AN EXPERIMENTAL STUDY ON PARTIAL REPLACEMENT OF CEMENT BY GGBS

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Abstract- *Concrete is the most world widely used construction material with about 6 billion tones being produced every year. In terms of per capita consumption, it comes next to water. The extraction of raw materials and emission of* CO_2 *during manufacturing of cement cause great damage to the environmental sustainability. So, it becomes the need to reduce cement consumption. Without compromising with strength and durability characteristics of the concrete, it can be done by partially replacing the cement by supplementary materials. These materials may be naturally occurring, industrial wastes or by-products that are less energy extensive. These pozzolanic materials when combined with calcium hydroxide, exhibits cementitious properties. Most commonly used pozzolanic materials are fly ash, metakaolin, silica fume and ground granulated blast furnce slag (GGBS). It needs to examine the admixtures performance when blended with concrete so as to ensure required strength, durability and reduced lifecycle cost. The present paper focuses on investigating characteristics of M35 grade concrete with partial replacement of cement by GGBS with 30%, 40% and 50%. The cubes and beams are tested for compressive strength and flexural strength respectively. From the experimental investigation, it was found that as the GGBS replacement level increased the workability increased. Also, both compressive strength and flexural strength of concrete increased as the GGBS content increased up to 40% but they decreased as the GGBS content increased above 40%.* It was also found that both *maximum compressive strength and maximum flexural strength of the concrete were achieved at 40% GGBS replacement. So, the optimum content of GGBS for compressive strength and flexural strength is 40%.*

Keywords – *Ground Granulated Blast Furnace Slag, Pozzolana, Compressive Strength, Flexural Strength, Ordinary Portland Cement.*

I INTRODUCTION

Concrete has been the major instrument for providing stable and reliable infrastructure since the days of Greek and roman civilization. Concrete is the most world widely used construction material with about 6 billion tons being produced every year. It is the only next to water in terms of per-capita consumption. Concrete is a mixture of cement, water and aggregates (fine and coarse) with or without chemical admixtures. The production of cement and using it in concrete both produce CO_2. 90% of all carbon emissions from concrete are from manufacturing of cement. The extraction of raw materials and emission of CO_2 during manufacturing of cement make cement to cause great damage to the environmental sustainability. The pollutants commonly emitted by cement plants are dust or particulate matter, NO_x, SO_x, CO_2 and methane among others. It is estimated that production of cement has increased from 1.5 billion tons in 1995 to 3.2 billion tons in 2016. The production of Portland cement worldwide is increasing 9% annually. The cement industry contributes around 7% of global carbon emissions. Particulate matter emissions from cement plants are very high. So, it becomes the need to reduce the cement consumption. The effective way of reducing cement consumption without compromising with strength and durability characteristics of concrete is to use supplementary cementing materials as a partial replacement of cement. These materials may be naturally occurring, industrial wastes or by-products that are less energy extensive. These pozzolanic materials when combined with calcium hydroxide exhibits cementitious properties. Most commonly used pozzolanic materials are fly ash, metakaolin, silica fume and ground granulated blast furnace slag (GGBS). The GGBS is a by-product in the manufacturing of iron and the amounts of iron and slag obtained are of the same order. It is obtained by quenching molten iron slag from a blast furnace in water or stream to produce a glassy, granular product which is then dried and ground into a fine powder. It is highly cementitious and high in calcium silicate hydrates (CSH). The present paper focuses on investigating characteristics of M35 grade concrete with partial replacement of cement by GGBS with 30%, 40% and 50%. The cubes and beams are tested for compressive strength and flexural strength for 7, 14 and 28 days respectively.

II EXPERIMENTAL PROGRAM

2.1 Plan of Experimentation

The experimental investigation is planned as follows:

1. To find the properties of the materials such as cement, sand, coarse aggregate, water and GGBS.
2. To obtain the Mix proportions of OPC concrete of M35 grade by IS 10262-2009.
3. To calculate the mix proportion with partial replacement of OPC by GGBS with 0%, 30%, 40% and 50%.
4. To prepare the concrete specimens such as cubes for compressive strength and beams for flexural strength for M35 grade with partial replacement of OPC by GGBS with 0%, 30%, 40% and 50%.

5. To cure the specimens for 7, 14 and 28 days.
6. To evaluate the mechanical characteristics of concrete such as compressive strength and flexural strength.
7. To evaluate and compare the results.

2.2 Properties of ingredients of concrete

The materials used in the experimental work namely cement, GGBS, fine aggregate and coarse aggregate (20 mm and 10 mm) have been tested in laboratory for use in mix designs. The details are as follows:

CEMENT

Ordinary Portland cement of 43 grade was used in this investigation. The properties of cement are as follows:

1. Specific gravity: 3.15 (Density bottle method)
2. Fineness: 3% (Sieve test)
3. Initial setting time: 90 min. (Vicat's apparatus)
4. Final setting time: 3 hrs 30 min. (Vicat's apparatus)
5. Standard consistency: 33% (Vicat's apparatus)

FINE AGGREGATE

The properties of fine aggregate are as follow:

1. Specific gravity: 2.794 (Density bottle method)
2. Fineness modulus: 4.153 (Sieve analysis)
3. Water Absorption of Sand: 1.0%
4. Free (Surface) Moisture of Fine Aggregate: Nil
5. Sieve Analysis of Fine Aggregate: Conforming to Zone I of table 9 of IS 383:2016

COARSE AGGREGATES

The properties of course aggregate of size 20 mm are as follows:

1. Specific gravity: 2.633
2. Fineness modulus: 2.765
3. Water Absorption: 0.5%
4. Free (Surface) Moisture of 20 mm Coarse Aggregate: Nil
5. Sieve Analysis of 20 mm Coarse Aggregate: Conforming to Table 7 of IS 383:2016

The properties of course aggregate of size 10 mm are as follows:

1. Specific gravity: 2.942
2. Fineness modulus: 0.842
3. Water Absorption: 0.58%
4. Free (Surface) Moisture of 10 mm Coarse Aggregate: Nil
5. Sieve Analysis of 10 mm Coarse Aggregate: Conforming to Table 7 of IS 383:2016

GGBS

Figure 1: GGBS

The chemical composition and physical properties of GGBS are shown in Table 1:

CHEMICAL COMPOSITION		PHYSICAL PROPERTIES	
Calcium oxide	40%	Colour	Off-white
Silica	35%	Specific gravity	2.9
Alumina	13%	Bulk density	1200 kg/m^3
Magnesia	8%	Fineness	360 m^2/kg

Table 1: Chemical Composition and Physical Properties of GGBS

2.3 Mix Design (as per IS 10262: 2009)

The following specifications were considered for Mix design:

1. Type of Cement: OPC 43 grade
2. Grade of Concrete: M35
3. Characteristic compressive strength required in field at 28 days = 35 MPa
4. Exposure Condition: Mild
5. Design mix target slump: 75-100 mm
6. Maximum Nominal Aggregate Size:20 mm
7. Fine Aggregate: Zone I
8. Specific gravity of water = 1
9. Specific gravity of coarse aggregate (20 mm) = 2.633
10. Specific gravity of coarse aggregate (10 mm) = 2.942
11. Specific gravity of fine aggregate = 2.794
12. Specific gravity of GGBS = 2.9
13. Minimum Cement Content: 340 kg/m3
14. Maximum Cement Content: 450 kg/m3
15. Maximum Water Cement Ratio: 0.55
16. Degree of Supervision: Good
17. Type of Aggregate: Crushed Angular Aggregate
18. Chemical admixture: None
19. Type of fine aggregate: Normal river sand
20. Type of vibration: Mechanical

The mix proportion for 1 m3 of concrete is shown in Table 2.

Grade	M35
Cement (kg/m^3)	348.327
Water (kg/m^3)	191.58
Fine aggregate (kg/m^3)	775.531
Coarse aggregate (kg/m^3)	1113.612 (60% of 20 mm and 40% of 10 mm)
w/c ratio	0.55

Table 2: Mix Proportion for 1 m^3 of concrete

The mix proportion for M35 grade concrete is 1: 0.55: 2.23: 3.20. Among the trail mix conducted, this mix proportion gave the required workability and strength.

2.4 Replacement of Cement by GGBS

The mix proportions with partial replacement of OPC by GGBS with 0%, 30%, 40% and 50% are shown in Table 3.

CONCRETE MIX	MIX PROPORTION
Conventional Concrete (0% GGBS replacement)	1 : 0.55 : 2.23 : 3.20
30% GGBS replacement	0.7 : 0.55 : 2.23 : 3.20
40% GGBS replacement	0.6 : 0.55 : 2.23 : 3.20
50% GGBS replacement	0.5 : 0.55 : 2.23 : 3.20

Table 3: Mix proportions for different GGBS replacements

2.5 Casting and curing of test specimens

3 specimens of standard cubes (150 mm × 150 mm × 150 mm) and 3 specimens of standard beams (500 mm × 100 mm × 100 mm) were casted for each concrete mix. 4 different concrete mixes of M35 grade were prepared in which cement was partially replaced by GGBS with 0%, 30%, 40% and 50% respectively. In all 12 specimens of cubes and 12 specimens of beams were casted. These specimens were cured for 7, 14 and 28 days.

2.6 Curing

After 24 hours of casting the test specimens, cubes and beams, were de-moulded and immediately immersed in clean and fresh water for curing for 7, 14 and 28 days.

III RESULTS

3.1 Tests for Workability

The results on tests for workability are shown in Table 4.

S. No.	% of GGBS	Compaction Factor	Slump (mm)
1	0	0.74	76
2	30	0.80	82
3	40	0.87	86
4	50	0.92	92

Table 4: Slump and Compaction Factor Values of concrete

S. No.	% of GGBS	Flexural Strength (N/mm^2)		
		7 days	14 days	28 days
1	0	2.8	4.2	5.4
2	30	3.2	4.6	5.8
3	40	3.8	4.8	6.4
4	50	3	4.4	5.2

3.2 Compressive Strength of Concrete

CTM of 2000 kN capacity was used. The cube specimen was placed in the machine in such a manner that the load was applied to the opposite sides of the cube cast. The specimen was aligned centrally on the base plate of the machine. The load was applied gradually without shock and continuously at the rate of approximately 140 kg/cm^2/min until failure. The test results for compressive strength are shown in Table 5 for 0%, 30%, 40% and 50% GGBS concrete of M35 grade at room temperature for 7, 14 and 28 days respectively.

S. No.	% of GGBS	Compressive Strength (N/mm^2)		
		7 days	14 days	28 days
1	0	28.82	39.82	43.34
2	30	30.58	41.14	44.66
3	40	33.44	43.34	47.08
4	50	29.92	40.04	43.78

Table 5: Compressive Strength of concrete

3.3 Flexural strength of concrete

The beam specimen was placed in the machine in such a manner that the load was applied along two lines spaced 13.33 cm apart. The axis of the specimen was carefully aligned with the axis of the loading device. The load was applied through two similar steel rollers, 38 mm in diameter, mounted at the third points of the supporting span that is spaced at 13.33 cm centre to centre. The load was applied without shock and increased continuously at a rate of 180 kg/min until the specimen failed. The test results for flexural strength are shown in Table 6 for 0%, 30%, 40% and 50% GGBS concrete of M35 grade at room temperature for 7, 14 and 28 days respectively.

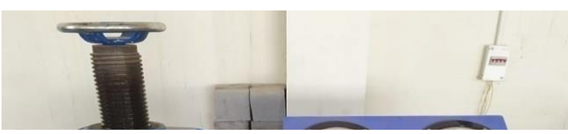

Table 6: Flexural Strength of concrete

Figure 2: Compression Testing Machine

Figure 3: Cube Specimen under Testing

Figure 4: Flexural Testing Machine (Beam specimen under Testing)

IV DISCUSSION ON RESULTS

4.1 Effect of variation of GGBS on Compaction Factor

The values of compaction factor for 0%, 30%, 40% and 50% GGBS concrete are shown in Figure 5.

TRENGTH (in N/mm^2)

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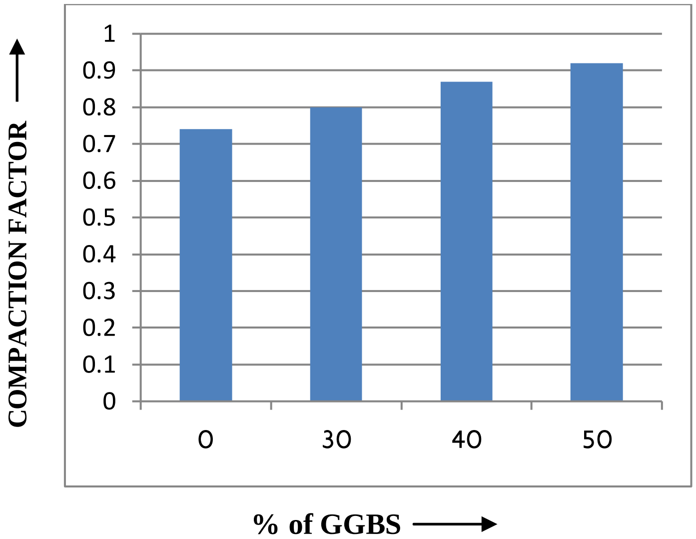

Figure 5: Compaction Factor of concrete v/s % of GGBS

4.2 Effect of variation of GGBS on Slump

The values of slump for 0%, 30%, 40% and 50% GGBS concrete are shown in Figure 6.

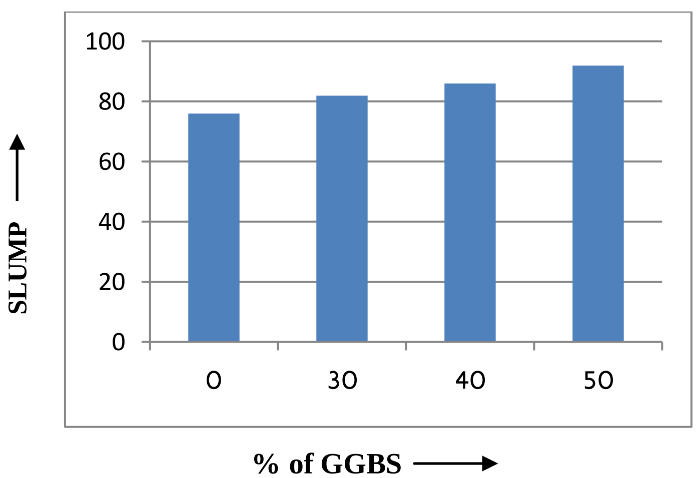

Figure 6: Slump of concrete v/s % of GGBS

4.3 Effect of variation of GGBS on compressive strength

The values of compressive strength for 0%, 30%, 40% and 50% GGBS concrete for 7, 14 and 28 days are shown in Figure 7.

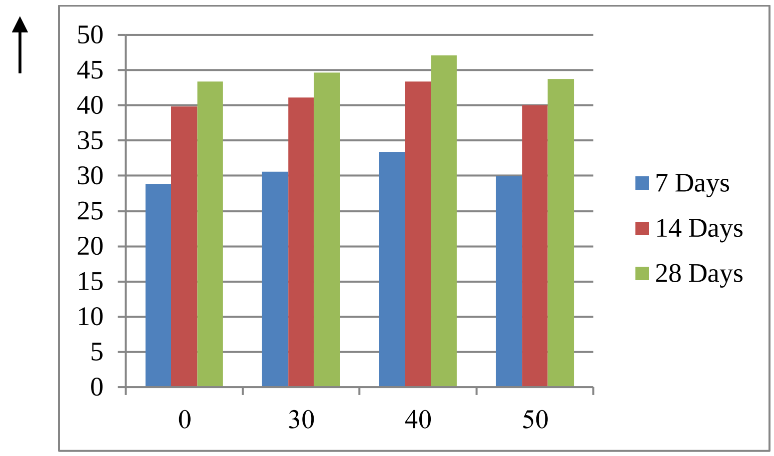

Figure 7: Compressive Strength of concrete v/s % of GGBS

4.4 Effect of variation of GGBS on flexural strength

The values of flexural strength for 0%, 30%, 40% and 50% GGBS concrete for 7, 14 and 28 days are shown in Figure 8.

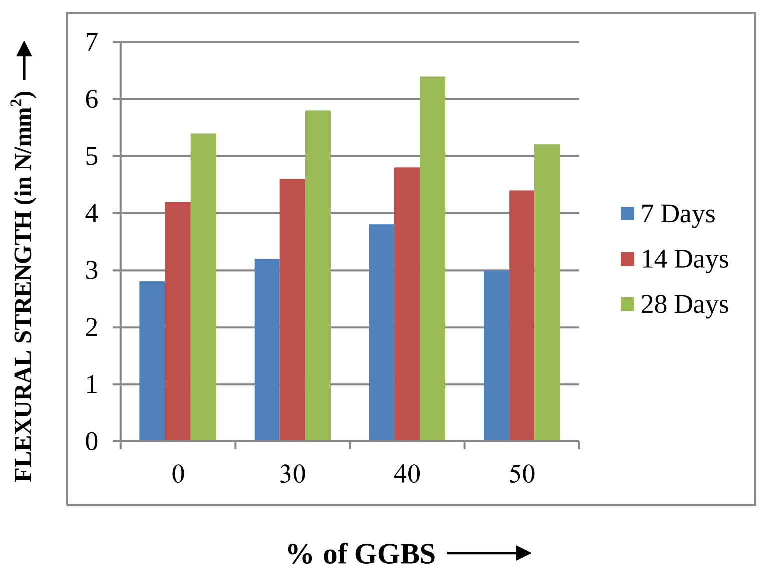

Figure 8: Flexural Strength of concrete v/s % of GGBS

V CONCLUSIONS

Based on the analysis of experimental results and discussion, the following conclusions can be drawn:

1. The workability of concrete increased with the increase in GGBS replacement level.
2. The compressive strength of concrete increased as the GGBS content increased up to 40% but the compressive strength decreased as the GGBS content increased above 40%.
3. The maximum compressive strength of the concrete was achieved at 40% GGBS replacement. So, the optimum content of GGBS for compressive strength is 40%.
4. The flexural strength of concrete increased as the GGBS content increased up to 40% but the flexural strength decreased as the GGBS content increased above 40%.
5. The maximum flexural strength of the concrete was achieved at 40% GGBS replacement. So, the optimum content of GGBS for flexural strength is 40%.

SCOPE FOR FURTHER STUDY

The study may further be extended for the followings:

1. To determine the percentage of GGBS partially replaced with cement to have maximum resistance against acidic environment.
2. To study other levels of replacement of GGBS.
3. To study combination of GGBS with different admixtures.
4. To study partial replacement of cement by GGBS for different grades of concrete.

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