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Ground Granulated Blast Furnace Slag (GGBS): Effect of Particle Size and Dosage on Compressive Strength with Microstructural Analysis of Concrete

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Abstract*: In the present investigation Ground Granulated Blast Furnace Slag (GGBS) is used as replacement to cement by weight. The GGBS is used as partial replacement for cement in the concrete mix with particles in the range of 125-250µm, 90-125µm, 45-90µm, 20-45µm and <20µm. The dosage of GGBS is varied from 10% to 40% at an increment of 10% to evaluate the compressive strength of concrete along with microstructural analysis of concrete. The microstructural study is carried out using scanning electron microscopy (SEM) and energy dispersive spectrometer (EDS).The two main compounds observed in the study are Silica and Calcium, their consumptions before and after the pozzolonic reactions. The optimum compressive strength is observed for <20 µm size particles at 20% replacement level and it is also observed that the consumption of calcium is more for the above said replacement.

Keywords: GGBS, Compressive Strength, scanning electron microscopy (SEM), Energy dispersive spectrometer (EDS).

I. INTRODUCTION

Ground Granulated Blast Furnace Slag (GGBS) is a byproduct of Iron industry and which is obtained from the manufacture of iron. The molten slag is a secondary product of sintering of the raw materials and this is quenched under high pressure of water jets, which results as granulates. The GGBS is obtained when the granulated slag is ground to a very fine powder with a specific surface area of 400-600m^2/kg. In the past research works has been taken place in the area of GGBS as an admixture for the concrete works. Concrete has a highly heterogeneous and complex microstructure; it is difficult to predict actual models of its microstructure from which the action of the contents can be properly predicted. The acquaintance of the microstructure, the properties and influences of the individual components of concrete and their inter-relationship are useful for working out control on the properties of concrete. The term microstructure indicates the structure which develops in concrete at a micro level, when water is added to cement and aggregates. To understand the cause, extent and mechanism of deterioration, or how to improve some of the properties of concrete, a thorough awareness of the basic microstructure of hardened concrete is required.Mechanical properties of concrete more often depend on its intrinsic microstructure. The high resolution capability of SEM coupled with EDS/EDXA has opened a world of opportunities in the field of concrete technology. Here in few important works are furnished as literature review to know the status of GGBS in the concrete arena. [1] The author reviewed the properties of GGBS for partial replacement of cement by weight for strength and durability properties by various researchers. [2] Investigated the strength development was slow during the first three days of hydration for concrete containing 40-65% GGBS as replacement for cement by weight.[3] The paper evaluates the properties of GGBS, reaction mechanism and its effect on strength and durability properties of concrete. [4] Investigated the mechanical properties such as compressive strength and flexural strength by partially replacing cement with slag for M 20 grade concrete. The optimum strength obtained for compressive strength was at 20% replacement and whereas for flexural strength it was at 10% replacement. [5] Reported the mechanical properties, abrasion resistance and chloride-ion permeability of concrete using GGBS. [6] Evaluates the strength and efficiency factors of hardened concrete, by replacing cement by various percentages of GGBS for M 35 grade of concrete. The optimum strength was obtained at 20% replacement.[7] presented an experimental study on combined effects of curing method and high replacement levels of GGBS for mechanical and durability properties of high performance concrete. The partial replacement was varied from 50-80% with W/C ratio of 0.4. The incorporation of slag at 50% and above replacement levels caused a reduction in strength.[8]The paper deals with replacement of various percentages of GGBS , different W/C ratios and curing temperature on mortar cubes for strength development.[9]Investigated the characteristics of M 30 concrete with partial replacement of cement by GGBS and sand with ROBO sand (crusher dust) for compressive and tensile

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strength.[10]The paper evaluated the percentage of silica (SiO_2) and alumina (Al_2O_3) in the GGBS for 3,7 and 28 days compressive strength on mortar cubes.
From the review it is noticed that no work has been carried out by taking the specific range size of GGBS particles for concrete works. Hence an experimental work is planned to study the behavior of compressive strength by varying the particle sizes (range) of GGBS along with microstructural analysis of concrete.

II. EXPERIMENTAL PROGRAMME

GGBS used in the experimental study is with particle sizes retained in the sieves, in the range of <20 µm, 20-45µm, 45-90 µm, 90-125 µm and 125-250 µm. The percentage of partial replacement of cement with GGBS is varied from 0% to 40% with an increment of 10%.The M 20 grade concrete mix was designed as per IS10262-2009 and mix adopted is 1:2.65:4.55 and water cement ratio as 0.5.The superplasticizer CONPLAST-SP430 was used in the experimental programme to obtain desirable workability. A total 240 cubes were cast and tested at 7, 14, 21 and 28 days.

III. MATERIALS

For the experimental investigations the following materials were used

A. Cement

The Ordinary Portland cement (OPC) of grade 53 was used. The physical and chemical compositions are presented in Table 1 and 2.

Table 1: Physical Properties of Cement

Specific gravity	Bulk density (kg/m^3)	Surface area(m^2/kg)
3.09	1865	340

Table 2: Chemical Properties of Cement

Cao	Sio_2	Al_2o_3	Fe_2o_3	Mgo	So_3	P_2o_5	K_2o	Na_2o	Tio_2
60.84	16.34	6.95	5.38	2.32	1.99	1.67	2.73	1.50	0.28

B. Fine Aggregate

River sand is used as fine aggregate, which is of grade II, based on particle size distribution. The properties are tabulated in Table 3.

Table 3: Physical Properties of River Sand

Sl no	Description	River sand
1	Specific gravity	2.57
2	Bulk density(loose)kg/m^3	1480
3	Bulk density(compacted)kg/m^3	1695
4	Fineness modulus	2.45
5	Grading zone	II

C. Coarse Aggregate

Crushed granite stone is used as coarse aggregate in the investigation.

D. Super Plasticizer

The super plasticizer (CONPLAST-SP430) used in the present work, and it is in the form of Sulphonated Naphthalene polymers complies with IS: 9103-1999.

Fig 1: Ground Granulated Blast Furnace Slag

Table 4: Physical Properties of GGBS

Specific gravity	Bulk density(kg/m^{3})	Surface area m^2/kg	Insoluble residue (%)	Loss on ignition (%)	Moisture content (%)
2.90	1220	416	0.14	0.19	0.14

Table 5: 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	33.77	33.77	13.24	8.46	0.05	0.65	2.23	0.23	0.01

IV. RESULTS AND DISCUSSIONS

The compressive strength for different dosages and different range of particle sizes are presented in the table 6 to 9. From the tables, it is observed that the compressive strength increases as the particle size decreases, which is observed for all the days of testing of the specimens. The maximum strength was observed for <20µm particle size and the lowest for 125-250µm particle size. The detailed explanation is given for 20% replacement of GGBS along with microstructural analysis for the same. For 20% replacement, the strength at 7 days, for <20µm particle size is 18.2 MPa, and the corresponding percentage increase is 25% when compared with control mix. Similarly for 125-250µm particle size, the strength is less than control mix, and the percentage decrease in strength is 13%.At 14 and 21 days, the percentage increase in strength for <20µm particle size, when compared with control mix is 17% and 24% respectively, whereas for 125-250 µm particle size there is an decrease in strength equal to 28% and 7%. At 28 days of testing, the percentage increase in strength at 10%, 20%, 30% and 40% replacements for <20µm particle size, when compared with control mix is about 5%, 12%, 7% and 1%. The optimum compressive strength is obtained at 20% replacement level. Hence, lesser the size of particles more is the strength.

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Table 6: Compressive strength at 10% replacement of cement by GGBS

Sl.No	Particle Size(μm)	Compressive Strength(Mpa)			
		7 days	14 days	21 days	28 days
Compressive strength for control mix		14.65	18.40	21.75	25.90
1	<20	17.1	19.10	24.30	27.40
2	20-45	15.8	17.60	22.80	26.00
3	45-90	14.3	16.00	20.30	24.00
4	90-125	13.5	15.20	19.30	23.00
5	125-250	12.0	13.50	18.00	21.00

Table 7: Compressive strength at 20% replacement of cement by GGBS

Sl.No	Particle Size(μm)	Compressive Strength(Mpa)			
		7 days	14 days	21 days	28 days
Compressive strength for control mix		14.65	18.40	21.75	25.90
1	<20	18.20	21.50	27.00	29.10
2	20-45	16.80	19.50	25.00	27.20
3	45-90	15.10	17.10	23.20	25.70
4	90-125	14.20	15.90	22.30	25.10
5	125-250	13.00	14.30	20.40	23.90

Table 8: Compressive strength at 30% replacement by GGBS

Sl.No	Particle Size(μm)	Compressive Strength(Mpa)			
		7 days	14 days	21 days	28 days
Compressive strength for control mix		14.65	18.40	21.75	25.90
1	<20	18.90	22.00	27.10	27.90
2	20-45	17.70	20.00	25.80	27.30
3	45-90	15.90	17.80	24.30	26.40
4	90-125	15.30	16.50	23.30	25.70
5	125-250	14.00	15.30	20.90	23.60

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Table 9: Compressive strength at 40% replacement by GGBS

Sl.No	Particle Size(μm)	Compressive Strength(Mpa)			
		7 days	14 days	21 days	28 days
Compressive strength for control mix		14.65	18.40	21.75	25.90
1	<20	16.2	18.1	24.5	26.3
2	20-45	15.2	17.3	23.1	25.3
3	45-90	14.3	16.1	21.5	24.3
4	90-125	13.6	15.3	20.6	23.6
5	125-250	12.1	13.2	18.3	21.8

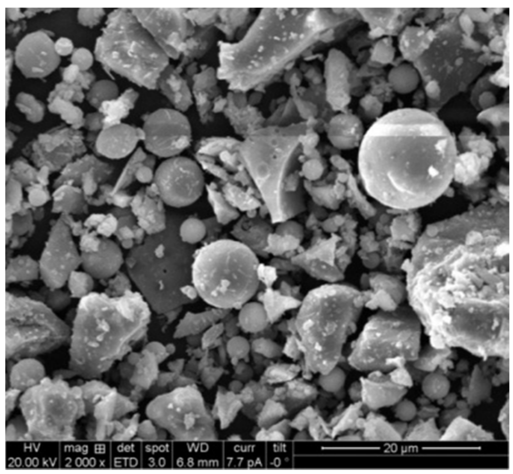

Fig 2: Sem Image for Cement

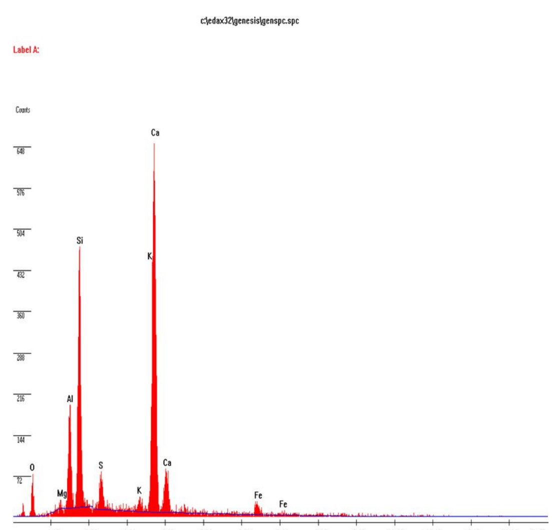

Fig 3: EDS for Cement

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

Table 10: EDS for Cement

Elem	Wt%	At %	K-Ratio	Z	A	F
O K	9.99	19.98	0.0152	1.0716	0.1421	1.0003
MgK	0.47	0.61	0.0029	1.0231	0.5939	1.0055
AlK	6.86	8.13	0.0497	0.9948	0.7218	1.0084
SiK	17.62	20.08	0.1408	1.0251	0.7749	--------
S K	3.40	3.39	0.0290	1.0108	0.8301	1.0155
K K	1.55	1.26	0.0151	0.9681	0.9432	1.0736
CaK	53.60	42.79	0.5095	0.9891	0.9596	1.0016
FeK	6.52	3.74	0.0564	0.8942	0.9669	1.0000
Total	100.00	100.00				

SEM image for cement (figure 2) shows the particles are spherical and non-spherical in morphology at 20 kv,2000 magnification , at working distance of 6.8 mm .The EDS/EDXA for cement(figure 3) shows the various elements and oxides present as percentage weight or atomic percentage weight. In the table 10, silica present is 17.62% and calcium is 53.60% by weight. By considering these two elements as reference, the investigations is carried out to know the physical mechanism and chemical mechanism involved in the pore structures of concrete that take place before and after addition of mineral admixtures. Figure 4 and 5 shows the SEM and EDS diagram for GGBS.

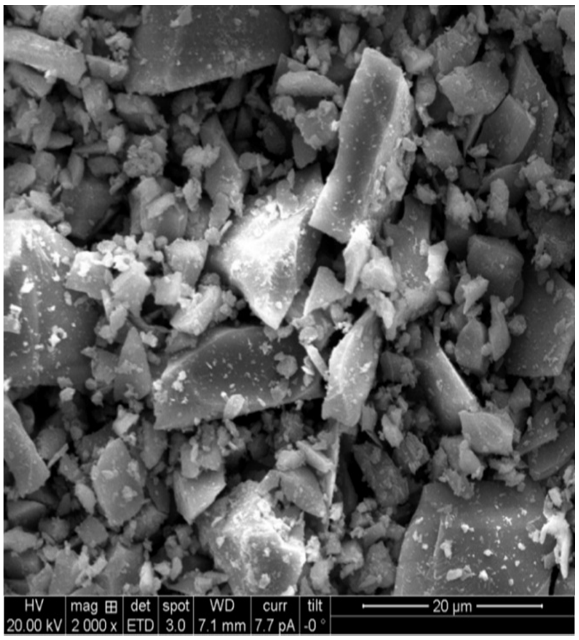

Fig 4: SEM Image for GGBS

The scanning electron microscopy (SEM) image in above figure 4 shows the morphology at 20µm magnification for GGBS. The image shows particle size, shape, before it is used in concrete mix.

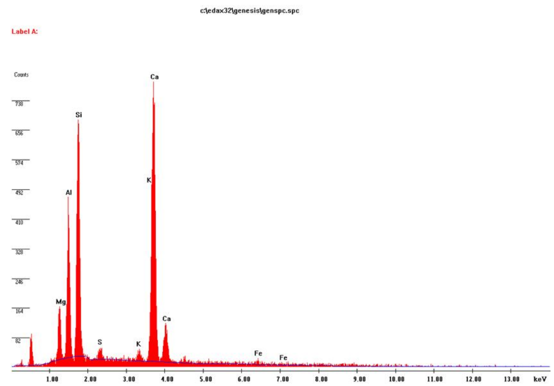

Fig 5: EDS for GGBS

The figure 5 shows the GGBS, when analyzed in energy dispersive spectrometer (EDS), before it is mixed in concrete as a mineral admixture. From the table for EDS, the percentage weight of two elements that are mainly investigated in the experiments is equal to 29.51 % (SiO_2) and 44.74 %(CaO) (Table not shown here).

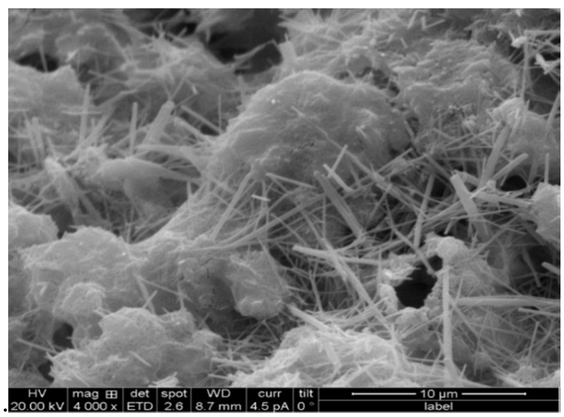

Fig 6: SEM Image At 20% Replacement of GGBS

The SEM micrograph indicates the cement replacement by 20% of GGBS, which modifies the products and pore structure of the hardened concrete. The figure 6 shows the needle shaped or pipe like structures without branches, called as ettringite and also platy crystals of calcium hydroxide. It is observed that the growth of ettringite in pores, which later solidifies and become a dense, compact mixture.

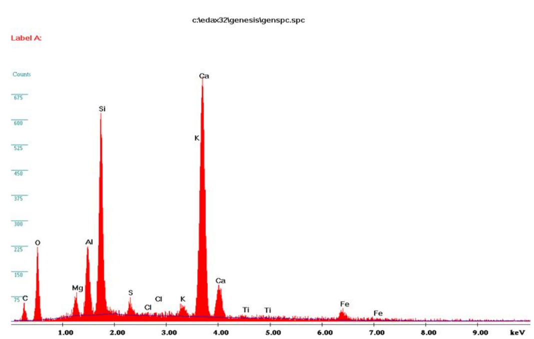

Fig 7: EDS At 20% Replacement of GGBS

Experimental investigations are carried out to replace 20% of GGBS by weight of cement in the concrete mix. The cubes casted were tested for compressive strength and a small portion of the cube was used for microstructural analysis. After recording the values for silica and calcium from GGBS and cement from earlier investigations (EDS table), the total quantity is noted as 20.0gm of silica and 51.83gm of calcium. From the EDS table, which shows the elements remained after the reaction has taken place and the same is confirmed from the peaks observed on the EDS graph (figure 7). The quantity of unreacted silica and calcium are equal to 17.63gms and 40.92gms.The consumed quantity is calculated as equal to 2.37gm and 10.91gms.The percentage increase in strength for <20µm particle size is 12%, when compared with control mix. The increase in strength is may be due to fact that the silica available for the pozzolanic reaction is higher in quantity to consume calcium hydroxide, which is further substantiated by the EDS table, which shows the consumed quantity of silica as 2.37gm and 10.91gm of calcium. Hence the strength is more.

V. CONCLUSION

A. As the particle size decreases, the strength increases, this is because of the increase in specific surface area which is required for the pozzolanic reaction to take place.

B. The specific surface area for cement is 340m^2/kg and GGBS it is 416m^2/kg, as the particle size decreases, strength observed is maximum. For <20µm particle sizes the strength observed is maximum at all replacement levels.

C. The 28 day compressive strength is optimum at 20% replacement level and is obtained for <20 µm particle size, the value is 29.1MPa. The percentage increase when compared with control mix for <20 µm particle size is equal to 12%, whereas for 125-250 µm particle size it is slightly lower than the control mix. The increase in strength for smaller size particles is due to the increase in specific surface area of GGBS and particle size distribution

D. The addition of GGBS modifies the products and the pore structure in hardened cementitious materials, also when higher is the GGBS content ,which results in denser structure, prevents water penetration by reducing the pore size in concrete, this is because GGBS reacts with calcium hydroxide to form extra C-S-H gel in the concrete matrix

E. From the tables of compressive strength for all replacement levels, it is observed that for <20µm particle size the strength is maximum at all days of testing, this is because more specific surface area is available for the pozzolanic reaction to take place (chemical mechanism). The percentage of GGBS unreacted in the reactions will occupy the capillary pores of cement particles (act as filler material known as physical mechanism), thus makes the mix more compact ,dense and impermeable ,hence more strength.

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