Performance of Carbon Fiber Reinforced GGBS Concrete

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***Abstract*—The present work deals with the results of experimental investigations on carbon fiber reinforced GGBS concrete. Effect of these fibers on various strengths of concrete are studied. Fiber content varied from 0.5 to 1.5% at an interval of 0.5 by weight of cement. Various strengths considered for investigation are compressive strength, flexural strength and split tensile strength. Cube of size 150 mm for compressive strength, beam of 100mmx100mmx500mm for flexural strength and cylinder of 150mm diameter and 300mm height for split tensile strength were casted. All the specimens were water cured for 7 and 28 days and tested subsequently. The workability is measured with the slump cone test. A comparison of results of carbon fiber reinforced GGBS concrete with that of normal concrete showed the significant improvements in the results of compressive strengths.**

***Index Terms*—Carbon fibers, Compressive Strength, Flexural strength, FRC, Split tensile strength, Superplasticizer, Workability, etc.**

I. INTRODUCTION

Concrete is a mixture of cement, fine aggregate, coarse aggregate and water in a definite proportion. Each ingredient in concrete has it's own purpose. Coarse aggregates provides strength whereas fine aggregates fills the voids between coarse aggregates to give a more dense and less permeable structure. Water added in concrete reacts with the cement to form the calcium silicate hydrate (C-S-H) gel responsible for strength in concrete.

Similarly cement is added in concrete as a binding material which helps in binding all ingredients to form a homogeneous mixture of required strength, workability and durability. Cement which is added in concrete undergoes a reaction with water which is called as the hydration reaction. This hydration reaction is exothermic in nature which releases tremendous amount of heat. This released heat causes loss of water. This high temperature resulted from heat of hydration may cause thermal cracking and consequently reduction of the mechanical properties of concrete. Such a cracks are really dangerous as it may reduce strength, durability, water tightness and many more.

So, to avoid this effects due to sudden increased temperature during hydration process following measures can be taken.

1) Use of cement which will release less amount of heat during hydration
2) Reducing the proportion of tricalcium aluminate (C3A)
3) Less grinding of cement
4) Using mineral admixtures or pozzolanic materials which will reduce the heat of hydration.

Pozzolanic materials are siliceous or siliceous and aluminous materials, which in themselves posses lesser or no cementitious properties, but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide evolved on hydration, at ordinary temperature, to form compounds, possessing cementious properties.

II. LITERATURE REVIEW

Use of carbon fibers in concrete improves tensile and flexural properties, lowers drying shrinkage, thermal conductivity. Carbon fiber also provides cathodic protection to steel reinforcement in concrete[1]. This research uses carbon fiber to strengthen wooden bridge beam. By wrapping carbon fiber around wooden bridge beam increases the bending, stiffness and shear strength of the beam. The effect due to defects in wood like knot, checks, splits, etc. Will also be overcome by using carbon fiber[2]. The effect of carbon fiber on the fresh properties, mechanical properties of self compacting concrete by inclusion of carbon fibers were studied. Upto saturation limit of 1.5%, carbon fibers improves both fresh and strength properties of concrete. Beyond saturation limit, workability and strength properties starts to reduce[3]. Reactive powder concrete with three different types of single fibers namely steel fiber, glass fiber and carbon fiber were used to investigate compressive strength, modulus of elasticity, splitting tensile strength, flexural strength of concrete[4]. Concrete with use of carbon fiber was prepared to investigate flexural strength, peak deflection, flexural toughnes. Four point loading test was used. Optimum dose of carbon fiber was found out to be 1.5%[5]. The mechanical properties and microstructure of coral concrete with carbon fiber was investigated. Effect of carbon fiber on coral concrete were investigated to find the cube compression strength, axial compression strength, split tensile strength, elastic modulus and poisson's ratio[6]. Mechanical properties and qualities of concrete with partial replacement of cement with silica fume, metakaoline and GGBS were studied. Out of these three pozzolanic materials, silica fume gave maximum compressive strength and split tensile strength[7]. Investigation by partial replacement of cement with metakaoline and GGBS was done. Maximum 28 days compressive strength was obtained with 20% partial replacement of cement with metakaoline and 10% partial replacement of cement with GGBS. Splitting tensile strength of concrete was maximum with 10% GGBS replacement and 20% metakaoline replacement[8].

III. SYSTEM DEVELOPMENT

The present research study is based on experimental work and requires preliminary investigations in a methodological manner. This research work was done to find the effects of ground granulated blast furnace slag (GGBS) and carbon fibers to normal concrete. Compressive strength, flexural strength and split tensile strength was investigated in this study.

For the grade M50 concrete, the mix proportion was find out using the Indian standard method (IS-10262:2019). Before commencing the concrete mix, all materials should be kept at room temperature, which is around 27°C ± 3°C. Each ingredient is weighed separately using a digital electronic weighing machine, following the mix details. The mixing process is carried out using a concrete mixer. Cement and aggregates are thoroughly mixed in a dry state to ensure maximum blending and uniformity, while preventing the intrusion of foreign matter. When mixing, every effort is made to prevent the loss of any water or other ingredients.

The concrete mix was compacted in the mould on a vibrating table and left on a platform for 24 hours before demoulding. The specimens were then placed in a clean and fresh water curing tank with a temperature maintained around 27°C ± 2°C. They were cured for a period of 7 days and 28 days before being tested for the respective strength properties.

Fig. 1: Chopped Carbon Fibers

COMPRESSION STRENGTH TEST

By using 150 mm x 150 mm x 150 mm cube test specimens, a compression test was performed to measure the compressive strength of carbon fibre reinforced GGBS concrete, following IS-516: 1959[9]. The test setup, failure pattern of the cube and the core of the failed cube in compression can be seen in fig. 1 and fig. 2. The maximum force applied during the test (Pc) is divided by the cross-sectional area (A) resulting in the specimen's compressive strength, using the formula:

$F_{cu}=P_c/A$

where, F_{cu}= Compressive strength in MPa

P_c= Maximum applied load in KN

A= Cross sectional area inmm^2

FLEXURAL STRENGTH TEST

Concrete flexural strength was assessed using beam specimens with dimensions of 100x100x500mm. During the test, the beam specimen was positioned in a machine in such a way that the load was applied to the uppermost surface as cast in the mould along two lines, which were spaced 200 mm apart, resulting in two- point loading. The axis of the specimen was carefully aligned with the axis of the loading device.

The rate of loading should be increased gradually without any sudden impact, increasing at a rate of 180 kg/min[10]. The setup for the flexure test of concrete prisms can be observed in fig. 3, while fig. 4 illustrates the failure pattern of the prism during the flexure test. The flexural strength of the specimen is calculated using the following expression:

$F_{cr} = PL/(bd^2)$

where, Fcr= Flexural strength

P = Maximum applied load in kN

b= Measured width of specimen in mm

d= Measured depth of specimen in mm

SPLIT TENSILE STRENGTH TEST

An indirect technique frequently employed to assess the tensile strength of concrete is the split tensile test. This test is conducted because conducting a direct tension test on concrete is challenging. In the split tensile test, the concrete specimen is compressed to the point where tensile stress causes the specimen to fail. In this study, a cylindrical specimen is split along its centre plane parallel to the edges to conduct the split tensile test. The opposing edges of the cylinder receive the compressive load. The split tensile test was performed according to IS-5816: 1999 to determine the tensile strength of Carbon Fiber Reinforced GGBS Concrete.[10] Cylindrical test specimens measuring 150mm in diameter and 300mm in height were used and tested after 7 days and 28 days. The test setup can be seen in fig. 5, while the failure pattern of the cylinder in tension is shown in fig. 6.

The following formula is used to get the cylinder's split tensile strength:

$F_t = (2P_t) / (\pi\ d\ L)$

where, Pt = Split tensile force in KN

d = Diameter of cylinder in mm

L = Length of cylinder in mm

Ft = Split tensile strength of concrete in N/mm^2

IV. RESULT AND DISCUSSION

The outcomes of tests conducted on specimens of regular concrete mix and carbon fibre reinforced concrete mix at ages 7 and 28 have been recorded and tabulated. Various tests including compression strength test, split tensile strength test, and flexure strength test have been conducted on hardened concrete in the laboratory. These tests have been performed according to the relevant standards and experimental test procedures. While all other tests were performed on hardened (dry) concrete after 7 and 28 days of curing, the work-ability of concrete was evaluated on fresh (wet) concrete.

1.Workability of concrete:

The workability of fresh normal concrete mix, concrete with partial replacement of cement with GGFS and carbon fiber reinforced GGBS concrete mix was assessed using the slump cone test. The results of the slump test have been recorded and presented in below table. The results in the table 1 and 2 indicate that the slump value decreases as the percentage of GGBS and carbon fibers increases in the concrete. The reduction in slump is more pronounced for higher GGBS and carbon fiber content. A graph illustrating the variation of slump with respect to fiber content (%) has been plotted and is shown in Graph 2 for M50.

Table 1: Workability of concrete (Percentage of GGBS)

Mix Designation	GGBS Content	Workability
M0	0	120
M10	10	114
M20	20	107
M30	30	98
M40	40	89
M50	50	80

Fig. 2: Workability of concrete with variation of GGBS

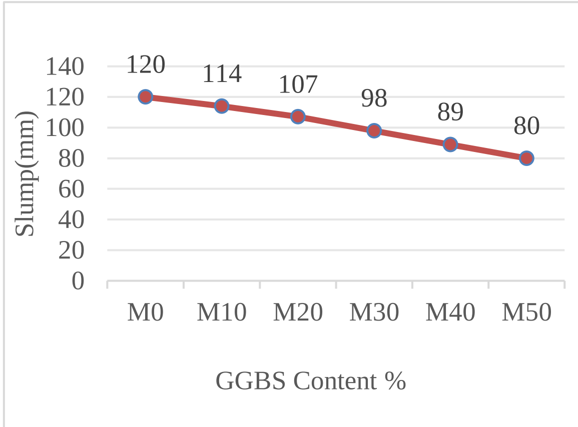
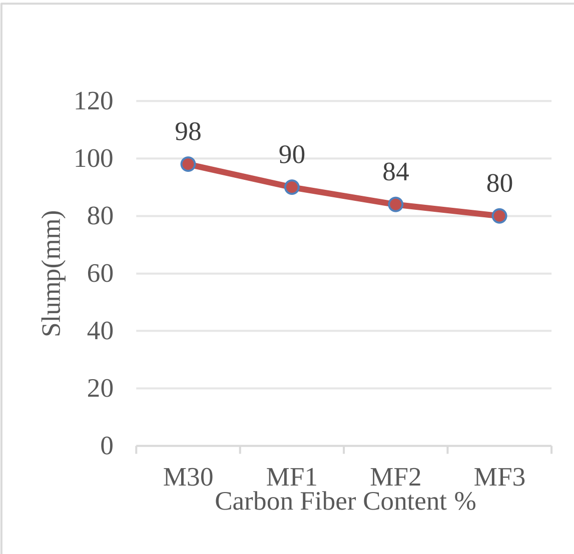


Table 2: Workability of concrete (Percentage of carbon fiber)

Mix Designation	GGBS Content	Carbon fiber	Workability
M30	30	0	98
MF1	30	0.5	90
MF2	30	1.0	84
MF3	30	1.5	80

Fig. 3: Workability of concrete with variation of carbon fibers



Workability is measured in terms of slump value in mm. Results from table 2 indicate that for same mix proportion and same superplasticizer dose with same aspect ratio of fiber but increase in fiber content (%), workability is reduced. The workability was seen gradually decreasing with the increase in the fiber content.

2. COMPRESSIVE STRENGTH TEST

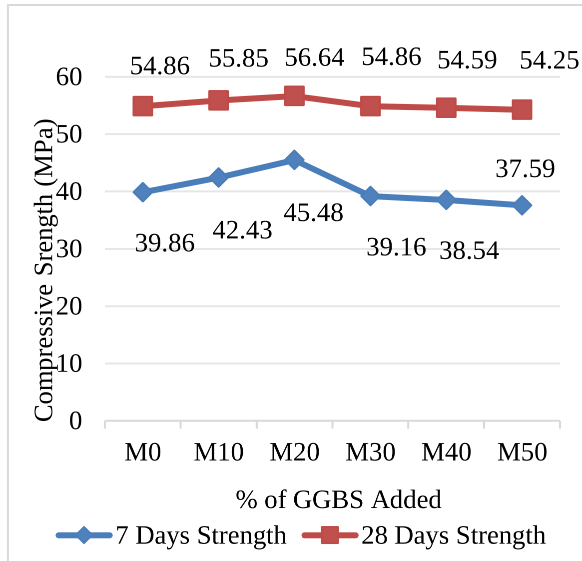
A cube compression test was performed on standard cubes of plain concrete, concrete with varying percentage of GGBS and concrete with 30% GGBS and carbon fiber of size 150 x 150 x 150mm after 7 days and 28 days of immersion in water for curing. The was conducted on compression testing machine (CTM). Carbon fiber percentage ranging from 0.5% to 1.5% were added in concrete with interval of 0.5%.

Table 3: Compressive strength of concrete (Percentage of GGBS)

Mix Designation	GGBS %	Avg. Comp. Strength		%Variation	
		7Day	28Day	7Day	28Day
M0	0	39.86	54.86	0.00	0.00
M10	10	42.43	55.85	6.45	1.80
M20	20	45.48	56.64	14.09	3.24
M30	30	39.16	54.86	-1.75	0
M40	40	38.54	54.59	-3.31	-0.5
M50	50	37.59	54.25	-5.7	-1.11

The compressive strength was seen increasing with the increase in the percentage of GGBS. The compression strength was 54.86 MPa and it increased to 56.64 MPa with 20% GGBS addition for the replacement of cement. But later addition of GGBS reduced the compression strength of concrete.

Fig. 4: Compressive strength of concrete with variation of GGBS



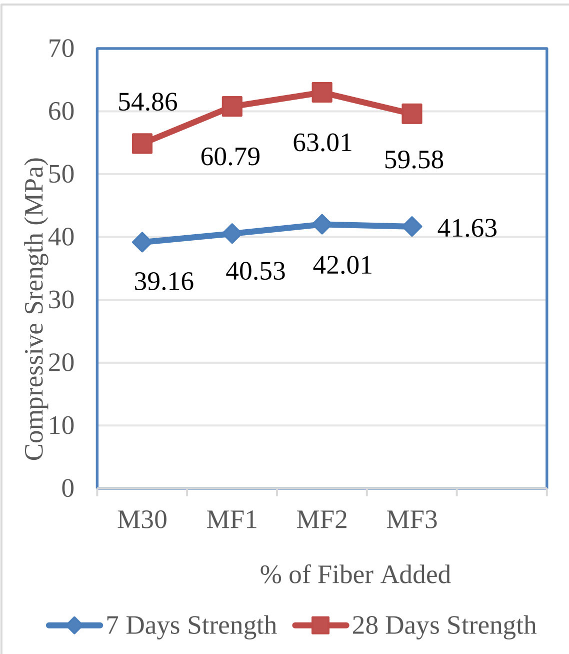
Test results of concrete with partial replacement of cement by ground granulated blast furnace slag (GGBS) are shown in table 3. The value of compressive strength was seen 54.86MPa with 0% GGBS and was increased upto 56.64MPa with 20% cement replacement with GGBS at 28 days water curing. Compressive strength was 39.86MPa with 0% cement replacement by GGBS whereas the value was increased to 45.48MPa with 20% cement replacement by GGBS at 7 days water curing.

Table 4: Compressive strength of concrete (Percentage of carbon fiber)

Mix Designation	GGBS %	Carbon fiber	Compressive strength		% Variation	
			7 Day	28 Day	7 Day	28 Day
M30	30	0	39.1	54.8	0.0	0.0

			6	6		
MF1	30	0.5	40.53	60.79	3.49	10.81
MF2	30	1.0	42.01	63.01	7.28	14.85
MF3	30	1.5	41.63	59.58	6.30	8.60

Fig. 5: Compressive strength of concrete with variation of carbon fibers



The experiment shows that with addition of carbon fibers the compressive strength increased. The tests showed compression strength of 54.86 MPa with 0% carbon fibers and it increased to 63.01 MPa with addition of 1.00% carbon fibers by 14.85%.

3. FLEXURAL STRENGTH TEST

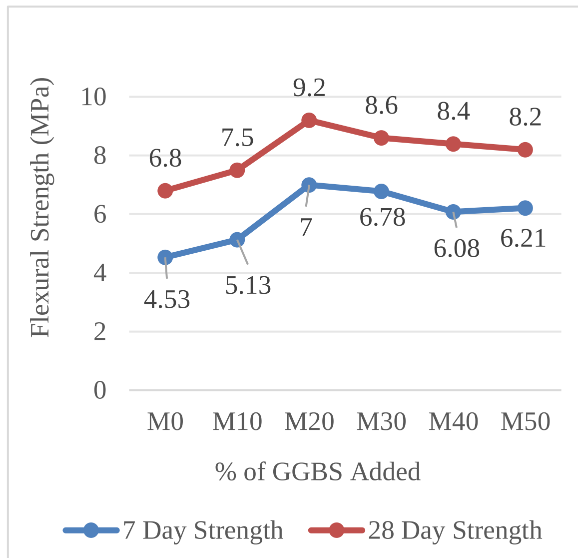
Flexural strength is obtained for various GGBS volume percentage and results are presented in table 5. The variation of flexural strength with respect to fiber volume fraction is shown in table 6. This test was conducted on a beam specimen of size 100x100x500 mm after curing the specimen for 7 days and 28 days. Universal testing machine was used to perform this test.

Table 5: Flexural strength of concrete (Percentage of GGBS)

Mix Designation	GGBS %	Flexural Strength		%Variation	
		7 Day	28 Day	7 Day	28 Day
M0	0	4.53	6.8	0.00	0.00
M10	10	5.13	7.5	13.24	10.29
M20	20	7.00	9.2	54.52	35.29
M30	30	6.78	8.6	49.67	26.47
M40	40	6.08	8.4	34.21	23.53
M50	50	6.21	8.2	37.08	20.59

The flexural strength was increasing with the partial replacement of cement with GGBS. Upto 20% cement replacement by GGBS, the flexural strength was increased upto 9.2 MPa. After 20% cement replacemnt flexural strength was seen decreasing.

Fig. 6: Flexural strength of concrete with variation of GGBS



The flexural strength performed on concrete beams of size 100x100x500 mm. It has been observed that the flexural strength was 6.8MPa of normal concrete with 0% GGBS fraction which increased to 9.2MPa with 30% cement replacement with GGBS. After 30% GGBS replacement with cement in concrete, the flexural strength has been seen decreasing.

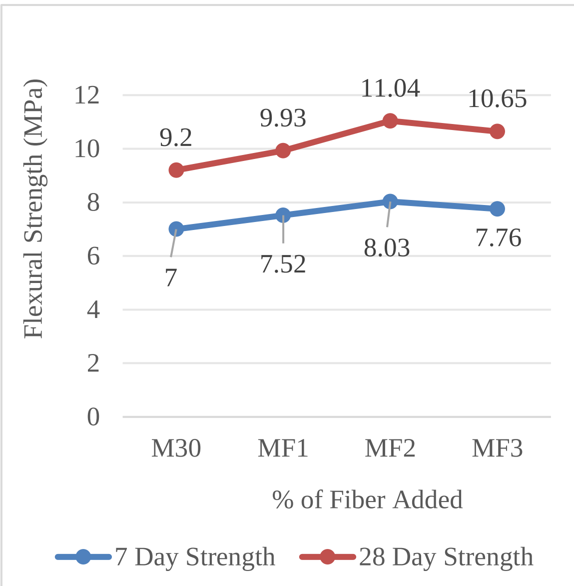
Table 6: Flexural strength of concrete(Percentage of carbon fibers)

Mix Designation	GGBS %	Carbon fiber	Flexural strength		% Variation	
			7 Day	28 Day	7 Day	28 Day
M30	30	0	7.00	9.2	0.0	0.0
MF1	30	0.5	7.52	9.93	7.42	7.93

MF2	30	1.0	8.03	11.04	14.71	20.0
MF3	30	1.5	7.76	10.65	10.85	15.76

As the carbon fiber content increased in the concrete, the flexural strength was incresed. Upto 1% inclusion of carbon fibers in concrete, the flexural strength was increased by 20%. But after 1% addition of carbon fiber, the flexural strength was decreasing.

Fig. 7: Flexural strength of concrete with variation of carbon fibers



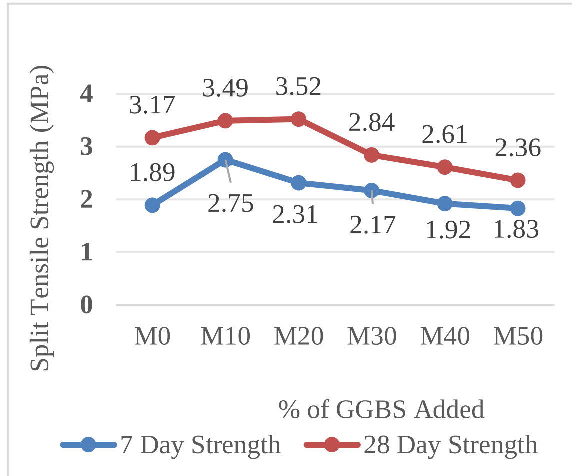
4. SPLIT TENSILE STRENGTH TEST

The split tensile strength test of concrete with partial replacement of cement by GGBS is conducted. The results of this test are presented in table 9 for 7 days and 28 days strength. Split tensile test results after addition of carbon fiber are shown in table 10 for 7 days and 28 days. This test was conducted using universal testing machine (UTM) on a cylindrical specimen of 150mm diameter and 300mm height.

Table 7: Split tensile strength of concrete(Percentage of GGBS)

Mix Design ation	GGB S %	Split Tensile Strength		%Variation	
		7 Day	28 Day	7 Day	28 Day
M0	0	1.89	3.17	0.00	0.00
M10	10	2.75	3.49	45.50	10.09
M20	20	2.31	3.52	22.22	11.04
M30	30	2.17	2.84	14.81	-10.41
M40	40	1.92	2.61	1.58	-17.66
M50	50	1.83	2.36	-3.17	-25.55

Fig. 8: Split tensile strength of concrete with variation of GGBS

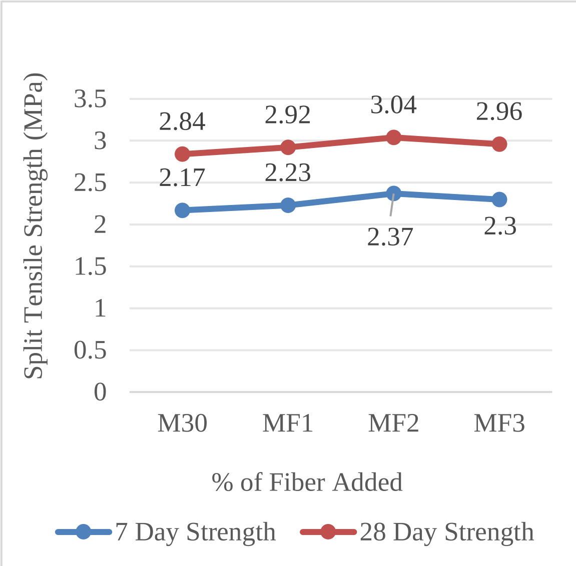


The split tensile test was performed on concrete cylinder of diameter 150mm and height 300mm. The test showed that the tensile strength was 3.18 MPa with 0% GGBS and it increased to 3.52 MPa with 20% GGBS replacement with cement. After 20% GGBS cement replacement, strength started to decrease.

Table 8: Split tensile strength of concrete(Percentage of carbon fiber)

Mix Desig nation	GG BS %	Carb on fiber	Split Tensile strength		% Variation	
			7 Day	28 Day	7 Day	28 Day
M30	30	0	2.17	2.84	0.0	0.0
MF1	30	0.5	2.23	2.92	2.76	2.81
MF2	30	1.0	2.37	3.04	9.21	7.04
MF3	30	1.5	2.30	2.96	5.99	4.23

Fig. 9: Split tensile strength of concrete with variation of carbon fibers



The split tensile test result showed that after addition of carbon fibers in concrete the tensile strength increased upto 3.04 MPa with 1% carbon fiber addition. After 1%, tensile strength was seen decreasing.

V. CONCLUSION

This chapter shows the summery of the present work, major conclusions and application of the carbon fiber reinforced concrete. Following conclusions are drawn from the results:

1) The workability of fresh concrete goes on decreasing as the percentage of ground granulated blast furnace slag and carbon fiber are increased. Maximum slump value was recorded was 120 mm of normal concrete which reduced to 80 mm with 50% cement replacement by GGBS. With addition of carbon fibers, workability was decreased.

2) The compressive strength of normal concrete was recorded as 39.86 MPa and 54.86 MPa after 7 days and 28 days respectively. The compressive strength was increased to 39.16 MPa and 54.86 MPa with 20% cement replacement by GGBS after 7 days and 28 days respectively. After further cement replacement with GGBS, compressive strength decreases. The compressive strength was increased to 42.01 MPa and 63.01 MPa with 1% addition of carbon fiber after 7 days and 28 days curing respectively. The increase of 7.28% and 14.85% was recorded.

3) The maximum flexural strength achieved was 7.00 MPa and 9.2 MPa (7 days and 28 days)at 30% cement replacement with GGBS. With addition of 1% carbon fiber the flexural strength was further increased to 8.03 MPa and 11.04 MPa after 7 days and 28 days curing. An increase of about 20% was seen.

4) The value of split tensile strength was 2.31 MPa and 3.52 MPa by 30% cement replacement with GGBS after 7 days and 28 days curing respectively. The tensile strength increased to 2.37 MPa and 3.04 MPa with addition of 1% carbon fiber which increased by 9.21% and 7.04% after curing of 7 days and 28 days.

5) The optimum fiber content to improve the compressive strength, flexural strength and split tensile strength is observed at 1.00%.

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