Micro Structural Study of Slag and Slag Sand in Cement Mortar

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Abstract
This study has been undertaken to envisage the viability of partially replacing Granulated Blast Furnace Slag Sand (GBFSS) to natural fine aggregate and Ground Granulated Blast Furnace Slag (GGBFS) to Ordinary Portland Cement individually and amalgamated in varied mix proportions. The hardened mortar cubes were subjected to compression and microstructural analysis at the end of 3, 7, 28, 56 and 90daycuring. The compressive strength of 30% and 35%mix proportion of individually and blending (GBFSS and GGBFS) were found to be 38.71N/mm^{2,} 41.84N/mm^{2}and 39.37N/mm^{2}for90-day curing. Compressive strength results obtained were 17%, 23% and 18% higher than the reference. The structural and morphological characteristics of the GGBFS, slag sand and crushed mortar were analysed by EDX, SEM and XRD. XRD results clearly suggested that the mortar cube was crystalline and GGBFS and Slag sand was amorphous in nature. Partial replacement of OPC and RBS by GGBFS and GBFSS not only eliminates the waste management problems and impacts on the environment, but also leads to the sustainable development through conservation of natural resources.
Keywords: GGBFS, GBFSS, Compressive Strength, SEM, XRD

Introduction

Cement industry is a high energy consumption industry, and its CO2emission accounts for about 7% of global CO2emissions [1].When compared with cement, GGBFS requires less than a fifth of energy produced and emits less than a tenth of the CO2. GGBFS and GGBFS are by-products of iron and steel manufacturing industry. Approximately 1 tonne of stainless steel slag is generated while producing 3 tonnes of stainless steel and it should be noted that 50 million tons per year of steel slag is produced as a by-product in the world [2].Major steel plants in India generates 7760561 MT of GGBFS per annum. The main constituents of GBFS include CaO, SiO_2, and Al_2O_3. In addition, it contains small amount of MgO, FeO and sulfide as CaS, MnS and FeS[3].Research pertaining to recycling and utilization of steel slag in different fields have been carried out in recent years [4].

Aggregate, which makes up 70% of the concrete volume, is one of the main constituent materials in concrete production. Due to the high cost of natural sand used as a fine aggregate and the rising emphasis on sustainable construction, there is a need for the construction industry to search for alternative materials[5].To meet the great demand on aggregates, many mountains and rivers have been exhaustingly exploited, which destroy the environment. Fly-ash, a by-product of thermal power plants possessing pozzolanic property is widely used as a partial replacement to cement [2]. Nowadays, many kinds of industrial wastes are used as mineral admixtures to replace some part of cement. Utilization of mineral admixtures is beneficial to the reduction in emission of greenhouse gases and improves the mechanical properties of cement [3].Many researchers have studied the properties of cement concrete using fly ash, silica fume and GGBFS as cement replacement materials, but not much work has been carried out on the mechanical properties of mortar using supplementary materials like GGBFS.

This study intends to explore the possibility of utilizing GBFSS and GGBFS as a partial replacement to binder material and fine aggregate in cement mortar and compare the results with natural aggregate. Micro-structural analysis employing XRD and SEM to know the morphological changes in the solidified matrix are also evaluated.

Materials and Methods

All the materials and the procedures used in this research work is in accordance with Bureau of Indian Standards specifications. Ordinary Portland cement (Brand - Coromandel) of 43 Grade used as a binder material. The GBFS was procured from JSW Cement Ltd and the test certificate issued by the company is illustrated in Table 1. Sieved using 4.75µ, R-SAND and GBFSS were used as fine aggregates. The cement was analysed for routine parameters. The cubes were cast with CM 1:3 and water cement ratio of 0.5. Laboratory tap water (Bore-well) was used for mixing and curing. The mortar cubes were subjected to compression test using compression testing machine (2000kN, Aimil, 2014), at the curing ages of 3, 7, 28, 56 and 90 days. Specimens were cured at room temperature with 25±3o C and 95±10% relative humidity. In totality, 465 mortar cubes were cast. For each curing, cubes were cast in triplicate and tested to get the concordant values. The test was carried out on compressive testing machine (Brand-Aimil, Capacity-2000KN).
The EDX, SEM and XRD analysis of the raw SLAG SAND, GBFS and hardened solidified matrix were carried out using Scanning Electron Microscope (Thermo Fisher Scientific, S-3400N, 2014) and X-ray Diffraction (3KW) (Rigaku, Smart Lab, 2014).

Table 1: Characteristics of Granulated Blast Furnace Slag, (JSW Cement Ltd)

Sl No.	Characteristics	Requirement as per IS: 12089 -1987	Test Results
1	SiO_2 (%)	-	33.30
2	Al_2O_3 (%)	-	21.74
3	Fe_20_3 (%)	-	0.80
4	Cao (%)	-	34.50
5	Mgo (%)	17.0 (Max)	8.30
6	Loss on Ignition (%)	-	0.33
7	IR (%)	5.0 (Max)	0.31
8	Manganese Content (%)	5.5 (Max)	0.09
9	Sulphide Sulphur (%)	2.0 (Max)	0.45
10	Glass Content (%)	85 (Min)	90
11	Moisture Content (%)	-	11.74
12	Particle Size Passing 50.0 mm	95%	100%
13	Chemical Moduli $(CaO + MgO + Al_2O_3)/ SiO_2$	> or equal to 1.0	1.93

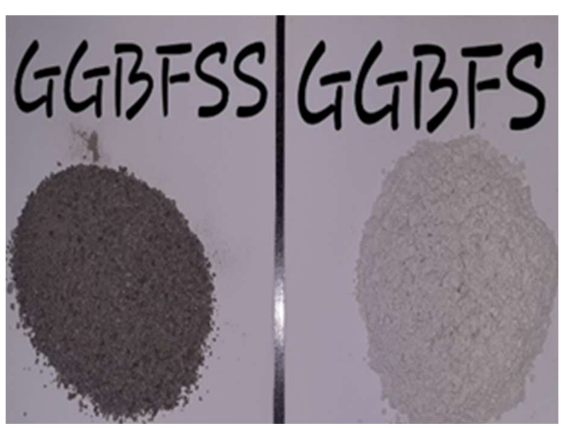

Plate1:Slag Sand and Slag

The quantity of ingredients used to cast one cube for varied mix proportion of R-sand, GGBFS and GBFSS is indicated in Table 1 and Table 2.respectively.

Table 1: Ingredients used for one mortar cube of mix

Volume	Cement	R-Sand	GGBFS	GBFSS	Water (mL)
	in kg				
49.8cm^3 of Mortar	0.164	0.656	0.164	0.669	82.1

Table 2:Varied Mix proportion of mortar with W/B of 0.5

Proportion, %					Proportion, %				
MIX	Cement	R-Sand	GGBFS	GBFSS	MIX	Cement	R-Sand	GGBFS	GBFSS
CM	100	100	-	-	M24	80	80	20	20
					M25	75	75	25	25
					M26	70	70	30	30
M1	100	95	-	5	M27	65	65	35	35
M2	100	90	-	10	M28	60	60	40	40
M3	100	85	-	15	M29	55	55	45	45
M4	100	80	-	20	M30	50	50	50	50
M5	100	75	-	25					
M6	100	70	-	30					
M7	100	65	-	35					
M8	100	60	-	40					
M9	100	55	-	45					
M10	100	50	-	50					
M11	95	100	5	-					
M12	90	100	10	-					
M13	85	100	15	-					
M14	80	100	20	-					
M15	75	100	25	-					
M16	70	100	30	-					
M17	65	100	35	-					
M18	60	100	40	-					
M19	55	100	45	-					
M20	50	100	50	-					
M21	95	95	5	5					
M22	90	90	10	10					
M23	85	85	15	15					

LEGEND

R-Sand- River sand
OPC- Ordinary Portland Cement
GBFSS- Granulated blast furnace slag sand
GGBFS- Ground granulated blast furnace slag
CM- Control mix

1.M1-M10 – Replacement of R-Sand by GBFSS
2. M11-M20 – Replacement of OPC by GGBFS
3. M21-M30 - Replacement of OPC & RBS by GGBFS &GBFSS in Combination

Results and Discussion

Basic properties

The materials used in mortar specimens had diverse properties and behaviour. The properties of materials were determined as per the standard specifications and the results obtained is represented in Table 3.

Referring to Table 3, it can be observed that all the parameters are well within the threshold limits. Nevertheless, the Initial and final setting time of GGBFS exceeded the threshold value. It is almost double the value of that of cement. This is due to lack of calcium chloride content.

Table 3: Basic test results of Cement, GGBFS R-SAND and GBFSS

Property	Cement	GGBFS	Fine Aggregate		Threshold Value	Specification
			R-SAND	GBFSS		
Sp. gravity	3.14	3.24	2.57	2.61	Fine Aggregate: 2.6-2.8	IS 383(1970) IS 2386-3(1963)
Std. consistency (%)	32.3	30.3	-	-	26-33	IS 4031-4 (1988)
Initial setting time (min.)	39.7	80.3	-	-	30 (Minimum)	IS 4031-5 (1988)]
Final setting time (min.)	497	1080	-	-	600 (Maximum)	IS 4031-5 (1988)]
Fineness (%)	5.4	5.2	-	-	<10	IS 4031-1 (1996)
Fineness Modulus	-	-	2.76	2.7	Fine sand: 2.2-2.6 Medium sand: 2.6-2.9 Coarse sand: 2.9-3.2	IS: 383(1970)
Water absorption (%)	-	-	0.41	0.56	Coarse aggregate: <1.4 Fine Aggregate:<2	IS 2386-3(1963)
Bulk density, (g/cc)	-	-	1.6	1.4	-	IS 2386-3(1963)
% air voids	-	-	34.1	2.9	-	IS 2386-3(1963)

Sieve analysis of R-SAND and GBFSS

Based on the sieve analysis results of fine aggregates, the R-SAND and GBFSS belongs to zone II and the gradation curve obtained is represented in Figure 1.

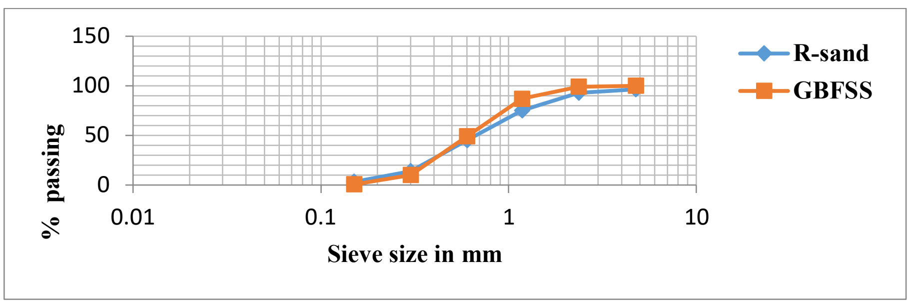

Figure 1: Gradation curve of R-SAND and GBFSS

Compressive strength

Table 5represents the compressive strength of partially replaced GBFSS to R-sand. With the increase in replacement level of GBFSS to R-sand, gain in strength was observed. This increment in strength was observed up to30% replacement of GBFSS. Then onwards, it started showing a declining profile for all the curing ages. The maximum value of compressive strength obtained at the end of 90-day curing was 38.71 N/mm2 which was 17% higher than the reference. Nevertheless, it can be observed that for all the curing ages, the values obtained were more than that of the reference cube.

Table 4: Compressive strength of partially replaced GBFSS to R-sand

Curing, Day	R-sand (100%)	M1 (5%)	M2 (10%)	M3 (15%)	M4 (20%)	M5 (25%)	M6 (30%)	M7 (35%)	M8 (40%)	M9 (45%)	M10 (50%)
3	12.22	14.17	14.69	14.88	15.18	15.50	16.18	15.52	14.47	14.41	14.19
7	15.26	15.98	16.32	16.88	17.30	18.05	18.57	18.11	17.47	15.52	14.73
28	22.83	24.15	24.53	26.88	28.67	30.44	32.20	27.69	25.36	22.16	21.44
56	30.70	31.84	32.71	33.75	34.69	36.16	36.98	32.57	31.16	29.57	26.22
90	32.26	33.21	34.17	35.66	36.30	37.77	38.71	38.17	35.82	33.37	31.76

The compressive strength results obtained for partial replacement of GGBFS to OPC is indicated in Table 6. For GGBFS replacement to OPC, delay in setting time was observed. With every increase in replacement percent for a constant W/C ratio of 0.5% the setting time got increased. When the replacement level was 35%,maximum gain in strength was observed for all the curing periods. For 90-day curing, a maximum compressive strength of 41.8N/mm2 was observed. Further for all the replacement levels the strength declined

Table 5: Compressive strength of partially replaced GGBFS to OPC.

Curing age, Day	R-sand (100%)	M11 (5%)	M12 (10%)	M13 (15%)	M14 (20%)	M15 (25%)	M16 (30%)	M17 (35%)	M18 (40%)	M19 (45%)	M20 (50%)
3	12.22	14.57	15.04	15.48	15.78	16.12	16.54	16.88	16.08	15.58	15.14
7	15.26	16.86	17.51	17.89	18.61	19.41	20.32	18.71	16.89	14.17	13.65
28	22.83	23.81	26.06	29.07	29.85	31.38	31.90	32.55	30.64	21.04	17.71
56	30.70	32.16	32.57	33.79	35.12	36.30	37.22	38.67	36.36	34.63	33.49
90	32.26	33.75	35.1	36.04	37.34	38.45	39.73	41.84	38.17	36.86	34.29

Combining both GGBFS and GBFSS and partially replaced to R-sand and OPC the maximum gain in strength was observed at 30% (M26) was 39.73N/mm2 at the end of 90 day curing when compared to controlled specimens. Further increase in replacement decrease in strength was observed. The test results of varied proportions for all the curing ages

Table 6: Compressive strength of replacement of GBFSS & GGBFS for R-SAND & OPC

Curing, Day	R-sand 100%	M21 5+5	M22 10+10	M23 15+15	M24 20+20	M25 25+25	M26 30+30	M27 35+35	M28 40+40	M29 45+45	M30 50+50
3	12.22	15.64	17.81	18.03	18.99	19.53	21.94	20.54	18.11	15.92	15.28
7	15.26	22.97	24.39	25.36	26.24	28.49	31.36	28.43	26.98	22.57	18.79
28	22.83	24.29	25.82	26.70	28.45	31.02	32.44	31.40	28.11	26.98	25.82
56	30.70	28.87	31.36	32.65	36.10	36.66	38.73	38.03	34.65	32.14	29.91
90	32.26	33.95	34.67	35.80	36.68	38.07	39.37	37.49	36.16	34.65	34.11

Microstructural Analyses

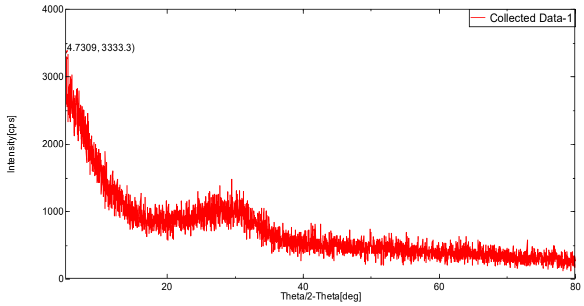

Figure1: XRD of GGBFS

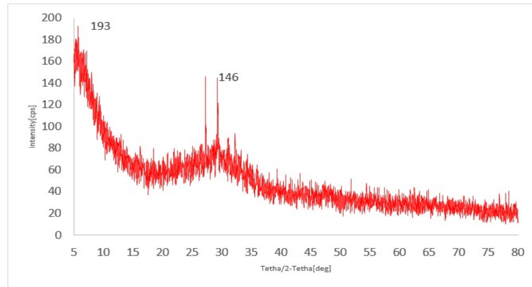

Figure2: XRD of GBFSS

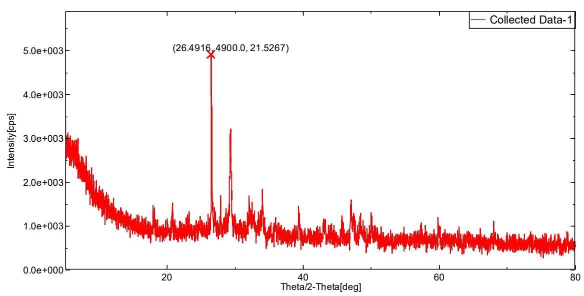

Figure 3: XRD of control specimen cured for 3-day

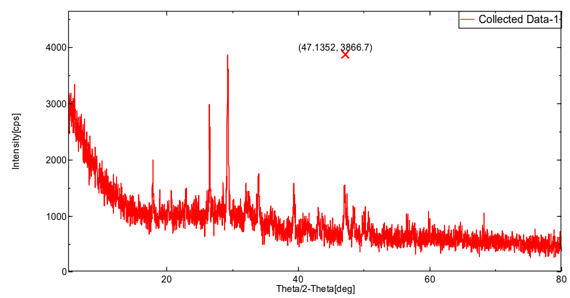

Figure 4: XRD of control specimen cured for 7-day

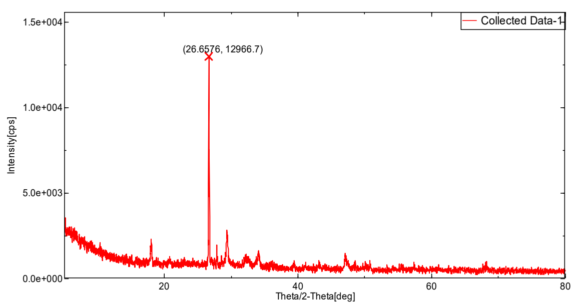

Figure 5: XRD of M6 specimen cured for 3 day

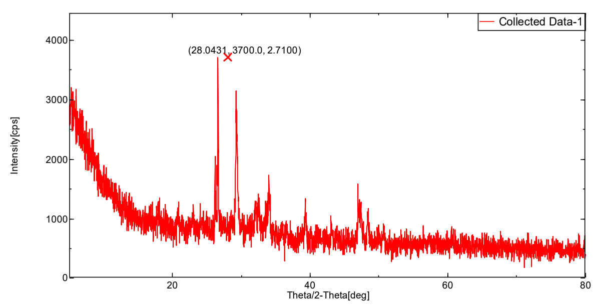

Figure 6: XRD of M6 specimen cured for 7day

XRD patterns of GBFSS & GGBFS samples are shown in Fig. 1 & 2. It can be observed that the peaks are complicated and some of them are overlapped. The main compositions are calcium silicate phase (C_3S, C_2S), and RO phase. There are few amounts of olivine, rhodonite and alite were observed.

The XRD patterns of 3 and 7 day hydrated cement (Fig. 3 & 4) indicates the presence of Quartz, Ettringite, Alite(C_3S), Belite(C_2S), Gehlenite (C_2AS) and portiandite (CH) Phase. The variation of characterises peak of C_3S was consumed in the hydration reaction.

Fig. 5 & 6 indicates the broad and diffuse background peak with maxima around d≈26.6 & 28.04 in the hydrated sample of slag sand and slag. The result of short range order of Cao-Sio_2-Al_2O_3-MgO was observed. In addition to the common C-S-H phase, the formation of α-C_2SH was also observed in the hydration product of slag sand and slag.

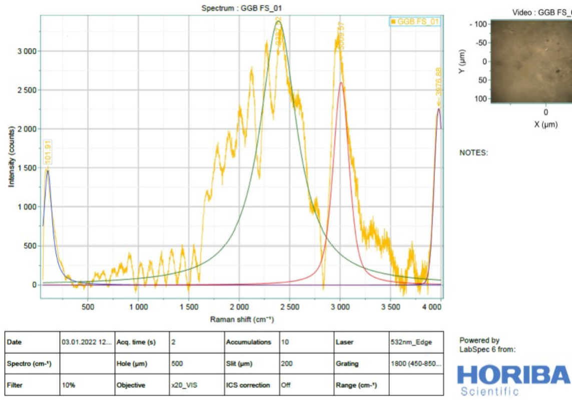

Figure 7: Raman spectroscopy of GGBFS

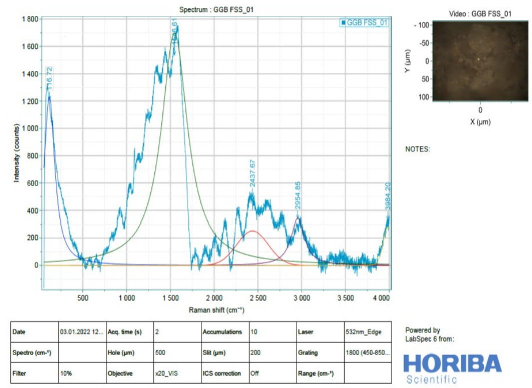

Figure 8: Raman spectroscopy of GBFSS

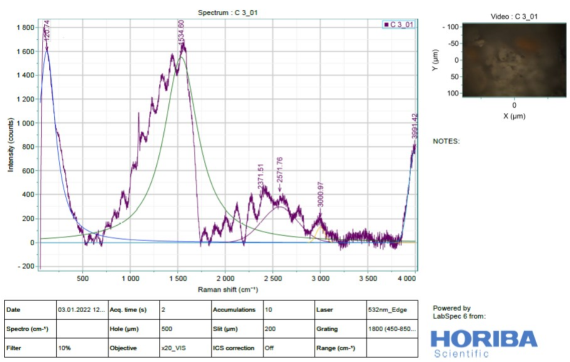

Figure 9: Raman spectroscopy of control specimen cured for 3-day

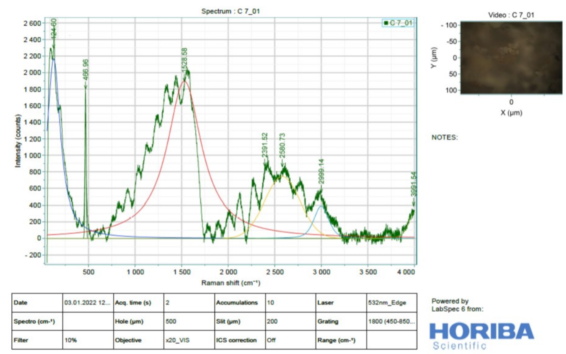

Figure 10: Raman spectroscopy of control specimen cured for 7-day

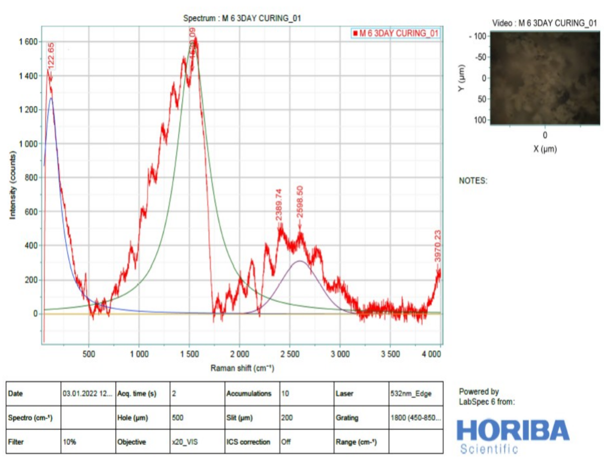

Figure 11: Raman spectroscopy of M6 specimen cured for 3 day

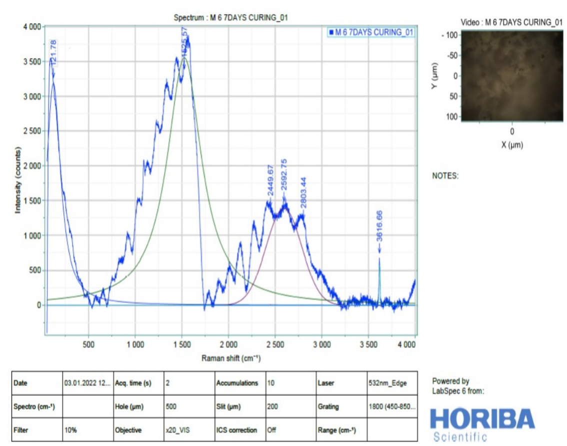

Figure 12: Raman spectroscopy of M6 specimen cured for 7day

Conclusion

Based on experimental investigations conducted in this research paper following conclusions and recommendations were made for the potential use of GGBFS and GBFSS.

1. GBFSS when partially replaced (30%) to R-SAND the optimum compressive strength results for 3, 7-, 28-, 56- and 90-day curing were 16.8N/mm^2, 18.57N/mm^2, 32.20N/mm^2, 36.98N/mm^2 and 38.71 N/mm^2 on par with that of control mix.

2. GGBFS when partially replaced (35%) to OPC optimum compressive strength results for 3, 7-, 28-, 56- and 90-day curing were 16.88 N/mm^2, 18.71N/mm^2, 32.88N/mm^2, 38.67N/mm^2 and 41.84 N/mm^{2}when compared to controlled mix.
3. GBFSS and GGBFS when partially replaced (30%) to R-SAND and OPC in blending, the optimum compressive strength results for 3, 7-, 28-, 56- and 90-day curing were 21.94N/mm^2, 31.36N/mm^2, 32.44N/mm^2, 38.73N/mm^2 and 39.37 N/mm^2 when compared to controlled mix.

4. As the percentage increased beyond optimum the compressive strength declined.

5. Finally, it can be concluded that partial replacement of GGBFS as cementitious material and GBFSS as fine aggregate in construction industry, not only reduces the waste management problems and impacts on environment, but also reduces the consumption of natural resources leading towards sustainable development.

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