PROPERTIES OF CONCRETE INCORPORATED WITH GGBS

Ishwar Chandra Thakur[1], N.Kisku[2], J.P.Singh[3], Sheo Kumar[4]

[1]M.Tech. Scholar, Structural Engineering, Civil Engineering Department, B.I.T. Sindri, Jharkhand, India
[2]Assistant Professor, Civil Engineering Department, B.I.T. Sindri, Jharkhand, India
[3]Associate Professor, Civil Engineering Department, B.I.T. Sindri, Jharkhand, India
[3]Associate Professor, Civil Engineering Department, B.I.T. Sindri, Jharkhand, India

Abstract

Throughout the world, the most widely used construction material is concrete. It is the second most consumed substance on the earth after water. As concrete being used for construction of most of the buildings, bridges etc., it has been labelled as the backbone to the infrastructure development of nation. It is commonly made by mixing Portland cement with sand, crushed rock and water. It is very clear that among the all components, aggregate and water is largely available material in India at very low cost. As cement is comparatively high cost it would be advisable to use other locally available industrial and agricultural waste material to replace the cement partially. Ground Granulated Blast-furnace Slag (GGBS) is a non-metallic and non-hazardous waste material of Iron Industry. Therefore the minimization of this waste material without a harmful effect on nature has a vital importance.The present work focused on the utilization of GGBS in concrete which can be suitably used under the Indian conditions. For this purpose, the various tests on properties of green and hardened concrete have been performed. The properties of green concrete have been analyzed by workability of concrete in terms of slump value whereas the properties of hardened concrete have been analyzed in terms of mechanical and physical properties of concrete. The mechanical properties of hardened concrete include the compressive strength, flexural strength and split tensile strength whereas physical properties includes the dry & moist density and water absorption of hardened concrete. On the basis of present work we found that GGBS in concrete improves workability, compressive strength, flexural strength, split tensile strength and decreases the density & water absorption characteristics of hardened concrete. As a result the cost of concrete decreases. Also GGBS leads to the significant reduction in the quantity of cement which enables the reduction in CO_2 emission and reduction in energy consumption in production of cement.

Keywords: *GGBS, cement, fine and coarse aggregate and concrete*

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1. INTRODUCTION

Ground granulated blast furnace slag (GGBS) is a sustainable material which helps in greener environment by reducing the energy consumption and carbon dioxide (CO_2) gas emission. Only cement industry accounts for around 5% global carbon dioxide emissions. It emits CO_2 gases both directly and indirectly. Direct emission of CO_2 occurs through the chemical process called *calcination* whereas burning of fossil fuels to heat the kiln indirectly results in CO_2 gas emission. It has been reported that the manufacture of one tonne of Portland cement would require approximately 1.5 tonnes of mineral extractions together with 5000 MJ of energy, and would generate 0.95 tonne of CO_2 equivalent [18]. As GGBS is a by-product of iron manufacturing industry, it is reported that the production of one tonne of GGBS would generate only about 0.07 tonne of CO_2 equivalent and consume only about 1300 MJ of energy [18].

GGBS is obtained from iron manufacturing industries, when Silicate and aluminate impurities from ore and coke are combined with flux lowered the viscosity of slag. Molten iron is then tapped off, the remaining molten slag, which consists of mainly siliceous and aluminous residue, is then water-quenched rapidly below 800^oC in order to prevent the crystallization of merwinite and melilite, resulting in the formation of a glassy granulate. This glassy granulate is then dried and grounded into fine powder, which is known as ground granulated blast furnace slag (GGBS). The main component of blast furnace slag are CaO (30-50%), SiO_2 (30-40%), Al_2O_3 (8 -24%) and MgO (1-18%) which is close to the chemical composition of portland cement. It is commonly used in combination with portland cement in concrete for many applications. Concrete made with GGBS has many advantages, including improved strength [5,6,13,16], durability [3,9,13], workability [1,2,19], economic and environmental benefits [9]. The only drawback in the use of GGBS concrete is that its strength development is considerably slower under the standard curing conditions than that of portland cement concrete, although the ultimate strength is higher for the same water–binder ratio [2, 3, 16]. In the construction of large structural concrete elements where heat dissipation is slow, there can be a significant rise in temperature within the first few days after casting due to the exothermic reaction of the binder [4].

The main objective of the present work is to develop a high performance concrete (HPC) by the use of GGBS. Therefore, the experimental program has been undertaken with the objectives to check the compressive, tensile and flexural strength of concrete grade M30. In addition to this the density and water absorption characteristics of hardened concrete was also evaluated. In whole of the experimental works cement was partially replaced by 10%, 20%, 30%, 40%, 50%, 60% and 70% GGBS.

2. MATERIAL USED

The materials used in experimental investigation include:

2.1 Cement

Ordinary Portland cement of 43-grade conforming to IS: 8112-1989 was used in this project under the brand name Reliance Cement.

2.2 GGBS

Ground Granulated Blast-furnace Slag (GGBS) used in this project is the mixed slag from Tata Steel, Jamshedpur and Electro Steel Chandankyari, Dhanbad, Jharkhand. The physical & mechanical properties of cement and GGBS are given in table 1.

Table-1: Physical & mechanical properties of cement& GGBS

Test	Cement	GGBS
Color	Gray	Off white
Consistency	25%	33%
Soundness	4 mm	--
Initial setting time	110 minutes	--
Final setting time	290 minutes	--
Specific gravity	3.13	2.95
Fineness (sieving on 90µm)	8.5 %	0%
Fineness (Blain's air permeability)	302 m^2/kg	320 m^2/kg
Bulk density	1.48 gm/cm^3	1.29 gm/cm^3
Compressive strength	N/mm^2	
3days	23.33	--
7days	34.33	--
28 days	46.18	--

Chemical Properties

The test for Chemical Properties of Cement & GGBS has been performed using X-Ray Fluorescence Machine at ACC Plant Sindri. The result of which are given in table 2.

Table-2: Chemical Properties of Cement & GGBS

Chemical Composition	Cement	GGBS
CaO	63.20	35.27
SiO_2	21.06	34.72
Al_2O_3	5.72	19.11
MgO	1.90	8.46
Fe_2O_3	4.38	0.5
SO_3	2.04	0.18
Na_2O	0.25	0.16
K_2O	0.87	0.58
Cl	0.01	0.01
TiO_2	0.40	0.65
P_2O_5	0.09	0.01
Mn_2O_3	0.07	0.14 (MnO)
Glass Content	--	95

2.3 Fine and Coarse Aggregate

The aggregate passing through the sieve size 4.75mm is termed as fine aggregate and those which retained on 4.75 mm sieve is termed as coarse aggregate. River sand obtained from Barakar River were used as fine aggregate whereas mechanically crushed angular coarse aggregate from a quarry situated in Baliyapur, Dhanbad were used coarse aggregate. All the properties of aggregates were tested in accordance with IS: 2386(part I to IV) -1963 and the results obtained were confirmed with IS 383-1970. Table 3 summarizes the properties of fine and coarse aggregate.

Table-3: Properties of fine and coarse aggregate

Test	Fine Aggregate	Coarse Aggregate
Zone/type	II	Crushed angular
Free (surface) moisture	0.60%	0.20%
Water Absorption	1.10%	0.45 %
Fineness Modulus	2.78	7.25(fraction I- 20mm) 6.29(fraction II- 10mm)
Specific gravity	2.62	2.89
Unit weight(Compact)	1.63gm/cc	1.90gm/cc
Unit weight(Loose)	1.58gm/cc	1.67gm/cc

2.4 Water

Water which is suitable for drinking is satisfactory for use in concrete. It was tested and checked for permissible limit as per the IS: 3025 and IS: 456-2000. Properties of water as obtained are given in table 4.

Table-4: Properties of water

Solids	**Result**	**Permissible Limit**
Organic	55 mg/l	200 mg/l
Inorganic	1200 mg/l	3000 mg/l
Sulphate(SO_3)	75 mg/l	400 mg/l
Chloride (Cl)	1150 mg/l	2000 mg/l for P.C.C. 500 mg/l for R.C.C.
Suspended matter	510 mg/l	2000 mg/l
pH	6.8	> 6

3. EXPERIMENTAL PROCEDURE

Experimental procedure has been described in the following paragraphs.

3.1 Mix Design

Proportioning of concrete mix for M30 grade of concrete has been achieved by concrete mix design as per IS 10262:2009. Composition of constituent material per cubic meter of concrete for different batches is given in table 5.

Table-5: Proportioning of the concrete mix

Mix Designation	Cement %	GGBS %	Water (Kg)	Cement (Kg)	GGBS (Kg)	FA (Kg)	CA (Kg)
R_0	100	0	188	425	0	653	1236
R_{10}	90	10	188	383	42	653	1236
R_{20}	80	20	188	340	85	653	1236
R_{30}	70	30	188	298	127	653	1236
R_{40}	60	40	188	255	170	653	1236
R_{50}	50	50	188	213	212	653	1236
R_{60}	40	60	188	170	255	653	1236
R_{70}	30	70	188	127	298	653	1236

3.3 Mixing Technique

Hand mixing technique has been adopted in the whole experimental work at temperature of 27° ± 2°C and relative humidity 90 percent. In each batch 6 specimen of cube of dimension 150mm x 150mm x 150mm, 6 specimen of cylinder of dimension 150mm diameter x 300mm height, and 3 specimen of beam of dimension 100mm x 100mm x 500mm has been made.

3.4 Properties of Fresh Concrete

The property of fresh concrete has been assessed by workability in terms of slump value. The test of which has been performed in accordance with IS 1199:1959. The results of which are given below in table 6.

Table-6: Slump test of concrete

Mix type	R_0	R_{10}	R_{20}	R_{30}	R_{40}	R_{50}	R_{60}	R_{70}
Slump (mm)	60	63	65	68	70	73	71	67

From above table, it is observed that the slump value of concrete increases as the percentage of GGBS increases up to 50% replacement and then decreases. The increase in slump value is due to the higher smoothness and fineness of slag increases the entrainment of air in the matrix, subsequently increasing the volume of paste.

3.5 Properties of Hardened Concrete

Hardened concrete properties have been analyzed in the terms of compressive, flexural & split tensile strength, dry & moist density and water absorption. As the development of strength is time dependent hence these tests has been performed after a different curing period. One sample each of cube and cylinder has been tested at 7 and 28 days for compressive strength and split tensile strength of concrete respectively while the beam has been tested after curing period of 28 days for flexural strength of concrete.

Compressive Strength

This test was performed in accordance with IS 516:1959 on the cube of size 150mm x 150mm x 150mm. The result of which is given below in table 7.

Table-7: Compressive strength of concrete

Mix type	7 days		28 days	
	Avg. Compressive Strength (N/mm^2)	% variations over R_0	Avg. Compressive Strength (N/mm^2)	% variations over R_0
R_0	26.22	0	38.74	0
R_{10}	25.04	-4.50	40.30	+4.03
R_{20}	24.00	-8.47	41.78	+7.84
R_{30}	23.56	-10.14	43.11	+11.28
R_{40}	23.26	-11.29	47.26	+21.99
R_{50}	22.96	-12.43	49.85	+28.68
R_{60}	21.26	-18.92	47.63	+22.95
R_{70}	19.11	-27.12	44.22	+14.15

Graph showing the variation of compressive strength of concrete with different percentage of GGBS is presented below in figure 1.

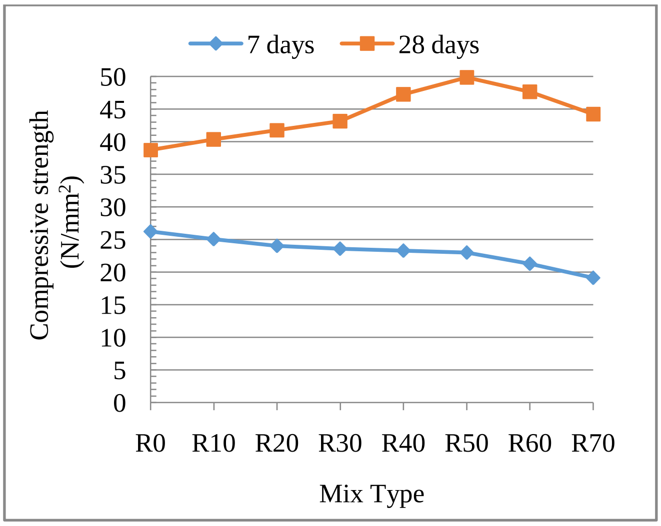

Fig-1: Compressive strength of concrete

From the above fig., it is observed that compressive strength of concrete with increasing percentage of GGBS decreases after 7days but increases after 28 days with optimum percentage of 50% replacement by GGBS. It indicates the slower rate of reaction of matrix by incorporation of GGBS. At optimum percentage of GGBS the compressive strength is 28.68% higher than that of conventional cement concrete.

Split Tensile Strength

This test was performed in accordance with IS 5816:1999 on the cylinder of diameter 150mm and height 300mm. The result of which is given below in table 8.

Table-8: Split Tensile Strength of concrete

Mix type	7 days		28 days	
	Split tensile Strength (N/mm^2)	% variations over R_0	Split tensile Strength (N/mm^2)	% variations over R_0
R_0	2.64	0.00	2.93	0.00
R_{10}	2.48	-6.25	3.09	+5.64
R_{20}	2.41	-8.93	3.21	+9.68
R_{30}	2.26	-14.29	3.28	+12.10
R_{40}	1.82	-31.25	3.42	+16.94
R_{50}	1.72	-34.82	3.51	+20.16
R_{60}	1.51	-42.86	3.59	+22.58
R_{70}	1.37	-44.76	3.47	+12.21

Graph showing the variation of split tensile strength of concrete with different percentage of GGBS is presented in figure 2.

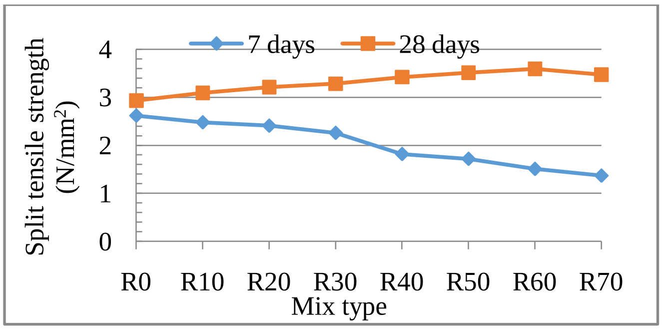

Fig-2: Split tensile strength of concrete

From the fig., it is observed that split tensile strength of concrete with increasing percentage of GGBS decreases after 7days but increases after 28days with optimum percentage of 60% replacement by GGBS. It indicates the slower rate of reaction of matrix by incorporation of GGBS. At optimum percentage of GGBS the Split tensile strength is 22.58% higher than that of conventional cement concrete.

Flexural Strength

This test was performed in accordance with IS 516:1959 on the beam of dimension 100mm x 100mm x 500mm which were tested at 28 days curing period and average of which were found out. The result of which is given in table 9.

Table-9: Flexural Strength on concrete

Mix type	28 days	
	Avg. Flexural Strength (N/mm^2)	% variations over R_0
R_0	3.87	0.00
R_{10}	4.18	+8.01
R_{20}	4.36	+12.66
R_{30}	4.39	+13.44
R_{40}	4.63	+19.64
R_{50}	4.92	+27.13
R_{60}	4.73	+22.22
R_{70}	4.39	+13.44

Graph showing the variation of flexural strength of concrete with different percentage of GGBS is given in figure 3.

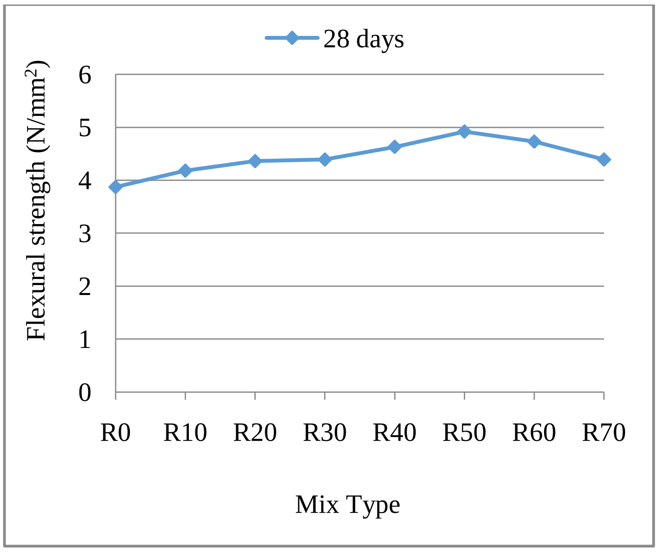

Fig-3: Flexural strength of concrete

From the graph, it may be observed that the flexural strength of concrete with increasing percentage of GGBS increases after 28 days with optimum percentage of 50% replacement by GGBS. At this stage of replacement of cement with GGBS flexural strength is 27.13% higher than that of conventional cement concrete.

Dry and Moist Density

Dry & moist density of concrete has been determined in accordance with ISO: 6275-1982 and NT BUILD 200. The value of which are given in table 10.

Table-10: Dry and moist density of hardened concrete

Mix type	Dry Density		Moist Density	
	Avg. density (gm/cm^3)	% variation over R_0	Avg. density (gm/cm^3)	% variation over R_0
R_0	2.71	0.00	2.84	0.00
R_{10}	2.65	-2.41	2.75	-3.14
R_{20}	2.63	-3.09	2.73	-3.83
R_{30}	2.51	-7.63	2.60	-8.41
R_{40}	2.48	-8.57	2.56	-9.59
R_{50}	2.45	-9.72	2.51	-11.62
R_{60}	2.43	-10.31	2.48	-12.43
R_{70}	2.39	-12.10	2.43	-14.36

Graph showing the variation of dry and moist density of hardened concrete with different percentage of GGBS is presented in figure 4.

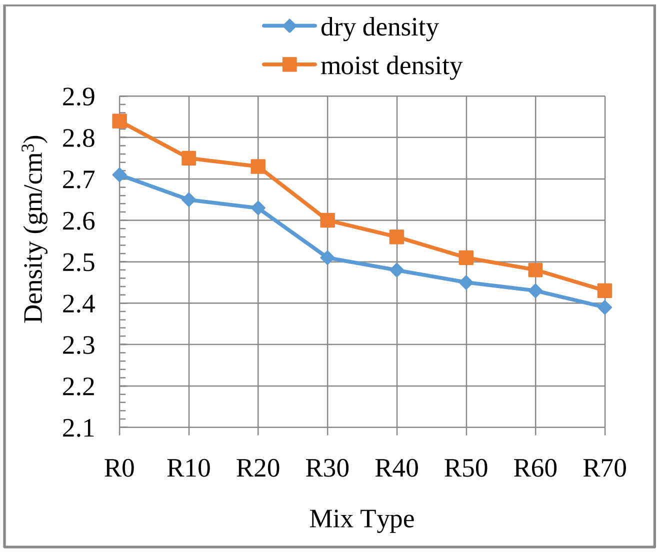

Fig-4: Dry and moist density of hardened concrete

From the above fig., it is observed that the dry and moist density of concrete decreases as the percentage of GGBS increases. From the above results, it is concluded that the GGBS can be used to produce the concrete of lower density.

Water Absorption

Water absorption of concrete has been determined in accordance with ISO: 6275-1982 and NT BUILD 200. The value of which are given in table 11.

Table-11: Water Absorption of hardened concrete

Mix type	Avg. water absorption %	% variation over R_0
R_0	4.50	0.00
R_{10}	3.72	-17.37
R_{20}	3.69	-17.96
R_{30}	3.61	-19.75
R_{40}	3.35	-25.66
R_{50}	2.30	-48.96
R_{60}	2.04	-54.74
R_{70}	1.81	-59.79

Graph showing the variation of water absorption of hardened concrete with different percentage of GGBS is presented in figure 5.

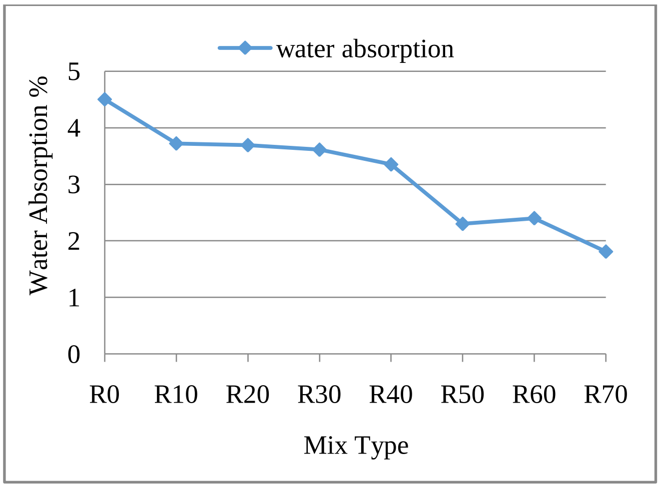

Fig-5: Water absorption of hardened concrete

From the above fig., it is observed that the water absorption of concrete decreases as the percentage of GGBS increases. From this result, it is concluded that the GGBS can be used to improve the water impermeability characteristics of structure. Hence the corrosion of reinforcement may be retarded & durability of R.C.C. structure may be increased.

3.6 Cost Analysis

Material cost estimation includes cost of water, cement, fine aggregate and coarse aggregate for a particular design mix. As per the mix design calculation we obtained that the weight of water, cement, fine aggregate and coarse aggregate are 188 kg, 425 kg, 653 kg and 1236 kg respectively for 1 m^3 of dry concrete. As the water is largely available material in India hence its cost can be neglected. Present study shows that the replacement of cement by GGBS can be done as much as 60% (by weight). Analysis of the cost of concrete with and without GGBS is given below in table 12.

Table-12: Cost of material per cubic meter of concrete

Item name	Rate	Conventional concrete		GGBS concrete		% saving
		Quantity	Cost	Quantity	Cost	
GGBS	₹ 0.50 Per kg	---	---	255 kg	₹ 128	
Cement	₹ 400 per bag	8.50 bags	₹ 3400	3.40 bags	₹ 1360	
Fine aggregate	₹ 860 per m^3	0.249 m^3	₹ 214	0.249 m^3	₹ 214	
Coarse aggregate	₹ 2500 per m^3	0.428 m^3	₹ 1070	0.428 m^3	₹ 1070	
			∑=₹ 4684		∑=₹ 2772	40.82 %

From the above table, we observe that the use of GGBS in concrete saves money up to 40.82% over the conventional cement concrete. This is a significant saving of money. Hence GGBS concrete is more economical.

4. CONCLUSION

1. Slump value of concrete increases as the percentage of GGBS increases up to 50% replacement and then decreases. The increase in slump value is due to the higher smoothness and fineness of slag increases the entrainment of air in the matrix, subsequently increasing the volume of paste.
2. Compressive strength of concrete with increasing percentage of GGBS decreases after 7days but increases after 28 days with optimum percentage of 50% replacement by GGBS. It indicates the slower rate of reaction of matrix by incorporation of GGBS. At optimum percentage of GGBS the compressive strength is 28.68% higher than that of conventional cement concrete.
3. Split tensile strength of concrete with increasing percentage of GGBS decreases after 7days but increases after 28days with optimum percentage of 60% replacement by GGBS. It indicates the slower rate of reaction of matrix by incorporation of GGBS. At optimum percentage of GGBS the Split tensile strength is 22.58% higher than that of conventional cement concrete.
4. Flexural strength of concrete with increasing percentage of GGBS increases after 28 days with optimum percentage of 50% replacement by GGBS. At this stage of replacement of cement with GGBS flexural strength is 27.13% higher than that of conventional cement concrete.
5. Dry and moist density of concrete decreases as the percentage of GGBS increases. From the above results, it is concluded that the GGBS can be used to produce the concrete of lower density.
6. Water absorption of concrete decreases as the percentage of GGBS increases. From this results, it is concluded that the GGBS can be used to improve the water impermeability characteristics of structure.Hence the corrosion of reinforcement may be retarded & durability of R.C.C. structure may be increased.
7. Use of GGBS in concrete saves money up to 40.82% over the conventional cement concrete. This is a significant saving of money. Hence GGBS concrete is more economical.

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REFERENCES

[1] ACI Committee 233 Report, Slag Cement in Concrete and Mortar, ACI 233R-03, American Concrete Institute, Farmington Hills, Mich, 2003.
[2] Duos, C., and Eggers, J., "Evaluation of Ground Granulated Blast Furnace Slag in Concrete (Grade120)", Rpt. No. FHWA/LA-99/336, Louisiana Trans. Res. Center, Baton Rouge, Louisiana, Oct. 1999, 45 p.
[3] J. Bijen, "Blast Furnace Slag Cement for Durable Marine Structures", Stichting BetonPrisma, Netherlands, 1996.
[4] J.G. Sanjayan, B. Sioulas, "Strength of slag-cement concrete cured in place and in other conditions", ACI Mater. J. 97 (5) (2000) 603–611.
[5] K. Suvarna Latha, M V Seshagiri Rao, Srinivasa Reddy. V. "Estimation of GGBS and HVFA Strength Efficiencies in Concrete with Age"International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249 – 8958, Volume-2, Issue-2, and December 2012.
[6] Li, C., Yoda, A., and Yokomur, T., "Pore Structure, Strength and Carbonation of Cement Pastes Containing Ground Granulated Blast-Furnace Slag," Fly Ash, Silica Fume, Slag and Natural Pozzolana in Concrete, SP 178, American Concrete Institute, Farmington Hills, Mich., 1998, pp. 875-892.
[7] Malhotra, V. M. 1987. "Properties of fresh and hardened concrete incorporating ground granulated blast furnace slag". In Supplementary cementing materials for concrete, ed. V. M. Malhotra, 291-331. Ottawa: Canadian Government Publishing Centre.
[8] Malhotra, V. M. 1983. "Strength and durability characteristics of concrete incorporating a pelletized blast-furnace slag". In ACI special publication SP-79.
[9] Malhotra, V.M., "Mechanical Properties and Freezing and Thawing Durability of Concrete Incorporating Ground Granulated Blast Furnace Slag," Canadian Journal of Civil Engineering, V. 16, No. 2, 1989, pp. 140-156
[10] MojtabaValinejad Shoubi, Azin Shakiba Barough and Omidreza Amirsoleimani (2013). "Assessment of the Roles of Various Cement Replacements in Achieving Sustainable and High Performance Concrete". International Journal of Advances in Engineering and Technology, 6 (1): 68-77.
[11] Moir, G. K., and J. S. Lumley. 1989. "Influence of partial cement replacement by ground granulated furnace slag on the expansion of concrete prisms containing reactive aggregate". In 9th international conference on alkali-aggregate reaction: Proceedings, 199-204. Kyoto, Japan.
[12] Neville, A. M., "Properties of Concrete", 4th Ed., John Wiley and Sons, Inc., pp.665-666
[13] Peter W.C. Leung, and Wong, H.D. (2010). "Final Report on Durability and Strength Development of Ground Granulated Blast Furnace Slag Concrete". Geotechnical Engineering Office, Civil Engineering and Development Department, the Government of Hong Kong.

[14] Peterson, N.K., and Hale, M., "The Durability, Permeability, and Strength of Concrete Mixtures Containing Ground Granulated Blast Furnace Slag and Fly Ash," Presentation, ACI National Convent ion, Washington, D.C., 2004.
[15] Rose, J. 1987. "The effect of cementitious blast-furnace slag on chloride permeability of concrete". In ACI special publication SP-102: Corrosion, concrete and chlorides, ed. F. W. Gibson, 107-25. Detroit: American Concrete Institute
[16] Shariq, M., Prasad, J., and Ahuja, A.K. (2008). "Strength Development of Cement Mortar and Concrete Incorporating GGBFS". Asian Journal of Civil Engineering (Building and Housing), 9 (1), 61-74.
[17] Scott A, Alexander MG (2007) the influence of binder type, cracking and cover on corrosion rates of steel in chloride contaminated concrete, Mag concr Res 59(7) : 495-505
[18] S. Arivalagan (2014) "Sustainable Studies on Concrete with GGBS As a Replacement Material in Cement", Jordan Journal of Civil Engineering, Volume 8, No. 3, 2014
[19] V.S. Tamilarasan, Dr. P. Purumal, Dr. J. Maheswaran "workability study on concrete with GGBS as a replacement material for cement with and without super plasticizer", International Journal of advanced Research in Engineering & Technology, ISSN 0976-6480 (print), ISSN 0976-6499(Online) Vol. 3, Number 2, July-December 2012.
[20] Wang Ling, Tian Pei, and Yao Yan. (2004). "Application of Ground Granulated Blast Furnace Slag in High- Performance Concrete in China". International Workshop on Sustainable Development and Concrete Technology, Organized by China Building Materials Academy, PRC, 309-317.