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Research Article

Effect of Addition of Ground Granulated Blast Furnace Slag (GGBS) on Mechanical Properties of Fiber Reinforced Concrete

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Abstract

In this investigation ground granulated blast furnace slag (GGBS) is used as an alternative binder and filler materials for Ordinary Portland cement (OPC). This paper deals with the results of an experimental investigation on structural properties of fiber reinforced concrete with GGBS. M50 grade of concrete was considered for the study. Cement was replaced by GGBS with 0%, 10%, 20%, 30% & 40% by weight of cement. Percentage of steel fiber was kept constant as 1.5%. The variables were size of aggregate (10mm 12 mm & 20mm) and variable percentage of GGBS to study the effects of size of aggregate and percentage of GGBS on workability, dry density, compressive strength and flexural strength. Cubes of 150mmx150mmx150mm size for compressive strength, beams of 100 x 100 x 500 mm for flexural strength were cast. Specimens with replica of GGBS were wet cured upto 56 days while normal concrete was cured upto 28 days. All specimens were tested subsequently to study the strength performance of this concrete. Workability of GGBS fiber reinforced concrete was found to be increased with increase in GGBS percentage. Results of compressive strength, cost effectiveness and toughness indices under flexural loading condition for ground granulated blast furnace slag fiber reinforced concrete are presented.

Keywords: *Ground granulated blast furnace slag, steel fiber, compressive strength, flexural strength, workability, strength of concrete, optimum GGBS content, toughness indices*

1. Introduction

In the recent years, there is great development in the area of admixture. Now a day, the pozzolanic admixtures like fly ash, micro silica are commonly used to enhance performance characteristic of concrete. It is need of time to design and construct the structures which will have great durability and strength and which have led to develop concept of high strength concrete. It is needful to find out the substitute to micro silica without sacrificing the quality and performance of high strength concrete. One of the better alternate to the micro silica is ground granulated blast furnace slag.

GGBS concrete is a type of concrete in which a part of cement is replaced with GGBS, which is an industrial waste. If concrete mix is replaced with ground granulated blast furnace slag as a partial replacement for Portland cement, it would provide environmental and economical benefits. GGBS has some pozzolanic properties it leads to increase the compressive strength of concrete. To minimize the brittleness of concrete fibers are added. Fiber reinforcement substantially enhances the toughness and durability of concrete. To minimize this brittleness of high strength concrete with replacement of cement with GGBS by addition of steel fibers an experimental investigation was represented by Neeraja .D (D. Neeraja, 2013) his study concluded that GGBS with 40% replacement with 1% steel fibers gives better results for M50 concrete, beyond that limit strength gradually decreases. Steel fiber acts as crack arrestors in concrete.

Fiber efficiency and fiber content are important variable controlling the performance of FRC (Balguru P.N. *et. al*. 1992). GGBS prove to be good alternative binder to replace the cement at 50-60% replacement level. Concrete with GGBS gives less strength as compared to normal concrete at 28 days but GGBS concrete will gain strength upto 56 days. Beyond 56 days concrete with GGBS gives significantly more strength than normal concrete mix (K. Ganesh Babu *et. al*, 2000). GGBS concrete is denser than concrete with ordinary Portland cement because of its more fineness. GGBS also acts as filler material in concrete by filling fine pours. GGBS of particle diameter of less than 3 micrometer just contribute to early strength of mortar. For long term strength of mortar, GGBS with more diameters only have micro-aggregate effect (Huiwen wan *et. al*, 2000).

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Although the cementitiousness of GGBS is much weaker than Portland cement, GGBS takes micro-crystal-core effect for cement hydration process. GGBS is activated in an alkaline environment. This is great advantage to decrease hydration process of cement. Jiang.J (J. Jiang, 2002) presented increase in flexural and compressive strength increase with the increase surface area of the GGBS.

Research Significance

This research provides information concerning the behavior of GGBS FRC for high strength concrete under flexure. The influence of size of aggregate on concrete and replacement of cement with GGBS was carried out. Effect of GGBS on compressive strength and cost of concrete is also studied. The toughness of high strength concrete including GGBS is anticipated to improve flexural strength when reinforced with randomly distributed steel fiber. In that respect by taking constant steel fiber, effectiveness of various percentages of GGBS with various size of aggregate addition to high strength concrete is studied. Formulation relating to load deflection to size of aggregate and GGBS replacement level and concrete strength is presented.

2. Experimental Investigation

2.1 Materials

In present work various materials are used; OPC 53 Grade, GGBS, fine aggregate: natural river sand, coarse aggregate, water and steel fibers.

A. Cement**:** Ordinary Portland cement of 53 grade conforming to IS 12269-1987 (I.S. 12269, 1987) has been used. The specific gravity of cement was 3.15. The physical properties of cement obtained on conduction of appropriate tests as per IS12269-1987 (I.S. 12269, 1987). Results shown in Table.1

Table1: Physical Properties of Cement according to IS 12269:1987 and GGBS according to IS-4031-1988

Properties	Cement	GGBS
Fineness: Specific Surface	3.75	4.25
Specific gravity	3.15	2.87
Standard consistency of cement (%)	24%	34%
Setting time of cement A. Initial setting time(min) B. Final setting time (min)	 135 240	180

B. GGBS**:** GGBS used in this experimental work is procured from Sona Alloys Pvt. Ltd. Ground granulated blast furnace slag is the by-product of smelting ore to purify metals. Slag has pozzolanic reaction which allows the increase of compressive strength. The physical properties of GGBS are presented in Table 1 as per IS 4031-1988 (IS 4031,1988).

C. Fine aggregates: Locally available river sand conforming to grading zone II of IS 383-1970[15] has been used as fine aggregate. The fineness modulus is 2.9, Specific gravity is 2.8.

D. Coarse Aggregates: The Coarse aggregate used is crushed (angular) aggregate conforming to IS383:1970 (IS383-1970). Various sizes of aggregates are used in experiment as 10mm, 12mm and 20mm. The results of sieve analysis conducted as per the specification of IS 383 -1970 (IS383-1970). Fineness modulus is 6.25, specific gravity is 2.61.

E. Water: Clean potable water is used for casting and curing operation for the work.

F. Steel Fiber**:** Hook ended Steel fibers were used throughout the experiment. (I.S.O. 9001:2000) certified hook ended steel fiber conforming to (ASTM A820) type 1 standards are used for experimental work. Fibers made available from Stewols India Pvt. Ltd. Nagpur. Details are given in table 2.

Table 2: Physical properties of Steel Fibers

Sr. no	Properties	Results
1	Diameter of fibre (D_f)	1 mm
2	Length of fibre (L_f)	50 mm
3	Aspect ratio (L_f) / (D_f)	50
4	Modulus of elasticity	200 Gpa
5	Tensile strength	>1100 Mpa

2.2: Mix Proportion

Mix design was carried out using (I.S. 10262:2009). Mix proportions shown in Table 3

Table 3: Mix Proportions by IS 10262-2009

Unit of batch	Water (Liters)	Cement (Kg)	F.A. (Kg)	C.A. (Kg)	Size of Agg. (mm)
Cubic meter content	157.60	450.2	757.46	1059.6	20
Ratio	0.35	1	1.68	2.35	
Cubic meter content	166.20	474.88	736.40	1030.17	12
Ratio	0.35	1	1.53	2.169	
Cubic meter content	169.6	484.57	729.08	1019.9	10
Ratio	0.35	1	1.505	2.105	

2.3: Specimen Preparation and Curing

A total of 36 specimens were cast for each group of aggregate. Three groups of mixtures were prepared, each containing 18 cubes of 150 mm size and 18 beams of 100x100x500 mm size. The Specimens details are given in Table 4.

All the concrete mixtures were mixed for a total of 4 minute in a laboratory by hand mixing. The constituent material at various mix proportions were thoroughly mixed in a dry condition to obtain uniform concrete mix. The quantity of water calculated as per the water-cement ratio was mixed thoroughly to obtain uniform cohesive concrete. The steel fibers were sprinkled in concrete at the very end to ensure uniform fiber dispersion and care was taken to avoid balling of fibers. After uniform fresh concrete was achieved the fresh concrete is poured in to the specimen moulds. Casting of cubes and beams were conducted in three layers. Each layer was compacted by table vibrator and top surface was leveled and smoothed using a trowel.

Table4: Specimens Details

Size of Ag-g	Concrete Specification	Designation	cubes	Beams
10 mm	Normal Concrete (N.C.)	G 10	3	3
	N.C. + 1.5%SF	G 10-0	3	3
	N.C. +1.5%SF+ 10% GGBS	G10-10	3	3
	N.C. +1.5%SF+ 20% GGBS	G10-20	3	3
	N.C. +1.5%SF+ 30% GGBS	G10-30	3	3
	N.C. +1.5%SF+ 40% GGBS	G10-40	3	3
12 mm	Normal Concrete	G12	3	3
	N.C. + 1.5%SF	G12-0	3	3
	N.C. +1.5%SF+ 10% GGBS	G12-10	3	3
	N.C. +1.5%SF+ 20% GGBS	G12-20	3	3
	N.C. +1.5%SF+ 30% GGBS	G12-30	3	3
	N.C. +1.5%SF+ 40% GGBS	G12-40	3	3
20 mm	Normal Concrete	G20	3	3
	N.C. + 1.5%SF	G20-0	3	3
	N.C. +1.5%SF+ 10% GGBS	G20-10	3	3
	N.C. +1.5%SF+ 20% GGBS	G20-20	3	3
	N.C. +1.5%SF+ 30% GGBS	G20-30	3	3
	N.C. +1.5%SF+ 40% GGBS	G20-40	3	3

After casting all the specimens were left in the curing room for 24 hrs. Concrete specimens were demolded and cured in 20+-2^{0}C. The test specimens were cured according to ASTM Standard (ASTM C192-88).

2.4 Testing of specimens

2.4.1. Properties of fresh concrete:

The workability of GGBS concrete was determined with the help of slump cone test and wet density was obtained by measuring the weight and volume of wet concrete, with the help of standard cylinders results of these properties are as per Table.5.

2.4.2. Test conducted on hardened concrete

Computation of strengths was carried out after destructive testing of normal and GGBSSFRC specimen. Each test was carried out in triplicate, results were averaged and recorded.

2.4.3 Cube compressive strength

The compressive tests were conducted as per I.S. (I.S.516-1959) standard test method as shown in figure 1. A cube was subjected to a concentrated compressive force where failure under compression was expected to occur. The test setup and loading arrangement are as shown in figure.1. A calibrated stiff CTM with capacity of 2000kN was used for testing of the cube specimen and the load was applied at a rate of 140kg/cm^2 per minute as per (I.S.516-1959). During the testing the deflection was monitored with the help of dial gage having least count of 0.01mm.

2.4.4 Flexural strength

The two point bending beam tests were conducted on flexure specimens as per I.S. (I.S.516-1959) method as shown in figure 2. Dial gage was attached to the neutral axis of beam to get accurate deflection at the rate of maximum load test setup as suggested by (P.N.Balguru 2000) as shown in figure 2. A calibrated stiff UTM with capacity of 600kN was used for testing of the flexure specimens and load was applied at the rate of 400kg/minute for 150mm size of beam as per I.S. (I.S.516-1959). During testing the deflection was monitored with the help of dial gage apart from the ram-displacement obtained from the machine. The standard test method is based on determining amount of energy required to deflect the beam.

Fig: 1 Compression testing

Fig: 2 Flexural strength testing

3. Result and Discussion

3.1 Properties of fresh concrete.

The workability of GGBS FRC is determined with the help of slump cone test and wet density is obtained by measuring the weight and volume of wet concrete with the help of standard cylinder. Table 5 shows that workability increases with increase in GGBS content. Maximum workability is found at 30% - 40% GGBS replacement for M50 concrete. Results of the properties are shown in Table 5. Comparison of % increment in slump is made with plain concrete.

Table 5: Properties of Fresh Concrete

Concrete	Slump (mm)	Wet density (WD)(Kg/ m3)	% increase in slump	% increase in WD
G 10	10	2590.61	-	-
G 10.0	5	2595.11	-50	0.17
G 10-10	5	2602.27	-50	0.45
G 10-20	8	2608.51	-20	0.69
G 10-30	10	2610.61	0	0.77
G 10-40	16	2617.53	60	1.03
G12	12	2591.61	-	-
G 12.0	10	2592.59	-16.67	0.037
G 12-10	16	2595.46	33.33	0.148
G 12-20	20	2627.16	66.67	1.37
G 12-30	24	2630.61	100	1.50
G 12-40	15	2632.42	25	1.57
G 20	15	2638.02	-	-
G 20.0	8	2638.52	-46.67	0.018
G 20-10	10	2694.35	-33.33	0.021
G 20-20	15	2691.98	0	0.020
G 20-30	24	2697.38	60	0.022
G 20-40	30	2717.58	100	0.030

3.2 Compressive strength

This strength was determined by carrying out a cube compressive test on 150 mm size cube using UTM. The compressive strength was calculated by formula given in I.S (I.S. 516-1959).

$$f_{cu}=\frac{Pc}{A} \quad (1)$$

Where f_{cu} is the compressive strength of specimen, Pc is load in compression, A is area of cube. The compressive strength and percentage increment in compressive strength of GGBS concrete shown in Table 6

3.3: Flexural Strength

For determining this strength each specimen of size 100x100x500 was supported over a span of 400 mm and two point loads were applied at the middle third of the span. The central deflection was recorded upto first crack. All the beams were loaded upto failure. The flexural strength calculated by formula given in I.S (I.S. 516-1959)

$$f_{cr}=\frac{P_{max}L}{bh^2} \quad (2)$$

Where, *fcr* is the flexural strength. P_{max} is the peak load on the specimen, *L* is effective length, *b* is width of beam, h is depth of beam. The average of three test specimens was considered for determining the flexural strength

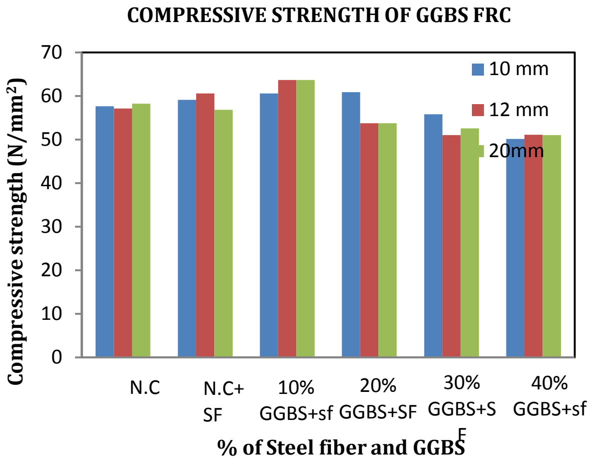

Fig 3: Compressive Strenght of GGBS F.R.C.

Table 6: Compressive Strength of Concrete

Concrete	Comp. strength (N/mm²)	% increment in Comp. strength	Cost compariso n w. r. to. NC (%)	Cost compariso n w. r. to. FRC (%)
G 10	57.69	-	-	-
G 10.0	59.15	2.53	+17.22	-
G 10-10	60.60	5.04	+8.88	-7.15
G 10-20	61.09	5.89	+0.56	-14.21
G 10-30	55.80	-3.27	-7.75	-21.31
G 10-40	50.14	-13.08	-16.09	-28.42
G12	57.16	-	-	-
G 12.0	59.15	3.48	+6.33	-
G 12-10	60.60	5.99	+6.01	-7.15
G 12-20	61.01	6.78	+0.33	-14.32
G 12-30	51.14	-10.70	-8.66	-21.49
G 12-40	51.04	-10.53	-17.01	-28.65
G 20	56.83	-	-	-
G 20.0	58.83	3.51	+16.00	-
G 20-10	60.60	6.63	+17.67	-7.18
G 20-20	61.91	8.93	+0.68	-14.388
G 20-30	52.61	-7.42	-8.99	-21.35
G 20-40	51.01	-10.24	-17.32	-28.33

The values of Flexural strength obtained were also calculated as per I.S.(I.S. 456:2000).

$$fcr = 0.7\sqrt{fcu} \quad (3)$$

where, *fcr* is the flexural strength. *fcu* compressive strength of the specimen. The results related to flexural strength have been presented in table 7, 8 and 9.

3.4. Flexural Toughness Indices:

As per ASTM (C-1018, 2011) recommendations the flexural toughness indices is expressed as the ratio of amount of energy required to deflect a beam at a specific value. The toughness indices I5 defined by following relationship

$$I5=\frac{\text{Area under the Load}-\text{Deflection Curve upto }3\delta}{\text{Area under the Load}-\text{Deflection Curve upto }\delta} \quad (3)$$

Where δ is the deflection at the first crack. The indices I_{10} and I_{20} are also defined as the ratios of the area under load-deflection curves upto 5.5δ and 10.5δ times the first crack deflection, divided by the area upto the first crack deflection respectively. The toughness indices values are given in Table10. It has been observed that the flexure toughness indices of GGBS FRC show marginal variation

Table 7: Load deflection, flexural strength of 10 mm aggregate concrete

Designation	Load (KN)	Max Deflection	Flexural strength by Eq(2)	% Increment	Flexural strength I.S456
G10	22.5	0.065	9.00	-	5.31
G10.0	23.75	0.065	9.58	6.44	5.38
G10.10	24.08	0.21	9.69	7.00	5.44
G10.20	24.41	0.30	9.76	8.44	5.46
G10-30	22.41	0.21	8.44	-0.44	5.23
G10-40	20.95	0.11	8.38	-6.88	4.95

Table 8: Load deflection, flexural strength of 12 mm aggregate concrete

Designation	Load (KN)	Max Deflection	Flexural strength by Eq(2)	% Increment	Flexural strength I.S456
G12	21.69	0.05	8.676	-	5.29
G12.0	21.88	0.35	8.752	0.875	5.38
G12.10	22.00	0.38	8.80	1.42	5.44
G12.20	23.30	0.27	9.32	7.42	5.46
G12-30	21.48	0.28	8.592	-0.99	5.00
G12-40	20.73	0.35	8.292	-4.44	5.01

Table 9: Load deflection, flexural strength of 20 mm aggregate concrete

Designation	Load (KN)	Max Deflection	Flexural strength by Eq(2)	% Increment	Flexural strength I.S456
G20	22.31	0.045	8.924	-	5.27
G20.0	23.03	0.25	9.212	3.28	5.36
G20.10	23.53	0.3	9.412	5.46	5.44
G20.20	24.59	0.211	9.84	10.26	5.50
G20-30	20.54	0.245	8.216	-7.93	5.07
G20-40	19.18	0.24	7.67	-14.05	4.99

3.5. Elastic Constant

In the analysis of structure elastic constant viz. E, μ & G are always required. The modulus of elasticity of FRC can be calculated using law of mixture as suggested by Hannant (D. J. Hannant, 1978) as given below:

$$E_{fc} = E_f.V_f.(n_1.n_2) + E_m(1-V_f\, x.n_1.n_2) \quad (4)$$

Where,

n_1= (1/6),

n_2= (L/2L_c)

L- Length of fiber

Lc- Embedded length of fiber

V_f - Fiber volume fraction

E_f - Modulus of elasticity of composite

E_m– Modulus of elasticity of fiber

E_{fc}– Modulus of elasticity of concrete.

The modulus of elasticity of FRC can be determined using the formula given by I.S. 456 (I.S. 456-2000) Depending upon strength of concrete (f_{cu})

$$E_{fc} = 5\sqrt{f_{cu}} \quad (5)$$

Where, f_{cu} is Compressive strength of concrete. A formula is proposed by Ghugal and Deshmukh (Ghugal *et. al.*, 2006) for calculate modulus of elasticity of GFRC in term of volume fraction (v_f) and cube compressive strength. This formula is also applicable for other fiber reinforced concrete.

$$E_{fc} = 5(1 - 2.65V_f)\sqrt{f_{cu}} \quad (6)$$

Where, f_{cu} - Compressive strength of concrete

V_f - Fiber volume fraction

The modulus of elasticity of GGBS concrete presented in table 11, 12 & 13.

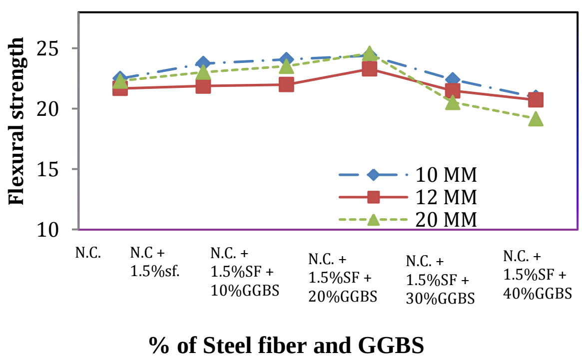

Fig 4: Comparison of Flexural Strength of Beams

Table 10: Toughness Index

Designation	I_5	I_{10}	I_{20}	I_{30}
G10	5.44	11.1	-	-
G10.0	5.6	10.0	17.23	-
G10.10	5.44	11.06	20.11	27.33
G10.20	5.4	10.90	19.4	26.1
G10.30	5.44	11.11	20.22	26.78
G10.40	5.42	8.95	14.61	-
G12	5.66	-	-	-
G12.0	5.4	10.5	19.9	26.3
G12.10	5.33	9.90	19.80	27.80
G12.20	9.28	11.09	21.87	32.18
G12.30	9.4	10.57	20.46	29.6
G12.40	5.33	9.78	22.11	30.51
G20	5.4	-	-	-
G20.0	4.83	10.37	-	-
G20.10	5.52	10.47	23.88	32.58
G20.20	9.47	11.29	24.44	36.91
G20.30	9.27	10.82	22.58	45.88
G20.40	5.29	10.23	18.82	22.94

Table 11: Modulus of Elasticity 10mm Agg. Concrete

Designation	Modulus of Elasticity (GPa)		
	Using Law of Mixture (Equation 4)	Using I.S. 456 [22] (Equation 5)	Using Ghugal Equation 4
G10	37.97	37.97	37.97
G10-0	38.78	38.45	36.92
G10-10	39.25	38.92	37.37
G10-20	39.41	39.08	37.52
G10-30	37.67	37.34	35.86
G10-40	35.68	35.34	33.99

Table 12: Modulus of Elasticity 12mm Agg. Concrete

Designation	Modulus of Elasticity (GPa)		
	Using Law of Mixture (Equation 4)	Using I.S. 456 [23] (Equation 5)	Using Ghugal[24] (Equation 6)
G12	37.80	37.80	37.80
G12-0	38.45	38.12	36.61
G12-10	39.25	38.92	37.37
G12-20	39.38	39.05	37.50
G12-30	36.10	35.76	34.33
G12-40	36.06	35.72	34.30

Table 13: Modulus of Elasticity 20 mm Agg. Concrete

Designation	Modulus of Elasticity (GPa)		
	Using Law of Mixture (Equation 4)	Using I.S. 456 [23] (Equation 5)	Using Ghugal[24] (Equation 6)
G20	37.80	37.69	37.69
G20-0	38.68	38.35	36.82
G20-10	39.25	38.92	37.37
G20-20	39.67	39.34	37.77
G20-30	39.59	36.26	34.82
G20-40	36.05	35.71	34.29

Conclusions

The following conclusions are drawn from the results and discussion of this investigation:

1) The workability of fresh GGBS fiber reinforced concrete increase with increase in GGBS content for FRC. The wet density of concrete increases with increase in the GGBS replacement level.
2) The compressive strength of cubes increases with 20% GGBS replacement in every group of aggregate. For 10mm aggregate 61.09 MPa strength achieved at 20% replacement level, for 12 mm aggregate 61.01 MPa strength achieved at 20% replacement of cement with GGBS and for 20m aggregate with 20% GGBS shows 61.91 MPa compressive strength.
3) Results showed 20% replacement of GGBS shows significantly increase in strength and also it has same cost as compared to normal concrete and 14% less cost as compared to fiber reinforced concrete for 10 mm aggregate concrete. 40% replacement gives comparatively less strength as compared to normal concrete but it reduces cost 16% with respect to Normal concrete and 28% less cost with respect to FRC
4) For 12 & 20 mm aggregate concrete 20% replacement of GGBS with concrete shows increase in strength by 6% – 9%. and its cost is same as normal concrete with respect to normal concrete and 14% less cost with respect to FRC
5) The flexural tensile strength of all the aggregate grouped concrete shows that all mix having 20% GGBS was optimum level which gives 8 -10% more strength than normal concrete. Flexural strength calculated by equation 2 overcomes equation 3and % increment in flexural strength calculated that is 10.26% for 20 mm aggregate at 20% GGBS replacement.
6) The Load-Deflection behavior indicates that for the flexure member there is increase in deflection with increased load carrying capacity as compared to that normal concrete. This shows the increase in flexural stiffness and toughness up to 20% replacement of cement with GGBS.
7) Flexural strength has good performance for 10% and 20% replacement of cement with steel fiber. which is more than normal concrete.
8) Elastic constants of GGBS FRC are obtained by various methods. The computed values of modulus of elasticity are excellent agreement with those of law of mixture and proposed formula by Ghugal..

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