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Experimental Investigations on Cement Replacement by GGBS in Concrete

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Abstract: *The concrete is probably the most extensively used construction material in the world with about six billion tones being produced every year. It is only next to water in terms of per-capita consumption. However, environmental sustainability is at stake both in terms of damage caused by extraction of raw material and CO_2 emission during cement manufacture. This brought pressures on researchers for the reduction of cement by supplementary materials. These materials may be naturally occurring, industrial wastes or by product that are less energy intensive. These materials (called pozzoloans) when combined with calcium hydroxide, exhibits cementitious properties. Most commonly used pozzaloans are fly ash (FS), silica fume (SF), Ground granulated blast furnace slag (GGBS) and metakaolin (MK). This needs to examine the admixtures performance when blended with concrete so as to ensure a reduced life cycle cost. The present study reports the results of an experimental work, conducted to evaluate the strength characteristics study, compressive strength, flexural strength and modulus of elasticity of concrete. In durability study conventional and GGBS concrete is tested by conducting acid attack, sulphate attack and RCPT. The property of concrete made by partially replacing the cement by various % of GGBS such as 10%, 20%, 30%, 40% and 50% by volume in M_{30} grade of concrete. The experimental results revealed that GGBS 20% replacement concrete have 15% more compressive strength then conventional mix. The compressive strength of GGBS concrete were calculated at the curing age of 28, 56 and 90 days. thus the optimum replacement % is found to be 20% by the volume of cement.*

Key Words: *Cement, GGBS, partial replacement, mechanical property, durability property*

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I. Introduction

Concrete is typically the most massive individual material element in the built environment. If the embodied energy of concrete can be reduced without decreasing the performance or increasing the cost, significant environmental and economic benefits may be realized. Concrete is primarily comprised of Portland cement, aggregates and water. Although Portland cement typically comprises only 12% of the concrete mass, it accounts for approximately 93% of the total embodied energy of concrete and 6% to 7% of the world wide Carbon dioxide (CO2) emissions. Besides this, dust emission during cement manufacturing is one of the main issues facing the industry.

The industry handles millions of tons of dry material. Even if 0.1% of this is lost to the atmosphere, it can cause havoc environmentally. This has made the researchers worldwide to look for addition of cementitious materials in concrete to reduce the usage of cement in concrete. Efforts are being carried out to conserve energy by means of promoting the use of industrial wastes or by-products, which contain amorphous silica in its chemical composition, as mineral admixture for partial replacement of cement. The utilization of pozzolanic materials in concrete as partial replacement of cement is gaining immense importance today, mainly on account of the improvements in the long-term durability of concrete. The pozzolanic materials are classified into two categories. They are natural pozzolans, which are of volcanic origin and man-made pozzolans, which include industrial by-products such as Fly Ash (FA), Ground Granulated Blast furnace Slag (GGBS), Rice Husk Ash (RHA), Silica Fume (SF), etc. The use of pozzolanic material based blended cement concrete is growing rapidly in the construction industry, which will result in saving of energy, environmental protection and conservation of resources.

II. Materials And Methods.

a) Cement

Ordinary Portland cement available in local market of standard brand was used in the investigation. Care has been taken to see that the procurement made from a single batch and is stored in airtight Containers to prevent it are being affected by atmospheric, and humidity. The cement which used was 53 grade ordinary Portland cement (OPC) confirming to IS8112-– 1989 standard.

b) GGBS

Ground Granulated Blast furnace Slag is a by-product of iron manufacturing industry. Iron ore, coke and limestone are fed into the furnace, and the resulting molten slag floats above the molten iron at a temperature of about 1500oC to 1600oC.The chemical composition of cement and GGBS are given in Table 1.

Table 1 Chemical Compositions

S.NO	COMPOSITION	CEMENT (%)	GGBS (%)
1	Silicon dioxide	20.72	39.18
2	Aluminium oxide	4.88	10.18
3	Iron oxide or Ferric oxide	2.95	2.02
4	Calcium oxide	61.83	32.82
5	Magnesium oxide	1.39	8.52
6	Sulphur trioxide	2.33	-
7	Sodium oxide	0.19	1.14
8	Potassium oxide	0.67	0.30
9	Chloride ion	0.0060	-
10	Loss on ignition	3.17	0.63
11	Insoluble Materials	1.0	0.88

c) Fine Aggregate

The locally available river sand was used as fine aggregate in the present investigation. The sand is free from clay matter, salt and organic impurities. The sand is tested for its various properties like Specific Gravity, Fineness modulus, Bulk Density etc in accordance with IS 2386-1963. Fine aggregate passing through 4.75mm I.S. sieve and retained on 0.075mm I.S. sieve was used. It confirms to grading zone – II, The specific gravity and fineness modulus.

d) Coarse Aggregate

Machine Crushed angular granite metal of maximum size of 20mm retained on 4.75mm I.S. sieve confirming to IS 383-1970 was used in the present investigation. It is free from impurities such as dust, clay particles and organic matter etc. The coarse aggregate is also tested for its various properties.

e) Water

Water is the least expensive but most important ingredient of the concrete. The water, which is used for making concrete should be clean and free from harmful impurities like oil, alkalis, acids etc. in general, the water which is fit for drinking should be used for making concrete.
The physical properties of materials are given in table 2.

Table 2 Physical Properties of Materials

Sl. No	Materials	Test	Results
1.	Cement	Specific gravity	3.15
2.	GGBS	Specific gravity	2.92
3	Fine aggregates	Specific Gravity	2.73
4	Coarse aggregates	Specific gravity	2.84
5	Fine aggregates	Fineness modulus	2.36
6	Coarse aggregates	Fineness modulus	7.33

III. Experimental Investigations

a) Design Mix

A mix M_{30} was designed as per IS 10262: 2009 and the same was used to prepare the test specimens. Optimal dosage selection of GGBS in concrete mix, modified cubes (percentage ranging from 10% to 50%) are prepared and compared with conventional concrete cubes with mix proportion of 1:1.59:2.95 are prepared. The replacements of OPC with GGBS are made on volume basis. The W/C ratio is taken 0.40 for all the mixes. The result of mix design of the concrete is given in table 3.

Table 3 Mix Specification for 1m^3 Concrete

Sl. No	Particulars kg/m^3	Conventional	10% GGBS	20% GGBS	30% GGBS	40% GGBS	50% GGBS
1	Cement	427	387.58	348.16	308.74	269.32	229.9
2	GGBS	0	39.42	78.84	118.26	157.68	197.1
3	Fine Aggregate	680	680	680	680	680	680

5	Coarse Aggregate	1258	1258	1258	1258	1258	1258
6	Water	171	171	171	171	171	171
7	Superplasticizers	2.135	2.135	2.135	2.135	2.135	2.135

In these investigations, mechanical properties of 45 cube specimens of 150mm x 150mm x 150mm are tested for compression strength test, 18 cylinder specimens of 150mm diameter x 300mm height are tested for modulus of elasticity of concrete test and 18 prism specimens of 100mm x 100mm x 100mm are tested for flexural strength test at 28, 56 and 90 days of curing. Durability properties of 18 cube specimens of 150mm x 150mm x 150mm are tested for acid, sulphate and chloride resistance test and 6 cylinder specimens of 100mm diameter x 200mm height are tested for rapid chloride penetration test at the age of 28 days of curing.

IV. Results And Discussion

The mechanical and durability properties of cement concrete containing various % of GGBS at the age of 28, 56 and 90 days are discussed below.

I.MECHANICAL PROPERTIES

Specimens stored in water should be tested immediately on removal from the water and while they are still in the wet condition. Surface water and grit shall be wiped off the specimens and any projecting fins removed. Specimens when received dry shall be kept in water for 24 hours before they are taken for testing.

a) Compressive Strength Test

A cube compression test was performed on standard cubes of plain and GGBS of size 150mm x 150mm x 150mm at 28, 56 and 90 days of curing. Results are given in table 4 and bar chart between conventional and GGBS concrete is show in fig 1.

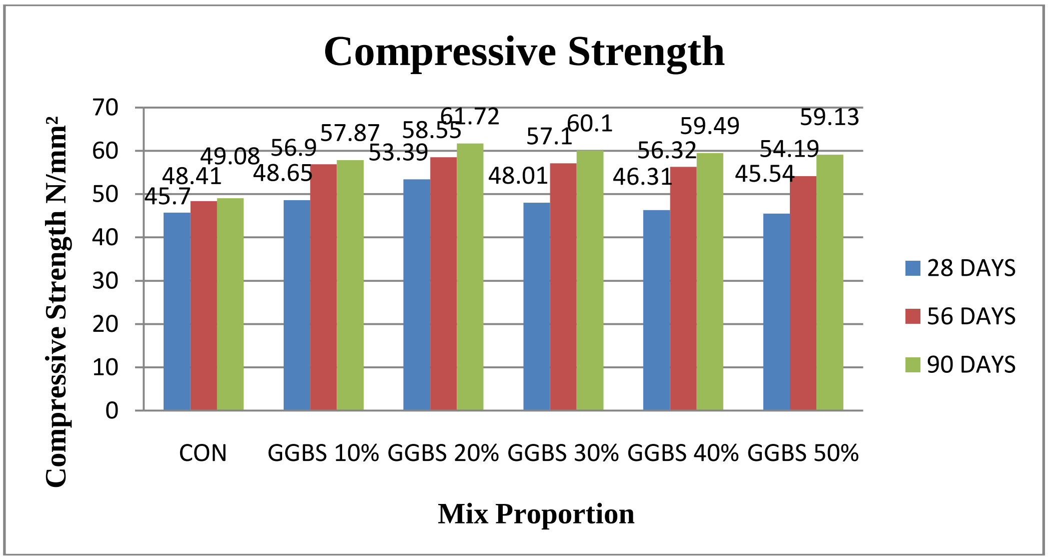

Fig 1 Compressive Strength Test Results

Table 4 Compressive Strength Test Results

S.NO	Mix Designation	28 days strength (N/mm^2)	56 days strength (N/mm^2)	90 days strength (N/mm^2)
1	Conventional	45.70	48.41	49.04
2	GGBS 10%	48.65	56.90	57.87
3	**GGBS 20%**	**53.39**	**58.55**	**61.72**
4	GGBS 30%	48.01	57.10	60.10
5	GGBS 40%	46.31	56.32	59.49
6	GGBS 50%	45.54	54.19	59.13

- The cube compressive strength results of conventional and 20% GGBS partially replaced concrete mix at the ages of 28, 56 and 90 days are presented in table 5.1.
- The increase in compressive strength of M_{30} grade concrete with GGBS at replacement of 0, 10, 20, 30, 40 & 50 percentage of GGBS at the various stages are plotted in the form of graphs are shown in figure5.1.
- The 10% GGBS replacement in concrete increased strength of 6%, 14.9% and 15.26% 0f higher strength at 28, 56 and 90days than the conventional concrete.
- The 20% GGBS replacement in concrete increased strength of 14.4%, 17.3% and 20.48% 0f higher strength at 28, 56 and 90days than the conventional concrete.
- The 30% GGBS replacement in concrete increased strength of 4.8%, 15% and 18.40% 0f higher strength at 28, 56 and 90days than the conventional concrete.
- The 40% GGBS replacement in concrete increased strength of 1.3%, 14% and 17.56% 0f higher strength at 28, 56 and 90days than the conventional concrete.
- The 50% GGBS replacement in concrete increased strength of 10.6% and 17.06% 0f higher strength at 56 and 90days than the conventional concrete. But 0.3% lesser strength than conventional concrete due to pozzolanic reaction.

b) Flexural Strength Test

The flexural strength was made as per the IS: 516-1959 specification by flexural machine for different proportion of concrete mix. For this study the concrete beams of size 100mm x 100mm x 500mm were prepared. The beams were placed normal to the casting and symmetrical two point load system was adopted for the flexural tensile strength test. The deflection of the beams was measured by the dial gauge of LC=0.01mm, which was placed in the middle third portion of the beam. Results are given in table 5 and bar chart between conventional and GGBS concrete is show in fig 2.

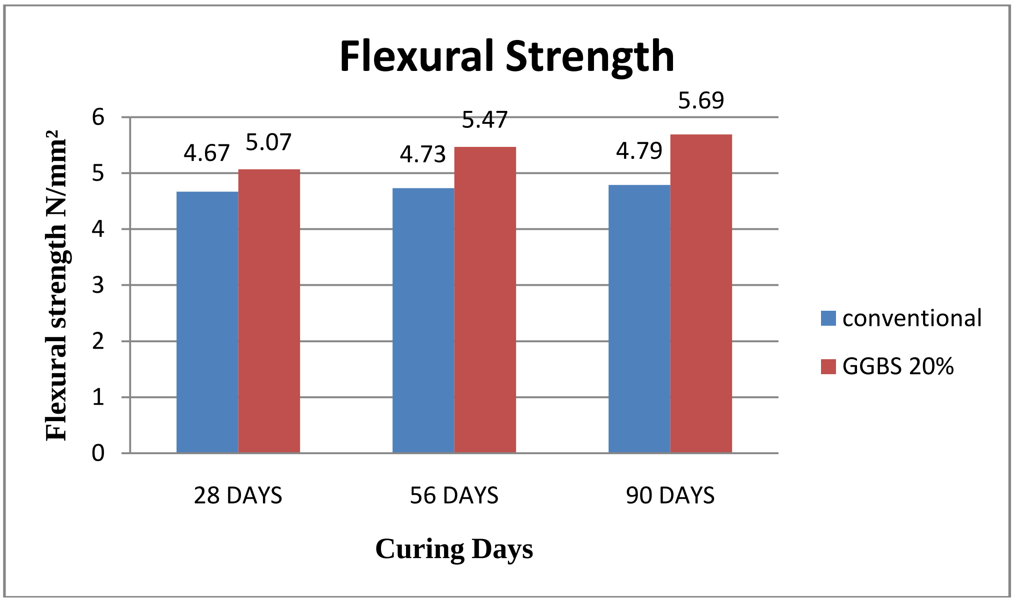

Fig 2 Flexural Strength Test Result

Table 5 Flexural Strength Test Results

Sl. No	Mix designation	Experimental value (N/mm^2)			Theoretical Value ($0.7\sqrt{f_{ck}}$) (N/mm^2)		
		28 days	56 days	90 Days	28 Days	56 days	90 Days
1	Conventional	4.69	4.83	4.89	4.73	4.87	4.90
2	GGBS	5.07	5.47	5.69	5.11	5.35	5.49

- This result shows that the optimum 20% of GGBS replaced in concrete showed excellent result compared with controlled mix as shown in Fig.5.2.
- It is clear that the flexural strength value of 20% GGBS replaced concrete mix gives 7.88%, 14.62% and 17.93% at 26, 58 and 90 days of curing attain higher value than the conventional concrete.

c) Modulus of Elasticity of Concrete

The modulus of elasticity of concrete was made as per the IS: 516-1959 specification by compression testing machine for different proportion of concrete mix. For this study the concrete cylinder of size 150mm diameter x 300mm height was prepared. The cylinder was placed normal to the compressive testing machine and dial gauge is fixed in the d. The deflection of the beams specimen as shown in Fig.3 and the least count measured by the dial is 0.01mm.The values of modulus of elasticity of concrete is given in table 6.

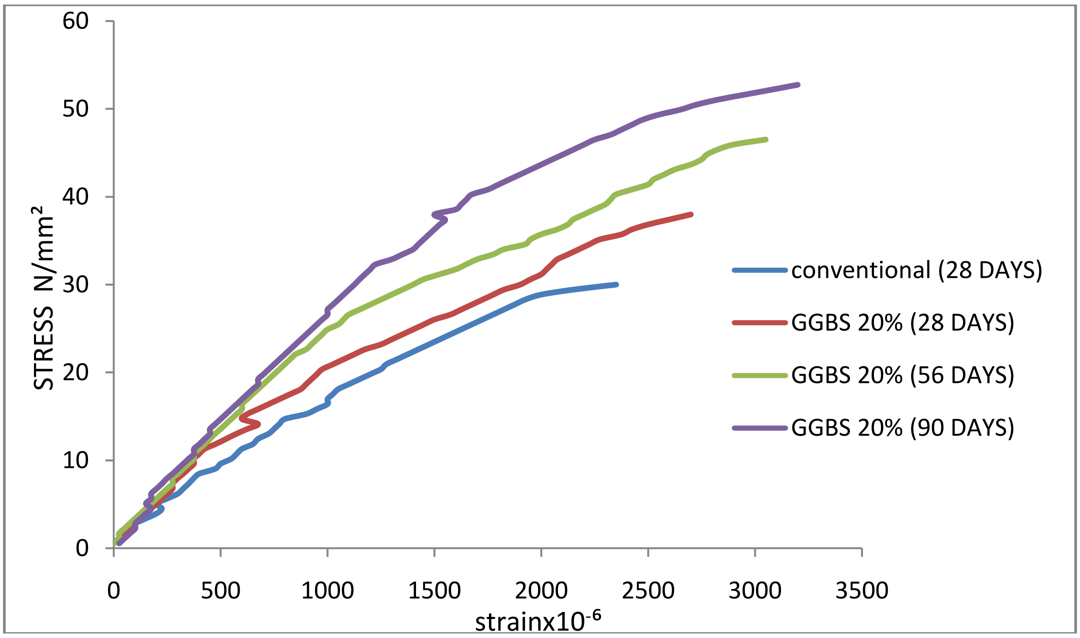

Fig 3 Modulus of Elasticity of Concrete Results

Table 6 Modulus of Elasticity of concrete Test Results

Sl. No	Mix Designation	Experimental value (N/mm^2) (x10^4)			Theoretical Value $5000\sqrt{f_{ck}}$ (N/mm^2) (x10^4)		
		28 days	56 Days	90 Days	28 days	56 Days	90 Days
1	Conventional	3.39	3,43	3.48	3.38	3.47	3.50
2	GGBS	3.67	3.79	3.89	3.65	3.82	3.92

- The Fig. 5.3 shows that the stress-strain curves for different mix with different ages are obtained under modulus of elasticity of concrete test.
- The GGBS of 20% replaced concrete obtained 7.67%, 10.55% and 12.63% at 28, 56 and 90 days of curing attain higher modulus of elasticity than the conventional concrete.

II. DURABILITY PROPERTIES

a) Rapid Chloride Penetration Test

The test method consist of monitoring the amount of electrical current passed through 50mm thick slices of 100mm nominal diameter cores or cylinders during 6hours at 30 minutes interval.

A potential difference of 60v dc is maintained across the ends of the specimens. One of which is immersed in a sodium chloride solution. The other in a sodium hydroxide solution. The total charge passed in coulombs has been found to be related to the resistance of the specimen to chloride ion penetration. The left hand side (-) of the test cell is filled with 3% NaCl. The right hand side (+) of the test cell is filled with a 0.3N NaOH solution. AASHTO T277, "standard method of test for rapid determination of the chloride permeability of concrete". The tests results are compared to the values are given in the table 7.

Table 7 Rapid Chloride Penetration Test Results

Sl. No	Type of mix	Coulombs	Remarks
1	Conventional	2843	Moderate
2	GGBS 20%	1819	Low

b) Sulphate Resistance Test

The resistance of concrete to sulphate attacks was studied by determining the loss of compressive strength for variation in compressive strength and weight of concrete cubes immersed in sulphate water having 5% of sodium sulphate (NA_2SO_4) by weight of water. The concrete cube of 150mm x 150mm x 150mm size after 28 days of water curing and dried for 2days were immersed in 5% of Na_2SO_4 added water for two weeks. The concentration of sulphate water was maintained throughout the period. After 2 weeks immersion period, the concrete cubes were removed from the sulphate water and after wiping out the water and girt from the surface of cubes tested for compressive strength. This accelerated test finds out the loss of compressive strength for accessing sulphate resistance of concrete.

Table 8 Result for Sodium Sulphate Resistance Test (14 Days)

Mix Designation	Before Immersion Weight (kg)	After Immersion Weight (kg)	Compressive Strength (N/mm^2)	
			Before Strength	After Strength
conventional	8.600	8.575	45.70	44.37
	8.740	8.720		
	8.530	8.505		
GGBS 20%	8.490	8.480	53.39	52.41
	8.530	8.515		
	8.540	8.525		

c) Acid Resistance Test

To perform the acid attack studies in the present investigation immersion technique was adopted. After 28days curing 150mm x 150mm x 150mm cube specimens were immersed in hydrochloric acid (HCl) of percentage 5% solution. The solution was kept at room temperature and solution was replaced at regularly at least once a week to maintain uniformity. The solution was replaced at regular intervals to maintain concentration of solution throughout the test period. The evaluation was conducted after 14 days from the date of immersion. After removing the specimens from solution, the surface were cleaned with a soft nylon wired brush under running tape water to remove weak product and loose material from the surface. The specimen was allowed to surface dry and the compressive strength of specimens was found out and the average percentage of loss of weight and compressive strength were calculated are given in table 9.

Table 9. Result for Hydrochloric Acid Resistance Test (14 Days)

Mix Designation	Before Immersion Weight (kg)	After Immersion Weight (kg)	Compressive Strength (N/mm^2)	
			Before Strength	After Strength
conventional	8.900	8.755	45.70	42.75
	8.500	8.350		
	8.800	8.650		
GGBS 20%	8.240	8.145	53.39	51.19
	8.560	8.465		
	8.460	8.370		

d) Chloride Resistance Test

Chloride attack on concrete has been reported from many other parts of the world. 150mm x 150mm x 150mm size cube specimens are taken out from after 28 days of water curing then the cube specimens are allow drying and noting the initial weight. The surfaces of the specimens are thoroughly noted. Then 3% NaCl are mixed per liter of ordinary water. Cube specimens are then immersed completely in the chloride solution for 14 days and maintain uniformity. After 14 days the cube specimens are taken out from the chloride solution and kept dried. Then the specimens are weighed and the compressive strength of the specimens are noted and tabulated as given in table 10.

Table 10 Result for Chloride Resistance Test (14 Days)

Mix Designation	Before Immersion Weight (kg)	After Immersion Weight (kg)	Compressive Strength (N/mm^2)	
			Before Strength	After Strength
conventional	8.650	8.635	45.70	44.28
	8.580	8.570		
	8.710	8.695		

GGBS 20%	8.520	8.515	53.39	52.34
	8.420	8.415		
	8.600	8.590		

6) REGRESSION ANALYSIS

The equations generated were helped to find out the strength of concrete at all replacement levels. Empirical correlations were developed by MS Excel software. The most significant assignment of this research work was developed of empirical correlations for estimating strength parameters prior to the defined scope of the work.

The empirical correlations were developed based on three significant criteria:

✓ Prediction of Compressive Strength of Single combination mixes

The performance of the statistical model to predict the compressive strength of concrete using variable inputs in the mixture matrix performed well and was confirmed by the experimental values with the coefficient of determination and the input variables for single combination mixes were given in Table 11.

Table 11 Input Variables for Single Combination Mixes

S.No	Cement	GGBS	28 Days	56 Days	90 Days
1	427	0	43.6	48.35	49.16
2	427	0	46.89	48.8	48.8
3	427	0	46.71	48.08	49.29
4	387.58	39.42	48.8	57.11	57.8
5	387.58	39.42	49.11	56.71	58.4
6	387.58	39.42	48.04	56.89	57.4
7	348.16	78.84	52.62	58.67	61.78
8	348.16	78.84	54.71	59.02	61.42
9	348.16	78.84	52.84	59.96	61.95
10	308.74	118.26	48.4	57.74	60.26
11	308.74	118.26	46.62	57.33	60.18
12	308.74	118.26	49.01	56.22	59.86
13	269.32	157.68	45.82	54.89	59.56
14	269.32	157.68	45.91	55.47	59.42
15	269.32	157.68	47.2	55.6	59.2
16	229.9	197.1	44.58	53.87	5959.06
17	229.9	197.1	45.16	54.44	59.15
18	229.9	197.1	46.62	54.27	59.2

Coefficient of determination R^2 is defined as the proportion of the total variation in Y explained by the regression of Y on X. The coefficient of determination ranges from 0 to 1 and also it could be interpreted as the fraction of uncertainly explained by the fitted model. The variables were considered for empirical equations arrived in single combination mixes of input variable such as cement, ratio of cement and GGBS. The input variables were substituted equation. The equations derived for 28 days, 56 days and 90 days compressive strength with two variables were given below:

For 28 days strength

$$f_c = 30.0337+ 0.035916 (C) +0.080712 (GGBS)$$

Coefficient of correlation (R^2): 0.915

Average -ve difference: 1·481 %

Average +ve difference: 1.273%

Regression coefficient: 0.95

The predicted strengths from the analysis were compared with experimental values at 28 days shown in figure 4.

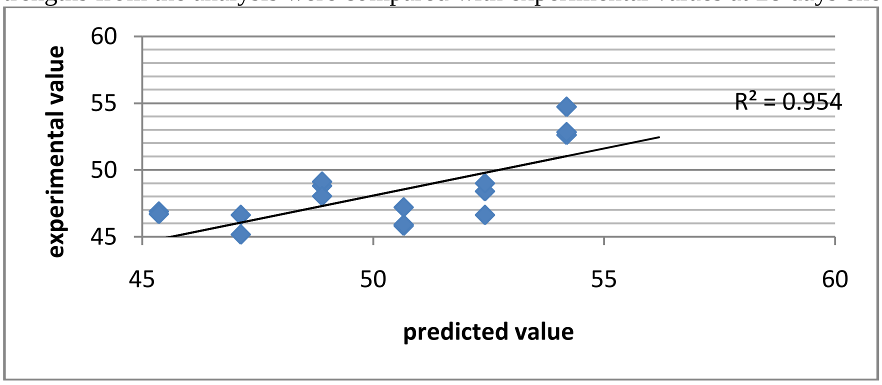

Fig 1 Predicted Vs Experimental Values at 28 days

For 56 days strength
f_c = 45.72053+0.008317(C)+0.0827317(GGBS)
Coefficient of correlation (R^2): 0.915
Average -ve difference: 1·481 %
Average +ve difference: 1.273%
Regression coefficient: 0.926
The predicted strengths from the analysis were compared with experimental values at 56 days shown in figure 5.

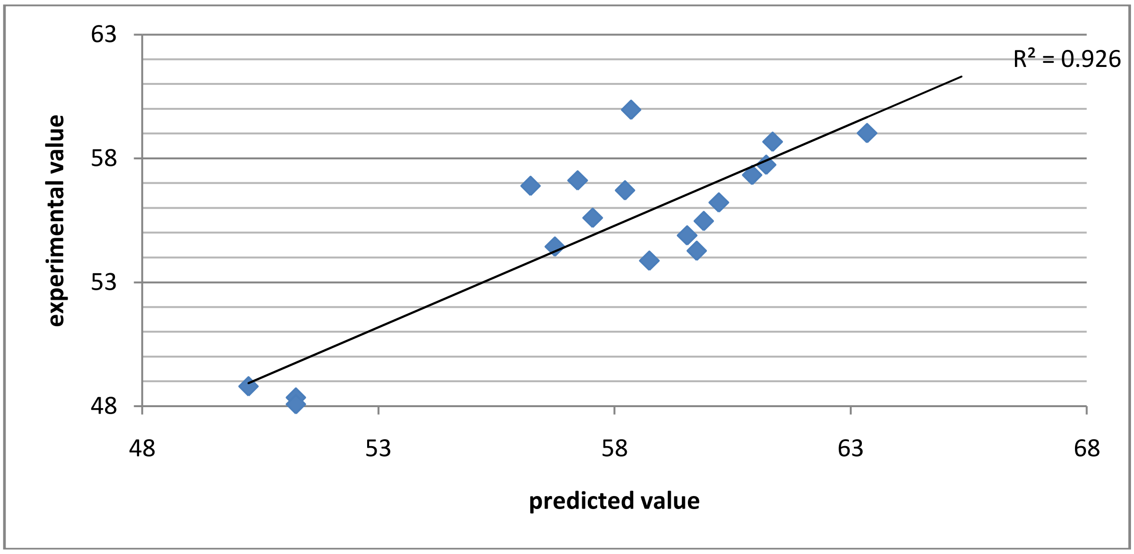

Fig.5 Predicted Vs Experimental Values at 56 days

For 90 days strength
f_c = 49.11577+0.003218(C)+0.0710423(GGBS)
Coefficient of correlation (R^2): 0.918
Average -ve difference: 1·701 %
Average +ve difference: 1.983%
Regression coefficient: 0.904
The predicted strengths from the analysis were compared with experimental values at 90 days shown in figure 6.

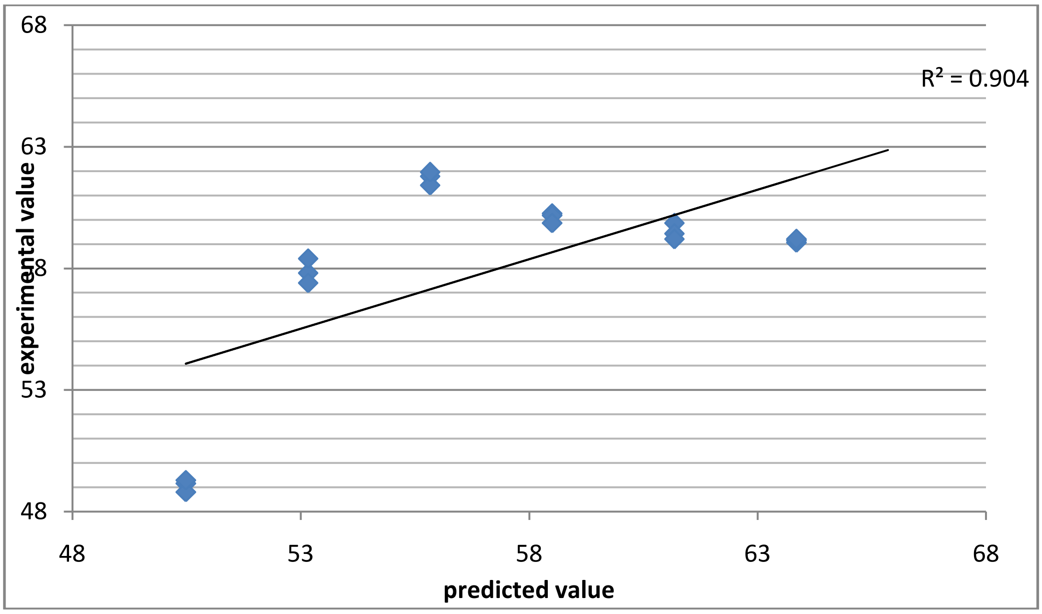

Fig.6 Predicted Vs Experimental Values at 90 days

V. Conclusion

The following conclusions were drawn from the experimental investigations are listed below:

- It was found that the optimum mix of concrete was 20% GGBS replaced concrete.
- Mechanical properties
  - ✓ The 20% GGBS concrete have 14.4% increased in cube compressive strength than conventional concrete.
  - ✓ The modulus of elasticity of concrete has 7.67% higher value than the conventional concrete.
  - ✓ The 20% GGBS concrete have 7.88% increases in flexural strength than conventional concrete.
  - ✓ The strength variations mainly depend on the pozzolanic reaction form more dense of calcium silicate hydrate (C-S-H) gel due to GGBS.
- Durability properties
  - ✓ The rapid chloride penetration test which was showed that the conventional concrete have 2703 Coulombs with moderate penetration, but 20% GGBS concrete have 1908 Coulombs with low penetration.
  - ✓ The chloride resistance test which conducted showed that the 20% GGBS concrete give 50% less weight loss and 12% less strength loss than the conventional concrete.
  - ✓ The acid resistance test which showed that the 20% GGBS concrete gives 34% less weight loss and 35% less strength loss than the conventional concrete.
  - ✓ The sulphate resistance test which showed that the 20% GGBS concrete give 44% less weight loss and 37% less strength loss than the conventional concrete.
- It is concluded that the GGBS is good replacement for cementitious material in concrete.

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