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STRENGTH AND BEHAVIOUR OF HIGH PERFORMANCE CONCRETE WITH GGBS

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Abstract - *The demand for large quantities of High performance concrete (HPC) for their utilization in the construction of buildings, hydraulic structures, bridges, rigid pavements, etc is observed to increase greatly. As a result, higher quantities of cement clinker is manufactured which consequently increases the amount of carbon-dioxide (CO_2) being emitted. Which causes serious environmental hazards. Hence it is a prime concern to devise a solution to this problem. An attempt to provide a partial solution to this problem is made in the project by replacing OPC used in concrete by 40% to 50% of pozzolanic materials such as GGBS. This solution comes with added benefits such as GGBS is a low-cost waste material, improved performance of concrete, protection from sulphate and chloride attack (durability), higher ultimate strength, higher proportion of strength improving CSH, reduced free lime content, provides a near-white colour of concrete surface at no extra cost rather than the undesired stone-grey colour of conventional concrete. HPC is the concrete that satisfies unique performance & homogeneity requirements that cannot be achieved conventionally. This was formulated by designing a mix for concrete of grade M60 which gave the quantities of cementitious material, aggregates, W/C ratio, water & superplasticizers. Six different mixes from conventional concrete, 10% GGBS up-to 50% GGBS were mixed and casted into cubes & cylinders for testing compressive strength and split tensile strength. Finally, comparing strengths of the various mixes of concrete and finding optimum percentage for cement replacement with GGBS.*

***Key Words**: High Performance Concrete (HPC), Ground Granulated Blast Furnace Slag (GGBS), Superplasticizer, Ordinary Portland Cement (OPC), Compressive & Split Tensile Strength, Conventional Concrete (CC).*

1. INTRODUCTION

The main objective of this paper is to design a high-performance concrete of grade sixty [1] and observe the variations in characteristics of the resulting concrete, mainly compression and split tensile strength, on varying the proportions of GGBS in the overall cementitious content as calculated in the mix-design [2] and therefore determine the optimum percentage of replacement of cement by GGBS at which the compression and split tensile strengths reach the peak values [3].

To achieve such high strengths, it is necessary to maintain a very low water-cement ratio. But it is equally important to retain enough slump, i.e. workability to allow the concrete to be pumpable, which is hard to achieve at such low ratios of W/C. The superplasticizers become very useful in this situation, which acts a water-reducer and hence have to be chosen suitably [4].

Keeping these constraints in consideration the mix design for high performance concrete was formulated using the code book IS:10262-2009. In which the W/C ratio & concentration of superplasticizer were kept as a constant. Whereas the quantities of fine aggregate and coarse aggregate vary in accordance with the quantity of cement in cementitious materials (C: FA: CA). Finally, the various mixes of concrete were casted into cubes & cylinders, cured & tested in compression testing machine to determine their respective compressive & split tensile strengths [5].

To obtain accurate results, each and every constituent materials of concrete have to be selected and tested precisely for their desired characteristics [6].

1.1 Constituent Materials of Concrete

i) GGBS: It is a waste-recyclable material formed on quenching the molten slag from melted iron ore rapidly by water and then ground into a fine powder. This product was supplied by the JSW cement company along with its manufacturer's specification. It consists of approximately 40% each of SiO_2 and CaO which is similar to composition of Portland cement. It increases the strength of concrete after 28 days; initial rate of strength gain is low [7].

ii) OPC: 53 grade specifications conforming to IS:12269-1987. It is constituted of lime, silica, alumina, iron oxide, magnesia, alkali, sulphur, etc.

iii) Super Plasticizer: Master Glenium sky-8580 is a reddish-brown liquid provided by BASF construction chemicals Pvt. Ltd. Conforming to IS:9103-1999 has been used. It is based on poly carboxylic ether (PCE). It is free of chloride & low alkaline content. It is compatible with all types of cement [8].

iv) FINE AGGREGATES: Hard, strong, clean, durable particles of natural sand or crushed stone/gravel should be used. They have to be free from lumps, soft or flaky particles. Mica or any other deleterious materials present would affect the strength as well as durability of concrete. Zone-II or zone-III Fine Aggregates as per IS:383 are preferred.

v) COARSE AGGREGATE: Clean, hard, strong, dense, non-porous, eqi-dimensional (i.e not flaky or elongated) and durable fragments of crushed stone/gravel, natural gravel or a combination of them are preferable.

vi) WATER: Potable water is preferred. It should not contain dissolved salts and impurities.

2. METHODOLOGY

2.1 Tests on Materials

i) Cement: the following results were obtained on conducting tests in laboratory.

Table-1: Test Results of Cement

Sl.no	Properties	Test Result
1.	Fineness	7.4%
2.	Initial setting time	165 minutes
3.	Final setting time	380 minutes
4.	Compressive strength 3 days 7 days 28 days	 39.5 N/mm² 51.0 N/mm² 69.2 N/mm²
5.	Standard Consistency	34%
6.	Specific Gravity	3.15

ii) GGBS: Other specifications were given by manufacturer

Table-2: Test Results of GGBS

Sl. No	Property	Test Result
1.	Specific Gravity	2.91
2.	Fineness (m^2/Kg)	392

iii) Superplasticizer: Specifications as given by manufacturer

Table-3: Specification of Superplasticizer

Aspect	Reddish Brown Liquid
Relative Density	1.11 at 25°C
pH	≥6 at 25°C
Chloride Ion Content	0.2%

iv) Fine Aggregate & Coarse Aggregate: the following results were obtained on conducting tests in laboratory.

Table-4: Test Results of Aggregates

TEST	Fine Aggregate	Coarse Aggregate
Specific Gravity	2.6	2.7
Water Absorption	1%	1%
Fineness modulus	2.88	1.84
Free surface Moisture	Nil	Nil

2.2 Mix Design

- The mix design was carried out as per the Indian standards (IS:10262-2009) for M60 grade concrete using Ordinary Portland cement.

Step (1): - Design stipulation for proportioning

a) Grade designation = M60
b) F_{ck} = 60 N/mm²
c) Type of cement = OPC 53 grade (IS 12269)
d) Aggregate size = 20mm down size
e) W/C ratio = 0.35
f) Workability = 150mm slump
g) Exposure condition = Moderate
h) Method of concrete placing = Pumping
i) Chemical admixture = Superplasticizer

Step (2): - Test data for materials

a) Cement used = Birla super 53 grade
b) Specific gravity of cement = 3.15
c) Specific gravity of coarse aggregate = 2.7
d) Specific gravity of fine aggregate = 2.6
e) Water absorption of coarse aggregate = 0.5%
f) Water absorption of fine aggregate = 1%
g) Free surface moisture of coarse aggregate = Nil
h) Free surface moisture of fine aggregate = Nil
i) Sieve analysis of coarse aggregate = Graded
j) Sieve analysis of Fine aggregate = Confirming to grading zone II

Step (3): - Target strength for Mix Proportioning

$$f'_{ck} = f_{ck} + 1.65\,S$$

where, f'_{ck} = Target average compressive strength at 28 days.

f_{ck} = Characteristic compressive strength at 28 days.

S = Standard deviation = 3 N/mm²

f'_{ck} = 60 + 1.65 * 3 = 64.95 N/mm^2

Step (4): - Selection of water cement ratio

From IS 456-2000, Table 5 the maximum W/C ratio for moderate condition is 0.60. By trial mix and experience, we adopted W/C ratio= 0.35.

Since 0.35 < 0.6 (hence O.K)

Step (5): - Selection of water content

From Table-2 of IS 10262-2009 for 20mm size of aggregate, of 150mm slump is 186 litres.Required W/C ratio for 150 mm slump can be obtained by increase by about 3% for every addition of 25mm slump, therefore 150mm slump increases by 12%. Hence estimated water content for 125mm slump; 186+ (12/100*186) = 208.32 litre.

As superplasticizer is used water content can be reduced up to 30% based on trials; Water content reduction = 29/100* 208.32 = 60.413 litres, 208.32 – 60.413 = 148 litres.

Step (6): - Calculation of volume for cement concrete

a) Cement content = 148/0.35 = 423 Kg/m^3
b) Revised water content = 423*0.35 = 148 litre
c) Volume of coarse aggregate = 0.65*0.90 = 0.585 m^3
d) Volume of fine aggregate = 1 – 0.585 = 0.415 m^3
e) Volume of cement = (423/3.1)*(1/1000) = 0.1364 m^3
f) Volume of water = 0.148 m^3
g) Volume of superplasticizer = 0.50/100*423 = 2.115 litres, (2.115/1.115) * (1/1000) = 0.001905 m^3
h) Volume of all in aggregates = 1-(0.1364+0.148+0.001905) = 0.7137 m^3
i) Mass of coarse aggregate = 0.7137*0.585*2.7*1000 = 1127.289 kg/m^3
j) Mass of fine aggregate = 0.7137*0.415*2.6*1000 = 770.082 kg/m^3
k) Adjustments for water absorption of aggregates, corrected water content = 148+(770.82*0.01) + (1127.289*0.005) = 161.35 kg/m^3
l) Mix ratio; cement: FA: CA = 1: 1.82: 2.66

Table-5: Calculated quantities for 1m^3 of concrete

Contents	Quantity (Kg/m^3)
Cementitious material	423
Water	161.35
Fine aggregate	770.08
Coarse aggregate	1127.29
Superplasticizer	2.115
W/C ratio	0.35

Table-6: Mix Proportions of M60 Concrete for 1m^3 Along with GGBS

Type of Design	Cement (in Kg)	Fine Aggregate (in Kg)	Coarse Aggregate (in Kg)	GGBS (in Kg)
CC	423	770	1127	-
CC + 10% GGBS	381	769	1126	42
CC + 20% GGBS	338	768	1124	85
CC + 30% GGBS	296	761	1122	127
CC + 40% GGBS	254	766	1121	169
CC + 50% GGBS	212	765	1120	211

- The compression tests were carried out on cubes of size 150mm*150mm and Brazilian test (split tensile strength) were carried out with cylinders of size 150mm diameter and 300mm height [9].
- The percentage of cement replaced with GGBS were varied between 10 % to 50 % and compared with the conventional concrete mix.
- The cubes were tested for compressive strength at 7, 14 and 28 days of curing for each mix and cylinders were tested for split tensile strength at 28 days of curing for each mix and the comparisons were tabulated [10].

3. RESULTS & DISCUSSIONS

- The compression test and split tensile test were carried out in a compression testing machine of 2000 kN capacity.
- Three cylinders were casted for each mix, and tested at 28 days and the average results obtained were as follows;

Table-7: Split tensile test results

Concrete + GGBS	Split tensile strength at 28 days (Mpa)
Conventional concrete (CC)	3.39
CC + 10% GGBS	3.86
CC + 20% GGBS	3.97

CC + 30% GGBS	4.00
CC + 40% GGBS	4.01
CC + 50% GGBS	3.50

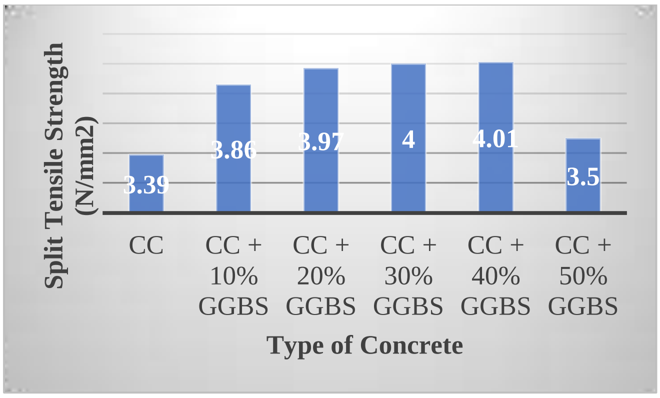

Chart-1: Split tensile strength values

- Nine cubes were casted for each mix, three each for 7, 14 and 28 days and the average results obtained were as follows

Table-8: Compressive test results

Type of concrete	Age of concrete in days	Compressive strength in N/mm²	Avg Compressive Strength (N/mm²)
CC	7	31.56	35.47
		39.37	
		35.47	
	14	49.38	43.42
		37.47	
		43.42	
	28	63.11	63.11
		60.22	
		66.00	
CC+10%GGBS	7	38.40	38.4
		42.13	
		34.67	
	14	47.64	47.64
		41.24	
		54.04	
	28	61.73	65.11
		68.49	
		65.11	
CC+20%GGBS	7	39.24	39.07
		38.71	
		39.28	
	14	54.89	54.88
		44.93	
		64.84	
	28	75.24	68.71
		62.18	
		68.71	
CC+30%GGBS	7	42.93	46.71
		50.49	
		46.71	
	14	53.29	61.02
		68.76	
		61.02	
	28	70.27	70.27
		65.64	
		74.89	
CC+40%GGBS	7	43.33	47.96
		47.96	
		52.58	
	14	62.18	62.17
		53.33	
		70.98	
	28	72.31	72.31
		75.60	
		69.02	
CC+50%GGBS	7	29.69	30.10
		25.56	
		29.64	
	14	44.13	41.96
		41.96	
		39.78	
	28	68.04	64.84
		64.84	
		61.64	

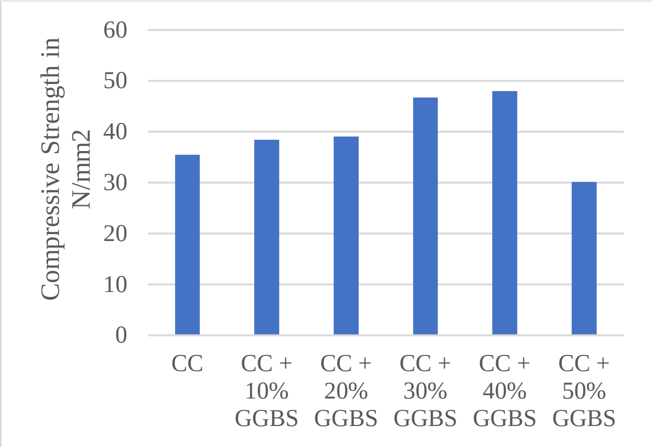

Chart-2: Compressive strength in N/mm² (7days)

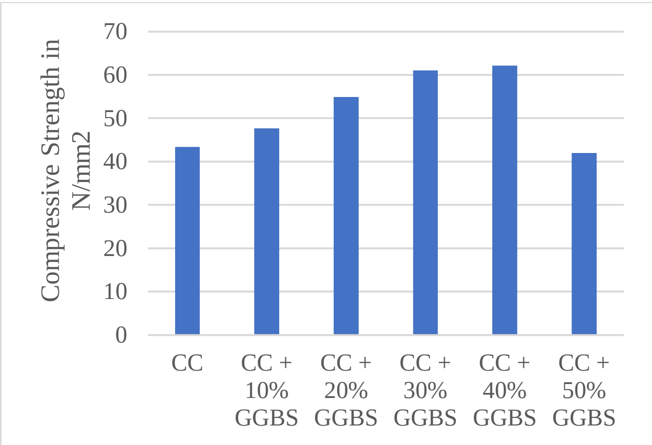

Chart-3: Compressive strength in N/mm² (14days)

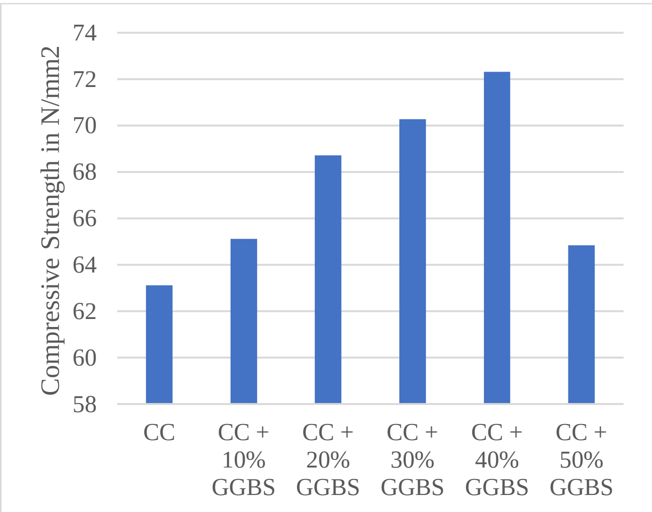

Chart-4: Compressive strength in N/mm² (28days)

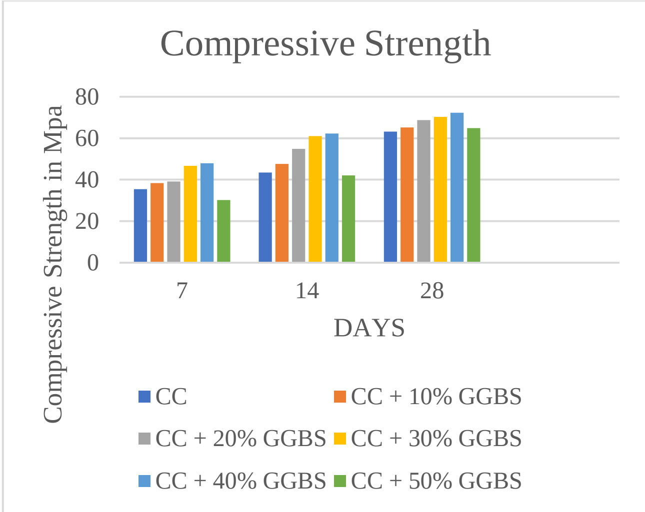

Chart-5: Compressive strength value

4. CONCLUSION

A total of 56 cubes and 18 cylinders with different compositions namely CC, CC+10% GGBS, CC+20% GGBS, CC+30% GGBS, CC+40% GGBS and CC+50% GGBS were casted and tested. Based on the observations, the following conclusions are made:

- The optimum percentage of GGBS replacing cement is 40% at which maximum compressive strength and split tensile strength is achieved with values 72.31 N/mm² and 4.01 N/mm² respectively.
- There is an increase of about 12.72 % of compressive strength and 12.36 % of split tensile strength from conventional concrete to CC+40% GGBS concrete.

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