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Effect of Particle Size on Compressive Strength of Concrete with Ground Granulated Blast Furnace Slag as Admixture Along with Microstructural Analysis

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ABSTRACT: The investigation presents the effect of Ground Granulated Blast Furnace Slag (GGBS) and their proportion in concrete with particular size of particle passing through a set of sieves with different dosages. GGBS effect was studied as replacement to cement in varied proportions of 10, 20, 30 and 40% and the size of particles for each replacement is varying from 90µm-75 µm, 75µm-45 µm and <45µm. The results show that, at 30% replacement of cement, the compressive strength is optimum for particle size of <45 µm. The results indicate that, GGBS addition for concrete has yielded the maximum strength at 30% GGBS replacement for <45µm particle size. The microstructure study of concrete is conducted with help of scanning electron microscopy (SEM) and energy dispersive spectrometer (EDS), to find the percentage of consumption of various elements before and after the reactions.
The challenges in the study is to choose the specific size of sieves, for sieving the mineral admixture GGBS and to investigate the microstructure of concrete with partial replacement of cement by GGBS (specific range).

Keywords: GGBS, Compressive Strength, Scanning Electron Microscopy (SEM), Energy dispersive spectrometer (EDS).

Abbreviations: GGBS, Ground Granulated Blast Furnace Slag; SEM, Scanning Electron Microscopy; EDS, Energy Dispersive Spectrometer.

I. INTRODUCTION

The cement industry is looking for new materials to enhance the mechanical properties of concrete. In development of material strength, the mineral admixtures also contribute in cement industry to increase the properties of concrete mix.
For cement, in the recent past many admixtures came in as replacement to the cement and sometimes as additives also. In this view herein the experimental investigations have been focused to study the effect of GGBS on concrete. The mineral admixture used in the study here is, ground granulated blast furnace slag (GGBS), which is a by product obtained from iron manufacturing industry. The specific surface area of GGBS used in the investigations will be usually between 400-600m^2/kg.
Research has been in progress with GGBS as partial replacement for cement in various concrete constructions.
Concrete is heterogeneous and has complex microstructure, and it is difficult to visualize the models of its microstructure and predict real action and reaction of the contents. The associates of the microstructure, the properties and influence of the individual mechanisms of concrete and their inter-relationship are useful for obtaining the control over properties of concrete. The term microstructure designates the structure which progresses in concrete at micro level, when water is added to the matrix. The mechanical properties of concrete often depend on its fundamental microstructure. The high-resolution SEM attached with EDS/EDXA has unlocked a world of opportunities in the field of concrete technology.
Few literatures are reviewed to understand the status of GGBS in the field of concrete. Jerry W. Hamling and Richard W. Kriner [1] investigated the 3 and 7-day compressive strength of mortar cubes with slag. J. Hogan and J.W. Meusel [2] evaluated the strength and durability properties of cement and concrete cubes with GGBS as replacement. Luiz Fernandez and V. Mohan Malhotra [3] investigated the resistance to abrasion, chloride ion and permeability of concrete with partial replacement of cement by GGBS. R. Siddique [4] reviewed durability properties of concrete with partial replacement of cement by GGBS. Atul Dubey, Dr R. Chandak, Prof R.K. Yadav [5] investigates the compressive strength of concrete with GGBS, as partial replacement, with percentage varying from 5% to 30%. S. Arivalagan [6] the paper evaluates the strength and other mechanical properties by replacing cement by various percentages of GGBS for M 35 grade concrete. Erhan Guneyisi, Mehmat Gesoglu [7] Investigated the mechanical and durability properties of high-performance concrete. S.J. Barnett, M.N. Soutsos, S.G. Millard, J.H Bungey [8] investigated the higher strength of mortar cubes at higher temperatures, for GGBS as partial replacement. Mohammad Bolhassani and Mohammadreza Samani [9] investigations were carried on nanosilica, both in powder and colloidal form for specific area of particles on workability and mechanical properties. Rami A. Hawileh, Jamal A. Abdalla, Fakherdine Fardmanesh, Poya Shahsana, Abdolreza

Khalili [10] Studied the effect of using GGBS as partial replacement to cement in RCC beams to obtain the compressive & tensile strength for different concrete mixes. Qin yong Ma Ying Zhu [11] Investigated high performance concrete using varying dosages of nano silica &basalt fibers to find the compressive & tensile strength along with microstructure Analysis (SEM). Huang Yameia, Wang Lihuab, [12] Studied the particle shape parameters of natural sand & lime stone manufactured sand by DIP method, after analysis found that, compressive strength is greater than natural sand concrete.

V. Nagendra, C. Sashidhar, S.M. Prasanna Kumar [13] Investigated the compressive strength of concrete cubes for specific range of particles, with varying dosages of admixture. The optimum strength was obtained at 20% replacement for microsilica and 20%+4% for combination of both microsilica and nanosilica.

The research investigations are to improve the mechanical properties of concrete with partial replacement of cement by mineral admixtures (usually a byproduct), with different percentage replacements, to arrive at maximum strength in concrete. In most of the studies river sand is used as fine aggregate, but in our investigations, M-sand is used as fine aggregate.

In the present study, instead of using the admixtures directly as supplied from the manufacturer, it is sieved by a set of specific sieves, for different percentage replacements of cement by GGBS to analyze the strength along with microstructure of concrete (Analysis), to know the elements/compounds involved, before and after the reactions.

With respect to earlier investigations, it is observed that very little progress is done regarding specific size of GGBS particles in concrete. Therefore, an experimental work is intended to investigate the compressive strength by varying the particle sizes (range) of GGBS and also completely replacing river sand by M-sand along with microstructural analysis of concrete.

II. EXPERIMENTAL PROGRAM

The normal procedure is to consider the mineral admixture as an addition or partial replacement with cement, as supplied from the manufacturer, for different grades of concrete to determine the mechanical properties of concrete.

The experimental program was planned with the effect of GGBS and studied along with the specific particle sizes as variable. The GGBS, for experimental work with specific particle sizes passing through sieves of 90μm -75μm,75μm -45μm and<45μm are used. The percentage replacement of cement with GGBS is varied from 10% to 40% with an increment of 10%. From this it is possible to identify the effective replacement dosage of GGBS. The cubes were prepared in moulds and tested in compression testing machine at 7, 14, 21 and 28 days. The M 30 grade concrete mix was designed as per IS 10262 code, and mix proportions were arrived at1:1.20:2.30 with water cement ratio of 0.5. For workability of the mix, super plasticizer Conplast-SP430 was used during experimental program.

III. MATERIALS AND METHODS

For experimental investigations the following materials with their properties mentioned in the table are adopted.

Cement: Ordinary Portland cement (OPC) of grade 53 with physical and chemical properties, as presented in Table 1 and 2 are used.

M-sand: Fine aggregate used in the study is M-sand of grade II, as per code provisions.

Coarse aggregate: Crushed stone of size 20 mm down size obtained from the crusher is used in the investigation. The properties of the coarse aggregate tested in accordance with IS 2386:1963.

Super Plasticizer: To enhance the workability of concrete CONPLAST-SP430 is used as super plasticizer.

Water: Portable water available locally is used for mixing and curing of the specimens.

Ground Granulated Blast Furnace Slag (GGBS): The GGBS utilized in the experiments is obtained from JSW Steel Tornagal, Bellary (District), Karnataka, which is shown in Fig. 1. The properties of GGBS is presented in the Table 3 and 4.

Fig. 1. Ground granulated blast furnace slag (GGBS).

Table 1: Physical properties of cement.

Specific gravity	Bulk density (kg/m^3)	Surface area(m^2/kg)
3.10	1870	330

Table 2: Chemical properties of cement.

CaO	SiO_2	Al_{2O3}	Fe_{2O3}	MgO	SO_3	P_{2O5}	K_{2O}	Na_{2O}	TiO_2
60.54	16.64	6.55	5.78	2.52	1.79	1.87	2.53	1.40	0.38

Table 3: Physical properties of GGBS.

Specific gravity	Bulk density(kg/m$^{3)}$	Surface area m^2/kg	Insoluble residue(%)	Loss on ignition (%)	Moisture content (%)
2.85	1250	410	0.10	0.15	0.12

Table 4: Chemical composition of GGBS in percentage.

Binder	Sio_2	Cao	Al_2o_3	Mgo	Mno	Fe_2o_3	Sulphide sulphur	Sulphite sulphur	Total chlorides
GGBS	33.87	33.68	13.35	8.75	0.09	0.75	2.15	0.35	0.02

IV. RESULTS AND DISCUSSION

The effect of GGBS with different dosages and specific particle sizes were investigated for compressive strength. In the investigation, GGBS is replaced by varying the percentage, the obtained results are depicted in table 5. The maximum strength is observed for <45µm particles at 30% replacement of cement by GGBS. At 7 days the strength is 36.88MPa, the percentage increase is 20%, when compared with control mix. But for 75µm-45µm, the strength is 34.97MPa, the strength is 16% higher than the control mix. At 14 and 21 days, the percentage increase is 14% and 17% respectively. At 28 days, for <45µm, the percentage increase in strength for 10%, 20% and 30% Is 0.6%, 6% and 9% respectively, when compared with control mix. Hence the optimum compressive strength is obtained at 30% replacement for <45µm particle sizes.

From the investigations it is noted, as the particle size decreases, the strength increases, which is observed from the SEM and EDS figures of GGBS (replacements), after the reactions, and due to the chemical mechanism and physical mechanism, the morphology shows the matrix is dense and compact. GGBS when replaced with cement, it modifies the products and their pore structure of the hardened cementitious material, hence results in more compressive strength. The results tabulated in Table 5 indicates that there is an increase in strength, when compared with the previous investigations carried out for same grade of concrete (optimum strength is 20%).

Table 5: Compressive strength of concrete with GGBS replacement.

S.No.	Particle Size(µm)	Compressive Strength (Mpa)			
		7 days	**14 days**	**21 days**	**28 days**
Compressive strength for control mix		29.37	38.05	42.18	46.73
10% GGBS Replacement					
1.	90-75 µm	28.70	39.45	41.60	43.75
2.	75-45 µm	29.38	40.73	42.88	45.03
3.	<45 µm	29.73	41.36	43.21	47.03
20% GGBS Replacement					
1.	90-75 µm	36.80	39.90	43.10	45.95
2.	75-45 µm	37.44	41.70	44.66	47.85
3.	<45 µm	37.91	42.53	46.37	49.81
30% GGBS Replacement					
1.	90-75 µm	33.10	42.80	44.90	47.60
2.	75-45 µm	34.97	46.14	47.63	48.43
3.	<45 µm	36.88	46.24	48.96	51.50
40% GGBS Replacement					
1.	90-75 µm	32.80	40.60	43.50	45.50
2.	75-45 µm	33.10	42.65	44.30	45.75
3.	<45 µm	34.35	45.10	46.45	48.90

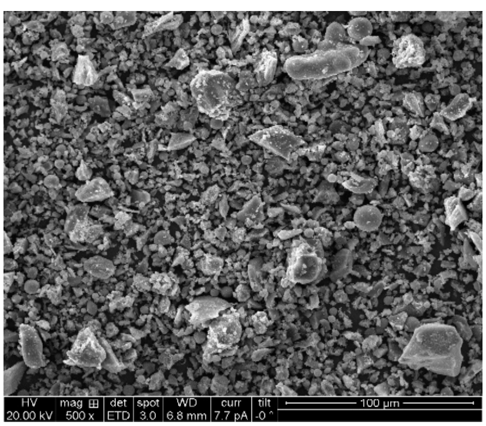

Fig. 2. SEM image for cement.

Fig. 2 shows the SEM image for cement, the particles are both spherical and non-spherical in appearance. Fig. 3 shows the EDS/EDXA for cement, the various elements and compounds present are detailed as percentage weight or atomic weight in the Table 6.

As shown in table, silica present in cement is 17.41% and calcium is 54.36% by weight, with these two elements as datum, the investigations is done to know the pozzolanic reactions that takes place before and after the replacement of admixture in concrete. Fig. 6 and 7 shows the SEM and EDS for GGBS.

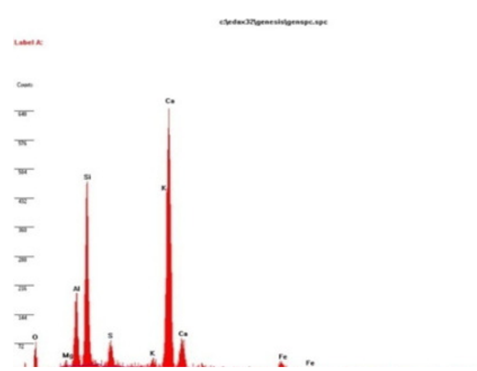

Fig. 3. EDS for cement.

Table 6: EDS for cement.

Elem	Wt %	At %	K-Ratio	Z	A	F
O K	9.57	19.19	0.0144	1.0714	0.1404	1.0003
MgK	0.65	0.86	0.0040	1.0229	0.5971	1.0056
AlK	6.86	8.16	0.0498	0.9946	0.7232	1.0084
SiK	17.41	19.89	0.1393	1.0249	0.7759	1.0061
S K	3.63	3.63	0.0310	1.0106	0.8315	1.0158
K K	1.66	1.37	0.0163	0.9679	0.9432	1.0744
CaK	54.36	43.53	0.5165	0.9889	0.9593	1.0014
FeK	5.85	3.36	0.0505	0.8941	0.9663	1.0000
		Total	100.00	100.00		

Z, A and F are corrections applied; Z- Atomic number; A-Absorption number; F-Fluorescence

Fig. 4. Shows the particles appear angular in shape, which helps in better bonding of particles in the concrete mix.

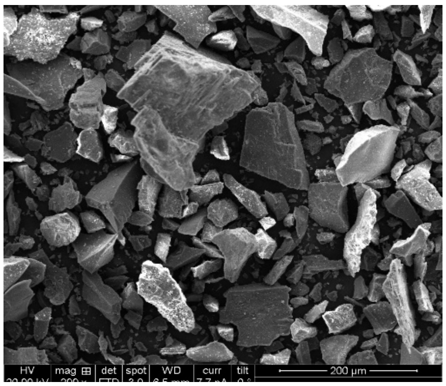

Fig. 4. Shows the SEM image for M-sand.

Fig. 5. Shows the EDS for M-sand, the peak for silica as the maximum content. The values (52.87%) can be observed in Table 7.

Fig. 6 shows the SEM image for GGBS, the particles appear here are also angular in shape.

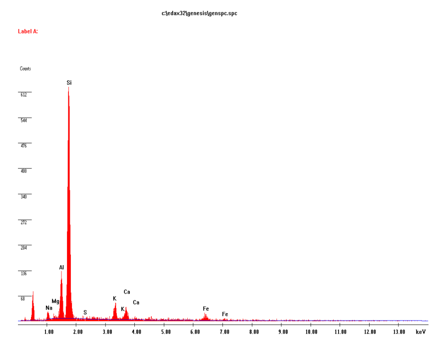

Fig. 5. Shows EDS for M-sand.

Table 7: EDS for M-sand.

Elem	Wt %	At %	K-Ratio	Z	A	F
O K	12.77	22.02	0.0350	1.0626	0.2578	1.0008
NaK	1.89	2.27	0.0104	0.9911	0.5495	1.0058
MgK	0.71	0.80	0.0050	1.0149	0.6809	1.0117
AlK	8.75	8.94	0.0695	0.9853	0.7916	1.0187
SiK	52.87	51.91	0.4342	1.0131	0.8097	1.0013
S K	0.34	0.29	0.0024	1.0004	0.7071	1.0031
K K	7.22	5.09	0.0621	0.9588	0.8911	1.0065
CaK	5.33	3.67	0.0474	0.9795	0.9053	1.0026
FeK	10.12	5.00	0.0884	0.8840	0.9880	1.0000
		Total	100.00	100.00		

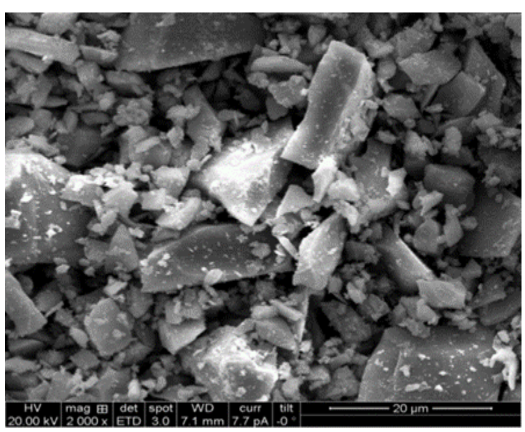

Fig. 6. SEM image for GGBS.

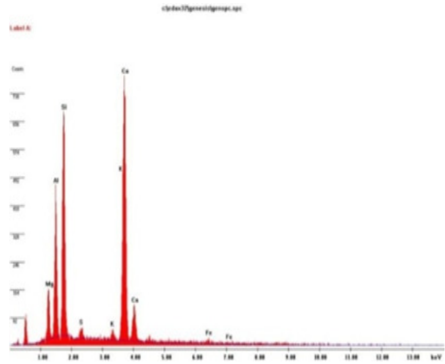

Fig. 7. EDS for GGBS.

EDS for GGBS is shown in Fig. 7 when analyzed in energy dispersive spectrometer (EDS), before mixing in concrete, shows the two peaks, they are silica 29.51% and calcium 44.74%.

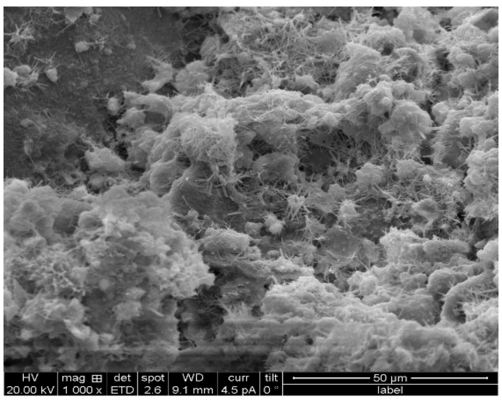

Fig. 8. SEM image at 30% replacement of GGBS.

Fig. 8 shows the SEM image at 30% replacement of cement by GGBS, it is observed here the needle shaped structures without branches, which are called as ettringite and the platy crystals are called calcium hydroxide. Further development of these ettringite in pores, solidifies and became dense and compact matrix.

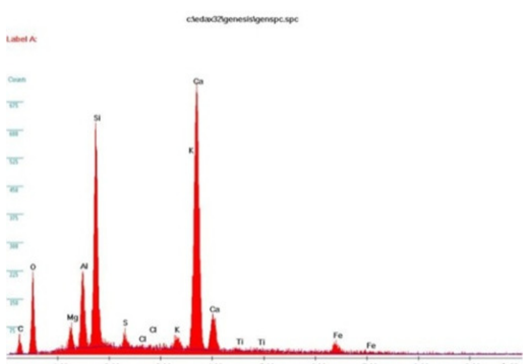

Fig. 9. EDS at 30% replacement of GGBS.

Fig. 9 shows the EDS for 30% replacement of cement by GGBS. A small portion of the cube is tested after 28 days is used for microstructural analysis. The peaks here indicate the elements remained after the reactions had occurred. This indicates further consumptions of silica from GGBS which has enhanced the strength of concrete (due to formation of additional CSH gel).

V. CONCLUSION

- When the particle size reduces the strength increases, this is because of the increase in specific surface area, which is essential for the pozzolanic reactions to take place.
- The 28-day compressive strength is maximum, for<45µm particle size, for all the percentage replacements. The percentage increase for 30% replacement, when analyzed with control mix for <45µm is 9% and that for 90-75µm particle size is 1.8%.
- The replacement of GGBS as mineral admixture for cement, alters the products and the pore structure in hardened cementitious materials and attains higher strength.
- From the investigations, it is observed that unreacted GGBS acts as filler material after the reactions, hence results in more strength.
- Due to reduction of 30% of cement in concrete matrix, it will also reduce the carbon dioxide emissions into the atmosphere.

VI. FUTURE SCOPE

The investigations can be further extended for
- Higher grade of concrete.
-Replacing with other mineral admixtures.
-Durability of concrete.

Conflict of Interest. The authors declare that there is no conflict of interest.

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