ISSN No: - 2456 - 2165

Studies on Optimum Usage of GGBS in Concrete

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Abstract :- Ground Granulated Blast furnace Slag (GGBS) is a byproduct from the blast furnaces used to produce iron. The use of GGBS serves as a replacement to already depleting conventional building materials and also as being a byproduct it serves as an Eco Friendly way of applying the product without dumping it along the dry land. The present technical report focuses on investigating the characteristics of concrete with partial replacement of cement with Ground Granulated Blast furnace Slag (GGBS) by replacing cement. The replacement level of GGBS in concrete is 0%, 5%, 20%, 35%, 50% by the total weight of cement. A total of 150 specimens has been cast and tested according to the IS Code. All specimens were moist cured for 7, 14 and 28 days for compressive strength, split tensile strength and flexural strength testing. The test results proved that the compressive strength, split tensile strength and flexural strength of concrete mixtures increases as the amount of GGBS increase. A numerical equation has also been developed to predict the strength of concrete containing various percentages of GGBS at different ages for M25 grade of concrete. After an optimal point, about 20 % of GGBS does not improve the compressive strength and split tensile strength of the concrete.

Keywords: *GGBS, Mechanical Properties, Numerical Equation, Optimum level.*

I. INTRODUCTION

Concrete is a mixture of cement, fine aggregate, coarse aggregate and water. Concrete plays a vital role in the development of infrastructure such as industrial building, residential building, bridges and highways, etc. leading to the utilization of a large quantity of concrete. On the other side, the cost of concrete is attributed to the cost of its components which is scarce and expensive, hence leading to usage of economically alternative materials in its yield. This requirement has drawn the attention of investigators to explore new replacements of ingredients of concrete.

Ground Granulated Blast furnace Slag (GGBS) is a byproduct from the blast furnaces used to make iron. These operate at a temperature of about 1500 degrees centigrade and are fed with a carefully controlled mixture of iron ore, coke and limestone. The iron ore is reduced to iron and the remaining materials from a slag that floats on top of the iron. This slag is periodically tapped off as a molten liquid and if it is to be utilized for the manufacture of GGBS it has to be rapidly quenched in large volumes of water. The quenching optimizes the cementitious properties and produces granules similar to coarse sand. This granulated slag is then dried and ground to a fine powder. It can also be referred to as "GGBS" or "Slag cement". The chemical composition of the GGBS was given in table 1.1.

The primary problem is the original conventional materials are consumed and we are in the search for alternate building materials which lands us here for the use of GGBS. Being a byproduct and waste using it effectively up to some extent serves as a step for a greener environment and at the same time keeping in mind that the strength of the concrete doesn't degrade by the usage GGBS.

Concrete made with GGBS cement sets more slowly than concrete made with ordinary Portland cement, depending on the amount of GGBS in the cementitious material, but also proceeds to gain strength over a longer period in production conditions. This issue in lower heat of hydration and lower temperature rise, and makes avoiding cold joints easier, but may also affect construction schedules where the quick mount is required. The last phase of the GGBS was shown in the figure 1.1.

So far in the literatures most of the work has done in the M30, M40 grade of concrete and very few has covered in the M20 grade of concrete using GGBS. Hence it is worth the experimenting to replace the GGBS in M25 grade of concrete and to find its optimum replacement level. The primary aim of this probe is to examine the mechanical behavior of concrete in the presence of GGBS, compared with conventional concrete. The compressive strength, split tensile strength, flexural strength of the concrete with GGBS were tested and analyzed in this study.

Figure – 1.1 GGBS

Table – 1.1 Chemical Compositions of GGBS

Binder	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O
Cement	20.7	4.8	2.9	61.8	1.3	0.2	0.6
GGBS	39.1	10.1	2.1	32.8	8.5	1.1	0.30

II. EXPERIMENTAL STUDY

2.1 Material used

The cement used in this study was ordinary Portland cement in M25 Grade of concrete. The specific gravity of cement used was 3.10. Ordinary Portland cement, 43 Grade conforming to IS: 8112-1989 was used. River sand passing through 4.75 mm IS sieve conforming to grading zone II of IS 383:1970 and having a specific gravity of 2.68 was used in this work. Crushed aggregate available from local sources with a maximum size of 20 mm having a specific gravity of 2.78 and conforming to IS 2386:1963 was used as coarse aggregate in this study. The GGBS having a specific gravity of 2.87 was used in this study to determine the optimum replacement level. The replacement level of the GGBS in concrete is 0%, 5%, 20%, 35% and 50% of the total weight of cement.

2.2 Mixing and curing

After the mix design the proportions were arriving and tabulated in table 2.1. Initially the dry materials, Cement, Aggregates & Sand are mixed. Further, GGBS were added into the dry mixture for another 1 minute. The fluid part of the mixture was then added to the dry materials and the mixing continued for further about 4 minutes. The total mixing time was 5 minutes. Compaction of concrete in three layers with 25 strokes of 16mm rod was carried out for each layer is done. The concrete was left in the mold and allowed to set for 24 hrs before the cubes were de-molded and placed in the curing tank until the day of testing. A sum of 150 specimens was cast and allowed for curing in the curing tank for 7, 14 and 28 days.

Table 2.1 Mix Proportion for $1m^3$

Mix	W/C	Water Kg/m^3	Cement Kg/m^3	Fine Aggregate Kg/m^3	Coarse Aggregate Kg/m^3	GGBS Kg/m^3
M25 0%	0.5	195	390	712.4	1105.68	0
M25 5%	0.5	195	370.5	712.4	1105.68	19.5
M25 20%	0.5	195	312	712.4	1105.68	78
M25 35%	0.5	195	253.5	712.4	1105.68	136.5
M25 50%	0.5	195	195	712.4	1105.68	195

2.3 Testing of Specimens

The mixtures of concrete containing GGBS added as partial cement replacement of 0%, 5%, 20%, 35% and 50% by weight and the specimens were tested. Hundred millimeter concrete cubes manufactured from each mixture, were tested for compressive strength after storage in water for a period of 7-days, 14-days and 28-days. The testing is carried out for compressive strength on the cubes as per IS: 516 – 1959. Compressive strength of cubes is determined by using compression testing machine (CTM) of 2000 KN. The testing is carried out for split tensile strength on cylinder as per IS: 5816 – 1999. Cylinders of 100mm diameter and 200mm length were used as test specimens to determine the split tensile strength of concrete for both cases (normal concrete and GGBS concrete). The cylindrical specimen was placed horizontally between the loading surfaces of the compression testing machine and the load was applied to the failure of the specimen. The concrete beams of size (100mm x 100mm x 500mm) were tested as per IS: 516 – 1959 for flexural strength. The maximum load at failure for compression strength, split tensile strength and flexural strength are tabulated in table 3.2, 3.3 and 3.4 respectively.

III. TEST RESULT AND DISCUSSION

3.1 Slump Test

Slump values with various proportions of GGBS replacing cement in M25 grade concrete were shown in the table 3.1.

Table 3.1 Slump values with various proportions of GGBS

Type of Concrete	Slump Value
Control concrete	32 mm
5% GGBS	37 mm
20% GGBS	41 mm
35% GGBS	47 mm
50% GGBS	52 mm

It is noted that the workability values of concrete with GGBS are more eminent than the control mixing. The workability of concrete increases with increase in GGBS percentage as shown in the figure 3.1. The curve indicates linear gain in workability and the workability reaches its maximum at 50% GGBS replacement.

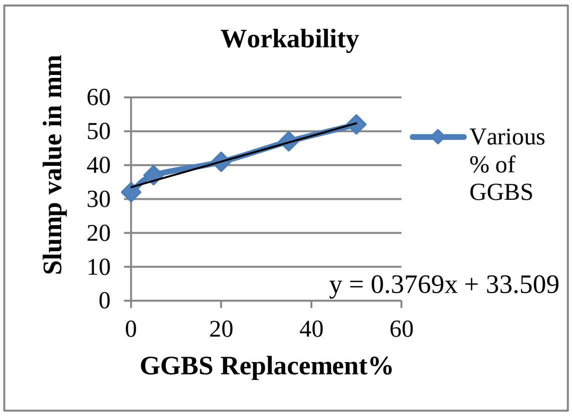


Figure 3.1. Workability of Concrete with varying % GGBS content

From the Figure 3.1, the numerical equation was found for the known percentage of GGBS. Using this equation, we can predict the workability value for different proportions of GGBS for M25 grade of concrete. In the equation ($y = 0.3769x+33.509$), x is the value of GGBS replacement level in percentage and y is the value of workability in millimeter.

3.2 Compressive Strength

A total of 60 cube specimens was cast to find out the compressive strength of the concrete. Compressive strength of concrete mixtures made with and without GGBS was determined at 7, 14, 28 days of curing. The average of three samples was taken for every testing age. The test results for compressive strength are presented in table 3.2 for M25 grade of concrete.

Table 3.2 Compressive Strength for M25 grade Concrete

Sl. No.	% of GGBS	Compressive Strength (N/mm^2)		
		7 days	14 days	28 days
1	0	21.25	28.25	31.56
2	5	28.15	30.30	31.75
3	20	31.10	33.50	35.10
4	35	23.01	24.32	32.50
5	50	20.75	24.26	30.25

It is observed that the compressive strength at early age (7 days & 14 days) of concrete increases upto 20% replacement of GGBS than the control mixture. As the curing period is prolonged, the compressive strength values of the GGBS concrete mix increase more than the control mix.

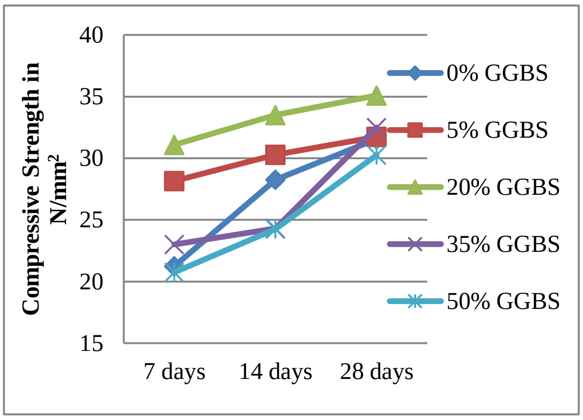


Figure 3.2. Compressive Strength of Concrete with varying GGBS content

From the Figure 3.2, it is observed that, about 20% replacement of cement with GGBS, concrete attains its maximum compressive strength (at 28 days) for M25 grade concrete. When the replacement exceeds 20% the compressive strength is found to be decreasing slightly. And at 20% replacement of GGBS, the compressive strength is greater than the other concrete mixtures.

3.2.1 Numerical Equation for Compressive Strength

The numerical equation for compressive strength of the concrete containing various percentages of GGBS has been derived from the Figure 3.2. From these numerical equation the value of compressive strength for the known percentage of GGBS can be predicted for M25 grade of concrete. The numerical equation of compressive strength at the age of,

7 days is $y = -0.0546x + 26.052$
14 days is $y = -0.1206x + 30.774$
28 days is $y = -0.0006x + 32.245$

Where,

x is the value of GGBS replacement level in percentage

y is the value of compressive strength in N/mm^2.

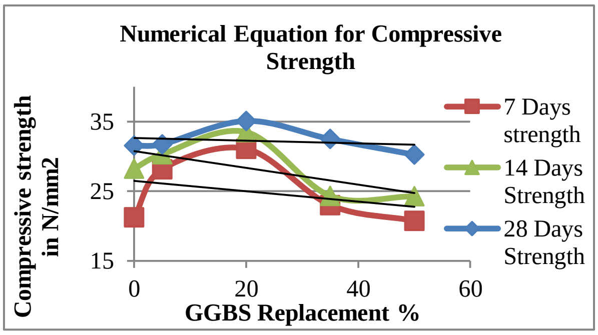


Figure 3.3 Numerical Equations for Compressive strength

3.3 Split Tensile Strength

A total of 45 cylindrical specimens was cast to find out the split tensile strength of the concrete and the average of three cylinders for each mix was tested. Split tensile strength of concrete specimens made with and without GGBS was determined at 7, 14, 28 days of curing. The test results for split tensile strength are presented in table 3.3 for M25 grade of concrete.

Table 3.3 Split Tensile Strength for M25 grade Concrete

Sl. No.	% of GGBS	Split Tensile Strength (N/mm^2)		
		7 days	14 days	28 days
1	0	2.62	2.75	3.61
2	5	2.74	3.36	3.70
3	20	3.49	3.66	4.06
4	35	2.96	3.38	3.60
5	50	2.38	3.13	3.49

It is observed that the early age (7 days & 14 days) split tensile strength values of GGBS concrete mixtures are nearly higher than the control mixtures. As the curing period is prolonged, the strength values of the GGBS concrete mixtures (not including 50%) increase more than the control mixtures. After 28 days the GGBS concrete (at 20%) has the higher split tensile strength values compared to the control mixtures with equivalent binder content.

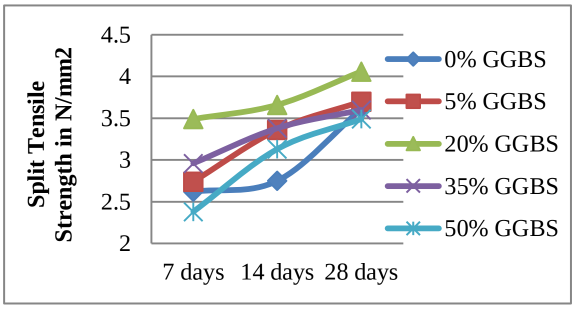


Figure 3.4 Split Tensile Strength of Concrete with varying GGBS content

From Figure 3.4, it is observed that at most 20% replacement of cement with GGBS, concrete attains its maximum split tensile strength for M25 grade concrete, when the replacement exceeds 20%, the split tensile is found to be decreasing slightly. And at 35% replacement of GGBS, the split tensile strength is greater than the 50% replacement of GGBS.

3.3.1 Numerical Equation for Split tensile strength

The numerical equation of the split tensile strength of the concrete containing various percentages of GGBS has been derived from the Figure 3.5. From this numerical equation the value of Split tensile strength for the known percentage of GGBS can be predicted for M25 grade of concrete. The numerical equation of split tensile strength at the age of,

7 days is $y = -0.0035x + 2.9153$
14 days is $y = -0.0038x + 3.1716$
28 days is $y = -0.0034x + 3.7673$

Where,

x is the value of GGBS replacement level in percentage

y is the value of compressive strength in N/mm^2.

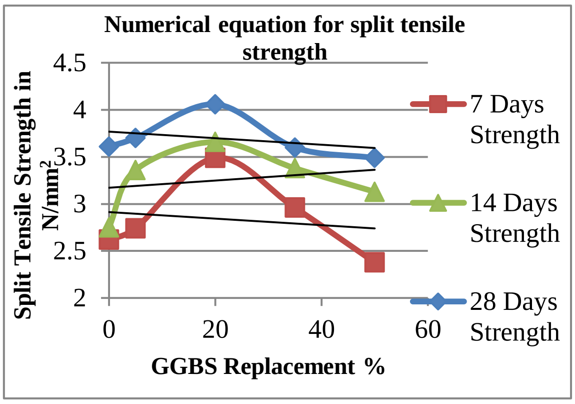


Figure 3.5 Numerical Equations for Split Tensile Strength

3.4 Flexural Strength

A total of 45 beam specimens (100mm x 100mm x 500mm) were casted to find out the flexural strength of the concrete and the average of three prisms for each mix was tested. Flexural strength of concrete mixtures made with and without GGBS was determined at 7, 14, 28 days of curing. The test results for split tensile strength are presented in table 3.4 for M25 grade of concrete.

Table 3.4 Flexural Strength of M25 grade Concrete

Sl. No.	% of GGBS	Flexural Strength (N/mm^2)		
		7 days	14 days	28 days
1	0	3.55	3.91	3.99
2	5	4.12	4.65	4.77
3	20	3.65	3.67	5.42
4	35	4.17	4.60	6.18
5	50	3.89	3.91	6.08

It is observed that the early age (7 days & 14 days) flexural strength values of GGBS concrete mixtures are nearly higher than the control mixtures. As the curing period is prolonged, the strength values of the GGBS concrete mixtures increase more than the control mixtures. After 28 days the GGBS concrete (at 35%) has the higher flexural strength values compared to the control mixtures with equivalent binder content.

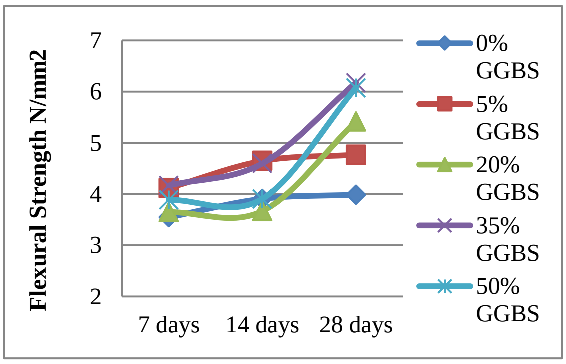


Figure 3.6 Flexural Strength of Concrete with varying GGBS content

From Figure 3.6, it is observed that at about 35% replacement of cement with GGBS, concrete attains its maximum flexural strength for M25 grade concrete, when the replacement exceeds 35%, the flexural strength is found to be decreasing slightly. And at 35% replacement of GGBS, the flexural strength is greater than the 50% replacement of GGBS.

3.4.1 Numerical Equation for Flexural strength

The numerical equation of flexural strength of the concrete containing various percentages of GGBS has been derived from the Figure 3.7. From this numerical equation the value of flexural strength for the known percentage of GGBS can be predicted for M25 grade of concrete. The numerical equation of compressive strength at the age of

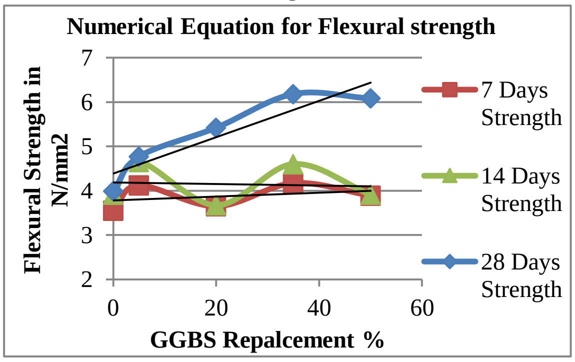
7 days is $y = -0.0101x + 8.722$
14 days is $y = -0.0041x + 9.6674$
28 days is $y = -0.0943x + 10.118$

Where,

x is the value of GGBS replacement level in percentage

y is the value of compressive strength in N/mm^2

Figure 3.7 Numerical Equation for Flexural strength



IV. CONCLUSION

The Following conclusions were drawn based on the experimental investigations carried out in this study.

- The workability of the concrete increases with the increase in the GGBS content for M25 grade concrete and the workability reaches its maximum at 50% replacement of GGBS.
- The present study shows that the replacement of GGBS in concrete can produce high strength than the conventional concrete mix.
- The early age compressive strength and split tensile strength at 7 days and 14 days has reached its maximum strength at 20% replacement of cement with GGBS for M25 grade of concrete.
- The early age flexural strength at 7 days and 14 days has reached its maximum strength at 35% replacement of cement with GGBS for M25 grade of concrete.
- It is observed that the strength level increases at 20% replacement of GGBS and falls at 35% replacement for compressive strength and split tensile strength.
- The concrete has reached its maximum compressive strength at 20% replacement of GGBS which is 11.1% greater strength than the nominal concrete strength.
- The concrete has reached its maximum split tensile strength at 20% replacement of GGBS which is 31.1% greater strength than the nominal concrete strength.
- The concrete has reached its maximum flexural strength at 35% replacement of GGBS which is 54.8% greater strength than the nominal concrete strength.
- The numerical equations for compressive strength, split tensile strength and flexural strength has been derived to predict the strength values at different replacement levels of GGBS for M25 grade for concrete.
- From this study, it has been concluded that the optimum percentage replacement of GGBS in M25 grade concrete is 20%.
- From the above experimental results, it is proved that GGBS can be used as a replacement of cement without affecting the strength of concrete.

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