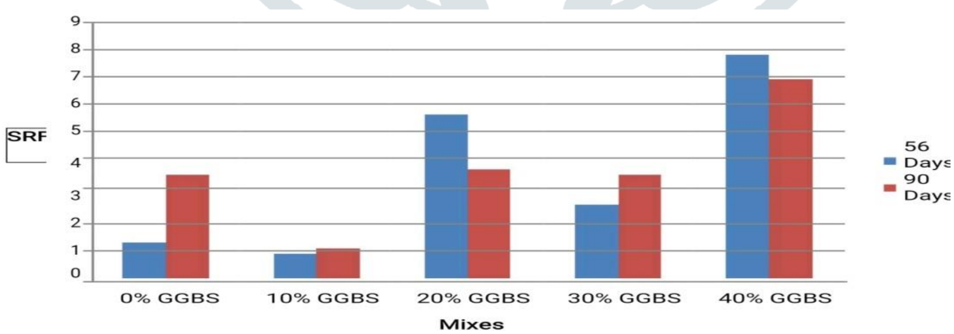

Figure 4.11: SRF of concrete with exposure to NaSO4

CONCLUSIONS

It is observed from table 4.1 that the workability is increased as the percentage of GGBS is increased in concrete.Based on literature, it is found that optimum0percentage of replacement of fine aggregate by granular steel slag is 40%.It is seen that optimum percentage of replacement of cement by GGBS is 30% with respect to strength behaviors.Compressive strength of concrete increased by 28%, flexural strength of concrete increased by 22%, split tensile strength of concrete increased by 15% at 30% replacement of cement.The increase in mechanical strength properties is due to denser matrix and pozzolanic activity of GGBS.Weight loss due to sulphate attack on concrete decreased with increase in percentage of GGBS. Over all 40%

replacement by GGBS shows high sulphate resistance among all in 56 and 90 days.Strength loss due to sulphate attack on concrete roughly increased with increase in percentage of GGBS. Over all 40% replacement by GGBS shows highest strength loss in concrete.It is concluded that optimum replacement of cement with GGBS can reduce global CO_2 emissions by 1.5%.

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