Effect of Size and Dosage of Mineral Admixtures: GGBS and Nanosilica on Compressive Strength with Microstructure Analysis of Concrete

[1]V Nagendra, [2]Dr C Sashidhar, [3]Dr S M Prasanna Kumar

[1]Research scholar, [2]Professor, [3]Director
Civil Engineering Department,
Nagarjuna College of Engineering and Technology, Bengaluru, Karnataka, India

***ABSTRACT*— The partial replacement of cement by weight with mineral admixtures like microsilica, GGBS, metakalin, nanosilica, will lower to some extent the environmental effect, reduces the carbon dioxide emissions. In the present investigations GGBS and nanosilica are used as mineral admixtures, with specific range of particles passing through sieves of different sizes and with varying dosages are used. For GGBS replacement only, the results indicated that at 20% replacement, the compressive strength is optimum for <20µm particle size at 28 days testing. When GGBS combined with nanosilica has yielded the maximum strength at 4%NS and 20% GGBS replacement for <20µm particle size (the percentage of GGBS is kept constant at 20% and nanosilica percentage is varied). The microstructural analysis is carried out using scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) .The elements analysed in the study before and after the pozzolinc reactions are silica and calcium, their consumptions in terms of percentage are obtained using energy dispersive spectrometer.**

***KEYWORDS*— Ground Granulated Blast Furnance Slag (GGBS), Nanosilica (NS), Compressive Strength, scanning electron microscopy, energy dispersive spectroscopy.**

I. INTRODUCTION

Ground granulated blast furnace slag (GGBS) is a byproduct obtained from the manufacture of iron. The molten slag, a secondary product of sintering of the raw materials, when quenched under high pressure water jets, granulates. The granulated slag, when ground to a very fine powder with a specific surface area of 400-600m^2/kg is called GGBS.

Nanotechnology has attracted considerable scientific interest due to the new potential uses of particles in nanometer (10^{-9}m) scale. The nano scale size of particles can result in dramatically improved properties from convential grain size materials of the same chemical composition. The nanosilica used in this investigation is having an specific surface area of 210m^2/gm.

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. The microstructure of concrete is described as an integrated system consisting of (i) hydrated cement paste (ii) coarse and fine aggregates and (iii) the interface between aggregate and hydrated cement paste, also known as interfacial transition zone (ITZ). The SEM has two modes of operation that are of prime importance

1) It has the ability to produce images with surface details in the range of 1-5 nm with sufficient depth of field to give three dimensional effects.

2) Secondly it can be utilized for electron beam production of x rays which facilitates in analysis of volumes as small as 1µm in diameter.

The earlier investigations on use of GGBS in concrete technology are usefull in replacing binding material and in turn the cost. Following are some of the investigations carried out by various researchers,

[1] Describes the use of GGBS as a separate cementitious material added along with Portland cement in the production of concrete.[2] Investigates the chemical composition of slag on product quality and also the percentage of silica and alumina in slag were found to produce the most significant correlations to the 3 and 7 day compressive strength of mortar cubes. [3] The paper evaluates the GGBS as a partial replacement for Portland cement in mortars and concrete for strength and durability properties. [4] Investigates the mechanical properties, abrasion resistance, and chloride-ion permeability of concrete incorporating GGBS. [5] Reviews the physical, chemical, mechanical and durability properties concrete incorporating GGBS as partial replacement for cement. [6] Investigates the characteristics of M 30 concrete with partial replacement of cement with GGBS and sand with ROBO sand or crusher dust. [7] The paper investigates the compressive strength of concrete with mineral admixtures as GGBS, as partial replacement with percentage varying from 5% to 30%. The optimum strength obtained was at 15% replacement. [8] The paper evaluates the strength and other mechanical properties by replacing cement by various percentages of GGBS for M 35 grade

concrete at different ages. [9] Reviewed the strength and durability properties of concrete by partial replacement of cement by GGBS. [10] The paper presents an experimental study on effects of curing method and replacement levels of GGBS on mechanical and durability properties of high performance concrete. [11] The paper aims to present the state of art of nanosilica application in concrete by focusing on the nanosilica properties. [12] The paper provides an overview of influence of nanosilica in concrete. [13] Investigates the silicafume particle size and dispersion in concrete by different methods. [14] The paper reviews the incorporation of mineral admixtures in high performance concrete.

II. EXPERIMENTAL PROGRAMME

In the experimental programme, the compressive strength of concrete with partial replacement of cement with GGBS is carried out with specific range of particle sizes passing through sieves of 125-250µm, 90-125µm, 45-90µm, 20-45µm and <20µm. The percentage replacement for GGBS is varied from 10% to 40% with an increment of 10% .For combination of GGBS and nanosilica, the percentage of GGBS obtained as optimum strength is taken as reference (20% replacement), and the percentage of nanosilica is varied as 2%, 4% and 6%. A total of 420cubes were cast and tested at 7, 14, 21 and 28 days. The cubes are of size 150mmX150mmX150mm with mix proportion of 1:2.65:4.55 and w/c ratio of 0.5. The superplasticizer used is Conplast-SP430.

III. MATERIALS

For the experimental investigations following materials were used

Cement: The cement used in the investigation is ordinary Portland cement (OPC) of grade 53. The physical and chemical compositions are presented in Table 1 and 2.

Table No 1 Physical Properties of Cement

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

Table No 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

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 No 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

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

Super Plasticizer: The super plasticizer used in the present work is CONPLAST-SP430 in the form of Sulphonated Naphthalene polymers complies with IS: 9103-1999, to improve the workability of concrete.

Water: Locally available portable water is used for mixing and curing of the specimens.

Ground Granulated Blast Furnace Slag: The GGBS used in the experimental work is supplied by JSW Steel Tornagal, Bellary (dist), and Karnataka. The physical and chemical properties are presented in the table 4 and 5.

Fig.1: GGBS Used In the Experimental Investigations

Table No 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 No 5 Chemical Composition of GGBS in Percentage

Binder	SiO_2	Cao	Al_2O_3	Mgo	Mno	Fe_2O_3	Sulphidesulphur	Sulphitesulphur	Total chlorides
GGBS	33.77	33.77	13.24	8.46	0.05	0.65	2.23	0.23	0.01

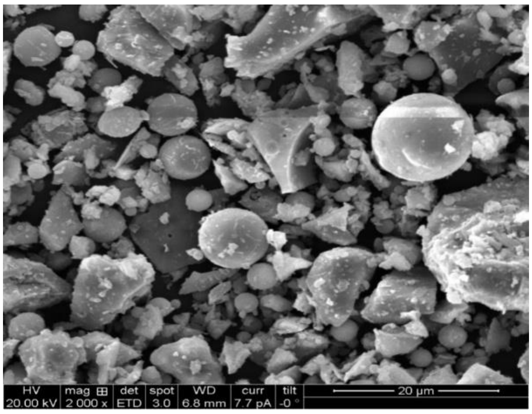
***Nanosilica**:* Nanosilica used in the present investigations is supplied by SISCO RESEARCH LABORATORIES, MUMBAI. The physical and chemical properties as provided by the supplier is tabulated in table no 6 and 7.

Table No 6 Physical Properties of Nanosilica

Particulars	Nanosilica
Specific gravity	2.2-2.5
Surface area m^2/gm	210
Particle size in nm	5-14
Bulk density kg/m^3	-
Loss on ignition (%)	0.67
PH	4.1

Table No 7 Chemical Properties of Nanosilica

Sl no	Chemical component	% by weight
1	Sio_2	99.97
2	Sio_3	-
3	Cl	-
4	Total alkali	-
5	Moisture content	-
6	Loss of ignition	0.67
7	PH	4.1



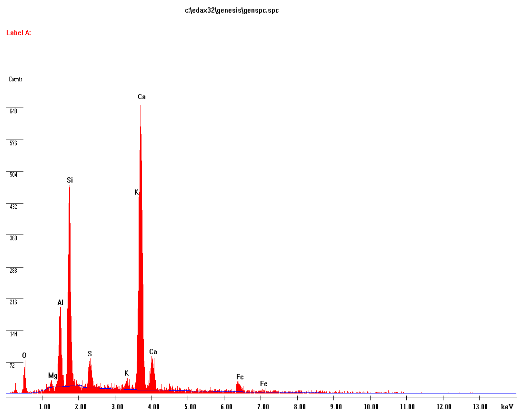


Fig.2: SEM Diagram for Cement

Fig.3: EDS for Cement

Table 8 EDS FOR CEMENT

	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				

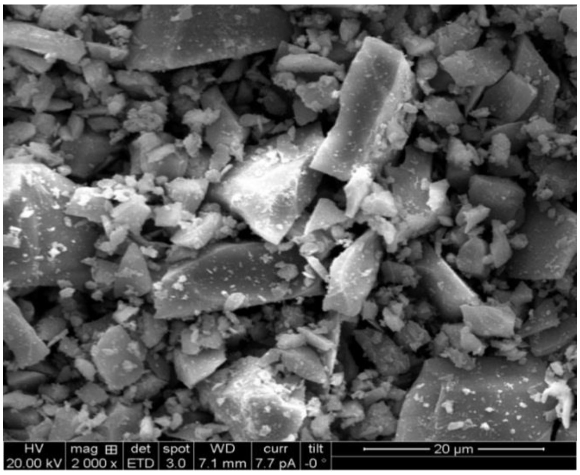


Fig. 4: SEM Image for GGBS

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.

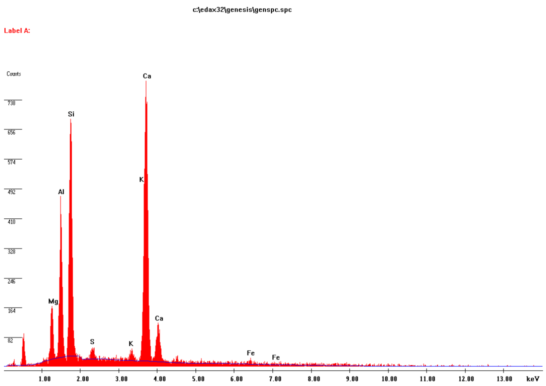


Fig.5: EDS for GGBS

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) (Tables not shown here).

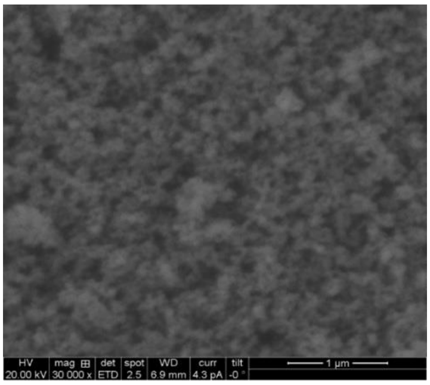


Fig.6: SEM Diagram for Nanosilica

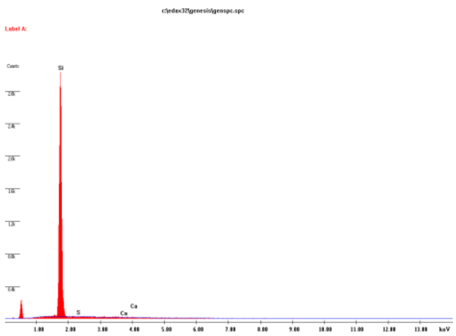


Fig.7: EDS for Nanosilica

Silica present as per EDS table in nanosilica is 99.71%

IV. RESULTS AND DISCUSSIONS

The compressive strength for GGBS and nanosilica with different dosages and specific range of particle sizes are investigated here, for their effect on compressive strength. In the first part of the investigation, when GGBS is replaced by varying the percentage, the results obtained are tabulated in the table no 9 to 12. The optimum strength is obtained for <20µm particles at 20% replacement level. At 28 days, the percentage increase in strength for 10%, 20% 30% and 40% replacement for <20µm particle size is 5%, 12%, 7% and 1% respectively, when compared with control mix. Hence the optimum compressive strength is obtained at 20%

replacement for <20µm particle sizes. From the tables, it is also observed that for <20µm particle size, the strength is maximum at all the replacements .From the investigations it is observed that, as the particle size decreases, the strength increases, which is due to the chemical mechanism and physical mechanism, that takes place due to the addition of GGBS into the concrete matrix. GGBS when replaced with cement, it modifies the products and their pore structure of the hardened cementatious material and also the quantity unreacted after the pozzolanic reactions, will act as filler material, hence results in higher compressive strength.

Table 13 to 15 shows, when nanosilica is combined with GGBS as replacement for cement, at different dosages, leads to increase in strength. The maximum strength is observed for <20µm particle size and the optimum strength is found at 20% GGBS and 4%NS replacement level. The percentage increase in strength, for combination of GGBS and NS, when compared for replacement of only GGBS has yielded strength of 22% for <20µm particle size.

Table No 9 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	19.1	24.3	27.4
2	20-45	15.8	17.6	22.8	26.0
3	45-90	14.3	16.0	20.3	24.0
4	90-125	13.5	15.2	19.3	23.0
5	125-250	12.0	13.5	18.0	21.0

Table No 10 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	18.2	21.5	27.0	29.1
2	20-45	16.8	19.5	25.0	27.2
3	45-90	15.1	17.1	23.2	25.7
4	90-125	14.2	15.9	22.3	25.1
5	125-250	13.0	14.3	20.4	23.9

Table No 11 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	18.9	22.0	27.1	27.9
2	20-45	17.7	20.0	25.8	27.3
3	45-90	15.9	17.8	24.3	26.4
4	90-125	15.3	16.5	23.3	25.7
5	125-250	14.0	15.3	20.9	23.6

Table No 12 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

Table 13 Compressive strength on replacement of 2% NS and 20% 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	19.60	24.60	29.60	32.10
2	20-45	18.50	22.60	27.40	30.20
3	45-90	16.80	19.30	24.80	28.00
4	90-125	15.70	18.00	23.40	26.20
5	125-250	14.20	16.70	21.80	24.40

Table 14 Compressive strength on replacement of 4% NS and 20% 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	20.30	26.30	31.90	35.40
2	20-45	19.50	25.30	28.90	32.40
3	45-90	18.20	23.40	26.40	29.80
4	90-125	17.40	22.40	24.60	28.60
5	125-250	16.40	20.20	23.50	26.20

Table 15 Compressive strength on replacement of 6% NS and 20% 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	18.60	24.90	28.60	33.30
2	20-45	17.30	22.50	26.80	31.10
3	45-90	16.40	20.30	25.40	28.60
4	90-125	15.90	18.80	24.40	27.10
5	125-250	14.50	17.40	22.30	25.40

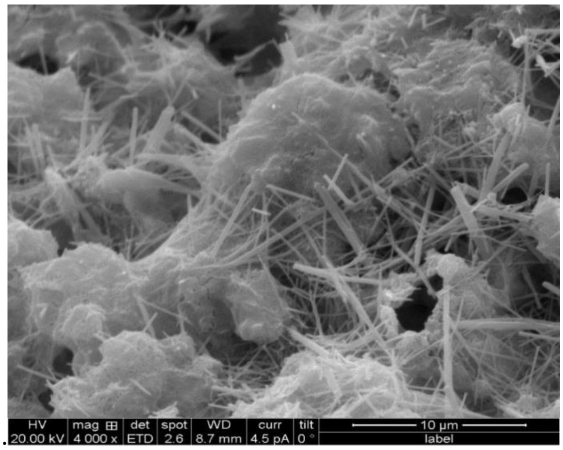


Fig.8: SEM Image at 20% Replacement of GGBS

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.

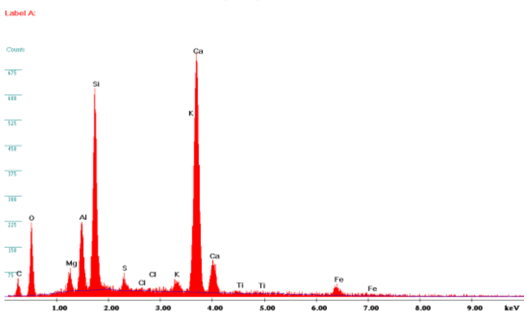


Fig.9: EDS At 20% Replacement of GGBS

The percentage weight of silica and calcium after reactions, (the consumed quantity of silica and calcium) are equal to 2.37gm and 10.91gm.

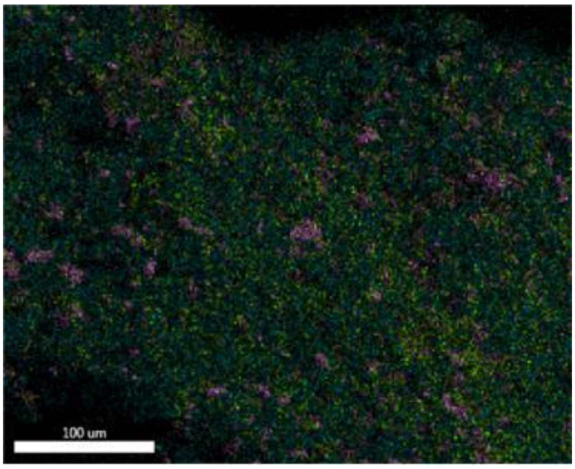


Fig.10: SEM Image at Replacement of 4% NS AND 20% GGBS

The SEM micrograph shown in the figure is dense and compact, as the brightest parts is less in number, which are nothing but the pores in concrete mix. The unhydrated cement grains appear as brighter, when compared to the C-S-H gel, which is darker. Since the mix is compact and dense, the strength is more here when compared to the other replacement levels.

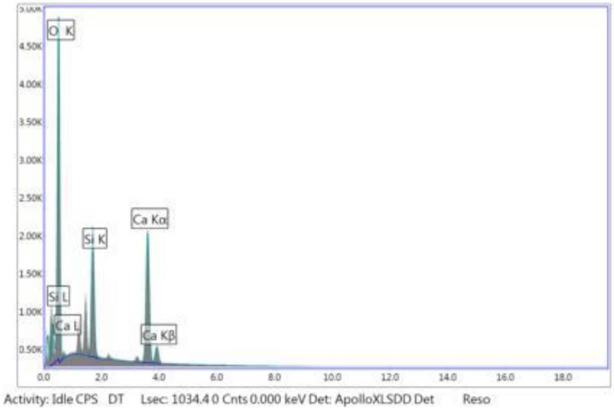


Fig.11: EDS at Replacement of 4% NS AND 20% GGBS

Table 16 EDS at Replacement of 4% NS AND 20% GGBS

Element	Weight %	Atomic %	Net Int.	Net Int. Error
O K	63.56	79.7	133.1	0.01
SiK	7.31	6.9	137.8	0.01
CaK	32.35	13.4	248.4	0

The table for EDS shows the elements which are unreacted after the pozzolanic reaction i.e. silica is 7.31gms and calcium is 32.35gms, which also confirmed by the peaks formed in EDS graph.The increase in strength is due to the higher percentage of nanosilica present in the concrete matrix which involves more actively in the pozzolanic reaction, hence more strength this is also supported by the EDS chart and table presented.

IV. CONCLUSION

1. As the particle size decreases, the strength increases, which is observed for all percentage replacements.
2. For <20µm particle size, the 28 day compressive strength is optimum, the percentage increase when compared with control mix is equal to 12% and that for 125-250µm particle size, it is slightly lower than the control mix.
3. The addition of GGBS modifies the products and the pore structure in hardened cementitious materials and results in higher compressive strength at all days of testing.
4. Since more specific surface area is available for the pozzolanic reaction to take place, and also GGBS which remained unreacted act as filler material.

5. The replacement of nanosilica with GGBS for compressive strength has yielded an optimum strength at 20%GGBS and 4% NS replacement level. The percentage increase in strength when compared with control mix is 37%, whereas for 125-250 µm particles, the strength is nearly equal to the control mix. It can be concluded that, since the particles are in nano scale in silica, hence more specific surface area is available for the pozzolanic reaction to take place, hence the mix is more compact, dense and impermeable, therefore maximum strength is achieved.

REFERENCES

[1] ACI committee 233-"Ground Granulated blast-furnace slag as a cementitious constituent in Concrete".

[2] Jerry W.Hamling and Richard W. Kriner "Evaluation of granulated Blast furnace slag as a cementitious admixture- A case study" American Society for testing and materials, PP 13-20,1992.

[3] .J.Hogan and J.W. Meusel "Evaluation for durability and strength Development of a ground granulated blast furnace slag "American Society for testing and materials, 1981, PP 40-52.

[4] Luiz Fernandez and V. Mohan Malhotra "Mechanical Properties, Abrasion resistance and chloride permeability of Concrete incorporating granulated blast furnace slag" ASTM, 1990, PP 8,7-100.

[5] R. Siddique "Ground granulated blast furnace slag" waste Materials and by-products in concrete, springer, 2008.

[6] Venu Malagavelli and P. N.Rao "High performance concrete with GGBS and Robosand" IJEST 2010, vol2, PP 5107-5113

[7] Atul Dubey, Dr R.Chandak, Prof R.K. yadav "Effect of blast Furnace slag powder on compressive strength of concrete", International journal of scientific and engineering research, 2012, Vol3, PP 1-6.

[8] S. Arivalagan "Sustainable studies on concrete with GGBS As a Replacement material in cement "Jordan journal of civil Engineering 2014, vol8, PP 263-270.

[9] Rafat Siddique "Utilization (recycling) of iron and steel industry By-product (GGBS), in concrete: strength and durability Properties, J mater cycles waste management, 2014, 16, PP 460-467.

[10] Erhan Guneyisi, Mehmat Gesoglu "A study on durability Properties of high performance concretes incorporating high Replacement levels of slag", materials and structures, 2008, 41, PP 479-493.

[11] G.Quercia and H.J.H. Brouwers "Application of nano-silica (ns) in Concrete mixtures" phd symposium Denmark, 2010.

[12] Maheswaran S, Bhuvaneshwari B, Palani G.S, Nagesh R Iyer and KalaiSelvam S. "An overview on the influence of nanosilica in concrete and a research initiative". Research journal of recent sciences, 2012, vol2, PP 17-24.

[13] Sidney Diamond, Sadananda Sahu "Densified silica fume: particle Sizes and dispersion in concrete". Materials and structures, 2006, 39, PP 849-859.

[14] Nima Farzadnia, Abang Abdullah Abang Ali and Ramazan Demirboga "incorporation of mineral admixtures in sustainable high performance concrete". IJSCET vol2, issue 1, 2011, PP 44-56.