An Experimental Investigation on Strength Properties of Concrete by Replacing Cement with GGBS and Silica Fume

Sowmya.S.M[1]; Premanand Kumbar[2]; Amar.R[3]
[1]PG Student, Dept. of Civil Engineering, GEC, HASSAN, India
VTU, Belgaum. Karnataka, India, 1E-mail:sowmyapattar7@gmail.com
[2]Assistant Professor. Dept. of Civil Engineering, GEC, HASSAN, India
[3]Assistant Professor. Dept. of Civil Engineering, GEC, HASSAN, India

Abstract:

Mineral admixtures such as ground granulated blast-furnace slag (GGBS), fly ash and silica fume are commonly used in concrete because they improve durability and reduce porosity as well as improve the interface with the aggregate. The lower cement requirement leads to a reduction for CO_2 generated by the production of Portland cement.

The experimental work is carried out to investigate the optimum percentage of GGBS and silica fume to replace cement effectively. An attempt is made to replace cement with GGBS with an interval of 10% and silica fume by constant proportion for minimum grade concrete i.e., M20 and is tested for fresh and hardened properties to identify the optimum percentage of GGBS and silica fume in concrete.

Compression test, split tensile test are conducted to know the strength of the concrete at different replacement percentages, Galvano static weight loss method (GWLM) is done to find the corrosion resistance of the blended concrete, Acid Resistivity Test is done to find the resistance of blended concrete towards acid and SEM is conducted to know the pozzolonic reaction that takes place inside blended concrete.

Keywords:

GGBS, Silica fume, compressive strength, tensile strength, GWLM, acid resistivity, SEM analysis

Introduction

Concrete is the most widely used man-made construction material in the construction world. With increase in demand of concrete, more and more new methods and new materials are being developed for production of concrete. Sometimes certain additives are added to it to improve some properties. A concrete using cement alone as a binder requires high paste volume, which often leads to excessive shrinkage and large evolution of

heat of hydration, besides increased cost. An attempt is made to replace cement by a mineral admixture like ground granulated blast furnace slag (GGBS) and silica fume in concrete mixes to overcome these problems.
Increasing the performance of concrete with the partial replacement of mineral admixture using GGBS along with chemical admixture eliminates the drawbacks besides enhancing durability characteristics.

Granulated blast furnace slag was first developed in Germany in 1853, and it has been used as a cementatious material in concrete since the beginning of the 1900s. In India, we produce about 7.8 million tons of Ground Granulated blast furnace slag as a bye product obtained in the manufacture of pig iron in the blast furnace. Ground granulated blast-furnace slag, is made from iron blast-furnace slag. It is non-metallic hydraulic cement consisting essentially of silicate sand alumina silicates of calcium developed in a molten condition simultaneously with iron in a blast furnace. The molten slag at a temperature of about 1500°C (2730°F) is rapidly chilled by quenching in water to form a glassy sand like granulated material. The rough and angular-shaped ground slag in the presence of water and an activator, NaOH or CaOH, supplied by Portland cement, hydrates and sets in a manner similar to Portland cement. Some slag concretes have a slag component of 70% or more of the cementitious material.

Silica fume was first discovered in Norway in 1947 when the environment controls started the filtering of the exhaust gases from furnaces. Silica fume can be utilized as material for supplementary cementations to increase the strength and durability. Silica fume consists of fine particles with specific surface about six times of cement because its particles are very finer than cement particles. Therefore silica fume reduces pore space when mixed with concrete. Silica fume concrete may be appropriate in places where high abrasion resistance and low permeability are of utmost importance or where very high cohesive mixes are required to avoid segregation and bleeding

Materials and Methods

Ordinary Portland cement 53 grade was used throughout this experimental investigation. The cement satisfied the requirements of Indian Standard Specification IS: 12269-1987. The properties of Cement are tabulated in **Table 1.** The GGBS used in the present investigation was taken from Jindal steel work, bellary district, Karnataka, India. The GGBS satisfied the requirements of Indian Standard Specification IS: 4031-1991, the Properties of GGBS are tabulated in **Table 2.** Silicafume used in this investigation was taken from ORGANO SUBLIMO EXTRACTS, baikampady industrial area, Mangalore, Karnataka, India and it satisfied the requirements as per

ASTM C 1240 and the properties are tabulated in **Table 3.**

characteristics	Value	As per IS: 12269-1987
Specific gravity	3.15	≤3.15
Fineness (%)	2	< 10%
Standard consistency(%)	31	-
Initial setting time(min)	90	> 30
Final setting time (min)	395	<600

Table 1:Physical properties of cement

Characteristics	Value
Colour	White
Fineness modulus	4
Specific gravity	2.85

Table 2: Physical properties of GGBS

Characteristics	Value	As per ASTM C 1240
Colour	Baby pink	-
Specific gravity	2.3	2.2-2.3

Table 3: Physical Properties of Silica fume

Preparation and casting of test specimens

Concrete cubes of size 150 × 150 × 150mm were casted for all the concrete mixes for compressive strength, 150 × 300mm size cylinders were casted for tensile strength, for Galvano Static weight loss method(GSWLM) cylinders of size 150 × 300mm were casted and for acid resistivity test cubes of size 150 × 150 × 150mm were casted. After 24 hours of casting the specimens were demoulded and put into water curing tank until 7, 14 and 28 days of testing for compression and tensile strength, but for GSWLM the cylinders were demoulded after 24 hours and kept in salt water without any curing in normal water and for acid resistivity test the cubes were kept in normal water curing for 7 days and later placed in acid water bath for 28 days time.

Mix Design

The cement concrete mix was prepar as per the procedure given in the relevant IS 10262:2009. with the fixed quantity of silica fume i.e 6% and for optimal dosage selection of GGBS in the in the concrete mix, modified cubes and cylinders(% ranging from 10% to 70%) are prepared and compared with plain cement concrete cubes and cylinders. Mix proportion used for the M20 grade of concrete is,

1:1.55:2.55:0.45

Mix No.	Ground granulated blast furnace slag	Silica fume	OPC
Mo	0	0	100
M1	10	6	84
M2	20	6	74
M3	30	6	64
M4	40	6	54
M5	50	6	44
M6	60	6	34
M7	70	6	24

Table 3 : Mix composition of different composite contents,wt %

Figure 1: Cube specimen failure under compressive load

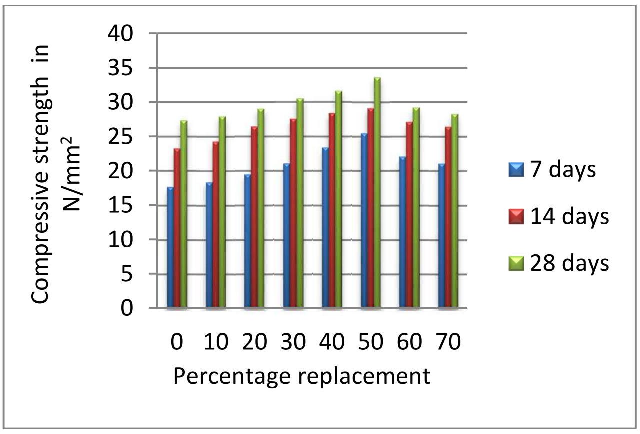

Figure 2: Compressive Strengths for 7, 14 and 28 days.

Results and Discussion

A. Compressive Strength Test

The compressive strength of concrete cubes replaced by cement with GGBS and fixed quantity of silica fume was determined at ages 7, 14 and 28 days and figure 2 shows the strength variation of the mix having GGBS replaced with cement.the test is conducted as per IS:516-1999

B. Split Tensile Test

The procedure of mix is as same as that of the compressive strength test. Figure 3 shows the tensile strength of cylinder specimen having cement replaced by cement with GGBS and the fixed quantity of silica fume. The test is conducted as per IS:516-1999.

Figure 3:Cylinder failure under tensile loading

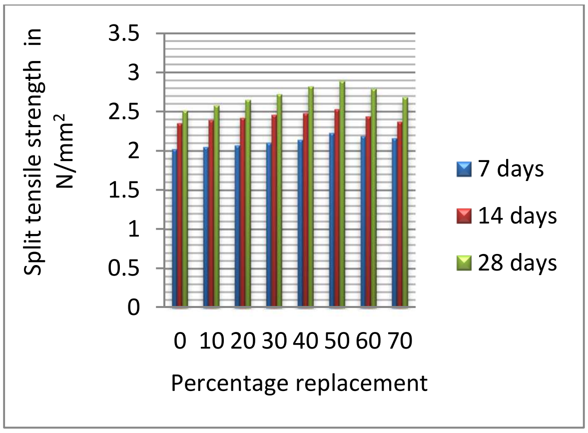

Figure 4: Tensile strength for 7, 14 and 28 days

C. Galvano Static Weight Loss Method.

Figure 5: GWLM setup

Test is done to find out the amount of corrosion that can be caused to the cylindrical specimen into which steel rods are embedded and that are immersed in the bath tub which contains 5% Nacl solution. 12v current is passed through the battery making the steel rods positive and the copper plate negative. The copper plate is connected to the negative terminal of the battery and is immersed inside the bath tub containing Nacl. The current is passed for 15 days and later the weight rods are noted down. Figure 9 represents the corrosion rate in mm/yr.

$$\text{Corrosion Rate } = \frac{K \times W}{A \times T \times D} \text{ (mm/yr)}$$

K = 87.6 in case of expressing corrosion rate in mm/yr.

T is the exposure time expressed in hours.

A is the surface area expressed in cm^2.

W is the mass loss in milli gram.

D is the density of the corroding metal (7.85 gm/cm^3).

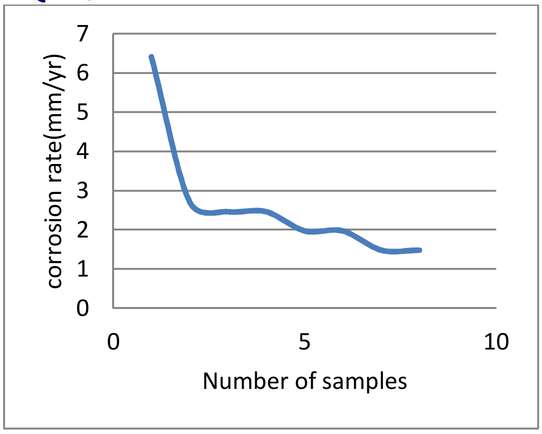

Figure 6: GWLM result

By referring the above graph, when only the cement used in concrete that is conventional concrete (C0),the corrosion rate is occurred in maximum percentage but, when the cement is replaced by GGBS and a fixed quantity of silica fume in concrete that is from mix 0 to the mix 70, the corrosion rate is decreases as long as more quantity of replacing materials compared to cement concrete. It concluded that the corrosion rate will be goes on decreases by increasing replacing percentage of GGBS.

D. Acid resistivity test

This test is performed to know how much the concrete and the other replacement levels can resist the acid attack that can counter attack directly on the specimen. The cubes are casted and de-moulded after 24 hours and are cured in normal water for 7 days and later taken out, dried in sun until they are properly dried. After drying is done the cubes are weighed and are placed in acid-water bath. P_H is maintained to 4. After 28 days the cubes are taken out from acid-water bath and dried and later weight is taken. Difference in weight signifies the ability of the concrete to resist acid attack.

Figure 7: conventional concrete

Figure 8: Cement + GGBS+SF (44%+ 50%+6%)

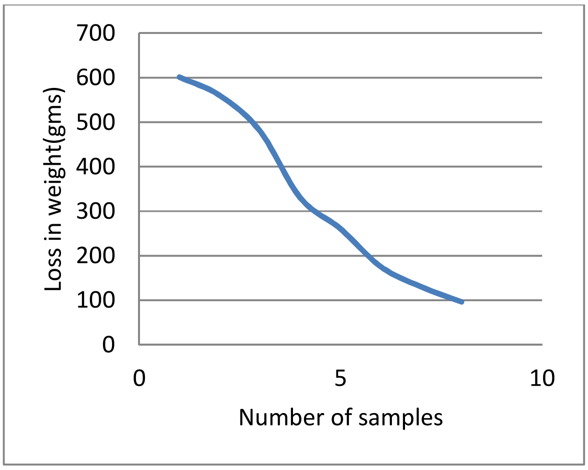

Figure 9: Acid Resistivity Results for 28 days

From the above graphs i.e. fig 9 it can be noted that as the percentage replacement of GGBS increases the weight in loss of the cube decreases and hence there is an increase in the strength also. This is because as the percentage of GGBS increases the permeability resistance of the concrete increases i.e. the pores that are present in the conventional mix are filled up by GGBS that has been replaced in higher percentages. Therefore with higher replacement of GGBS the ability to acid resistance is achieved.

E. Scanning Electron Microscope (SEM)

In this case the samples are carbon coated and are analysed using a scanning electron microscope (SEM) in the back scattered electron mode with an acceleration voltage of 20 Kev. The back scattered intensity was set to the same parameter for each sample. The SEM analysis of conventional concrete (C0), 50% replacement of GGBS with cement and 6% fixed quantity of silica fume($C50_{gs}$) with cement is shown in the figure below. Figures 10 and 13 shows the microstructure of the concrete. These 2 figures are analysed using **MATLAB** software. Textural segmentation using texture filters is done using Matlab software. Figures 11 and 14 are the output that are gained using the software. The software is used to clearly find out the dense microstructure of specimen.The coloured image is formed by connecting the particles of same size giving an individual colour as indicated in the scale. The size of the particle is indicated by mm micron.

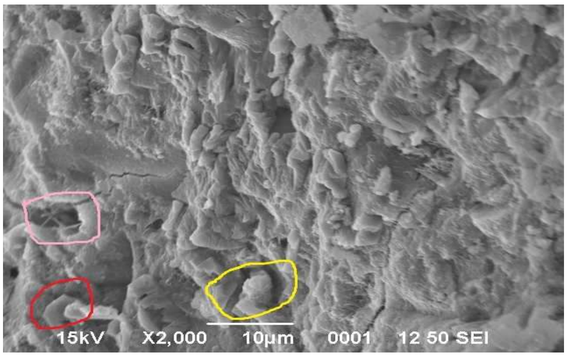

Figure 10: Conventional Concrete

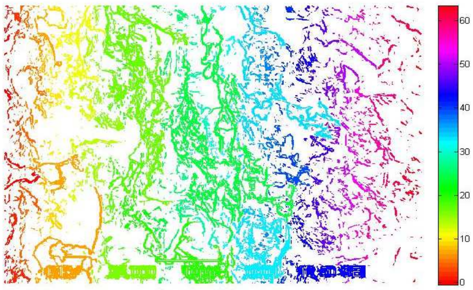

Figure 11: Coloured Image showing particular texture

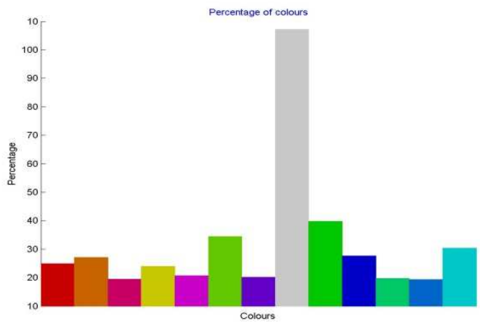

Figure 12: Percentage of colours

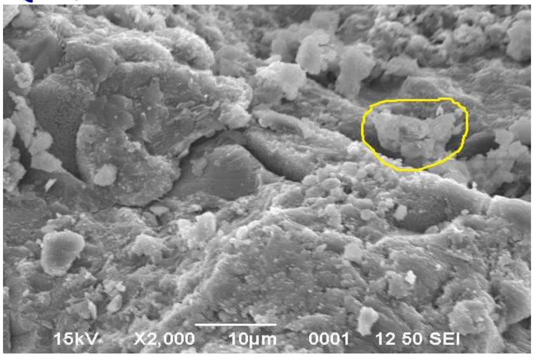

Figure 13: 50% GGBS and 6% silica fume

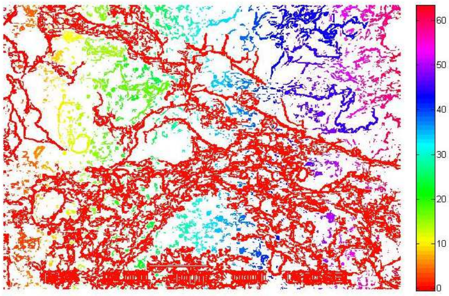

Figure 14: Coloured Image showing particular texture

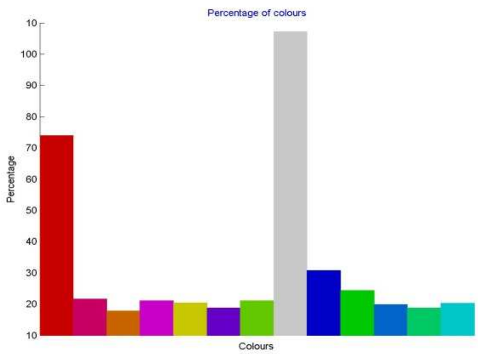

Figure 15: Percentage of colours

The above figures 12 and 15 represents the percentage of colours of the coloured images in the form of histogram. The scale denotes the size of the materials in micron. From the figure 11 and 14 it can be approximately judged that the materials varying from 0 to 20 microns are un-hydrated (un-reacted) or partially hydrated and materials varying from 20 to 40 microns are partially un-hydrated or hydrated and materials varying from 40 to 60 microns are hydrated. Figure 12 shows 27.16% hydrated materials, 42.62% partially un-hydrated or hydrated materials and 29.08% un-hydrated or partially hydrated materials. Figure 15 shows 74.55% hydrated materials, 32.23% partially un-hydrated or hydrated materials and 19.65% un-hydrated or partially hydrated materials. From this it can be concluded that figure 15 shows more dense structure as compared to figure 12. Due to the dense microstructure of the concrete, there is a good bonding between the materials due to which strength increases and the permeability resistance increases. Due to the increase in the permeability resistance of the concrete the corrosion effect on the re-inforcement can be controlled and the resistance to acid is also achieved.

Conclusion

From the experimental analysis and obtained results, the following conclusion are drawn,

- The fineness of GGBS is almost nearer to the cement. So its acts like a pozzoloanic behaviour.
- The workability has increased with the addition of GGBS. If further decreases with increase in percentage of GGBS.

- Target mean strength was achieved for all the percentage of replacing of GGBS with cement. But the compressive strength will decreases beyond the certain percentage of replacing of GGBS.
- Split tensile strength will increased up to certain percentage with the addition of GGBS and it further decreases with increase of GGBS content in concrete.
- Corrosion rate will be reduced with the increase in percentage of GGBS and with the fixed quantity of silica fume.
- In acid resistivity test, the weight loss is reduced and loss of strength will increased by increase in percentage of replacements.
- Finally the investigation is made to found out the optimum percentage of GGBS content as a partial replacement of OPC cement that is the mix $C50_{gs}$ is the optimum percentage of GGBS content.
  - The mix containing with the fixed quantity of SF i.e. 6% and 50% GGBS ($C50_{gs}$) replacing shows dense microstructure than mix containing Conventional concrete (C0). Due to the dense microstructure the permeability resistance of the concrete increases due to which the strength also increases.

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