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Experimental Study on High Volumes of Slag Concrete over Ordinary Portland Cement

M.S.Chennakesava Rao, N.V.N.Prabath

Department of Civil Engineering, MIST

Abstract: *One of the main challenges now confronting the concrete industry in India is to meet the demand posed by enormous infrastructure needs due to rapid industrialization and urbanization. With the shrinkage of natural resources to produce ordinary Portland cement (opc), increased use of suitable industrial waste materials having pozzzolanic characteristics that can replace cement clinker is one of the ways to meet the challenge. Such a policy has many-fold advantages-utilization of industrial waste in an eco-friendly way, preserving resources, and finally the improvement in properties of concrete culminating in the sustainable development of the society. GGBS is one such cement replacing pozzolanic material. The positive effect of using GGBS in concrete are now well known which includes the following. Producing concrete of better rheology, higher strength and enhanced durability. Saving in energy requirements in the production of opc.Preservation of limestone and coal reserves. Minimizing greenhouse gas emissions associated with manufacturing of opc. Environment friendly and economical disposal of millions tones of GGBS. Considering the above beneficial effects of using GGBS in concrete, this should be considered as resource material rather than an industrial waste. This research study presented the study of behavior of high volume of slag concrete and OPC concrete. The influence of slag content on compressive strength of high volume of slag concrete (cement : ggbs is 50:50) with different water/binder ratios and Ordinary Portland cement with different W/c ratios are investigated. The parameter of investigation included compressive strength test on high volume of slag concrete (cement : ggbs is 50:50)and 100% OPC with different w/b or W/c ratios for a period of 28days, 90days, and 180days. Specimens of 150mm cube moulds were cast and tested to study their parameters. The specimens incorporated with different water/binder ratios of 0.55, 0.50, 0.45, 0.40, 0.36, 0.32, 0.30, and 0.27.The strength of concrete is increasing with decrease in water/binder ratio. Due to slow pozzolanic reaction the high volumes of slag concrete achieves significant improvement in its mechanical properties at later ages.*

Keywords: *GGBS,POZZOLANIC*

1. INTRODUCTION

The use of ground granulated blast furnace slag (GGBS) to BS 66991 is a well-established means of producing durable concrete for the most demanding applications. GGBS modifies the properties of both fresh and hardened concrete and this Fact Sheet summarizes the most important effects of using GGBS in concrete.Cement, mortar and concrete are most widely used as construction material all over the world. It is difficult to find out alternate material for construction which is as suitable as that of such material from durability and economic point of view. Concrete structures located in an environment which are always subjected to aggressive loadings, both physical and chemical nature over their entire span. GGBS (Ground Granulated Blast furnace Slag) is a by-product of iron manufacturing slag, which is left after the molten iron is poured out of a blast furnace. The slag is formed from a combination of the lime stone/ dolomite that is used as a flux in the making of iron ore and coke ash. Slag with cementitious properties is made by rapidly cooling the molten slag to produce granules with a high content of glass. These granules are dried and ground to produce a cementitious materials.The use of industrial waste in PCC pavements has significant environmental and performance benefits. The amount of natural materials required and amount of landfill space used for both decreased, leading to cost savings. Substituting one ton of slag cement for one ton of Portland cement prevents almost one ton carbon dioxide emissions. Manufacturing slag cement uses only 15% of energy needed to make Portland cement.The following are the approximate equations showing the reactions of C_3S and C_2S with water.

$$2(3CaO.SiO_2) + 6H_2O \rightarrow 3CaO.2SiO_2.3H_2O + 3\,Ca(OH)_2$$

$$2(2CaO.SiO_2) + 4H_2O \rightarrow 3CaO.2SiO_2.3H_2O + Ca(OH)_2$$

The lack of durability of concrete is depended on presence of calcium hydroxide. The calcium hydroxide also reacts with sulphates present in soils or water to form Calcium Sulphate which further reacts C_3A and cause deterioration of concrete. This is known as sulphate attack. GGBS is one of the pozzolanic material which converts the $Ca(OH)_2$ into cementitious products. Utilization slag cement in concrete lessens the burden on landfills reduces emissions and conserves energy. One of the great benefits of slag cement is that Portland cement can be replaced in relatively large percentages using main stream technology. Carbon dioxide (CO_2) is classified as greenhouse gas. Between 165 and 374 pounds of CO_2 are saved per cubic yard of concrete by using a 50percent slag cement substitution, a 42 to 46 percent reduction in greenhouse gas emissions. Reducing the use of Portland cement in concrete by substituting portion of it with slag cement in concrete by substituting a portion of it with slag cement significantly reduces the embodied energy in a cubic yard of concrete. Raw materials for Portland cement are gathered through mining operations. A ton of Portland cement actually requires about 1.6 tons of raw material, because of mass lost due to emissions and other factors.

2. DETAILS OF THE PRESENT STUDY

Pozzolanic admixtures are generally being used along with the cement in concrete mixes so as to derive certain benefits like economy, durability, chemical resistance in permeability etc. The use of high volumes of GGBS has become on of the current topics of research possibility promoted by the availability of a wide range of chemical and mineral admixtures. In the present experimental investigation GGBS has been used in large volumes as an additional ingredient in concrete mixes. The strength of concrete is increasing with decrease in water/binder ratio. Due to slow pozzolanic reaction the high volumes of slag concrete achieves significant improvement in its mechanical properties at later ages.

3. OBJECTIVE OF THE STUDY

To study the properties of concrete using GGBFS.Comparing properties of ordinary concrete to slag concrete. To study the variations in compressive strength for various w/b ratios and age.Establishing relationship between w/c ratio and compressive strength.To establish relationship between w/b ratio for high volume slag concrete. From established equations predicting compressive strength of high volume slag concrete.

4. GGBS

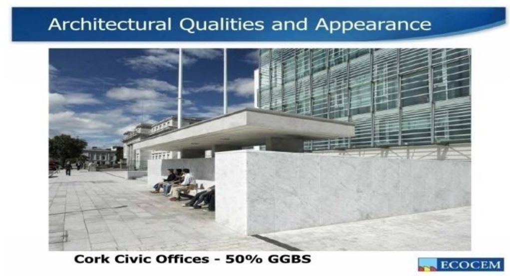
GGBS is one of the pozzolanic material which converts the $Ca(OH)_2$ into cementitious products. Utilization slag cement in concrete lessens the burden on landfills reduces emissions and conserves energy. One of the great benefits of slag cement is that Portland cement can be replaced in relatively large percentages using main stream technology.

Physical Properties of GGBS

Properties	Values
Relative density	2.85-2.95
Surface area m^2/kg	400-600
Colour	white
Bulk density(loose) tones/m^3	1.0-1.1
Bulk density(vibrated) tones/m^3	1.2-1.3

Chemical properties of GGBS

Components	Mass %
Silica as SiO_2	20
Calcium as CaO	65
Aluminum as Al_2O_3	5-10
Magnesium as MgO	2-8



5. PROPERTIES OF MATERIALS

Physical Properties of Fine and Coarse Aggregate

S.NO	Physical Properties	Test Results	
		Fine Aggregate	Coarse Aggregate
1	Specific Gravity	2.64	2.84
2	Bulk Dnesity (kg/m^3) a) Loose b) Compacted	 1290 kg/m^3 1565 kg/m^3	 1545 kg/m^3 1689 kg/m^3
3	Fineness Modulus	2.74	7.16
4	Water Absorption	1.72	0.35

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Sieve analysis of fine aggregate

Sieve size	Retained	% retained	Cumulative % retained	%passed
4.75mm	28	2.8	2.8	97.2
2.36mm	58	5.8	8.6	91.4
1.18mm	175	17.5	26.1	73.9
600µ	283	28.3	54.4	45.6
300µ	275	27.5	81.9	18.1
150µ	181	18.1	100	0

Fineness Modulus =2.74 Zone II

Sieve analysis of coarse aggregate

Sieve size	Retained	% retained	Cumulative % retained
40mm	0	0	0
20mm	830.0	16.6	16.6
10mm	4125.0	82.5	99.1
4.75mm	45.0	0.9	100.0
2.36mm	0.0	0.0	100.0
1.18mm	0	0	100
600µ	0	0	100
300µ	0	0	100
150µ	0	0	100
Total			715.7

Fineness Modulus of coarse aggregate = 715.7/100 = 7.16

Admixture Properties

S.No	Properties	As per IS : 9103-99	Values obtained
1	Physical state	-----	Dark brown colored liquid
2	Composition	-----	Blended Naphthalene Formaldehyde condensed liquid
3	Dry material content, %	0.95T≤DMC<1.05T	37.96
4	Ash content, %	0.95T≤AC<1.05T	12.14
5	Specific gravity	Within 0.02% of mfg.value	1.20
6	Chloride ion content, %	Within 10%, Within 0.2% Whichever is greater of mfg value	0.05
7	PH	Minimum 6	8.23
8	Recommended dosage	---	0.7-1.2% by wt. of cement

Analysis of Water (Limitations as per IS : 456-2000)

S.NO	Impurity	Maximum Limit	Results
1	PH Value	Shall not be less than	7.37
2	Suspended matter	2000	205
3	Organic matter mg/lit	200	30
4	Inorganic matter	3000	200
5	Sulphate (SO4) mg/lit	500	45
6	Chlorides (Cl) mg/lit	2000 for PCC	85

6. RELATIONSHIP OF W/B or W/C RATIO AND COMPRESSIVE STRENGTH OF HIGH VOLUME SLAG CONCRETE AND OPC CONCRETE

Quantities of Materials Required Per 1 Cu.m of High Volumes Slag Concrete

S. No	W/Binder ratio	Water (Lts)	Cement (kg)	GGBS (kg)	Fine Aggregate (kg)	Coarse Aggregate in Kg		Admixture in Kg	Mix cost
						20MM	12MM		
1	0.55	176	160	160	772	688	459	1.28	23
2	0.5	176	176	176	760	677	452	1.41	24
3	0.45	176	196	196	728	676	450	1.96	26
4	0.4	176	220	220	693	671	447	2.2	28
5	0.36	176	244	244	659	665	444	2.68	30
6	0.32	176	275	275	621	654	436	3.3	32
7	0.3	176	293	293	593	652	434	3.81	33
8	0.27	176	326	326	571	628	418	4.56	36

The designed mix proportions for high volume slag concrete

S.No	W/B Ratio	Cement and Slag contents (opc+ggbs)	Total cementitious in kg/cum	Designed mix proportions cem : fa : ca
1	0.55	(160+160)	320	1 : 2.41 :3.58
2	0.50	(176+176)	352	1 : 2.16 : 3.21
3	0.45	(196+196)	392	1 : 1.86 : 2.87
4	0.40	(220+220)	440	1 : 1.57 : 2.54
5	0.36	(244+244)	488	1 : 1.35 : 2.27
6	0.32	(275+275)	550	1 : 1.13 : 1.98
7	0.30	(293+293)	586	1 : 1.01 : 1.85
8	0.27	(326+326)	652	1 : 0.88 : 1.6

Workability Test Results

Cube Notation	W/binder ratio	Slump Values(mm)
HS1	0.55	75
HS2	0.5	80
HS3	0.45	65
HS4	0.4	90
HS5	0.36	100
HS6	0.32	120
HS7	0.3	130
HS8	0.27	140

Quantities of Materials Required Per 1 Cu.m of OPC Concrete

Sl. No	W/Cement ratio	Water (Lts)	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate in Kg		Admixture in Kg	Mix cost
					20M	12M		
1	0.55	176	320	777	693	462	1.6	26
2	0.50	176	352	766	682	455	1.76	28
3	0.45	176	392	733	681	454	2.35	30
4	0.40	176	440	699	677	451	2.64	32
5	0.36	176	488	666	672	448	3.17	34
6	0.32	176	550	629	662	441	3.85	37
7	0.30	176	586	601	660	440	4.4	39
8	0.27	176	652	580	637	425	5.22	42

The designed mix proportions for OPC concrete

S.No	W/C Ratio	Cement contents (opc)	Total cementitious in kg/cum	Designed mix proportions cem : fa : ca : water
1	0.55	320	320	1 : 2.43 :3.61
2	0.50	352	352	1 : 2.17 : 3.23
3	0.45	392	392	1 : 1.87 : 2.9
4	0.40	440	440	1 : 1.59 : 2.56
5	0.36	488	488	1 : 1.36 : 2.30
6	0.32	550	550	1 : 1.14 : 2.01
7	0.30	586	586	1 : 1.03 : 1.88
8	0.27	652	652	1 : 0.89 : 1.63

Workability Test Results

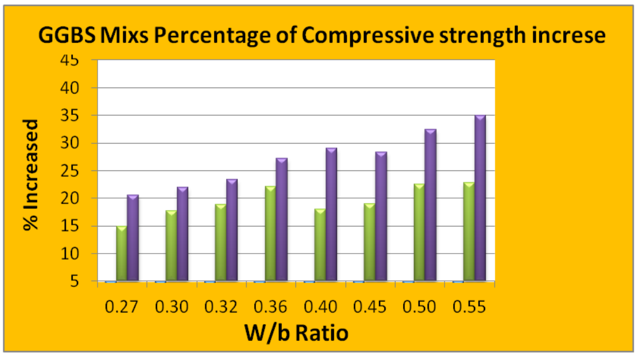
Cube Notation	W/binder ratio	Slump Values(mm)
HS1	0.55	65
HS2	0.5	70
HS3	0.45	70
HS4	0.4	85
HS5	0.36	95
HS6	0.32	115
HS7	0.3	120
HS8	0.27	130

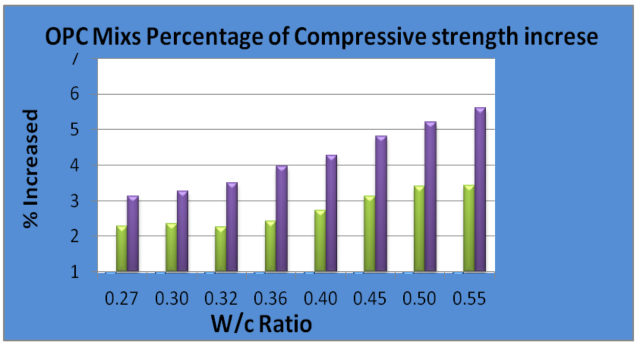
Cost Analysis:

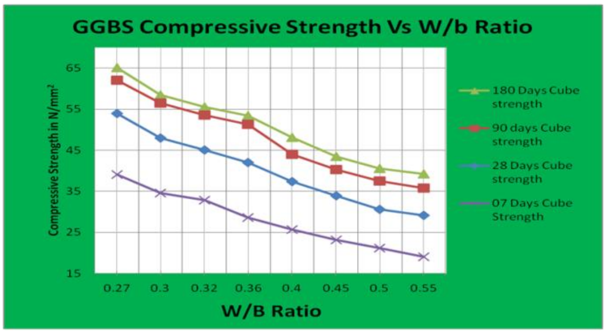
Cost saving over OPC mixes by using GGBS mixes

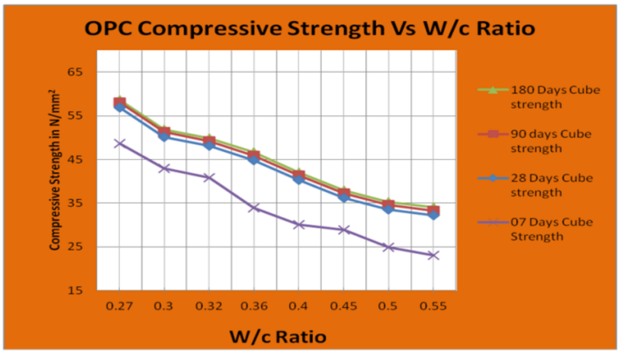
Raw	Ceme	GGB	20M	12M	SAN	Admixtu	Wate	
Avg.	5	3.1	0.600	0.350	0.6	30	0.00	
W/C	0.55	0.5	0.45	0.4	0.36	0.32	0.3	0.27
1 Cum	2372	248	2647	2824	300	3245	3387	364
1 Cum	2692	284	3039	3264	349	3795	3974	429
Cost	**320**	**352**	**392**	**440**	**488**	**550**	**586**	**653**

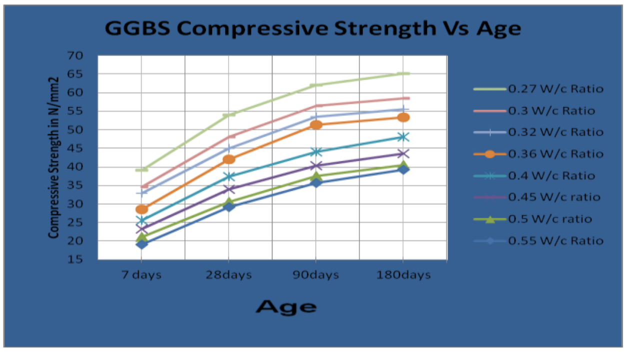
7. TEST RESULTS

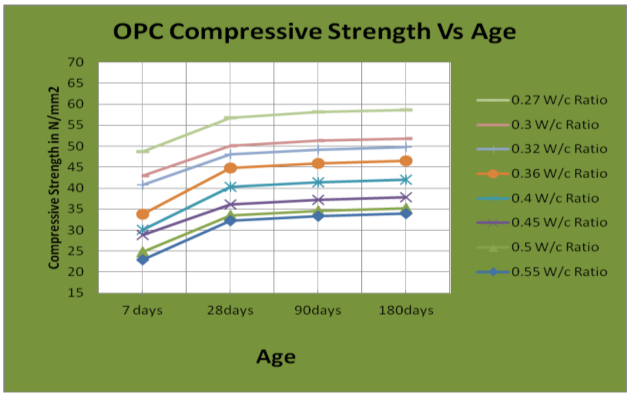


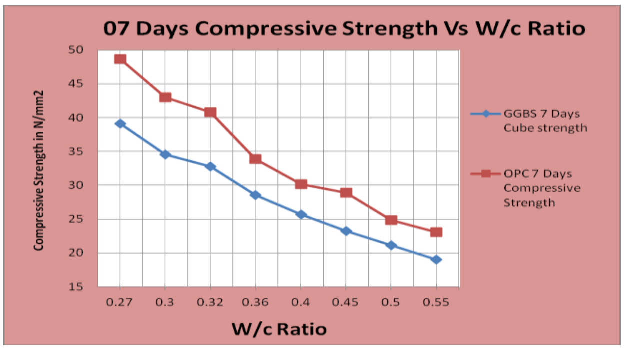


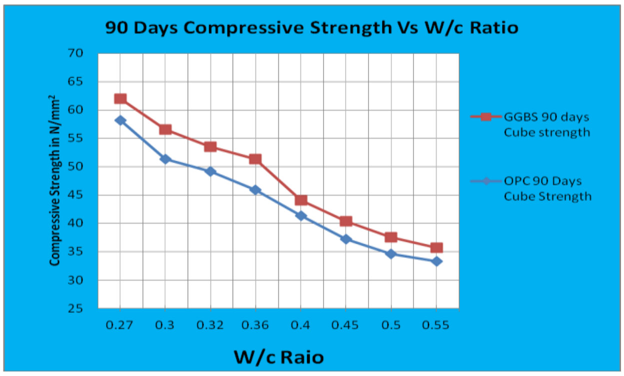


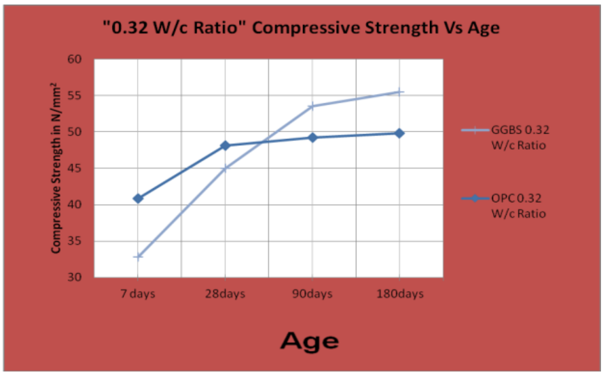


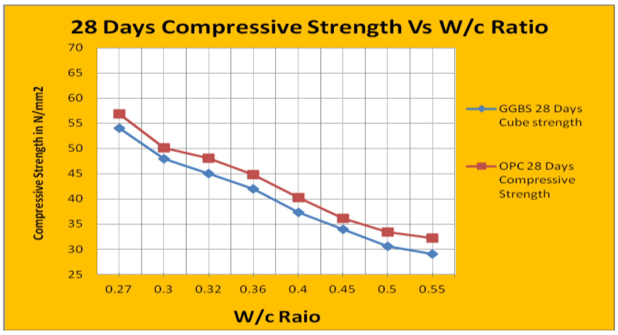


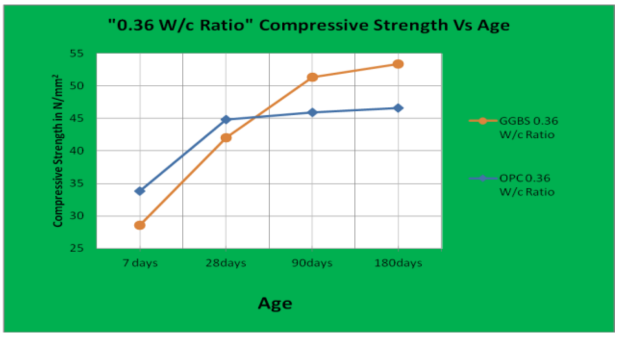


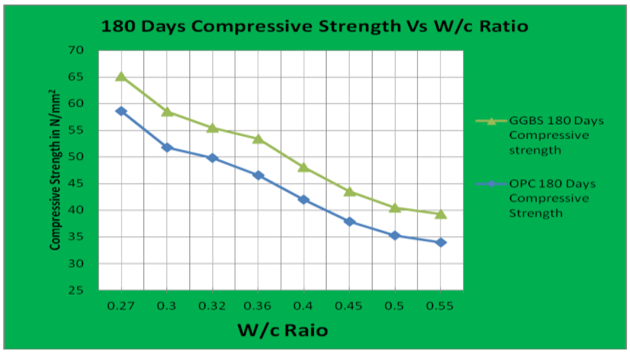


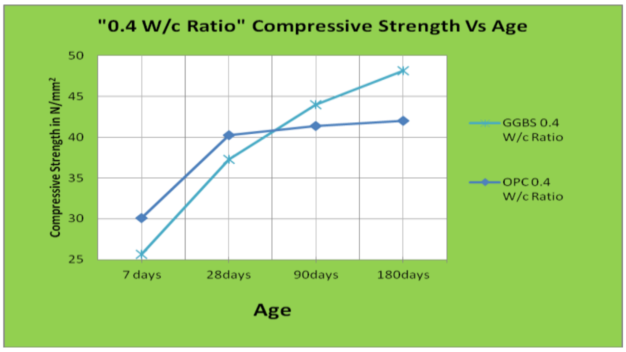

90 Days Compressive Strength Vs W/c Ratio
Compressive Strength in N/mm²
W/c Raio
GGBS 90 days Cube strength
OPC 90 Days Cube Strength

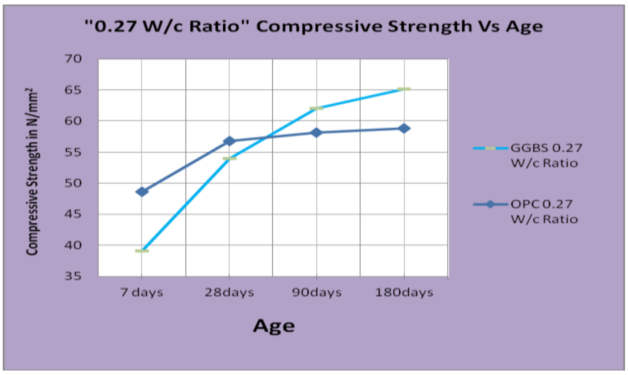

"0.32 W/c Ratio" Compressive Strength Vs Age
Compressive Strength in N/mm²
Age
GGBS 0.32 W/c Ratio
OPC 0.32 W/c Ratio

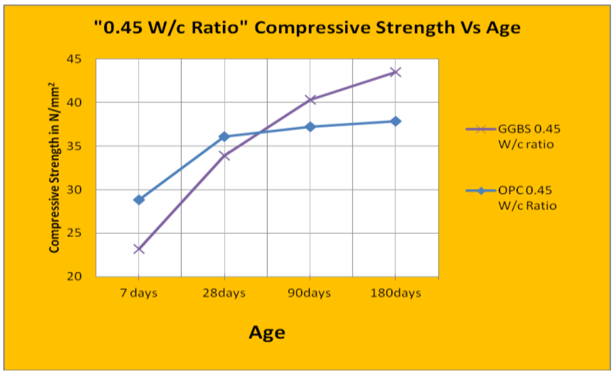

28 Days Compressive Strength Vs W/c Ratio
Compressive Strength in N/mm2
W/c Raio
GGBS 28 Days Cube strength
OPC 28 Days Compressive Strength

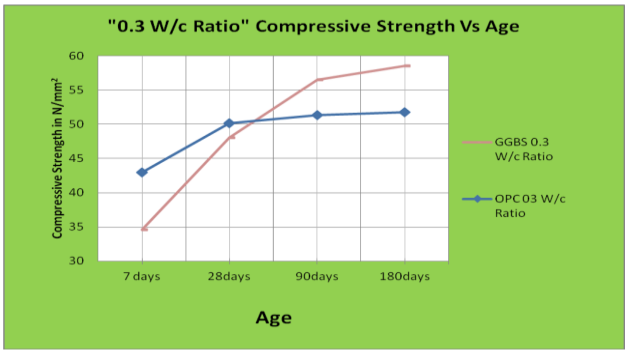

"0.36 W/c Ratio" Compressive Strength Vs Age
Compressive Strength in N/mm²
Age
GGBS 0.36 W/c Ratio
OPC 0.36 W/c Ratio

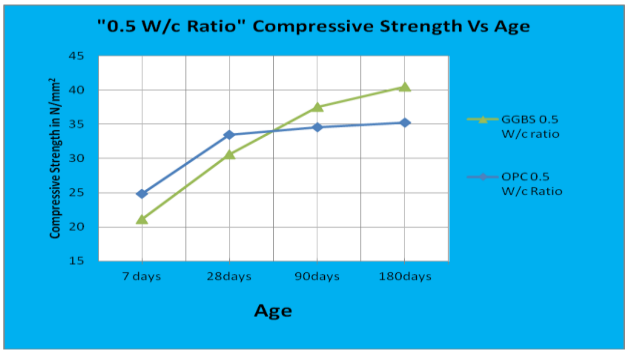

180 Days Compressive Strength Vs W/c Ratio
Compressive Strength in N/mm²
W/c Raio
GGBS 180 Days Compressive strength
OPC 180 Days Compressive Strength

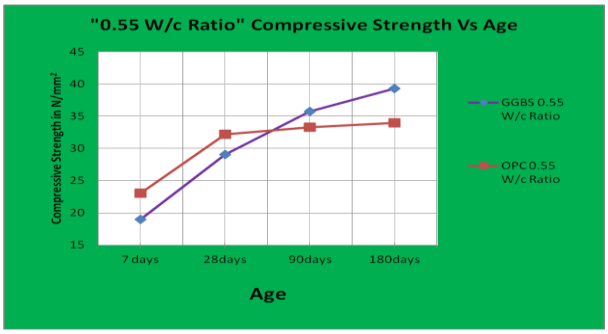

"0.4 W/c Ratio" Compressive Strength Vs Age
Compressive Strength in N/mm²
Age
GGBS 0.4 W/c Ratio
OPC 0.4 W/c Ratio


"0.27 W/c Ratio" Compressive Strength Vs Age
Compressive Strength in N/mm²
Age
GGBS 0.27 W/c Ratio
OPC 0.27 W/c Ratio


"0.45 W/c Ratio" Compressive Strength Vs Age
Compressive Strength in N/mm²
Age
GGBS 0.45 W/c ratio
OPC 0.45 W/c Ratio


"0.3 W/c Ratio" Compressive Strength Vs Age
Compressive Strength in N/mm²
Age
GGBS 0.3 W/c Ratio
OPC 03 W/c Ratio


"0.5 W/c Ratio" Compressive Strength Vs Age
Compressive Strength in N/mm²
Age
GGBS 0.5 W/c ratio
OPC 0.5 W/c Ratio



Conclusions

The following conclusions are drawn from experimental results

Strength gain in GGBS concrete

With the same content of cementitious material (the total weight of Portland cement plus GGBS), similar 28-day strengths to Portland cement will normally be achieved when using up to 50 per cent GGBS. At higher GGBS percentages the cementitious content may need to be increased to achieve equivalent 28-day strength. GGBS concrete gains strength more steadily than equivalent concrete made with Portland cement. For the same 28-day strength, a GGBS concrete will have lower strength at early ages but its long-term strength will be greater.

Colour

Ground granulated blast furnace slag is off-white in colour and substantially lighter than Portland cement. This whiter colour is also seen in concrete made with GGBS, especially at addition rates of 50 per cent and above. The more aesthetically pleasing appearance of GGBS concrete can help soften the visual impact of large structures such as bridges and retaining walls. For coloured concrete, the pigment requirements are often reduced with GGBS and the colours are brighter.

Setting times

The setting time of concrete is influenced by many factors, in particular temperature and water/cement ratio. With GGBS, the setting time will be extended slightly, perhaps by about 30 minutes. The effect will be more pronounced at high levels of GGBS and/or low temperatures. An extended setting time is advantageous in that the concrete will remain workable longer and there will be less risk of cold joints. This is particularly useful in warm weather.

Water demand

The differences in rheological behaviour between GGBS and Portland cement may enable a small reduction in water content to achieve equivalent consistence class.

Consistence

While concretes containing GGBS have a similar, or slightly improved consistence to equivalent Portland cement concretes, fresh concrete containing GGBS tends to require less energy for movement. This makes it easier to place and compact, especially when pumping or using mechanical vibration. In addition, it will retain its workability for longer.

Early age temperature rise

The reactions involved in the setting and hardening of concrete generate significant heat and can produce large temperature rises, particularly in thick- section pours. This can result in thermal cracking. Replacing Portland cement with GGBS reduces the temperature rise and helps to avoid early-age thermal cracking. There are a number of factors which determine the rate of heat development and the maximum temperature rise. These include the percentage of GGBS, the total cementitious content, the dimensions of the structure, the type of formwork and ambient weather conditions. The greater the percentage of GGBS, the lower will be the rate at which heat is developed and the smaller the maximum temperature rise.

As well as depressing the peak temperature, the time taken to reach the peak will be extended. For mass concrete structures, it is common to use 70 per cent GGBS to control the temperature rise. With thinner sections, significant savings in crack control reinforcement can be achieved even with lower levels of GGBS of 50 per cent or less.

Durability

Durability of concrete is related to its permeability / diffusion to liquids and gases and its resistance to penetration by ions such as cl - and so3+. Generally speaking, provided the concrete have been well cured GGBS blended concrete are likely to be more durable than similar concrete produced with only OPC.

Permeability:

In well cured containing blend of GGBS, the long term permeability is reduced due to continued hydration beyond 28days and overall finer pore structure.

Alkali-Silica Reaction:

Use of GGBS blend with OPC is one of the ways to reducing the Alkali Aggregate Reaction, when aggregate used in concrete is alkali reactive. Use of blend of GGBS with OPC reduces the total alkali content in cementitious material.

Sulphate Resistance:

Concrete containing GGBS are acknowledged to have higher resistance to attacke from sulphates than those made with only OPC. This is due to overall reduction in C3A level of concrete and to the inherent reduction in permeability. Provided Al2O3 of GGBS is less than 15% then concrete containing about 70% of slag is considered comparable to concrete produced with Sulphate Resistant Cement (SRC)

Chloride Ingress:

GGBS blended concrete is significantly more resistant to the ingress of chloride ions in concrete apart from reduced permeability. OPC used with GGBS blend chemically binds the chlorides with slag hydrates effectively reducing the mobility of chlorides thereby reducing the reinforcement corrosion risk.

Carbonation:

The influence of addition of GGBS on carbonation has been the subject of much research and ther still appears to be some disagreement as to its effects. The reasons for much of this debate appear to be related to the test procedures and conditions used in the studies and to the basis on which comparisons are made.

Alkalinity:

Despite the reduction in Ca(OH)2 caused by secondary slag hydration reactions the pH of paste remains at a level which is well in excess of that which would affect the passivity of the reinforcing steel.

Conclusion

GGBS blended concrete have been used successfully in concrete for many years in many countries throughout the world. From all the available technical literature it is suggested that there are potentially many technical benefits to be gained from using the GGBS. Where structures have to be designed for durability requirements in very aggressive environment GGBS blend mixes are recommended in standards of most developed and developing countries. Many countries have accepted the benefits and have recommended its use in their national standards. Once the user is made aware of the properties of the material and understood the benefits to be gained there is no reason why it should not continue to be used successfully and more often in existing and future project.

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AUTHORS' BIOGRAPHY

M.S.Chennakesava Rao was born in 1990. He graduated from Jawaharlal Nehru Technological University, Kakinada in the year 2011. He recieved M.Tech degree from Jawaharlal nehru University, Kakinada in the year 2015. He presently working as Assistant Professor in the Department of Civil engineering at Mother Teresa Institute of Science and Technology, India. His research area includes.

N.V.N.prabath was born in 1992. He graduated from Jawaharlal Nehru Technological University, Hyderabad in the year 2013. He received M.Tech degree from Jawaharlal nehru University, Hyderabad in the year 2015. He presently working as Assistant Professor in the Department of Civil Engineering at Mother Teresa Institute of Science and Technology, India. His research area includes.