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Experimental Studies and Analysis of Strength Properties of High Volumes of Slag Concrete for Rigid Pavements

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***Abstract:** Concrete is one of the most prevalent construction materials, in which cement is the main ingredient, playing important role in gaining the strength and also binding material. However, the higher consumption of cement raises its production which decreases sustainability of natural materials like limestone. In this context, the significance of substituting material is being increased. In the present study, GGBS (Ground Granulated Blast Furnace Slag) is used as the substituting material of cement with a proportion of 50:50. Ordinary Concrete (OC) without GGBS and High Volumes of Slag Concrete (HVSC) Cubes of size 150mm and beams of size 100 mm X 100 mm x 500 mm for various water-cement and water-binder ratios ranging from 0.55 – 0.27 are cast and tested for Compressive Strength and Flexural Strength for 28 days. Relations between w/c or w/b, Compressive Strength and Flexural strength of OC and HVSC are developed and represented by Nomograms. It is useful while choosing a mix for rigid pavements.*

***Keywords:** Ordinary Concrete, High Volumes of Slag Concrete, Compressive Strength, Flexural Strength and Nomograms.*

I. INTRODUCTION

Cement has been used widely as the binding material in concrete since 11 decades. The construction industry mainly depending on cement, which implies large amounts of cement production, however is having many drawbacks like high consumption of natural resources, production of $Ca(OH)_2$; it also causes leaching of concrete, particularly in the case of rigid pavements when they are exposed to soils consisting of sulphates. A large amount of research has been going on regarding substituting materials like Ground Granulated Blast Furnace Slag (GGBS), Silica Fume, Fly ash, metakaoline etc. Utilization of pozzolanic materials improves the strength as well as workability of concrete. GGBS is a waste material in the iron ore production. However, it consists of silicates, aluminosilicates and calcium- alumina silicates. Hence, it is a popular substituting material. Tremendous utilization of GGBS in concrete results in the sustainability of raw materials and environment. It reduces the usage of cement thereby reducing its production which in turn decreases greenhouse effect.

1.1. Literature Survey

A significant increase was observed in bulk density and Compressive Strength of M_{30} grade concrete in which natural aggregate was substituted by Steel Slag aggregate (Arivoli & Malathy, 2017).

Self-desiccation is less in the early periods (0 to 7 days) in case of GGBS concrete due to low hydration, but it is more in case of pure paste both w/cm (0.45 & 0.35). Porous hydration products content formed due to consumption of crystalline CH, causes autogenous shrinkage and is controlled by concrete with GGBS (Wei & Hansen, 2011). Growth of Compressive Strength in the case of slag concrete is insignificant at the early age of curing. The improvement in strength occurs at relatively rapid rate at later ages of curing which is dependent upon mix proportion of slag with cement (Islam & Islam, 2010).

The concentration of design mix is on synergistic interaction between Portland cement, slag by a judicious combination of fineness of slag, w/b, level of cement replacement and superplasticizers producing high durability concrete with Compressive Strength of 60 MPa to 100 MPa for 28 days. Such type of concrete is dense, homogeneous and crack-free microstructure with reduced heat of hydration (Swamy, 2007). GGBFS can be replaced with cement for the purpose of grouting and attainment of optimum Compressive Strength of concrete for 50% slag replacement under water curing condition. Drying shrinkage test result proved that the above grouting material with proper mix proportion is appropriate to be used in normal grade concrete repairs under hot climate (Hussin & Kang, 2007). Low Chloride penetration in case of concrete mixes with fly ash or slag when compared with concrete with Portland cement during 100 year service life (Michael & Phil, 1999). Concrete with GGBFS can be used in environments consisting higher temperatures. The variation of mechanical properties of this concrete is not significant between 27 ^{o}C and 100 ^{o}C. Higher temperatures, i.e more than 350 ^{o}C, a significant mass loss is observed. The percentage of GGBS used in concrete is limited to 20% (Rafat & Deepinder, 2012).

A nonlinear partial differential equation is used as solution model to analyze the pattern of chloride diffusion in fly ash and slag concretes (W-Hu Tsao & Ming-Te Liang, 2011). Some numerical methods are proposed to find the binder reaction for gaining of strength, the capillary cavities at different periods of curing and chloride diffusion coefficient (Ki-Bong Park & Han-Seung Lee, 2017).

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Concrete mixes with PFA and GGBS exhibit significant increase in resistance to chloride ingress than PC mixes (Bamforth, 1999). The partial substitution of natural aggregates with slag aggregates improves the strength in later ages (Zeghichi, 2006). The adhesion between the aggregate of crystallized slag and hydrated paste is good and it improves the strength. Alkali Aggregate reaction can be controlled by using Steel Slag powder as partial substituting material to Portland cement in concrete by its synergistic effect and mutual activation (Yun-feng & Yan, 2009). Artificial Neural Networks (ANN) is a more appropriate method than regression analysis (Yeh, 1998).

1.2. Research Significance

From the literature it is found that GGBS can be used as substituting material for cement in concrete. Also, no literature found the behavior of HVSC for different water binder ratios. Flexural strength of concrete is a significant parameter in designing of rigid pavement (As per IRC 58-2015, p.12). Accordingly, some relations are developed between w/c or w/b and OC and HVSC and also nomograms for Compressive Strength and Flexural strength of all concrete mixes.

1.3. Objective of Present Investigations

The scope of present study is to identify the suitable mix for the rigid pavement from the nomograms. The main objectives of the present investigations are

a. To determine percentage variation between OC and HVSC,
b. To propose empirical equations for w/b and Compressive strength and w/b and Flexural Strength for all concrete mixes.
c. To develop Nomograms for Compressive Strength and Flexural Strength for all concrete mixes.

II. EXPERIMENTAL INVESTIGATIONS

2.1. Cementitious Materials

Locally available 53 grade of Ordinary Portland Cement (Ultratech Brand.) (Confirming to IS: 12269) was used in the investigations. Ground Granulated Blast Furnace Slag (GGBFS) which is available locally was procured from Steel Plant, Visakhapatnam (Dt.), Andhra Pradesh. The physical requirements is in accordance with IS 1727- 1967, Reaffirmed2008 and chemical requirements with IS: 12089 – 1987, Reaffirmed 2008.

2.2. Superplasticizer

The Superplasticizer utilized was supplied by internationally reputed admixture manufacturers. Endure flowcon04 was manufactured by Johnson. Endure flowcon04 is dark brown colored liquid and is based as sulphonated naphthalene formaldehyde (SNF) super plasticizer (It complies with IS: 9103-1999, BS5075, ASTM C-494 was used). The super plasticizer is tested for properties like density and pH which were found to be 1.2 and minimum 6.

2.3. Fine Aggregate

The locally available river sand is used as fine aggregate in the present investigation. The sand is free from clay, silt, and organic impurities. The sand is tested for various properties like specific gravity, water absorption and fineness modulus of fine aggregate which were found to be 2.55, 1.72 and 2.74 respectively (in accordance with IS:2386-1963).

2.4. Coarse Aggregate

Machine crushed angular granite metal of 20mm nominal size from the local source is used as coarse aggregate. The combined grading (CA and FA) obtained in this work compares well with aggregate gradation for Pavement Quality Concrete (Table 3 of IRC: 15-2011) as shown in Fig. 1. The physical properties of aggregate used in the investigations as shown in Table 2.

2.5. Water

Locally available water used for mixing and curing which is potable, shall be clean and free from injurious amounts of oils, acids, alkalis, salts, sugar, organic materials or other substances that may be deleterious to concrete or steel.

Table 1.Properties of Cementitious Materials

Cement and GGBS Characteristics		
Component (%)	Cement	GGBS
a) Chemical Analysis		
Loss of ignition	2.08	1.15
Insoluble Residue (% by mass)	2.13	
Manganese Oxide (Max.) (%)		0.23
Magnesium oxide (Max.) (%)	1.00	6.6
Sulphur (S03)(Max.)(%)	1.74	0.6
Ratio of % of Alumina to Iron Oxide	1.18	-
Tricalcium aluminate (C3A), (% by mass)	6.20	-
Ratio of % of Lime to % of Silica, Alumina and Iron Oxide, when calculated by the formula: $\frac{CaO - 0.7\ SO_3}{2.8\ SiO_2 + 1.2\ Al_2O_3 + 0.65\ Fe_2O_3}$	0.96	-

Glass content (Min.) (%)	-	92.68
$\dfrac{CaO + MgO + {}^{1}/_{3}\,Al_2O_3}{SiO_2 + {}^{2}/_{3}\,Al_2O_3}$	-	1.08
$\dfrac{CaO + MgO + Al_2O_3}{SiO_2}$	-	1.83
b) Physical Analysis		
Normal Consistancy (%)	28.0	-
Initial Setting Time (min.)	115	-
Final Setting Time (min.)	345	-
Compressive Strength (28 Days) MPa	53.0	40
Fineness (m2/kg) (By Blaine's Air Permeability Method)	310	350
Soundness (mm) (By Le- Chatelier's Method)	0.5	-
Specific Gravity	3.1	2.86
Residue on 45 micron sieve, %	-	5

Table 2. Physical Properties of Aggregate

S. No.	Property	Test Results	
		Fine Aggregate	Coarse Aggregate
1	Specific Gravity	2.55	2.60
2	Bulk Density (kg/m3)		
	a) Loose	1450 kg/m3	1400 kg/m3
	b) Compacted	1650 kg/m3	1580 kg/m3
3	Fineness Modulus	2.74	7.16
4	Water Absorption	1.78	0.38

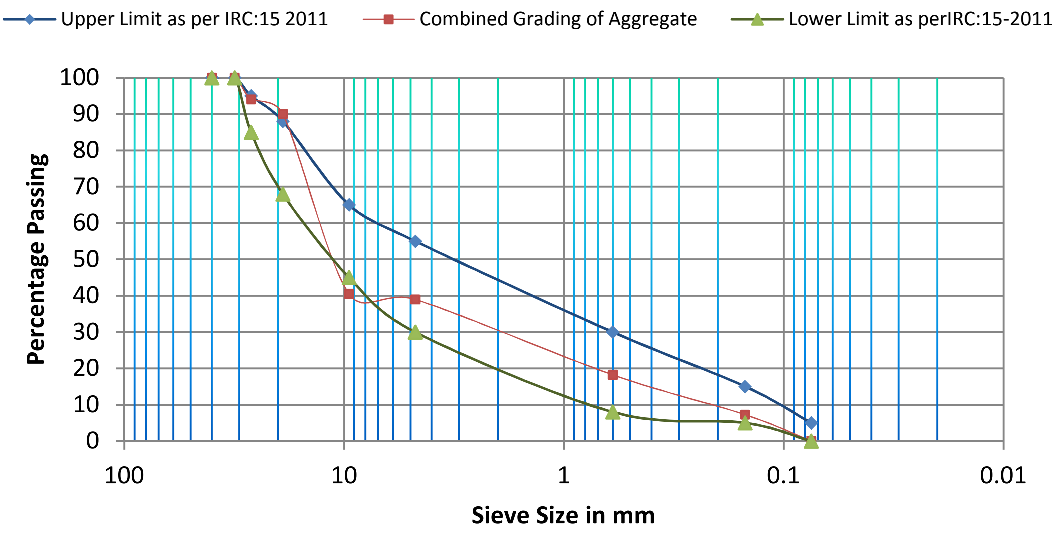

Fig.1 Particle Size Distribution Curve of Combined Aggregate

III. MIX PROPORTIONING

Mix Proportioning of OC and HVSC had been prepared (as per IS 456-2000 and IS 1026-1982). OC and HVSC mixes were prepared for various water- binder ratios ranging from 0.55 to 0.27 with 0% and 50% GGBS as replacement material for cement respectively are shown in Table 3.

3.1. Preparation, Casting and Testing of Specimen

The specimens of OC and HVSC were cast, cured and tested for Compressive Strength and Flexural Strength (as per IS: 516-1959, p.9).

3.2. Compressive Strength Test

Concrete cube specimens of size 150 mm are used to determine the Compressive Strength of Ordinary and High Volumes of Slag Concrete as per (IS 516-1959, p.11) for 28 days.

Table 3. Mix Proportions of Ordinary Concrete and High Volumes of Slag Concrete

	Mix Proportions of Ordinary Concrete and High Volumes of Slag Concrete							
Series	**OC**							
w/c or w/b	0.55	0.50	0.45	0.40	0.36	0.32	0.30	0.27
Mix	OC1	OC2	OC3	OC4	OC5	OC6	OC7	OC8
Cement (Kg)	320	352	392	440	488	550	586	640
FA(Kg)	786	775	743	692	659	623	565	518
CA(Kg)	1020	1005	1004	1016	1009	993	1023	1025
Superplasticizer (ml)	---	-----	1185	1133	2470	2780	2966	3295
Slump(mm)	80	75	70	75	85	95	110	120
Series	**HVSC**							
Mix	**HVSC1**	**HVSC2**	**HVSC3**	**HVSC4**	**HVSC5**	**HVSC6**	**HVSC7**	**HVSC8**
Cement(Kg)	160	176	196	220	244	275	293	326
GGBS(Kg)	160	176	196	220	244	275	293	326
FA(Kg)	781	769	737	687	653	616	557	511
CA(Kg)	1014	998	996	1006	998	982	1010	1010
Superplasticizer (ml)	--	---	---	1732	2122	3873	3882	4698
Slump(mm)	75	80	65	90	100	120	130	140

3.3. Flexural Strength Test

Beam specimens of Ordinary and High Volumes of Slag Concrete of size 100 x 100 x 500 mm, cast for various water-binder ratios are tested by applying third-point loading (as per IS 516, p.16) for 28 Days. Casting and testing of HVSC specimens are shown in Fig.2.

a) Casting of Specimens **b) Testing of Specimen**

Fig.2 Flexural Strength of HVSC

IV. RESULTS AND DISCUSSIONS

In this investigations, OC (0% GGBS) and HVSC (50% OPC replaced with GGBS) for different w/c ratios or w/b are cast and tested for Compressive Strengths and Flexural Strengths. Then, a relation between w/c and Compressive Strength of OC is developed for 28 days. Similarly, a relation between w/b and Compressive Strength of HVSC is also developed. Sample sizes of 3 are considered in the present study.

4.1. Variation of Compressive Strength of OC & HVSC for 28 Days

The Compressive Strengths of OC and HVSC for various water-cement or water-binder ratios are determined for 28 days as shown in Table 4.

Table 4.Variation of Compressive Strength of OC & HVSC for 28 Days

w/c ratio or w/b ratio	Compressive Strength (MPa) 28 Days		Variation (%)
	OC	HVSC	
0.55	38.94	29.50	24.24
0.50	42.68	31.00	27.37
0.45	60.24	35.00	41.90
0.40	60.99	38.30	37.20
0.36	66.22	43.60	34.16
0.32	70.86	46.70	34.10
0.30	72.52	50.10	30.92
0.27	72.61	55.05	24.18

It can be observed that the Compressive Strength of OC varied from 38.94 to 72.61 MPa with OC1 to OC8 respectively. For the corresponding HVSC mixes the Compressive Strength varies from 29.50 to 55.05 MPa respectively. OC mixes showed better Compressive Strength when compared to HVSC mixes. This was because the quantity of cement used for HVSC is about 50% less than that for OC. The percentage variation in Compressive Strength for OC mixes to HVSC is between 24% and 41%.

4.1.1. Empirical Equations

Empirical equations for Compressive Strength in terms of w/b for OC mixes, HVSC mixes and are shown in Table 5

This relation between water/cement and Compressive Strength is similar to that given by Duff Abrams in 1918. The relation is also valid for HVSC mixes with GGBS used as 50% replacement material to cement.

Table 5. Relation between Compressive Strength and Water/ Binder

Series	Relation between	Equation	R^2
General	Compressive Strength Vs w/c (Abram's)	$f_c = A/(B)^{w/b}$	-
OC	Compressive Strength Vs w/c	$f_c = 136/(8.75)^{w/b}$	0.98
HVSC	Compressive Strength Vs w/b	$f_c = 98.07/(9.6)^{w/b}$	0.99

4.2. Variation of Flexural Strength of OC & HVSC for 28 Days

The Flexural strengths of OC and HVSC are found out for 28 Days. The percentage variation of flexural strength of OC with respect to HVSC results are given in Table 6.

Table 6. Flexural Strengths of OC & HVSC for 28 Days with Percentage Variation

w/c or w/b	Flexural Strength (MPa) 28 Days		Variation (%)
	OC	HVSC	
0.55	3.76	3.94	-4.79
0.50	4.80	4.10	14.58
0.45	5.20	4.25	18.27
0.40	5.44	4.30	20.96
0.36	5.52	4.38	20.65
0.32	5.68	4.62	18.66
0.30	6.32	4.72	25.32
0.27	6.52	4.96	23.93

It is illustrated that the Flexural strengths of OC & HVSC varies from 3.76 MPa to 6.52 MPa and 3.94 MPa to 4.96 MPa respectively. A variation in Flexural strength of HVSC is observed between 14.58% and 25.32 % for 28 days with respect to 28 days' strength of OC.

For lower w/b ratios, HVSC shows better strengths which are obtained due to the hydrated product of cement compound in a grain of cement which firmly adheres to the unhydrated core in the grains of cement. This means that the unhydrated cement left in grain of cement will not reduce the strength of cement mortar or concrete as long as the products of hydration are well compacted (Shetty, 2012, p.19).

This leads to increase in strength of HVSC for lower water binder ratios.

In no case should the 28 days flexural strength of pavement quality concrete be less than 4.5 MPa (IRC 58-2011, p.13). From the results, it can be observed that HVSC with w/b ratio 0.32, 0.3 and 0.27 fulfil the above requirement. The HVSC mixes with higher w/b can also be used as DLC layer for the rigid pavement further which reduces the thickness of pavement.

4.2.1. *Empirical Equations*

Empirical equations for Flexural Strength in terms of w/b for OC and HVSC are shown in Table 7.

Table 7. Relation between Flexural Strength and Water/ Binder

Series	Relation between	Equation	R^2
OC	Flexural Strength Vs w/c	$fc = 10.15/(0.2)^{w/b}$	0.89
HVSC	Flexural Strength Vs w/b	$fc = 5.9/(0.48)^{w/b}$	0.95

4.3. Development of Nomograms

Nomograms are developed for w/c or w/b, Compressive Strength and Flexural Strength of OC and HVSC mixes for 28 days curing using the MATLAB software as shown in Fig. 3 & Fig.4. These nomograms facilitate to choose the required mix which is suitable for the particular loading and purpose.

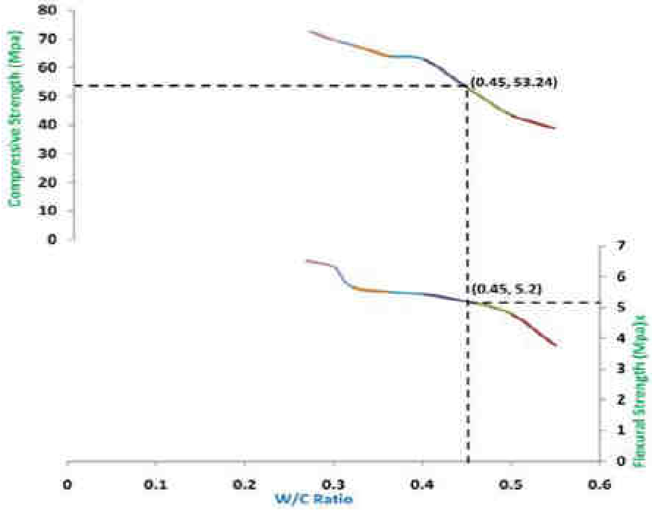

Fig.3 Relation between w/c and Compressive Strength and Flexural Strength of OC mixes represented by Nomogram

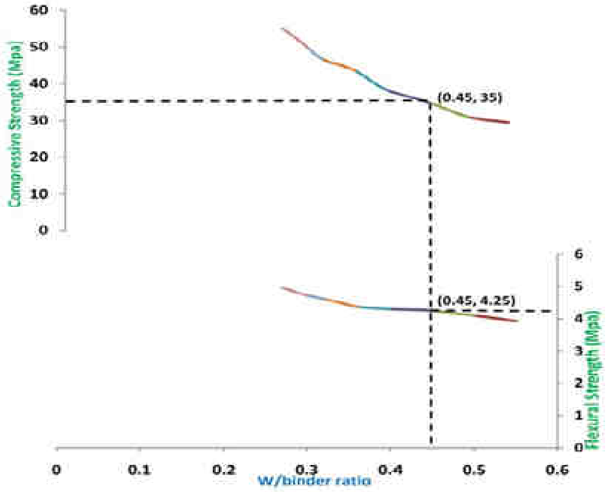

Fig.4 Relation between w/b and Compressive Strength and Flexural Strength of HVSC mixes represented by Nomogram

Nomograms for the relations between w/c or w/b and Compressive Strength and Flexural Strength of OC & HVSC are similar to the Nomograms (IRC 44- 1976, p.11).

V. CONCLUSIONS

The following conclusions are made from the present studies.

GGBS has good pozzolanic properties so that it improves the workability of HVSC which consists of high volumes of slag. This phenomenon is observed in case of HVSC1, HVSC2 & HVSC3 series. Moreover, addition of slag makes the concrete more impermeable due to micro filler action.

The Compressive Strength of OC & HVSC increase with decreasing water/cement or water/binder for 0.27 exhibiting compressive strength as high as 72.61MPa and 55.05 MPa respectively. The percentage variation in compressive strength for OC was from 24% to 42%. OC exhibits good strength than HVSC mixes as it has higher quantity of cement. HVSC mixes can be used as substituting material with good strengths at low water binder ratios.

The Flexural strength of OC & HVSC increase with decreasing water/cement or water/binder for 0.27 exhibiting compressive strength as high as 6.52 MPa and 4.96 MPa respectively. The percentage improvement in Flexural Strength for OC & HVSC is from 14% to 26 %. OC exhibits good strength than HVSC as it has higher quantity of cement. On replacement of cement by 50% GGBS helps it to reduce the cement content of concrete which tends to reduce the cost of concrete. It also protects the environment from pollution. HVSC mixes with w/b 0.32, 0.30 & 0.27 are recommended for Pavement Quality Concrete (PQC). The HVSC mixes with higher w/b can also be used as DLC layer for the rigid pavement further which reduces the thickness of pavement. Nomograms facilitate to choose the required mix which is suitable for the particular loading and purpose.

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