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Influence of GGBS on Mechanical Properties of High-Strength Concrete

S.P.Sangeetha
Associate Professor & HOD
Department of Civil Engineering
Aarupadai Veedu Institute of Technology,Vinayaka Missions University
Paiyanoor, spsangeetha81@gmail.com

***Abstract*— The Ordinary Portland Cement (OPC) is one of the main ingredients used for the production of concrete, as there is no alternative in the civil construction industry. Unfortunately, production of cement involves emission of large amount of carbon-dioxide gas in to the atmosphere, a major contributor for greenhouse effect and global warming. A number of studies are going on in India as well as abroad to study the impact of use of these pozzolanic materials as cement replacement. Hence this paper aims at studying the mechanical properties of concrete by replacing 30% - 70% ordinary Portland cement with GGBS at 28 and 56 days of curing. The parameters include workability, water absorption, setting time, compressive strength and tensile strength, stress strain characteristics and flexural strength. Relationship between compressive strength,tensile strength and flexure is also arrived. From the results it was found that Ordinary Portland Cement when replaced with GGBS upto 50% is found to posesss good pozzalanic properties and gains strength after 28 days.**

Keywords - ***Pozzolano, slag, flexure, compression, tensile strength***

I. INTRODUCTION

Concrete is the most massive individual material element in the built environment. Although portland cement typically comprises only 12% of the concrete mass, it accounts for approximately 93% of the total embodied energy of concrete and 6% to 7% of the world wide Carbon dioxide (CO_2) emissions. This has made the researchers worldwide to look for addition of cementitious materials in concrete to reduce the usage of cement in concrete. The utilization of pozzolanic materials in concrete as partial replacement of cement is gaining importance today, mainly on account of the improvements in the long-term durability of concrete ,which include industrial by-products such as Fly Ash (FA), Ground Granulated Blast furnace Slag (GGBS), Rice Husk Ash (RHA), Silica Fume (SF), etc. Ground Granulated Blast furnace Slag is a by-product of iron manufacturing industry. The use of mineral admixtures such as fly ash, GGBS and silica fumes are to overcome the adverse effect of calcium hydroxide produced during the hydration of cement in concrete. These mineral admixtures produce less percentage of calcium hydroxide when compared to Ordinary Portland Cement (OPC). GGBS is a by-product of iron manufacturing industry, it is reported that the production of one ton of GGBS would generate only about 0.07 tons of CO_2 equivalent and consume only about 1300 MJ of energy. The replacement of portland cement with GGBS will lead to a significant reduction of carbon dioxide gas emission. In India, we produce about 7.8 million tons of GGBS. Some of the recent studies in various parts of the world have revealed that GGBS can be efficiently used as a supplementary cementitious material in concrete. **Elsayed (2011)** investigated experimentally in his studies, the effects of mineral admixtures on water permeability and compressive strength of concrete containing Silica Fume (SF) and GGBS (FA) and observed that the strength and permeability of concrete containing silica fume, GGBS and high slag cement could be beneficial in the utilization of these waste materials in concrete work, especially in terms of durability. Efficiency of GGBS in concrete was investigated by **Ganesh Babu and Sree Rama Kumar (2000)** from the results of the investigations reported in recent years. The replacement levels in the concrete studied, varied from 10% to 80% and the strength efficiencies at 28 days were calculated. It was also observed that for obtaining equal strength in concretes at 28 days, an average of 8.5% and 19.5% cementitious materials has to be added at 50% and 65% cement replacement levels. **Shariq et al** has investigated the effect of curing procedure on the compressive strength development of cement mortar and concrete incorporating ground granulated blast furnace slag. The test results showed that the magnitude of compressive strength of mortar for standard sand is higher than the magnitude of river sand.

II. EXPERIMENTAL INVESTIGATIONS

To make concrete of desired strength, it is necessary to analyse the basic properties of the materials used for the study. Hence, investigations were conducted on the raw materials used for the casting of specimens. Ordinary Portland Cement with 53 grade is considered for the concrete mix. The GGBS used in the research was brought from a steel plant in Mangalore. It is off white in colour and has fineness in the range of 400 to 600m³/kg. It has the same main chemical constituents as ordinary portland cement, but in different proportions as shown in Table 1.

Table 1 Chemical Composition of OPC and GGBS

Chemical Constituent	Portland Cement	GGBS
CaO	65%	40%
SiO_2	20%	35%
Al_2O_3	5%	10%
MgO	2%	8%

Locally available river sand (coarse sand) was used as fine aggregate. Hard crushed granite stone, coarse aggregates confirming to graded aggregate of size 20mm and 10mm was used in the study. To improve the workability of concrete, poly carboxylic ether based super plasticizer Glenium B233 was used for this study. The mix design adopted for casting the specimens is M30. To study the mechanical behavior of concrete with GGBS, tests on workability, setting time, water absorption, compressive strength, split tensile strength and flexural strength were conducted on cube, cylinder and prism specimens. The specimens were cast and tested on 28 & 56 days of curing.

Setting time of mortar mix

The initial and final setting time of cement with varying replacement levels are shown in figure 2.It was observed from the figure that the use of slag in mortar resulted in an increase in setting time, as the initial rate of reaction of slag is slower than that of cement. The delay in setting time was closely linked to the slag replacement level, as higher amount of slag delayed the setting time.

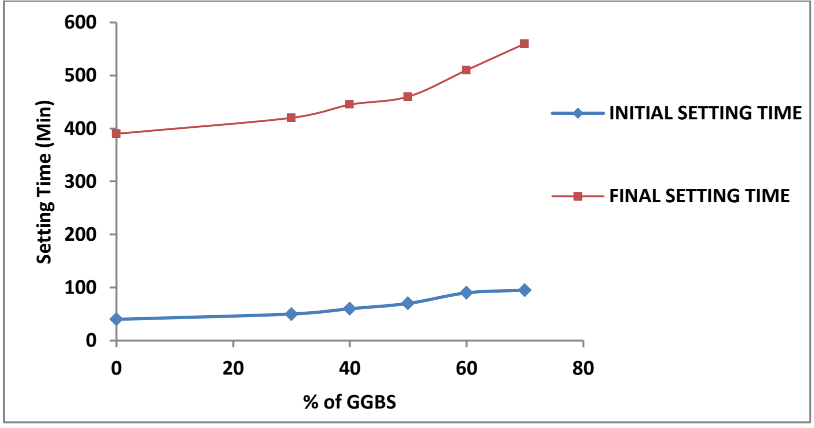


Figure 1 Setting Time of Mortar

Workability test

To determine the workability of fresh concrete the values of slump with 0% to 70% GGBS are found by slump cone test and tabulated in Table 4. Figure 2 shows the slump test on ordinary concrete and concrete with GGBS.

(a) Control concrete (b) Concrete with GGBS

Figure 2 Slump Test on Concrete Mixes

The test results showed that there was increase in slump flow as the GGBS content is increased up to 40% and beyond that the mix was quite stiff. The slump had shear type of failure as the GGBS content was increased. No segregation and bleeding in any of the mixes were observed.

Water absorption test

The water absorption test was conducted on concrete cubes of size 150mm. First, the concrete specimens were immersed in water. The weight of the specimen after removing from water is noted as saturated weight. After curing (28 and 56 days) the specimens were taken out from the curing tank and dried in an oven at 105°C for 24 hrs. The dry specimens were cooled to room temperature (25°C) weighed accurately and noted as dry weight. Weight of the specimen at predetermined intervals was taken after wiping the surface with dry cloth.

$$\% \, Absorption = \frac{Saturated\ weight\ -\ Dry\ weight}{Dry\ weight} \times 100$$

The control concrete specimens absorbed more water than the GGBS samples. The water absorption results in Table 4 suggest that the amount of water absorbed by the GGBS samples is lower than that absorbed by the control concrete samples and higher the GGBS content, the lower the amount of water absorbed.

Test on strength properties

Test on compression, flexure and tension were conducted on cube, cylinder and prism specimens. Figures 3 shows the comparison of compressive strength of concrete with age of concrete. The addition of slag to concrete had a significant effect on compressive strength. The concrete specimens with GGBS had low early strengths compared to control concrete. The low early strengths were expected based on the fact that slag cement is a latent hydraulic material. The difference in the strength gain relationships between OPC concrete and slag cement concrete is due to the fact that slag cement concrete had low strength at early ages, but had increased rates of strength gain beyond 28 days compared to OPC concrete. From the test results higher compressive strength for concrete is observed for mixes up to 40% GGBS at all ages. Even for concrete with 50% GGBS, the strength was equal to that of control concrete at 56 days.

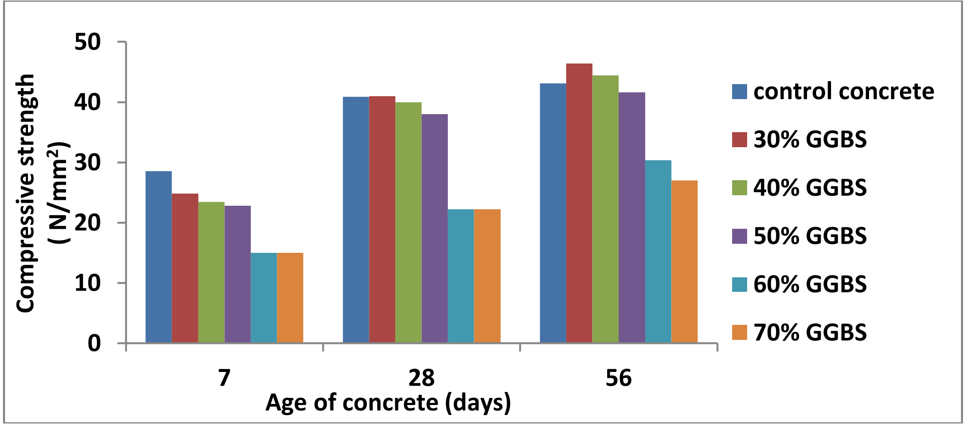


Figure 3 Compressive Strength Vs Age of Concrete

Up to 50% replacement, concrete with GGBS generally achieved strengths similar to control concrete till 28 days and after 28 days it exceeded the strength of control concrete. The reason is, GGBS is a hydraulically latent material and rate of hydration will be slow. It takes more than 28 days to obtain hydroxyl ions from the hydration product. But beyond 50% replacement there was gradual decrease in compressive strength which was due to the presence of unreacted GGBS, acting as a filler material in the paste and it could not enter into reaction. This indicates that the GGBS, which could not enter into reaction, behave like fine aggregate. The strength activity index which was calculated by considering the ratio between the compressive strength of concrete with GGBS to that of the control concrete at the ages of 7, 28 and 56 days for different replacement levels of GGBS is shown in Table 3.

Table 3 Strength Activity Index of Concrete Mixes with GGBS

% of GGBS	Strength Activity Index		
	7 days	28 days	56 days
30	0.868043	1.002445	1.052632
40	0.820791	0.97555	1.030605
50	0.79874	0.929095	0.996986
60	0.59923	0.667482	0.703918
70	0.525026	0.542787	0.626014

From Table 4, it is found that the activity index gradually decreased after 50% replacement of portland cement with GGBS.

The flexural strength was determined by testing standard test specimens (prisms) of size 100mm x 100mm x 700mm with various percentages of GGBS (0%, 30%, 40%, 50%, 60% and 70%) and tested at 28th and 56th day under symmetrical two-point loading. From the Figure 4, we find that there is increase in flexural strength of concrete when ordinary portland cement was replaced with 30% , 40% and 50% GGBS but it reduces for more than 50% replacement.

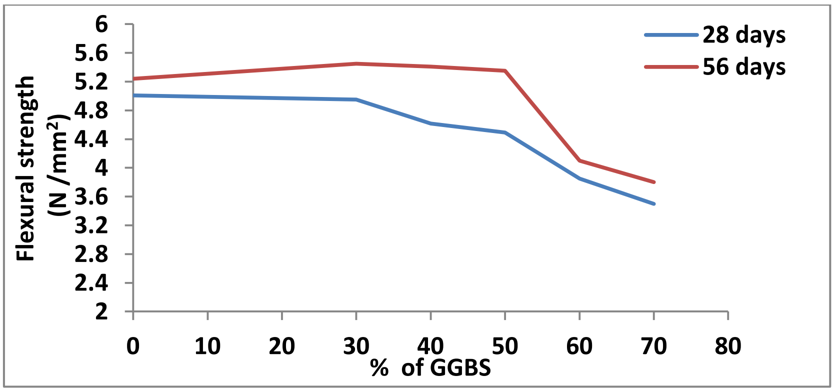
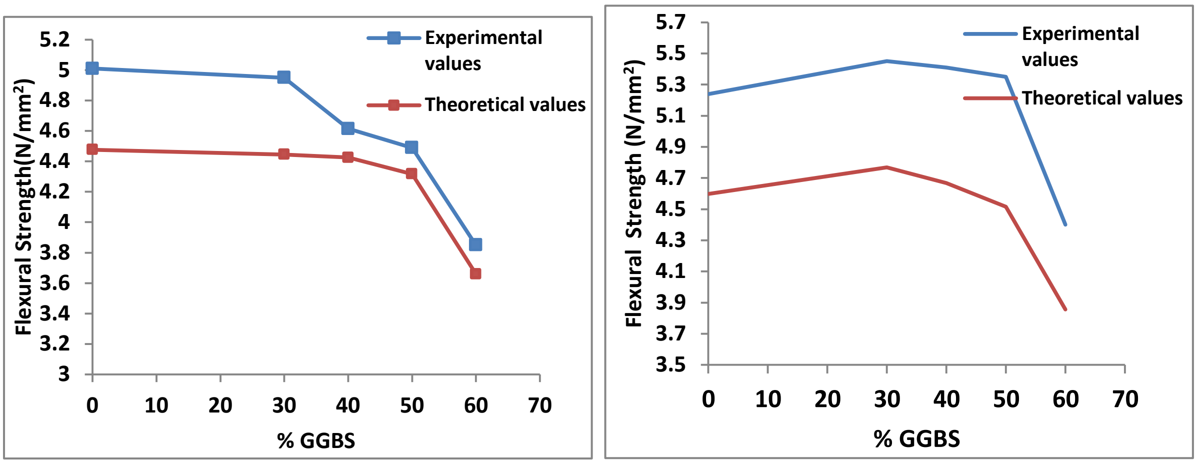


Figure 4 Flexural Strength Vs Percentage of GGBS

A comparison of theoretical value of flexural strength as per the IS codal provisons and experimental values are presented in Figure 5 (a) & (b).



(a) 28th day **(b) 56th day**

Figure 5 Comparison of Experimental and Theoretical Flexural Strength of Concrete

Similarly it was found that the split tensile strength of concrete with 30% and 40% GGBS is more than the control concrete specimens when tested at 56 days as shown in figure 6. But there is a gradual decrease in split tensile strength in concrete specimens beyond 50% GGBS.

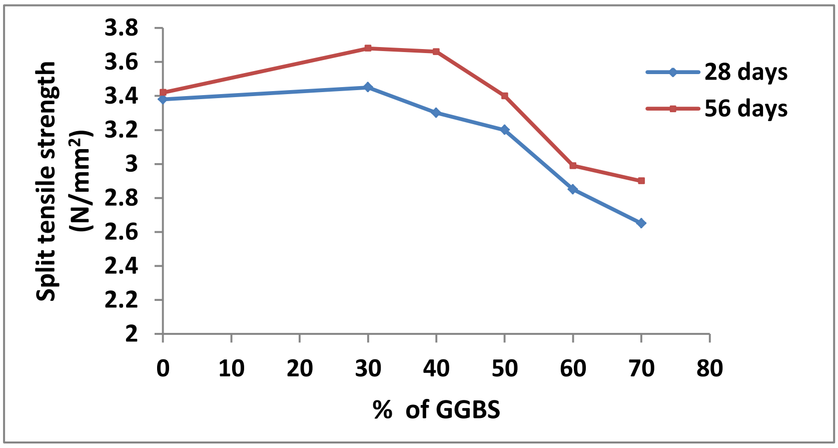
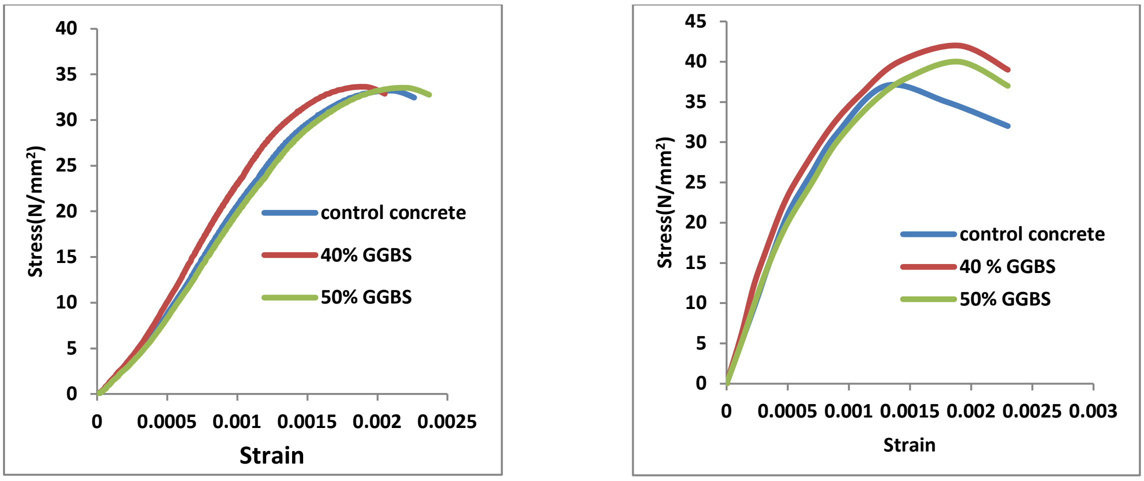


Figure 6 Split Tensile Strength Vs Percentage of GGBS

Compressive Uniaxial Stress-Strain Relationship for Concrete

The complete stress-strain history for concrete subjected to uniaxial compression provides data for use in characterizing the response of concrete to general loading. The stress-strain behavior of concrete with and without GGBS is calculated by testing cylinders of standard size, 150mm diameter and 300mm long in axial compression under strain control mode. A total of eighteen specimens were tested in axial compression to get the stress-strain behavior of concrete mixes of various replacement ratios of GGBS such as 0%, 40% and 50%. Three specimens were cast in each series. From the stress-strain values of control and GGBS mixes stress-strain plots were drawn. Normalized stress-strain values were calculated by dividing each stress value by the peak stress and dividing each strain value by strain at peak stress. From the normalized stress-strain values of mixes, the average normalized stress-strain curves were plotted for concrete with 0%, 40% and 50%, GGBS tested at 28 and 56 days shown in Figure 7 (a) & (b).

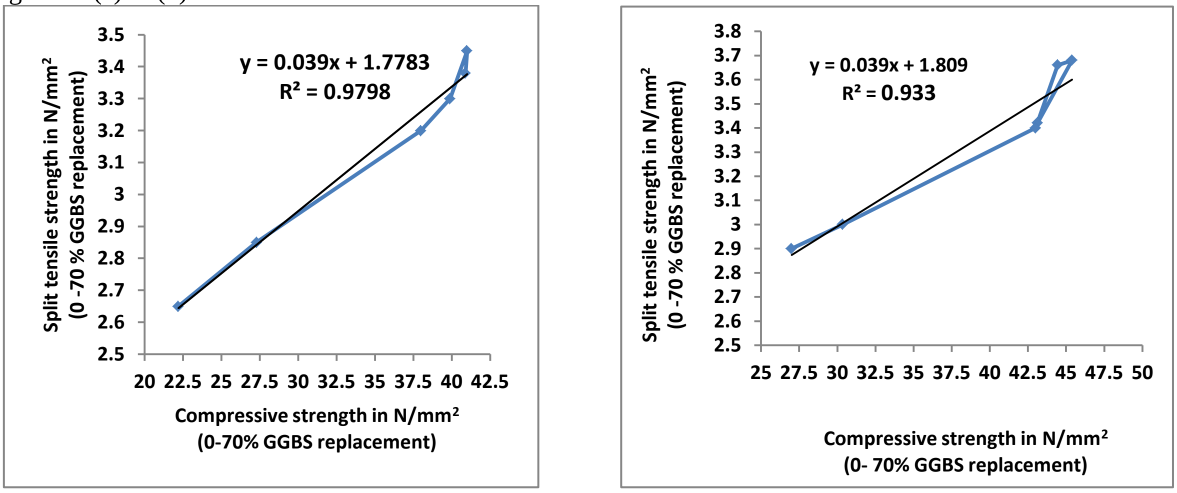


(a) 28 days **(b) 56 days**

Figure 7 Stress-Strain curves for concrete specimens

III REGRESSION ANALYSIS

Regression technique (RT) is the modelling of the relationship between 1 or more measured variables and another variable which is genuinely considered to be related to the measured variable. The relationship between cube compressive strength and split tensile was found out using regression analysis and is shown in Figures 8 (a) & (b).



(a) 28th day **(b) 56th day**

Figure 8 Relationship between Cube Compressive Strength and Split Tensile Strength

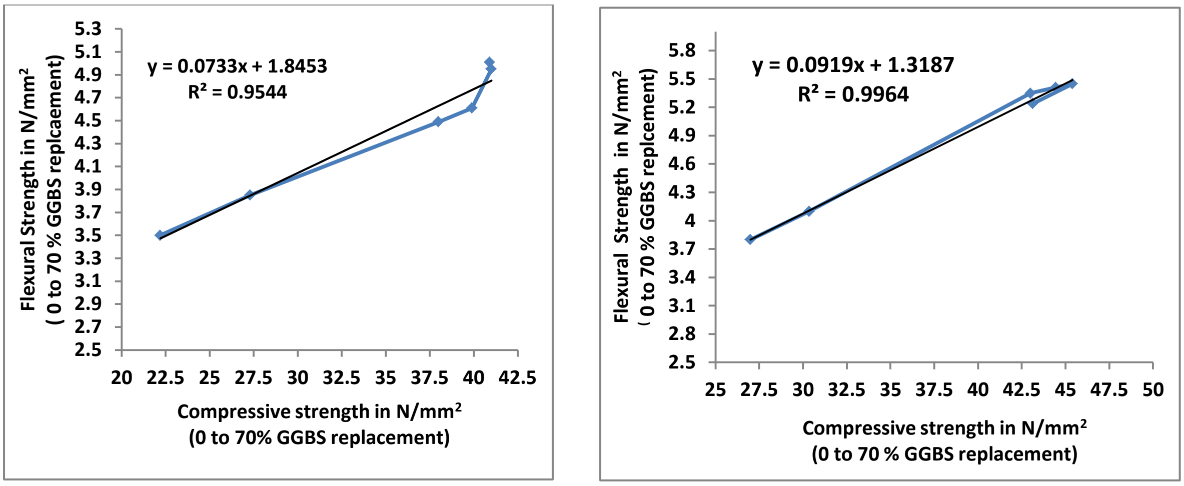
The relationship between split tensile strength and compressive strength was obtained using regression analysis as

$$f_t = 0.039\, f_c + 1.778 \quad (28 \text{ days}) \qquad (1)$$

$$f_t = 0.039\, f_c + 1.809 \quad (56 \text{ days}) \qquad (2)$$

where f_c = Compressive strength in N/mm^2 and f_t= Split tensile strength in N/mm^2

The relationship between compressive strength and flexural strength was found out using regression analysis and is shown in Figures 9 (a) & (b).



(a) 28th day **(b) 56th day**

Figure 9 Relationship Between Cube Compressive Strength and Flexural Strength

The relationship between flexural strength (f_{cr}) and compressive strength (f_c) is obtained as

$f_{cr} = 0.073\ f_c + 1.845$ (28th day) (3)

$f_{cr} = 0.091\ f_c + 1.318$ (56th day) (4)

Where, f_c = compressive strength in N/mm^2 and f_{cr} = flexural tensile strength in N/mm^2

The properties of concrete with varying proportions of GGBS are summarized in Table 4.

Table 4 Mechanical Properties of Control Concrete and Concrete with GGBS

% of GGBS in Concrete	Fresh Properties				Hardened Properties							
	Slump Values (mm)		Setting Time (min)		Water Absorption (%)		Compressive Strength (N/mm^2)		Split Tensile Strength (N/mm^2)		Flexural Strength (N/mm^2)	
	Initial slump	After one hour	Initial	Final	28 days	56 days	28 days	56 days	28 days	56 days	28 days	56 days
0	255	115	40	390	7	5.5	40.9	43.13	3.38	3.42	5.01	5.24
30	210	129	50	420	6.6	5.3	41	45.4	3.45	3.68	4.95	5.45
40	215	130	60	445	5.6	5.2	39.9	44.45	3.3	3.66	4.61	5.41
50	200	105	70	460	5.5	5.1	38.0	43.00	3.2	3.4	4.49	5.35
60	185	95	90	510	5.0	5.0	27.3	30.36	2.85	3.00	3.85	4.1
70	150	70	95	560	5.2	4.8	22.2	27	2.65	2.9	3.5	3.8

IV CONCLUSIONS

i. From the experimental results it is found that up to 50% replacement of GGBS, the compressive strength, split tensile strength and flexural strength values are found to be equal or comparable with that of control concrete specimens.
ii. It was also observed that the strength of concrete with GGBS at 28th day is lower than the control concrete.
iii. As the age of curing increases, the GGBS concrete mixtures exhibit higher strength values when compared to the control concrete.
iv. As the strength of concrete beyond 50% GGBS is found to be very less when compared to control concrete, flexural studies were carried out in RC beams with 0%, 40% and 50% GGBS.

FUTURE WORK

From the results obtained from the preliminary studies , flexural behavior of reinforced concrete beams with GGBS with respect to age will be studied in detail.

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