STUDIES ON STRENGTH BEHAVIOR OF HIGH VOLUMES OF SLAG CONCRETE

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Abstract

The Ground Granulated Blast Furnace Slag (GGBFS) is a waste of industrial material. It is relatively more recent pozzolanic material that has received considerable attention in both research and application. It is now recognized as a desirable cementitious ingredient of concrete. This research study presents the study of behavior of high volumes of slag concrete. The influence of slag content on Compressive strength, Split tensile strength and Flexural strength of High volumes of slag concrete (Cement : GGBFS is 50:50) specimens of different water-binder ratios are investigated for 28 Days, 90 Days,180 Days and 360 Days. Different water-binder ratios ranging from 0.55 to 0.27are considered for investigation. From the results, the relationship is developed between Compressive Strength, Split Tensile strength and Flexural Strength of High Volumes of Slag Concrete.

Key words: *High Volumes of Slag Concrete, GGBFS, Compressive Strength, Split Tensile strength, Flexural Strength.*

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1. INTRODUCTION

Cement, mortar and concrete are the most widely used construction material all over the world. The search for any material, which can be used as an alternative or as a supplementary for cement should lead to global sustainable development and lowest possible environmental impact. In recent years the use of GGBFS concrete is well recognized. Concrete mixes prepared by supplementary mineral admixtures such as Slag, Fly ash, Silica fume as partial replacement of ordinarily Portland cement gives new idea to reduce permeability of concrete.

Combining GGBFS and OPC at mixer is treated as equivalent to factory made PSC. Concrete with different properties can make by varying the proportions of GGBFS. The strength values corresponding to '0' day curing period mean the strength of the specimens after 30 days Plain Water curing. It is clearly demonstrated that the concrete specimens with cement slag proportions 70:30 gives lower strength deterioration for longer curing periods. In case of plain water curing, OPC concrete shows higher strength at initial ages than that for slag concrete. But for relatively longer curing periods, the differences between the results are seen to be decreased [1].

Curing concrete is one of the most important steps in concrete construction and regrettably, one of the most neglected. Effective curing is absolutely essential for surface durability. The curing of concrete involves maintaining a proper moisture vapor transmission rate (2% mvtr) immediately after concrete placement and throughout the ensuing period of approximately 28 days. In recent years there has been considerable discussion regarding the effects of curing on concrete containing Portland blast-furnace slag cement and concrete containing GGBF slag as a separate constituent [2].

As reported by Roy and Idorn, the early age strength developments of slag-cement mortars are lower than for OPC. However, by three days, the strengths of slag-cement mortars are equal to or greater than the OPC [3].

Wimpenny, determined that in general the highest 91-day compressive strength of slag mixes is obtained under 20^oC curing, the strength decreasing as the curing temperature is lowered. Increasing the curing temperature to 40^o C leads to a drop in strength at longer ages, in the case of OPC control mixes below those recorded at 5^oC [4].

A1-Kaisi, also showed that OPC and slag concretes cured under isothermal conditions at temperature of 20^o C tend to show a higher strength beyond 28 days than concretes cured isothermally at temperatures between $40\text{-}60^oC$ [5]. Pratas found from experiment that the strength loss in high volume slag concrete is more than normal concrete when the curing was not properly done. Curing duration of high volume slag cement concrete must be more than plain concrete [6].

Sasan Parniani stated that Concrete contain GGBF slag is more impressionable to poor curing conditions than concrete without GGBF slag. It means that strength loss in high volume slag concrete is more than normal concrete when the curing was not properly done. Curing duration of high volume slag cement concrete must be more than plain concrete [7].

David N. Richardson concluded that the compressive strengths of the 70% GGBFS PC field mix at all ages up to one year were about 2000 psi lower than the plain PC mix. The addition of a high range water reducer (HRWR) to the slag-PC mix narrowed the difference to about 1300 psi. When using the same PC type for both the control and slag-PC laboratory mixes, all slag-PC mixes had greater strengths than the plain PC mix [8].

Atul Dubey, showed that Concrete property can be maintained with advanced mineral admixtures such as blast furnace slag powder as partial replacement of cement 5 to 30%. Compressive strength of blast furnace slag concrete with different dosage of slag was studied as a partial replacement of cement. The optimum replacement of Ground Granulated Blast Furnace Slag Powder to cement without changing much the compressive strength is 15% [9].

According to Mohd Warid Hussin, the optimum compressive strength obtained for 50% slag replacement cement grout was above 30 MPa and its flexural strength was above 9 MPa under water curing condition. Result of drying shrinkage test strengthened the finding that the replacement of 50% slag as binder to cement mix with proper mix proportion is suitable to be used in normal grade concrete repairs under tropical climate [10].

As per Irene K. LaBarca, grade 120 slag cement is a viable material for use in highway pavement concrete design. While variations in mix materials and curing conditions cause changes in the performance of the hardened concrete, many options exist for combinations of materials that are successful with grade 120 slag cement at replacement levels up to 50% [11]. Mohammed Nadeem, Concrete of M20, M30 and M40 grades were considered for a W/C ratio of 0.55, 0.45 and 0.40 respectively for the replacements of 0, 30, 50, 70 and 100% of aggregates (Coarse and Fine) by slag. Whole study was done in two phases, i.e. replacement of normal crushed coarse aggregate with crystallized slag and replacement of natural fine aggregate with granular slag. The investigation revealed improvement in compressive strength, split tensile and flexure strength over control mixes by 4 to 8 %. The replacement of 100 % slag aggregate (coarse) increased concrete density by about 5 to 7 % compared to control mix. The slag could be effectively utilized as coarse and fine aggregates in all the concrete applications [12].

P. Venkata Mallikarjun Rao that concluded the substitution of natural coarse aggregate with slag increases compressive strength, flexural and Tensile Strength [13].

VENU MALAGAVELLI explained that M_{30} concrete with partial replacement of cement with Ground Granulated Blastfurnace Slag (GGBS) and sand with the ROBO sand (crusher dust). The cubes and cylinders are tested for both compressive and tensile strengths. The partial replacement of cement with GGBS and sand with ROBO sand helped in improving the strength of the concrete substantially compared to normal mix concrete [14].

Yousef Zandi1, explained that for 28 days, the flexural strength of the Together grinding Portland slag cements show more or less the same values with the separately ground ones for all of the Blaine fineness values. Finally, the flexural strength of the separately ground Portland slag cements show higher values than the Together grinding ones again for all of the Blaine fineness values at 90 days [15].

Gopal Charan Behera, concluded from experiment that the workability increases with increase in the percentage of slag as coarse aggregate in place of normal coarse aggregate. The weight of the cube increases with increase in the percentage of slag as coarse aggregate. The increase is nominal, so the concrete with slag can be used in structural works. Compressive strength increases with increase in the percentage of slag, so it is better to design compression members with it. Split tensile strength increases with increase in the percentage of slag, which can be regarded as a good sign from the durability point of view. Flexural strength of concrete with use of slag increases with increase in percentage of slag. There is no such change in the mechanical properties of hardened concrete up to 20% replacement of natural aggregate with slag [16].

2. RESEARCH SIGNIFICANCE

The use of Ground granulated blast furnace slag resulted from the strict enforcement of air-pollution measures designed to stop release of the material into the atmosphere. In the present study an attempt has been made to assess the suitability of Ground granulated blast furnace slag as cement replacement material in concrete making. In this study, the Compressive Strength, Split Tensile Strength and Flexural Strength of High Volumes of Slag Concrete using 50% GGBFS as replacement material of cement for various water-binder ratios 0.55, 0.50, 0.45, 0.40, 0.36, 0.32, 0.30, 0.27 at 28 Days, 90 Days, 180 Days and 360 Days Strengths were found out. And also comparing the Compressive Strength with Split Tensile Strength and Flexural Strength between the different water binder ratios and also with age and relationships were developed between them.

3. EXPERIMENTAL INVESTIGATION

CEMENT: Locally available 53 grade of Ordinary Portland Cement (Ultratech Brand.) confirming to IS: 12269 was used in the investigations. The cement is tested for various properties like Normal consistency, specific gravity, Fineness, Soundness, Compressive Strength , and Specific Surface area were found to be 28%, 3.10, 4%, 0.5 mm, 53Mpa and 3100 cm^2/g in accordance with IS:12269-1987.

GGBFS: GGBFS which is available in local market, brought from Steel Plant, Visakhapatnam (Dt.), Andhra Pradesh. The physical requirements in accordance with IS 1727- 1967 (Reaffirmed2008) and chemical requirements in accordance with IS: 12089 – 1987 (Reaffirmed 2008). The GGBFS is tested for various properties like Specific gravity and Fineness were found to be 2.2 and 3500 cm^2/g.

SUPER PLASTICIZER: The Super plasticizer utilized was supplied by internationally reputed admixture manufactures. Endure flowcon04 was manufactured by Johnson. Endure flowcon04 is dark brown colored liquid and it 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 were found to be 1.2 and minimum 6.

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 were found to be 2.55,1.72 and 2.74 in accordance with IS:2386-1963.

COARSE AGGREGATE: Machine crushed angular granite metal of 20mm nominal size from the local source is used as coarse aggregate. It is free from impurities such as dust, clay particles and organic matter etc., The coarse aggregate is also tested for its various properties. The specific gravity, water absorption and bulk density and fineness modulus of coarse aggregate were found to be 2.65, 0.38, 1490 kg/m^3 and 7.16 respectively.

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.

4. MIX DESIGN

Table.1 Quantities of Material required per One Cu. m. of High Volumes of Slag Concrete

W/Binder ratio	Water (Lts)	Cement (kg)	GGBS (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Super Plasticizer(ml)	Slump Values (mm)
0.55	176	160	160	763	990	0	75
0.50	176	176	176	749	971	0	80
0.45	176	196	196	715	966	0	65
0.40	176	220	220	662	971	45	90
0.36	176	244	244	625	961	55	100
0.32	176	275	275	587	936	100	120
0.30	176	293	293	529	959	100	130
0.27	176	326	326	477	945	120	140

Table.2 Compressive Strength Split Tensile Strength and Flexural Strength of High Volumes of Slag Concrete at 28 Days.

Specimen Notation	W/binder ratio	28 Days		
		Compressive Strength (Mpa)	Split Tensile Strength(Mpa)	Flexural Strength(Mpa)
HS1	0.55	29.09	2.06	3.80
HS2	0.50	30.60	2.15	3.83
HS3	0.45	33.90	2.61	4.10
HS4	0.40	37.30	2.62	4.20
HS5	0.36	42.00	2.75	4.28
HS6	0.32	45.00	2.91	4.32
HS7	0.30	48.00	3.53	4.42
HS8	0.27	54.00	3.66	4.76

Table.3 Compressive Strengths of High Volumes of Slag Concrete at 28 Days, 90 Days, 180Days and 360 Days.

Specimen Notation	W/binder ratio	Compressive Strength (MPa)			
		28 Days	90 Days	180 Days	360 Days
HS1	0.55	29.09	35.70	39.26	40.55
HS2	0.50	30.60	37.50	40.52	41.62
HS3	0.45	33.90	40.31	43.51	45.04
HS4	0.40	37.30	44.00	45.51	46.57
HS5	0.36	42.00	51.30	53.40	54.02
HS6	0.32	45.00	53.50	54.50	56.04
HS7	0.30	48.00	56.50	58.50	60.09
HS8	0.27	54.00	62.00	65.10	67.28

Table.4 Compressive Strengths of High Volumes of Slag Concrete at 28 Days, 90 Days, 180Days and 360 Days and their % increase in strength with respect to 28 Days.

Specimen notation	w/b ratio	28days	90days	% increase 90 days	180days	% increase in 180 days	360 Days	% increase in 360 days
HS1	0.55	29.09	35.70	23	39.26	35	40.55	39
HS2	0.50	30.60	37.50	23	40.52	32	41.62	36
HS3	0.45	33.90	40.31	19	43.51	28	45.04	33
HS4	0.40	37.30	44.00	18	45.51	22	46.57	25
HS5	0.36	42.00	51.30	22	53.40	27	54.02	29
HS6	0.32	45.00	53.50	19	54.50	21	56.04	25
HS7	0.30	48.00	56.50	18	58.50	22	60.09	25
HS8	0.27	54.00	62.00	15	65.10	21	67.28	25

Table.5 Split Tensile Strengths of High Volumes of Slag Concrete at 28 Days, 90 Days, 180Days and 360 Days and their % increase in strength with respect to 28 Days.

Specimen notation	W/b ratio	Split Tensile Strength (Mpa) (f_t)						
		28 Days	90 Days	% increase	180 Days	% increase	360 Days	% increase
HS1	0.55	2.06	2.58	25	2.71	32	2.86	39
HS2	0.50	2.15	2.66	24	2.90	35	3.00	40
HS3	0.45	2.61	3.05	17	3.20	22	3.48	33
HS4	0.40	2.62	3.08	18	3.23	23	3.63	38
HS5	0.36	2.75	3.22	17	3.54	29	3.80	38
HS6	0.32	2.91	3.64	25	3.76	29	3.95	36
HS7	0.30	3.53	4.05	15	4.23	20	4.53	28
HS8	0.27	3.66	4.19	15	4.38	20	4.58	25

Table.6 Flexural Strengths of High Volumes of Slag Concrete at 28 Days, 90 Days, 180Days and 360 Days and their % increase in strength with respect to 28 Days.

Specimen notation	W/b ratio	Flexural Strength (Mpa) (f_f)						
		28 Days	90 Days	% increase	180 Days	% increase	360 Days	% increase
HS1	0.55	3.80	4.12	8	4.22	11	4.32	14
HS2	0.50	3.83	4.20	10	4.24	11	4.40	15
HS3	0.45	4.10	4.34	6	4.60	12	4.70	15
HS4	0.40	4.20	4.45	6	4.84	15	4.92	17
HS5	0.36	4.28	4.60	7	4.95	16	5.08	19
HS6	0.32	4.32	4.90	13	5.15	19	5.20	20
HS7	0.30	4.42	5.10	15	5.22	18	5.25	19
HS8	0.27	4.76	5.25	10	5.45	14	5.50	16

Table.7 Ratio between Split Tensile and Compressive Strengths (%) and Flexural and Compressive Strengths (%) for HVSC at 28Days

Specimen Notation	W/binder ratio	28 Days				
		Compressive Strength	Split Tensile Strength (Mpa)	Ratio between Split Tensile and Compressive Strengths(%)	Flexural Strength (Mpa)	Ratio between Flexural and Compressive Strengths (%)
HS1	0.55	29.09	2.06	7.08	3.80	13.06
HS2	0.50	30.60	2.15	7.03	3.83	12.52
HS3	0.45	33.90	2.61	7.70	4.10	12.09
HS4	0.40	37.30	2.62	7.02	4.20	11.26
HS5	0.36	42.00	2.75	6.55	4.28	10.19
HS6	0.32	45.00	2.91	6.47	4.32	9.60
HS7	0.30	48.00	3.53	7.35	4.42	9.21
HS8	0.27	54.00	3.66	6.78	4.76	8.81

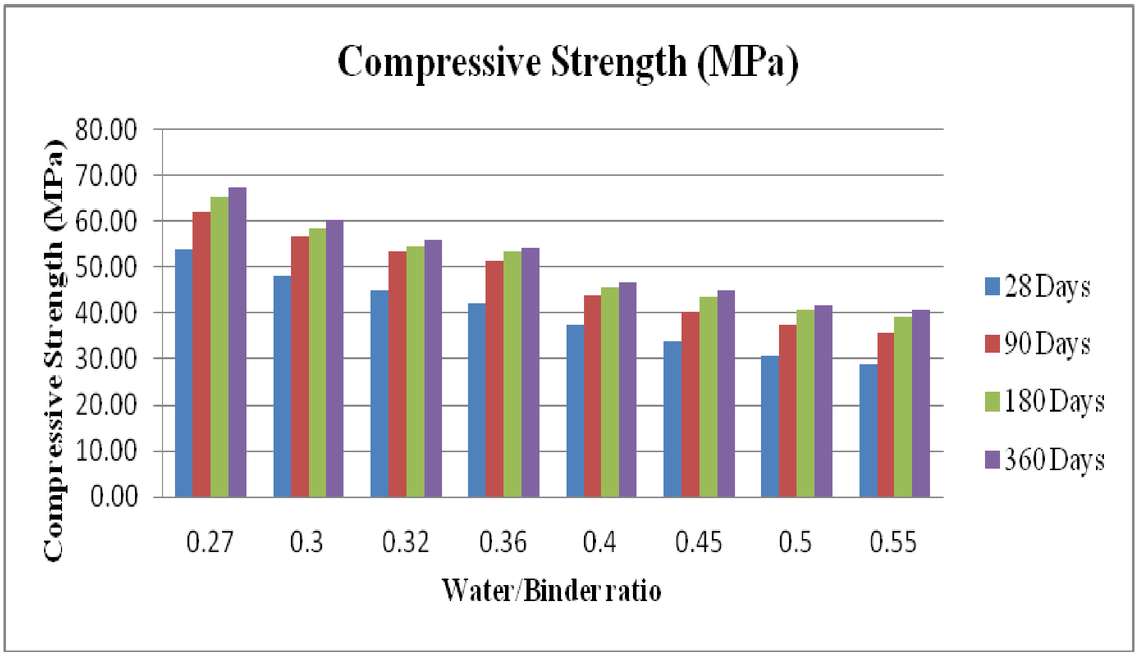

Fig 1 Compressive Strength of HVSC For various W/B ratios at 28 Days, 90 Days, 180 Days and 360 Days.

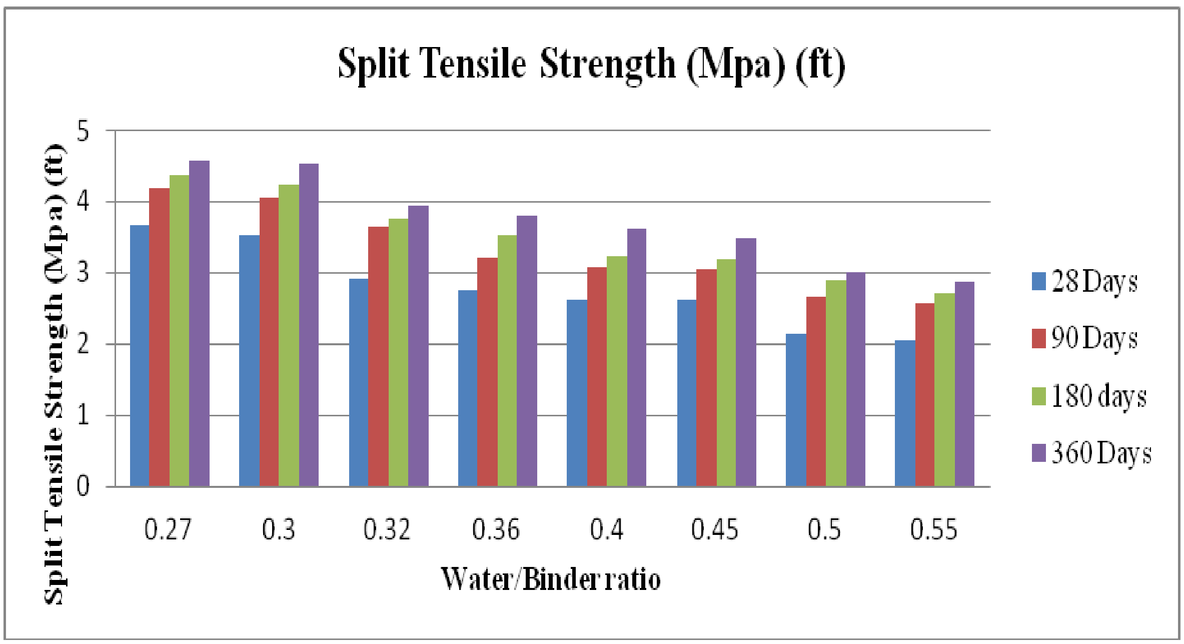

Fig 2 Split Tensile Strength of HVSC For various W/B ratios at 28 Days, 90 Days, 180 Days and 360 Days.

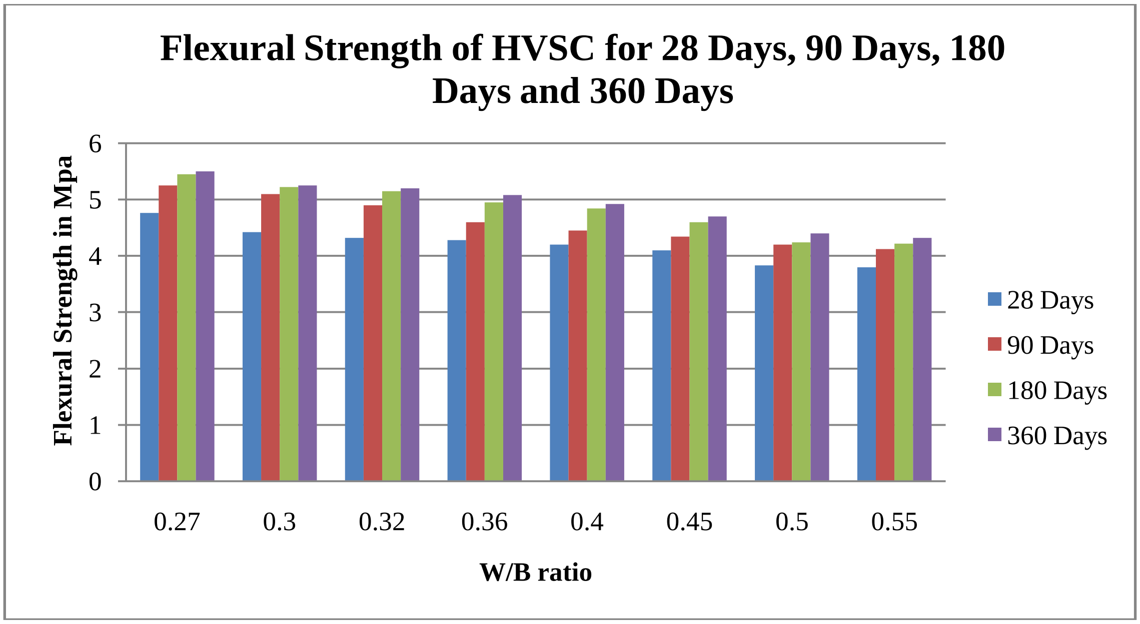

Fig 3 Flexural Strength of HVSC For various W/B ratios at 28 Days, 90 Days, 180 Days and 360 Days.

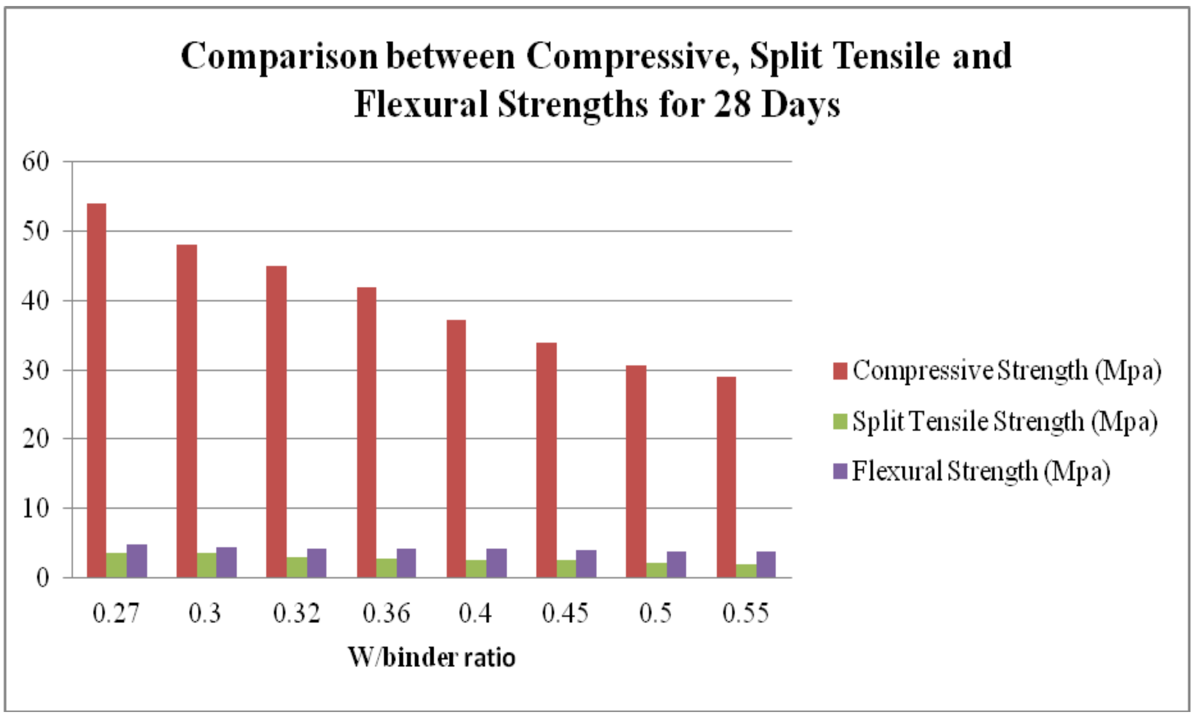

Fig 4 Comparison between Compressive Strength, Split Tensile Strength and Flexural Strength of HVSC For various W/B ratios at 28 Days

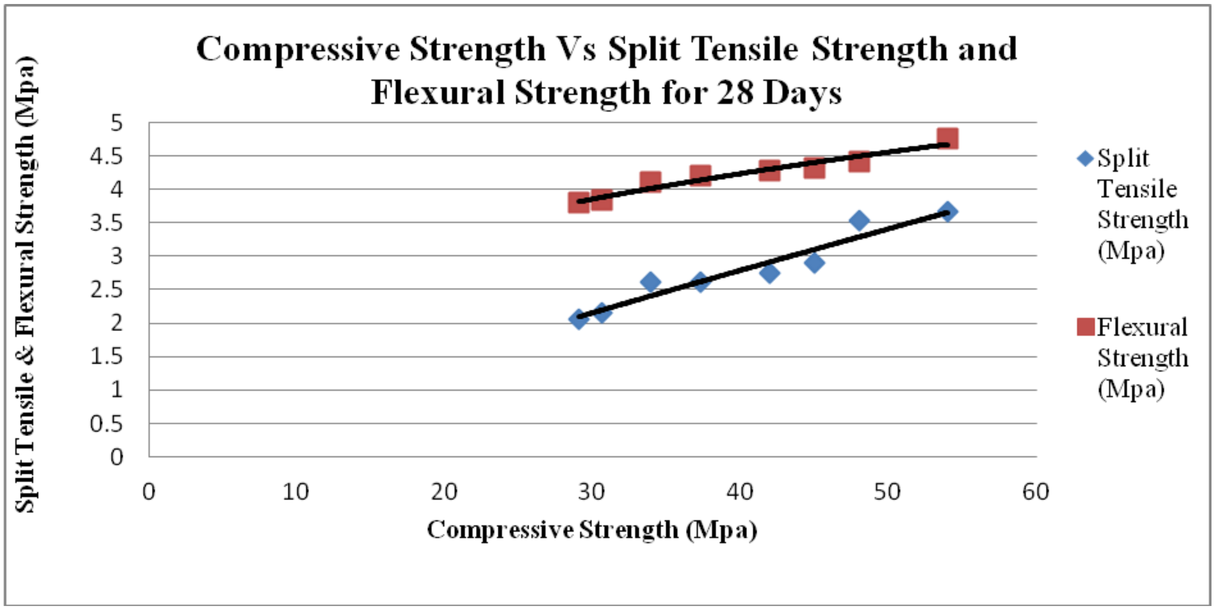

Fig 5 Comparison between Compressive, Split Tensile and Flexural Strengths for 28 Days

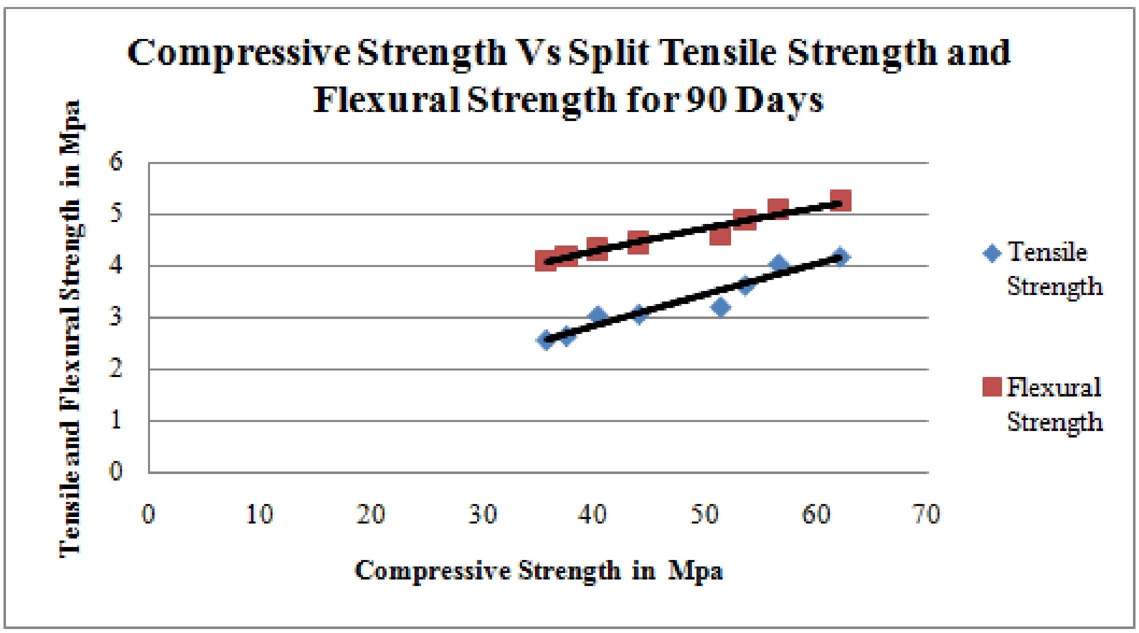

Fig 6 Comparison between Compressive, Split Tensile and Flexural Strengths for 90 Days

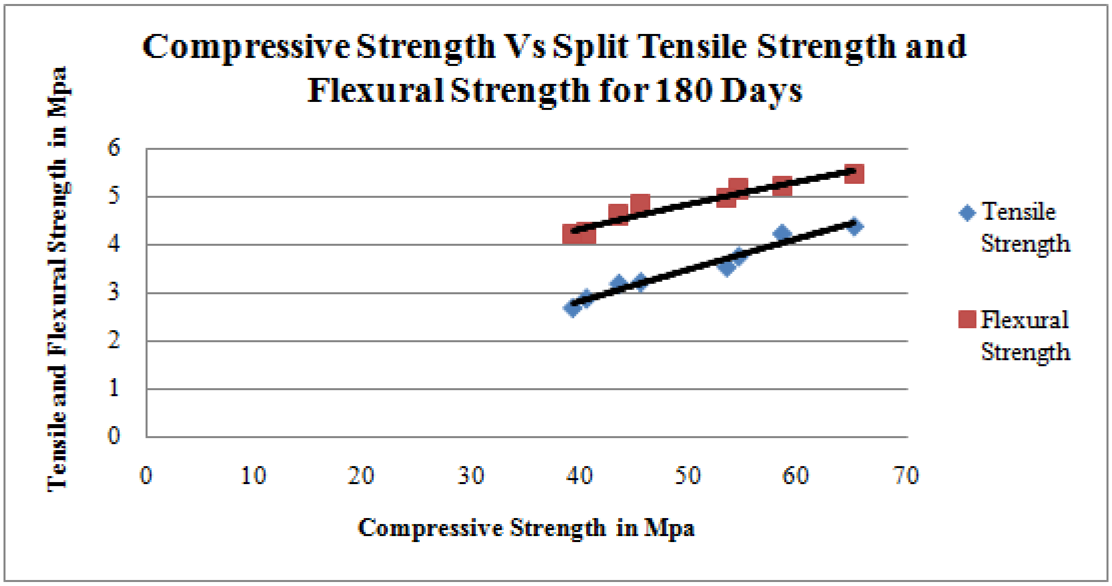

Fig 7 Comparison between Compressive, Split Tensile and Flexural Strengths for 180 Days

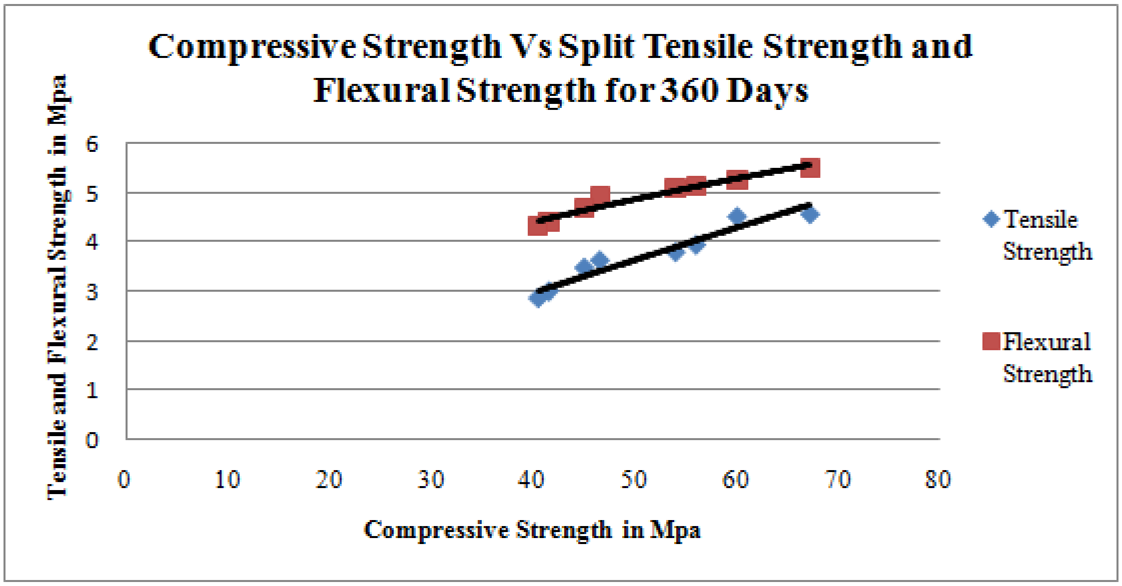

Fig 8 Comparison between Compressive, Split Tensile and Flexural Strengths for 360 Days

5. TEST RESULTS AND DISCUSSIONS:

The quantities of materials for one cubic meter of High Volumes of Slag Concrete are shown in table.1. Concrete mixes are designed as per IS : 10262.

The workability of different concrete mixes was measured in terms of Slump values. The test results are given in Table.1 for High Volumes of Slag Concrete. It can be seen from the table that a medium workability was maintained for almost all the mixes by addition of suitable quantities of super plasticizer.

5.1 Compressive Strength

The 28 days compressive strengths for various mixes are given in Table 3.& Table 4 and Fig.1. The main results indicated that the strengths varies from 29.09Mpa to 54.0Mpa, 35.60Mpa to 62Mpa, 39.26Mpa to 65.10Mpa and 40.55Mpa to 67.28Mpa for 28 days, 90 days, 180 days and 360 days of

High Volumes of Slag Concrete, with water/binder ratios varying from 0.55 to 0.27 respectively. It is observed that an increment in compressive strength 15 to 25 percent for 90 days, 20 to 35 percent for 180 days and 25 to 40 percent with respect to 28 days strengths. It is revealed that the High Volumes of slag concrete gains appreciable amount of strength later ages (90 days onwards).

5.2 Split Tensile Strength

From the observations, it is revealed that the rate of strength gain for High volumes of slag concrete is controlled by the slag with time and by its fineness and chemistry of the OPC. Furthermore it can be observed that the considerable amount of strength results of High Volumes of slag concrete appear for long time (180 days). The results are due to slower hydration of slag with $Ca(OH)_2$ and water.

The Split Tensile strengths at 28 days, 90 days, 180 days and 360days for various mixes are given in Table.5.and Fig.2. It is illustrated that the strengths varies from 2.06Mpa to 3.66Mpa, 2.58Mpa to 4.19Mpa, 2.71Mpa to 4.38Mpa and 2.86Mpa to 4.58Mpa for High Volumes of Slag Concrete, with water/binder ratios varying from 0.55 to 0.27 respectively. It is observed that an increment in split tensile strength 15 to 25 percent for 90 days, 20 to 35 percent for 180 days and 25 to 40 percent.

Equations for Compressive Strength *(f_c)* and Split Tensile strength *(f_t)* of High Volumes of Slag Concrete

Mathematical Equations were obtained expressing Compressive strength and Split Tensile strength for High Volumes of Slag Concrete

Table.3 & Table.5 and Fig.5 show the relation between compressive strength and split tensile strength of High Volumes of Slag Concrete at 28days. The equation obtained is

$$f_t = 0.10069\ (f_c)^{0.9019}$$ with 'R^2' equal to 0.92.

From Table.7 & Fig.4 the ratio between split tensile strength and compressive strength of High Volumes of Slag Concrete at 28 days varies between 6.47% and 7.70%.

From Table.3, Table.5 & Fig.6 the relation between compressive strength and split tensile strength of High Volumes of Slag Concrete at 90days The equation obtained is

$$f_t = 0.1221\ (f_c)^{0.8545}$$ with 'R^2' equal to 0.95.

From Table.3, Table.5 and Fig.7 shows the relation between compressive strength and split tensile strength of High Volumes of Slag Concrete at 180days. The equation obtained is

$$f_t = 0.0952\ (f_c)^{0.9187}$$ with 'R^2' equal to 0.94.

From Table.3, Table.5 and Fig.8 shows the relation between compressive strength and split tensile strength of High Volumes of Slag Concrete at 360 days. The equation obtained is

$$f_t = 0.1050\ (f_c)^{0.9063}$$ with 'R^2' equal to 0.92.

5.3 Flexural strength

The Flexural strengths at 28 days, 90 days, 180 days and 360 days for various mixes are given in Table.6 and Fig.3. It can be seen that the strength varies from 3.80Mpa to 4.76Mpa, 4.12Mpa to 5.25Mpa, 4.22Mpa to 5.45Mpa and 4.32Mpa to 5.50Mpa for High Volumes of Slag Concrete, with water/binder ratios varying from 0.55 to 0.27 respectively. It is observed that an increment in Flexural strength 5 to 10 percent for 90 days, 10 to 19 percent for 180 days and 14 to 20 percent for 360 days with respect to 28 days. Because of the phenomenon of pozzolanic activity, the strength of HVSC increases with increase in age.

Equations for Compressive Strength *(f_c)* and Flexural strength *(f_r)* of High Volumes of Slag Concrete

Mathematical Equations were obtained expressing Compressive strength and Flexural strength for High Volumes of Slag Concrete.

Table.3, Table.6 and Fig.5 shows the relation between Compressive strength and Flexural strength of High Volumes of Slag Concrete at 28days. The equation obtained is

$$f_r = 1.2631\ (f_c)^{0.3279}$$ with 'R^2' equal to 0.95.

From Table.7 the ratio between flexural strength and compressive strength of High Volumes of Slag Concrete at 28days, varies between 8.81% and 13.06%.

Table.3, Table.6 and Fig.6 shows the relation between Compressive strength and Flexural strength of High Volumes of Slag Concrete at 90days. The equation obtained is

$$f_r = 0.8667\ (f_c)^{0.4343}$$ with 'R^2' equal to 0.94.

Table.3, Table.6 and Fig.7 shows the relation between Compressive strength and Flexural strength of High Volumes of Slag Concrete at 180days. The equation obtained is

$$f_r = 0.6895\ (f_c)^{0.4986}$$ with 'R^2' equal to 0.97.

Table.3, Table.6 and Fig.8 shows the relation between Compressive strength and Flexural strength of High Volumes of Slag Concrete at 360days. The equation obtained is

$$f_r = 0.8246\ (f_c)^{0.454} \text{ with 'R}^2\text{' equal to 0.98}$$

From the results, it is observed that High Volumes of Slag Concrete with water binder ratio 0.27 exhibits good strengths in Compression, Tensile and Flexure at higher ages comparing with other proportions.

6. CONCLUSIONS

The following conclusions are drawn from experimental results

- In case of High Volumes of Slag Concrete, the super plasticizer is not added for higher water- binder ratios. However, the workability is maintained.
- The strengths of High Volumes of Slag Concrete are more because of later reaction of GGBFS with $Ca(OH)_2$ and water.
- There is an increase in compressive strength of High Volumes of slag concrete with water/binder ratios varying from 0.55 to 0.27 respectively. Similar pattern is also observed for Split Tensile strength and Flexural Strength.
- The GGBFS used in the investigations exhibits good Pozzolanic properties and can be used in the production of high strength High Volumes of Slag Concrete. High Volumes of GGBFS 50% can be used as substituting material with good strengths at low water binder ratios.
- An increment in compressive strength 15 to 20 percent for 90 days, 20 to 35 percent for 180 days and 25 to 40 percent for 360 days with respect to 28 days. It is revealed that the High Volumes of slag concrete gains appreciable amount of strength later ages (180 days).
- An increment in split tensile strength 15 to 20 percent for 90 days, 20 to 35 percent for 180 days and 25 to 40 percent for 360 days with respect to 28 days.
- An increment in Flexural strength 5 to 10 percent for 90 days, 10 to 19 percent for 180 days and 14 to 20 percent for 360 days with respect to 28 days.
- The relation between compressive strength and split tensile strength of High Volumes of Slag Concrete at 28 days. The equation obtained is $f_r = 0.10069\ (fc)^{0.9019}$ with 'R^2' equal to 0.92.
- The relation between compressive strength and Flexural strength of High Volumes of Slag Concrete at 28days. The equation obtained is $f_r = 1.2631\ (f_c)^{0.3279}$ with 'R^2' equal to 0.95.
- On replacement of cement by 50% GGBFS helps to reduce the cement content of concrete, thereby reducing the cost of concrete.
- Reuse of the slag helps to protect the environment from pollution.

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