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Compressive Strength Assessment using GGBS and Randomly Distributed Fibers in Concrete

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Abstract*: *India is producing enormous amounts of industrial by-products out of which 150 million tonnes of GGBS itself. Apart from disposal of this solid waste, engineers strive for its value addition through its use as a construction material for achieving better economy, eco-friendliness without compromising on technical aspects. In this study, varieties of concrete are mixed with GGBS as a replacement material for cement to understand its compressive strength and long term behaviour. It is seen from literature that the fibers enhance the performance of concrete. Accordingly, six trials were made with GGBS replacement along with variation of cement content, water cement ratio and steel fibers with aspect ratio 60 and variation in reinforcing indices. The workability of concrete increased with increasing the GGBS content and also observed there is a reduction in workability in fiber reinforced concrete. The results indicated that the concrete made with GGBS indicates the strength comparable to the concrete made with OPC for all replacement levels. There is a substantial decrease in strength at 80% replacement. While there is a substantial increase in long-term strength. The compressive strength of GGBS concrete was increased up to 19% than that of OPC concrete and also observed 5 to 12% strength increased in fiber reinforced concrete than GGBS concrete. For this purpose studied the compressive strength of concrete at the ages of 3, 7,28,56,90 and 180 days.

Keywords* : *GGBS; OPC; Steel fibres; Compressive strength

I. INTRODUCTION

In the present scenario, the global awareness is being increased about environmental pollution and reduction of carbon foot print. Concrete made by using OPC is the primarily used material in the construction sector accounting for about 30% of all materials on the planet and 70% of all resources in the built environment.

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The cement clinker production is highly expensive and harmful in view of ecologically and environmentally due to hazardous emissions of CO_2, NO_x and SO_x, which are the significant contributors to the "greenhouse gas (GHG) effect". To reduce greenhouse effect, different types of pozzolanic and cementitious materials, for example ground granulated blast furnace slag (GGBS), Silica Fume (SF) and Fly Ash (FA) are commonly
used in production of concrete. These pozzolanic and cementitious materials not only reduce the greenhouse effect but also progress durability, reduce porous nature and improve the interlocking with the aggregate and also provides better building and execution properties.
The utilisation of GGBS as mineral admixture needs only grinding, while comparing with the production of OPC it saves extensive amounts of energy. Due to its engineering benefits GGBS is getting more and more attention now, because of the reduction of ill effects on the environmental effects. The lower content of cement requirement for preparation of concrete results to a reduction of CO_2 [1-4]. The inclusion of mineral admixture consisting of slag has been recognized to get better engineering properties of concrete. When compared to production of OPC, GGBS releases less greenhouse gases into the environment and also requires less energy. GGBS is obtained from pig iron industry as a by-product; it contains high alumina and silica content and less lime content when compared to OPC. [5-6].The slag is generally a mixture of chemical formation like aluminum, silicon, calcium, magnesium, and oxygen, subsequently a GGBS-blended concrete is an eco-friendly concrete when compared to an OPC concrete and also improves workability and reduction in bleeding of concrete [7]. The mechanical properties of GGBS-mixed concrete were improvised in a well accepted manner [8-11]. [12] referred to that GGBS-mixed concrete exhibited an amount of reduction in the open porosity when compared to OPC concrete because of its particle size. Several investigations had been done at the impact of GGBS in numerous ways, specifically, workability of concrete [10], compressive strength [13-17], durability properties [16, 18]. Several researchers had been attempted to illustrate the various replacement levels and the impact of GGBS usage. Those are (i) rheological properties and workability aspects of blended concrete or mortar [10, 19-20], (ii) heat of hydration [21-27], (iii) setting times [28-31], (iv) the early age cracking [32] and (v) mechanical and durability properties [13, 33-43].

The major observations made from the literature review include (i) strength development of GGBS incorporated concrete vary significantly in relation to various replacement levels of cement by GGBS, water to cementitious material ratio, general cementitious materials, method of curing, age at testing and many other factors (ii) most of the studies were limited to 40-50% of partial replacement of cement with GGBS and (iii) very limited investigations were reported on fibre incorporated GGBS based concrete.

Although considerable work was done on GGBS based concrete, this paper provides additional information on GGBS based concrete by incorporating GGBS as cementitious material. Extensive studies were completed to evaluate compressive strength of GGBS integrated concrete considering (i) partial substitution of cement by GGBS up to 80% (ii) varying cement quantity (iii) varying water binder ratio (iv) effect of reinforcing index (0.3. 0.6 and 0.9) .In the present study, systematic investigations were completed on various percentage replacements of cement by GGBS with and without fibres.

II. MATERIALS AND METHODS

2.1. Cement

The ordinary Portland cement 53 grade (IS: 12269-1987) was used in this investigation with a specific gravity of 3.13 g/cm^3. Initial and final setting times of the OPC cement were 100 minutes and 312 minutes. Its Blains specific surface area and fineness of cement were 3513 cm^2/g and 9% respectively.

2.2. Ground granulated blast furnace slag (GGBS)

GGBS (IS 455-2015) was used in this investigation with a specific gravity of 2.88 g/cm^3. Its Blains specific surface area and fineness of cement were 4250 cm^2/g and 4% respectively.

2.3 Aggregates

In this study crushed stone crushed stone aggregate was used with a maximum size of 20 mm, its specific gravity 2.65. River sand was used as fine aggregate its specific gravity 2.62 (IS 383-1970)

2.4 *Water*

The water used in this investigation was potable water which is free from injurious amount of deleterious materials.

2.5 *Superplasticizer*

To improve the workability of concrete, poly carboxylic ether based superplasticizer in required dosage ranging from 0.3% to 1.2% by weight of cementitious material was added

2.6 *Steel fibres*

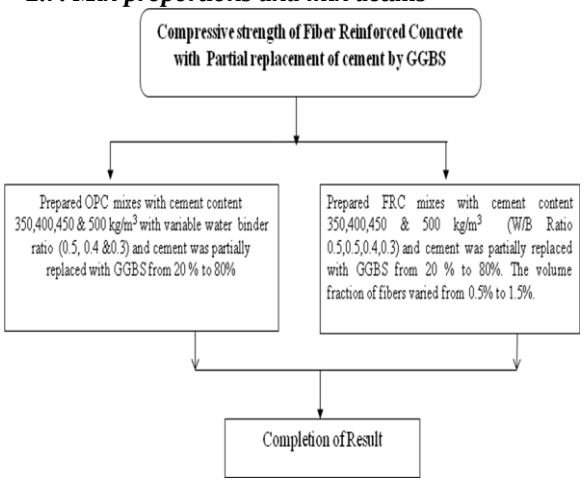
Hooked end steel fibres were used for some concrete mixes incorporated with GGBS. Salient features of steel fibres are shown in Fig. 1 and Table 1.

Table 1 Properties of steel fibres

Fiber Type	Hooked end steel fiber
Fiber Length (L)	30mm
Diameter (D)	0.5 mm
Aspect Ratio(L/D)	60
Tensile Strength	1100 N/mm^2
Young's Modulus	2x10^{5}N/mm^2
Density	7800 kg/m^3

Fig. 1 Steel fibres

2.7. Mix proportions and mix details



Several OPC and blended mixes were planned to evaluate compressive strength with and without fibres. The complete test matrix is shown in Table 2. Steel fibres were added for the identified mixes (mentioned in Table 2) as 0.5%, 1.0% &1.5% of volume of concrete, i.e three reinforcing indices (0.3, 0.6 and 0.9) were considered for this study. The reinforcing index is the product of the aspect ratio and volume fraction of fibres.

As mentioned below in table 2, several concrete mixes were cast. For some mixes, to improve the workability, poly carboxylic ether based superplasticizer in required dosage ranging from 0.3% to 1.2% by volume of concrete was added. Fig. 2 shows the workability of a GGBS based concrete mix. 100x100x100 mm size cubes were cast in six numbers for each proportion. Cubes were casted in two layers. Vibrating table is used for compaction of each layer and top of cube was leveled and smoothed by a trowel. All the moulded specimens were placed in the curing room for 24 h at the temperature of 27 ± 2^{o}C. After that, the specimens were demoulded and cured in 27 ± 2^{o}C until the time of testing the specimens. For the cases concretes with fibers, fibers in different proportions were added to mix after satisfying the slump of the respective mix. Fig. 3 shows typical cast specimens GGBS based concrete mixes .From the cured specimens, compressive strength was determined for 3, 7, 28, 56, 90 & 180 days. Fig. 4 presents the typical testing of specimen and the failure behaviour of specimen

Fig. 2 Measurement of workability

Fig. 3 Casting of concrete

Fig. 4 Typical test set up and failure of specimens

Table 3 exhibits the compressive strength of various mixes of GGBS based concrete without fibres at 3, 7, 28, 56, 90 and 180 days respectively. Table 4 exhibits the compressive strength of various GGBS based concrete mixes with fibres.

Table 2 -Various mix proportions planned for experiment

Cement quantity, kg/m^3	% of cement replacement by GGBS	Water to binder ratio (w/b)	Water to cement ratio (w/c)	Fine aggregate kg/m^3	Coarse aggregate kg/m^3	Mix proportion	Remarks
350	0, 20, 40,50, 60, 80	0.5	0.5, 0.62, 0.83,1.0, 1.25, 2.5	726	1135	1:2.07:3.24	With and without steel fibres
350	0, 20, 40,50 60, 80	0.4	0.4, 0.5, 0.66, 0.8,1.0, 2.0	763	1167	1:2.18:3.33	Without fibers only
350	0, 20, 40,50 60, 80	0.3	0.3, 0.37, 0.5, 0.6, 0.75, 1.5	800	1223	1:2.28:3.50	Without fibers only & SP added
400	0,20, 40,50, 60, 80	0.5	0.5, 0.62, 0.83, 1.0, 1.25, 2.5	683	1068	1:1.7:2.67	With and without steel fibres
400	0,20, 40,50, 60, 80	0.4	0.4, 0.5, 0.66, 0.8, 1.0, 2.0	725	1134	1:1.81:2.83	Without fibers only
400	0, 20, 40, 50, 60, 80	0.3	0.3, 0.37, 0.5, 0.6, 0.75, 1.5	767	1199	1:1.91:3.00	Without fibers only & SP added
450	0, 20, 40, 50, 60, 80	0.5	0.5, 0.625, 0.833, 1.0, 1.25, 2.5	640	1001	1:1.42:2.22	Without fibers only
450	0, 20, 40, 50, 60, 80	0.4	0.4,0.5,0.66, 0.8,1.0, 2.0	688	1075	1:1.53:2.39	With and without steel fibres
450	0, 20, 40, 50, 60, 80	0.3	0.3,0.375,0.5,0.6,0.75,1.5	734	1148	1:1.63:2.55	Without fibers only & SP added
500	0, 20, 40, 50, 60, 80	0.5	0.5, 0.63, 0.83, 1.0, 1.25, 2.5	597	934	1:1.19:1.86	Without fibers only
500	0, 20, 40, 50, 60, 80	0.4	0.4,0.5,0.66, 0.8, 1.0, 2.0	702	1097	1:1.40:2.19	Without fibers only
500	0, 20, 40, 50, 60, 80	0.3	0.3,0.375,0.5,0.6,0.75,1.5	702	1097	1:1.4:2.19	With and without steel fibres & SP also added

Table 3 - GGBS based compressive strength of concrete mixtures without fibres

Cement kg/m^3	GGBS kg/m^3	W/b	W/C	FA	CA	Mix proportion	Compressive strength in N/mm^2 (without steel fibers)					
							3 days	7days	28 days	56 days	90 days	180 days
350	**0**	**0.5**	**0.50**	**726**	**1135**	**1:2.07:3.24**	**28.83**	**35.66**	**49.33**	**50.56**	**51.55**	**53.77**
280	70		0.62				30.16	41.67	50.16	54.93	57.58	58.94
210	140		0.83				29.12	38.33	49.66	55.62	59.1	61.08
175	175		1.00				25.87	35.74	48.12	54.15	58.23	60.54
140	210		1.25				20.83	32.33	46.81	53.60	57.62	60.38
70	280		2.5				13.32	19.33	25.5	29.58	32.64	34.17

350	**0**	**0.4**	**0.40**	**763**	**1167**	**1:2.18:3.33**	**24.56**	**35.00**	**44.5**	**45.61**	**46.32**	**48.46**
280	70		0.50				38.53	46.51	52.66	56.35	60.56	62.14
210	140		0.66				36.64	42.71	50.33	53.85	59.39	61.86
175	175		0.80				31.23	39.83	48.46	51.43	58.12	61.31
140	210		1.00				21.54	27.35	46.33	49.57	57.68	60.69
70	280		2.00				17.83	21.15	37.16	44.59	47.75	49.65
350	**0**	**0.3**	**0.3**	**800**	**1223**	**1:2.28:3.50**	**35.95**	**42.54**	**59.92**	**64.02**	**65.25**	**66.64**
280	70		0.37				38.34	46.24	63.85	66.47	68.07	69.32
210	140		0.50				37.15	44.67	61.56	65.76	67.21	68.56
175	175		0.6				35.36	41.38	60.12	63.26	66.05	67.48
140	210		0.75				30.82	36.74	57.43	60.52	62.13	64.04
70	280		1.5				27.43	30.21	50.82	56.23	59.52	60.92
400	**0**	**0.5**	**0.50**	**683**	**1068**	**1:1.70:2.67**	**23.33**	**28.26**	**42.86**	**43.36**	**44.83**	**46.76**
320	80		0.62				24.90	30.20	44.50	47.10	50.73	52.29
240	160		0.83				23.80	29.10	43.00	46.08	50.91	52.68
200	200		1.00				21.08	25.28	38.48	44.28	46.91	49.25
160	240		1.25				19.98	24.06	37.00	42.06	45.88	48.29
80	320		2.50				19.01	23.98	33.40	39.20	42.42	44.42
400	**0**	**0.4**	**0.40**	**725**	**1134**	**1:1.81:2.83**	**23.80**	**32.20**	**45.30**	**46.02**	**47.22**	**49.23**
320	80		0.50				25.26	35.60	48.20	50.61	55.04	56.35
240	160		0.66				24.68	33.90	47.66	52.70	56.72	58.48
200	200		0.80				22.86	30.96	43.58	50.15	52.95	54.04
160	240		1.00				21.56	30.46	40.96	46.30	50.79	53.25
80	320		2.00				20.75	28.42	38.62	45.20	49.05	51.56
400	**0**	**0.3**	**0.30**	**767**	**1199**	**1:1.91:3.00**	**35.43**	**54.83**	**69.6**	**70.99**	**72.61**	**75.52**
320	80		0.37				38.62	59.36	74.26	82.80	86.88	87.26
240	160		0.50				36.90	57.32	71.42	79.63	84.96	87.85
200	200		0.60				33.96	52.68	68.42	76.63	83.26	86.89
160	240		0.75				33.20	52.30	65.46	74.62	81.56	85.10
80	320		1.50				32.60	50.08	64.00	72.32	80.32	83.20
450	**0**	**0.5**	**0.50**	**640**	**1001**	**1:1.42:2.22**	**24.67**	**33.60**	**43.83**	**44.28**	**45.96**	**47.39**
360	90		0.625				26.60	36.46	45.62	49.62	52.01	53.38
270	180		0.833				25.32	34.64	44.36	50.62	52.34	54.56
225	225		1.00				23.66	31.00	42.12	48.50	51.39	53.07
180	270		1.25				21.96	29.50	39.10	45.96	48.09	50.44
90	360		2.50				19.98	27.70	34.50	41.06	43.82	45.89
450	**0**	**0.40**	**0.40**	**688**	**1075**	**1:1.53:2.39**	**26.66**	**34.00**	**46.60**	**47.07**	**48.88**	**50.65**
360	90		0.50				28.26	40.26	54.62	58.16	61.72	63.91
270	180		0.66				27.26	38.26	49.12	54.61	58.45	60.42
225	225		0.80				25.80	32.64	45.20	52.50	55.14	57.86
180	270		1.00				23.60	31.20	43.50	48.16	53.94	56.12
90	360		2.00				21.86	29.78	37.56	44.06	47.70	48.83
450	**0**	**0.30**	**0.375**	**734**	**1148**	**1:1.63:2.55**	**36.54**	**57.80**	**71.61**	**73.04**	**75.19**	**77.67**
360	90		0.375				39.68	62.80	77.00	81.60	88.17	89.32
270	180		0.50				37.85	59.50	74.65	79.80	87.71	91.07
225	225		0.60				34.70	55.20	69.01	78.26	84.19	85.57
180	270		0.75				33.35	51.60	65.56	75.26	81.62	83.92
90	360		1.50				31.50	48.05	59.52	70.78	71.42	76.78
500	**0**	**0.50**	**0.50**	**597**	**934**	**1:1.19:1.86**	**26.33**	**35.66**	**49.30**	**50.68**	**51.56**	**53.15**
400	100		0.625				27.60	38.50	51.60	53.92	56.28	60.77
300	200		0.833				26.88	37.28	50.61	56.12	60.00	62.05
250	250		1.00				24.56	33.36	47.95	55.90	58.93	61.18
200	300		1.25				22.60	31.66	42.05	49.28	52.35	54.45
100	400		2.50				20.90	29.80	38.56	46.28	49.67	51.28
500	**0**	**0.40**	**0.40**	**650**	**1016**	**1:1.30:2.03**	**27.50**	**35.10**	**51.33**	**51.89**	**53.67**	**55.93**
400	100		0.50				29.84	41.34	58.92	63.86	66.58	68.94
300	200		0.66				27.60	39.20	52.62	59.10	62.35	64.66
250	250		0.80				26.24	33.96	48.63	56.10	59.33	61.03

200	300		1.00				24.94	32.00	45.26	54.26	56.30	58.82
100	400		2.00				22.30	30.50	41.42	49.30	52.60	55.38
500	**0**	**0.30**	**0.30**	**702**	**1097**	**1:1.40:2.19**	**39.30**	**59.30**	**76.28**	**78.19**	**80.25**	**82.96**
400	100		0.375				47.28	64.28	81.82	87.45	92.46	96.55
300	200		0.50				45.23	61.44	77.80	86.50	92.19	94.92
250	250		0.60				36.54	57.24	69.25	81.25	88.29	88.64
200	300		0.75				34.46	55.40	66.80	76.42	82.83	86.84
100	400		1.50				32.00	51.60	60.24	71.02	76.50	80.12

Table 4 GGBS based compressive strength of concrete mixtures with fibres

Cement	w/b	w/c	FA	CA	Wt. of GGBS	V_f (% volume fraction of fibers) (reinforcing index)	Compressive strength in N/mm^2 (with steel fibers)			
							28 days	56 days	90 days	180 days
350	0.5	0.5	726	1135	0	0.5 (0.3)	53.28	54.2	55.68	57.71
280		0.62			70		55.63	57.78	61.86	63.02
210		0.83			140		54.74	56.23	60.15	61.85
140		1.25			210		50.52	54.71	58.19	58.98
70		2.50			280		27.85	33.37	33.65	36.45
350		0.5			0	1 (0.6)	54.17	56.74	59.14	61.72
280		0.62			70		58.12	60.1	62.86	64.85
210		0.83			140		56.55	58.13	60.87	62.47
140		1.25			210		53.83	55.01	56.62	59.32
70		2.50			280		45.45	37.81	39.12	45.06
350		0.5			0	1.5 (0.9)	58.97	59.81	61.97	63.01
280		0.62			70		63.83	65.21	67.68	70.20
210		0.83			140		61.32	63.07	64.22	66.67
140		1.25			210		55.86	57.12	58.37	61.61
70		2.50			280		38.64	38.97	39.74	43.06
400	0.5	0.5	683	1068	0	0.5 (0.3)	45.98	48.21	52.28	55.67
320		0.62			80		48.65	52.46	57.13	60.41
240		0.83			160		46.87	50.91	55.58	58.29
200		1.00			200		43.21	47.67	50.11	53.71
160		1.25			240		40.11	43.34	47.84	49.82
80		2.50			320		35.24	39.63	42.66	44.54
400		0.5			0	1 (0.6)	46.2	48.19	53.13	56.33
320		0.62			80		49.98	54.72	59.52	61.17
240		0.83			160		50.45	55.38	59.02	63
200		1.00			200		44.6	48.01	51.73	55.62
160		1.25			240		41.98	45.11	48.56	51.26
80		2.50			320		40.26	41.59	43.88	47.6
400		0.5			0	1.5 (0.9)	48.1	51.34	55.79	58.17
320		0.62			80		50.98	54.92	61.17	64.01
240		0.83			160		52.34	55.89	61.45	65.43
200		1.00			200		46.28	50.07	53.73	58.91
160		1.25			240		43.45	47.34	50.05	53.69
80		2.50			320		41.68	44.77	45.84	48.78
450	0.4	0.4	688	1075	0	0.5 (0.3)	49.56	51.17	54.61	57.28
360		0.50			90		56.92	58.85	60.76	62.97
270		0.66			180		53.28	57.27	57.67	59.64
225		0.80			225		47.34	51.38	53.36	55.83
180		1.00			270		45.04	46.74	48.92	52.17
90		2.00			360		40.56	42.89	46.12	49.48
450		0.4			0	1.0 (0.6)	51.45	53.88	56.15	58.18
360		0.50			90		57.26	58.12	60.32	63.76
270		0.66			180		55.18	58.01	59.47	62.99
225		0.80			225		49.26	53.17	54.31	57.78
180		1.00			270		48.42	49.98	51.17	53.47

90		2.00			360		44.96	45.5	47.13	50.12
450		0.4			0		54.2	56.28	57.37	59.93
360		0.50			90		59.26	60.85	61.32	64.59
270		0.66			180	1.5 (0.9)	57.8	60.1	60.76	63.98
225		0.80			225		51.44	54.58	56.48	60.02
180		1.00			270		50.06	51.96	54.77	57.15
90		2.00			360		45.52	48.23	49.08	52.53
500	0.3	0.37	702	1098	0		79.42	82.25	83.18	84.23
400		0.37			100		87.69	89.74	92.05	95.11
300		0.50			200	0.5 (0.3)	83.37	87.26	90.12	94.58
250		0.60			250		71.13	82.02	82.59	86.15
200		0.75			300		69.09	75.23	76.95	80.64
100		1.5			400		64.07	70.11	73.15	77.28
500		0.37			0		81.42	85.28	87.45	90.15
400		0.37			100		86.48	91.02	95.16	98.77
300		0.50			200	1.0 (0.6)	84.28	90.08	93.59	96.94
250		0.60			250		79.26	84.65	87.35	92.25
200		0.75			300		75.05	80.09	84.68	87.43
100		1.5			400		71.35	74.73	79.81	81.11
500		0.37			0		83.27	85.95	88.12	90.05
400		0.37			100		87.54	91.54	96.32	98.88
300		0.50			200	1.5 (0.9)	85.12	90.02	93.83	97.05
250		0.60			250		81.25	85.66	87.98	90.67
200		0.75			300		76.41	81.13	84.01	86.75
100		1.5			400		72.1	78.57	81.17	83.34

III. RESULTS AND DISCUSSION

From Table 3, experimental results showed that the compressive strength

(i) for control concrete with cement quantity 350 kg/m^3 and w/b ratio 0.5, at the age of 28 days is 49.33 MPa and for 3 days is 28.83 MPa, which is about 58% of the strength of 28 days and the 7th day strength is 35.66, which is about 72% of the strength of 28 days. The strength at 56th, 90th and 180th day is 50.56MPa, 51.55MPa and 53.77MPa respectively. The percentage increase w.r.t 28th day strength is about 3%, 5% and 9% respectively.

(ii) For control concrete with cement quantity 280 kg/m^3, GGBS 70 kg/m^3 (20% replacement of cement of quantity 350 kg/m^3), with w/b ratio 0.5 and w/c ratio 0.62, at 28 days strength is 50.16MPa and for 3 days is 30.16MPa, which is about 60% of the strength of 28 days and the 7th day strength is 41.67MPa, which is about 83% of the strength at 28 days. The strength at 56th, 90th and 180th day is 54.93MPa, 57.58MPa and 58.94MPa respectively. The percentage increase w.r.t 28th day strength is about 9.5%, 15% and 17.5% respectively. The strength enhancement is observed at later period i.e beyond 28 days. The strength gain could be due to additional formation of CSH. For 40% and 60% replacement of cement by GGBS, the 28th and 180 days strength are 49.66MPa, 46.81 MPa and 61.08 MPa, 60.38 MPa respectively. For 80% replacement of cement by GGBS, at 28 days strength is 25.5 MPa, which is about 52% of OPC concrete and at 180 days, the strength is 34.17 MPa which is about 64% of control concrete.

(iii) For OPC concrete with cement quantity 350 kg/m^3 and w/b ratio 0.4, the strength at 28 days is 44.5 MPa. The strength at 28 days for 20%, 40%, 60% & 80% replacement of cement by GGBS is 52.66 MPa, 50.33 MPa, 46.33 MPa & 37.16 MPa respectively. The strength at 180 days for 20%, 40%, 60% and 80% replacement of cement by GGBS is 62.14MPa, 61.86MPa, 60.69MPa, 49.65MPa respectively. For control concrete, it is 48.46MPa. upto 60% replacement of cement by GGBS, compare the strength with that of OPC concrete at 28 days where as at 180th day, the strength is comparable with that of OPC concrete for all the replacements. Up to 60% replacement level, the enhanced strength is about 30% compared to OPC strength.

(iv) For OPC concrete with cement quantity 400 kg/m^3 and w/b ratio 0.5, the strength at 28 days is 42.86 MPa and at 180th day the strength is 46.76 which about 10% increase. The compressive strength at 28 days for 20%, 40%, 50%, 60% and 80% replacement of cement by GGBS is 44.5 MPa, 43.0 MPa, 38.48 MPa, 37.0 MPa & 33.40 MPa respectively. The strength at 180 days is 52.29 MPa, 52.68 MPa, 49.25 MPa, 48.29 and 44.42 MPa. Up to 60% replacement of cement by GGBS, the strength is comparable with that of OPC concrete at 28 days where as at 180th day; the strength is comparable with that of OPC concrete for all replacements.

(v) For OPC concrete with cement quantity 400 kg/m^3 and w/b ratio 0.4, the strength at 28 days is 45.3 MPa & at 180 days, the strength is 49.23 MPa. Up to 60% replacement of cement by GGBS, the strength is comparable with that of OPC concrete at 28 days where as at 180th day, the strength is comparable with that of OPC concrete for all the replacements. Up to 60% replacement level, the enhanced strength is about 10% compared to OPC strength at 180 days.

(vi) For OPC concrete with cement quantity 400 kg/m^3

and w/b ratio 0.3, the strength at 28 days is 69.6 MPa and at 180 days, the strength is 75.52 MPa. For all replacement levels of cement by GGBS, the strength is comparable with that of OPC concrete at 28 days where as at 180th day, the strength is enhanced by about 15% of OPC strength.

(vii) For OPC concrete with cement quantity 450 kg/m^3 and w/b ratio 0.5, the strength at 28 days is 43.83 MPa and at 180 days, the strength is 47.39 MPa. Up to 60% replacement levels of cement by GGBS, the strength is comparable with that of OPC concrete at 28 days and at 180 days, for all replacements, strength is comparable. The enhanced strength up to 60% replacement at 180th day is about 12% compared to OPC concrete.

(viii) For OPC concrete with cement quantity 450 kg/m^3 and w/b ratio 0.4, the strength at 28 days is 46.60 MPa and at 180 days, the strength is 50.65 MPa. Up to 60% replacement levels of cement by GGBS, the strength is comparable with that of OPC concrete at 28 days and at 180 days, for all replacements, strength is comparable. The enhanced strength up to 60% replacement at 180th day is about 20% compared to OPC concrete.

(ix) For OPC concrete with cement quantity 450 kg/m^3 and w/b ratio 0.3, the strength at 28 days is 71.61 MPa and at 180 days, the strength is 77.67 MPa. Up to 50% replacement levels of cement by GGBS, the strength is comparable with that of OPC concrete at 28 days as and at 180 days, up to60% replacements, strength is comparable. The enhanced strength is about 18% compared to OPC concrete at 180 days.

(x) For OPC concrete with cement quantity 500 kg/m^3 and w/b ratio 0.5, the strength at 28 days is 49.30 MPa and at 180 days, the strength is 53.15 MPa. Up to 50% replacement levels of cement by GGBS, the strength is comparable with that of OPC concrete at 28 days and at 180 days, for all replacements, strength is comparable. The enhanced strength up to 60% replacement at 180th day is about 15% compared to OPC concrete.

(xi) For OPC concrete with cement quantity 500 kg/m^3 and w/b ratio 0.4, the strength at 28 days is comparable up to 50% replacement levels of cement by GGBS and at 180 days, the strength is comparable for all replacement levels.

(xii) For OPC concrete with cement quantity 500 kg/m^3 and w/b ratio 0.3, the strength at 28 days is comparable up to 40% replacement levels of cement by GGBS and at 180 days, the strength is comparable for all replacement levels.

The results of compressive strength of fiber reinforced concrete given in Table 4, Those are (i) for OPC concrete with cement quantity 350 kg/m^3 and w/b ratio 0.5, reinforcing index 0.3 (0.5% steel fibres), the strength at 28 days is 53.28 MPa against 49.33 MPa without fibres. The enhanced strength is about 7%. The strength at 56th, 90th and 180th day is 54.2 MPa, 55.68 MPa and 57.71 MPa respectively against 50.56MPa, 51.55MPa and 53.77MPa without fibres. The strength is comparable at 28 days and 180 days up to 60% replacement of cement. With the increase of reinforcing index (0.6 and 0.9), it can be found that there is enhancement in strength by about 10% (reinforcement index = 0.6) and 18% (reinforcement index = 0.9) at 28th day and 180th day up to 60% replacement level compared to OPC concrete.

(ii) For OPC concrete with cemennt quantity 400 kg/m^3, w/b ratio 0.5, reinforcing index 0.3, the strength at 28 days and at 180 days is comparable up to 50% replacement levels of cement by GGBS. With the increase of reinforcing index (0.6 and 0.9), it can be found that there is enhancement in compressive strength by about 5% (reinforcement index = 0.6) and 10% (reinforcement index = 0.9) at 28th day and 180th day up to 60% replacement level compared to OPC concrete. Similar observations can be drawn for remaining cases, namely, 450 kg/m^3 (w/b = 0.4, reinforcing indices = 0.3, 0.6, 0.9); 500 kg/m^3 (w/b = 0.3, reinforcing indices = 0.3, 0.6, 0.9)

From Tables 3 and 4, the following general remarks :

Primarily the initial strength of GGBS based concretes (3, 7 and 28 days) is found to be lower than the OPC concretes with the same binder/ cementitious material. However, the curing period is prolonged (56, 90 and 180 days), the strength was increased at higher rate. The reason is that, the chemical reaction of slag is slow and the formation of $Ca(OH)_2$ requires some time. The strength of Ground Granulated Blast furnace Slag concrete will increase because the GGBS content is elevated as much as 60% alternative of cement through GGBS. The positive effects of GGBS in concrete are to provide dense packing and to avoid porous nature of concrete. Beyond 60%, the strength has been reduced. This may be because of un-reacted GGBS, could have acted as filler material

The improvement of compressive strength of concrete has been recognized by the hydration process of cement. Although the hydration of concrete containing GGBS compared to OPC concrete is slower [44, 45]. Especially when published reports demonstrated that, only 18–55% of the GGBS was reacted chemically by 28 days [44-48]. Generally concrete fails when compressed because the stress block at 45 degree angle is heavily sheared, as concrete being a brittle material fails at shear. By the addition of fibres against this shear plane helps to reduce shear stress in concrete by taking up some them-self, and hence increases the compressive strength. One other slightly less important fact is that they help to bind the concrete in the lateral direction. Confined samples always take slightly more load. Another important observation is with the addition of fibres, compressive strain increases and in turn moment carrying capacity increases. In addition to control cracking, plastic shrinkage, drying shrinkage, decrease the permeability by adding fibres to the concrete and also to reduce the effects due to impact and blast loadings. In the present study, it is observed that the strength of concrete was increased about 5% to 12% at 28 days to 180 days with an increase in the fiber content from 0.5% to 1.5%. This growth in strength might be the confining effect of fibres in the concrete. The confinement impact is associated with the fibre aspect ratio, orientation and density of the fibres but the workability of concrete adversely affected by increasing the fibre content.

IV. CONCLUSIONS

- It has been found that GGBS can be efficiently replaced by cement up to 60% without compromising the strength of GGBS based concrete in comparison with OPC concrete.
- The early age strength of GGBS based concretes (3, 7 and 28 days) is to be found lower than the OPC concretes with the equal binder material. Nevertheless, as the curing period is increased (56, 90 and 180 days), the strength of concrete is increased.
- The strength of GGBS concrete increased as the GGBS content is increased up to 60% replacement of OPC.
- Further, it was observed that with an increase in the fiber content from 0.5% to 1.5%, there is a marginal increase in the strength of approximately 5% to 12% at 28 days to 180 days. This increase could be the confining action of the fibers in the concrete.
- It has been observed that workability of concrete increased with increasing GGBS content.

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