International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 4, Issue 09, September-2018

AN EXPERIMENTAL STUDY ON THE BEHAVIOUR OF CONCRETE ON PARTIAL REPLACEMENT OF CEMENT WITH GROUND GRANULATED BLAST FURNACE SLAG

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Abstract: Concrete is the most widely used material in construction industry due to its high strength and stability. However environmental sustainability is at stake due to the damage caused by the extraction of raw materials and carbon-dioxide emission during cement manufacturing, so the industry is looking for the alternative supplementary cementitious materials. GGBS is useful in the design and development of high quality cement paste. The usage of GGBS serves as a replacement and also it is a by-product which is used as eco-friendly material by utilizing the product without dumping which is produced from the industrial waste from the blast furnace used to make iron. Use of GGBS not only reduces the cost of production but also helps to reduce the impact on environment by consuming material which is considered as a waste product.
The present study is conducted to investigate and evaluate the workability and strength characteristics of concrete of M20 grade concrete at different ages with partial replacement of cement with ground granulated blast furnace slag (GGBS) replacing cement in percentages of 10%,20%,30%,40% by weight. The mixes were designed using IS code. The concrete mixture produced in the form of cubes, cylinders, prisms are tested for compressive strength, split tensile strength and flexural strength. The Durability of concrete against acid attack was done after 91 days treatment with H_2SO_4.

1. Introduction

The most important part of concrete is cement. Cement is used as a binder material but that produces large amount of hydration. The production of cement results in release of large amount of carbondioxide. The release of carbondioxide gas is very harmful to the environmental changes. So researches are been carried out to reduce the usage of it and to find the alternative resources and ecofriendly technology are been developed for the effective management of resources. The replacement of natural resources and waste material is one of the way to reduce the usage of cement in the concrete.
Ground-granulated blast-furnace slag (GGBS) can be obtained by subjecting molten iron slag to high temperatures which produces a glassy, granular product. This obtained product is then dried and ground into a fine powder. The main components of blast furnace slag are calcium oxide, silicon dioxide, aluminum oxide and magnesium oxide. The increase in the content of calcium oxide results in raised slag basicity and increase in compressive strength. GGBS can help in making durable structures when combined with ordinary portland cement. GGBS has been widely used in all over the world for various purpose. Concrete made with GGBS cement tends to set slowly but gains strength over a longer period of time in production conditions. This helps us in achieving lower heat of hydration, lower temperature rises, avoids cold joints easily. But this can affect the construction schedule where fast setting concrete is required.

2. Literature Review

Chandar garg (2014) This study has described the variation of compressive strength, flexure strength and tensile strength, also workability and durability of different specimens having different percentage of GGBS and lime stone powder as a partial replacement of cement. From the results following conclusions are concluded that The workability of the concrete increases with the increase in the replacement levels. .From the results it is clear that maximum compressive strength is at 5-10% replacement of LP and GGBS. From the results it is clear that maximum tensile strength is at 5-10% replacement of LP and GGBS. From the results it is clear that maximum flexure strength is at 5-10% replacement of LP and GGBS. From the results of water absorption test it is concluded that durability of the concrete increases with the increase in replacement levels. Therefore limestone powder and ground granulated blast furnace slag can be used up to 30% (10%LP and 20% GGBS) as a partial replacement of cement.

Souvik Dasa et al. (2015)- In this study it presents Ground Granulated Blast Furnace Slag (GGBS) based Concrete Exposed to Artificial Marine Environment(AME) and Sustainable Retrofitting using Glass Fiber Reinforced Polymer (GFRP) sheets. Temperature fluctuation has also become a subject of interest for concrete structures. In the study they have casted sixteen numbers (16) of cylinders of M25 grade (BIS code specification) out of which 8 were incorporated with GGBS. Four cylinders of normal concrete and four cylinders of GGBS based concrete were exposed to artificially created marine environment in a temperature controlled curing tank. 3% NaCl+CaCl by weight solution is prepared for substitution of marine water. The ambient temperature in the curing tank is fluctuated between 25C to 50C for 60days to study the changes in GGBS based concrete strength in elevated temperatures.

V.Nagendra et al. (2016)-In this study the present investigation Ground Granulated Blast Furnace Slag (GGBS) is used as particles of specific size, as replacement to cement. The GGBS is placed in the concrete mix with particles of various uniform sizes of 250µm, 125µm, 90µm, 45µm and 20µm. The dosage of GGBS is varied from 10% to 40% at an increment of 10% for concrete to evaluate the compressive strength. The results showed that, for particle of size 20 µm, the strength is optimum, which is at 20% replacement level.

Akshaykumar Moogi and Swapnil Cholekar(2018)- The study is conducted by 1.5% of total dosage of fiber content was fixed with Supplementary materials Flyash and GGBS in varying percentages by weight of cement. Cubes and Beams are casted to check the compressive and flexural strength of concrete. In this experiment it is also aimed to study the effect BFRC when subjected to sulphate attack. Here study cited on effect of sulphate on basalt fiber reinforced concrete. Also checking the strength parameters compare the test results with sulphate and without sulphate attack.

3. Experimental Investigation

3.1 Materials Used

3.1.1 Cement

Ordinary Portland cement of 43 grade conforming to IS: 8112-1989. Physical properties of cement are shown in Table 1.

3.1.2 Fine Aggregate (River Sand)
The locally available river sand passing through 4.75 mm sieve and retained on 150 µ sieve, conforming to Zone-II of IS 383-1970 has been used as fine aggregate. Physical properties of fine aggregate are shown in Table 2.
3.1.3 Coarse Aggregate
Conventional coarse aggregate was used from an established quarry satisfying the requirement of IS 383-1970. The locally available crushed granite stone is used as coarse aggregate. The tests conducted on coarse aggregate are tabulated in Table 3.
3.1.4 GGBS
It is obtained from the company of ACC limited which is located in Auto Nagar, Visakhapatnam.
3.1.5 Superplasticizer
The superplasticizer used in this study was FORSOC Conplast SP430.

Table 1. Properties of cement

S.No.	Particulars of test	Test Results
1	Standard Consistency	32%
2	Initial setting time (min)	152 min
	Final setting time (min)	256 min
3	Specific gravity	3.12
4	Fineness (weight of cement retained on IS 90µ sieve)	3.46%
5	Compressive strength i)3days ii)7days iii)28 days	N/mm^2 20.94 32.64 46.481

Table 2. Properties of fine aggregate

S.No.	Particulars of test	Value
1.	Specific gravity	2.673
2.	Water absorption	1.2%
3.	Bulk density a. Loose state b. Compacted state	 1551 kg/m^3 1679 kg/m^3
4.	Fineness modulus	2.86
5.	Grading of sand	II
6.	Silt content	1%

Table 3. Properties of Coarse aggregate

S.No.	Particulars of test	Value
1.	Specific gravity	2.81
2.	Water absorption	0.51%
3.	Bulk density a. Loose state b. Compacted state	 1557.3 kg/m3 1751.70 kg/m3
4.	Fineness modulus	6.80
5.	Flakiness index	14.12%
6.	Elongation index	23.79%
7.	Crushing value	18.84%
8.	Impact value	14.33%

3.1.6 Mix Proportion

Mix design is a process of selecting suitable ingredients and determining their relative proportions with the objective of producing concrete of having certain minimum workability, strength and durability as economically as possible. The M20 grade concrete Mix design is made as per IS10262:2009. The table 4 below shows the mix design.

Table 4. Mix Proportions

Water (Liters)	Cement (Kg/m^3)	Fine aggregate (Kg/m^3)	Coarse aggregate (Kg/m^3)
153.6	320	730.03	1304.38 (782.628+521.752) (60%+40%)
0.48	1	2.281	4.076

4. Test Procedure

4.1 Slump cone Test

Slump cone test is a preliminary test conducted to determine the workability. In this thesis, slump test was conducted on the mix containing cement, fine aggregate, GGBS and coarse aggregate. The mix was prepared according to the proportions obtained from mix design. The prepared mix was then placed in slump cone in three layers with simultaneous tamping with a tamping rod for each layer. The slump cone is lifted and the change in slump is observed. The change in slump is measured with a steel rule and is noted down.

4.2 Compaction Factor Test

Compaction factor test is another test conducted to determine the workability of the prepared mix. In this test the mix is poured into the upper hopper of the compaction factor apparatus, and then the lever is pulled, which makes the mix fall down in to the lower hopper and then in to the cylinder under the action of gravity. Now the cylinder is weighed and the weight is noted down. The cylinder is now placed on the vibrator table and then compacted. The cylinder is again weighed and the weight of fully compacted cylinder is noted down. The compaction factor is found out with the help of the formula below.

$$\text{Compaction factor} = \frac{\text{Weight of partially compacted concrete}}{\text{Weihght of fully compacted concrete}}$$

4.3 Vee-Bee Consistometer Test

In this test, the mix is placed in the cone in three layers with simultaneous compaction. After the cone has been removed the circular glass plate attached to the apparatus is placed on the mix. The machine is switched on and the stopwatch is started. The time taken for the cone shaped to mix to transform into a cylindrical shaped mix is noted down. This time recorded is known as Vee-Bee time.

4.4 Compressive Strength Test

In this test, the cubes that have been cast in the cubical mould of dimensions 150mmx150mmx150mm, placed in curing tank for 7, 28, 56, and 91 days and then dried until it is free from moisture are tested in a compression testing machine. The cubes are placed in the machine and then load is applied until failure. The load obtained is recorded and the compressive strength is calculated using the formula below.

$$\text{Compressive strength} = \frac{P}{A}\ (\text{N/mm}^2)$$

Where,

P = load applied to the specimen.

A = Cross-sectional area of cube on which the load is applied (150mm x 150mm)

4.5 Splitting Tensile Strength

In this test, cylinders of dimension 150mm x 300mm have been cast in cylindrical moulds, placed in curing tank for 7, 28, 56 and 91 days and dried until free from moisture. These cylinders are placed in the testing machine and the load is applied until failure. The ultimate load is recorded and then the splitting tensile strength is calculated according to the formula given below.

$$F_t = \frac{2P}{\pi\ x\ D\ x\ L}\ \text{N/mm}^2$$

Where, P= Maximum load applied to the specimen.

D = Cross sectional dimension of cylinder on which load is applied.

L = Length of specimen in mm.

F_t = Split tensile strength. (N/mm^2)

4.6 Flexural Strength

In this test, prisms of dimensions 500mm x 100mm x 100mm were cast in the appropriate moulds, placed in curing tank for 7, 28, 56 and 91 days, and then dried until free form moisture. Before the testing of these prisms, two lines with a gap of 5 cm from each of the ends are drawn. Now from this 5 cm lines, two more lines with a gap of 13.33 cm are drawn. This is for the purpose of three point loading. The prism is placed in the testing machine and then load is applied on the roller plate placed on the lines drawn on the prism. The prism is loaded until failure and the ultimate load is recorded. The flexural strength is calculated with the help of the formula given below.

$$F_b = P\ x \frac{L}{B\ x\ D\ x\ D}\ \text{N/mm}^2 \text{ (when tensile crack length is greater than 13.33cm)}$$

$$F_b = \frac{3Pa}{B\ x\ D\ x\ D}\ \text{N/mm}^2 \text{ (when tensile crack length is between 11.0cm to 13.33cm)}$$

Where,

F_b = Flexural strength of the specimen.

P = maximum load applied to the specimen.

L = Length in mm of the span on which the specimen was supported.

B = width of the specimen.

D = depth of specimen.

4.7 Durability

Durability is defined as the ability of concrete to withstand factors of weathering, abrasive actions, and exposure to freeze and thaw characteristics. In this thesis main focus was given to the resistance of concrete with GGBS towards acid attack. H_2SO_4 was chosen for the test.

4.7.1 Sulphuric Acid

Sulphuric acid attack causes extensive formation of gypsum in the regions close to the surfaces, and tends to cause disintegration mechanical stresses which ultimately lead to spalling and exposure of the fresh surface. Owning to the poor penetration of Sulphuric acid, the chemical changes of the cement matrix are restricted to the regions close to the surfaces. The chemical reactions involved are:

$$Ca(OH)_2 + H_2SO_4 \longrightarrow CaSO_4 + 2H_2O$$

$$3CaO + 2SiO_2 + 3H_2O + H_2SO_4 \longrightarrow CaSO_4 + 2H_2O + Si(OH)_4$$

5. Discussion of Test Results

5.1 Workability

The values of slump cone test, compaction factor and Vee-Bee time obtained from present investigation are presented in Table 5, 6 and 7 respectively. The slump and the compaction factor values are decreasing, whereas the Vee-Bee time is increasing as the quantity of GGBS is increasing.

Table 5 Workability in terms of Slump Cone test.

Grade of Concrete	M20				
Percentage Replacement of GGBS	0%	10%	20%	30%	40%
Slump (mm)	28	39	48	54	59
Percentage of Admixture required for Slump (25-75mm)	0.4%	0.5%	0.6%	0.7%	0.8%

Table 6- Workability in terms of Compaction Factor test

Grade of concrete	M20				
Percentage Replacement of GGBS	0%	10%	20%	30%	40%
Compaction factor	0.77	0.77	0.84	0.85	0.91

Table 7- Workability in terms of Vee-Bee time

Grade of concrete	M20				
Percentage Replacement of GGBS	0%	10%	20%	30%	40%
Vee-Bee time	15.61	17.41	9.86	13	9.52

5.2 Compressive strength

The results of compressive strength are obtained and are presented in Table 8. The variation of compressive strength with respect to GGBS content is shown in figure 1.

Table 8 Compressive strength values

Compressive strength at the age (days)	M20+0% GGBS (MPa)	M20+10% GGBS (MPa)	M20+20% GGBS (MPa)	M20+30% GGBS (MPa)	M20+40% GGBS (MPa)
7	18.94	20.13	23.14	22.12	21.16
28	28.12	30.14	32.94	30.96	29.14
56	31.26	34.24	37.02	35.21	34.02
91	34.48	37.97	40.02	38.96	36.23

From the charts it can be observed that with the increase in the quantity of GGBS up to 20%, the compressive strength has increased by 17.14% over conventional concrete. Hence 20% of GGBS can be taken as optimum content.

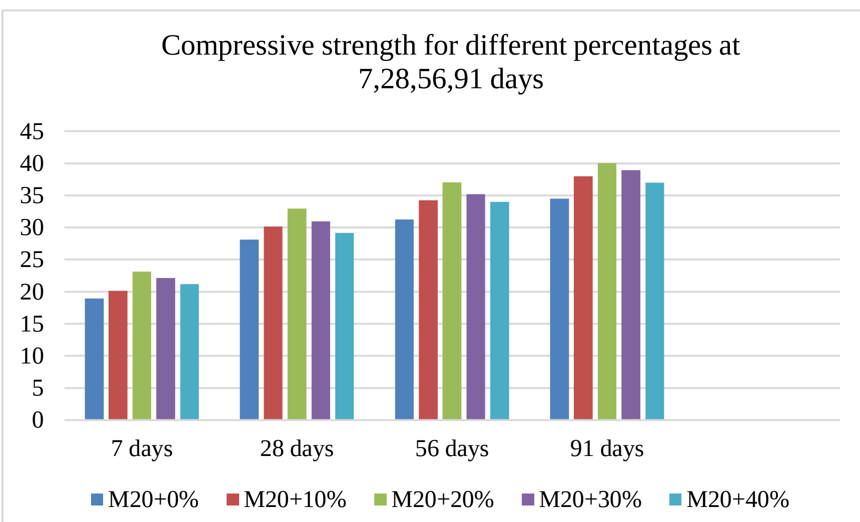

Fig 1. Compressive strength (N/mm^2)

5.3 Split Tensile strength

The results of split tensile strength are obtained and are presented in Table 9. The variation of split tensile strength with respect to GGBS is shown in Fig 2.

Table 9. Split Tensile strength values

Split Tensile strength at the age (days)	M20+0% GGBS (MPa)	M20+10% GGBS (MPa)	M20+20% GGBS (MPa)	M20+30% GGBS (MPa)	M20+40% GGBS (MPa)
7	1.65	2.17	2.28	2.24	1.95
28	2.73	2.92	3.06	2.66	2.54
56	3.30	3.32	3.52	2.50	2.62
91	3.31	3.44	3.53	3.31	3.02

From the charts it can be observed that with the increase in the quantity of GGBS up to 20%, the split tensile strength has increased by 12.09% over conventional concrete. Hence 20% of GGBS can be taken as optimum content.

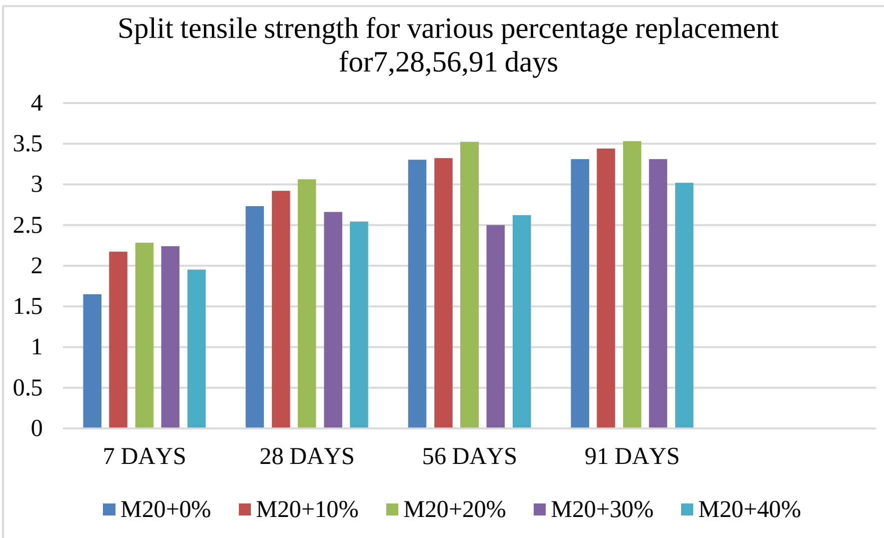

Fig 2. Split Tensile strength (N/mm^2)

5.4 Flexural Strength

The results of flexural strength are obtained and are presented in Table 10. The variation of flexural strength with respect to GGBS is shown in figure 3.

Table 10. Flexural Strength values

Flexural strength at the age (days)	M20+0% GGBS (MPa)	M20+10% GGBS (MPa)	M20+20% GGBS (MPa)	M20+30% GGBS (MPa)	M20+40% GGBS (MPa)
7	4.05	4.34	5.46	4.70	4.23
28	5.12	5.34	5.99	5.59	5.20
56	5.32	5.64	6.04	5.76	5.70
91	5.64	5.89	6.09	5.72	5.20

From the charts it can be observed that with the increase in the percentage of GGBS up to 20%, the flexural strength has increased by 16.99% over conventional concrete. Hence 20% of GGBS can be taken as optimum content.

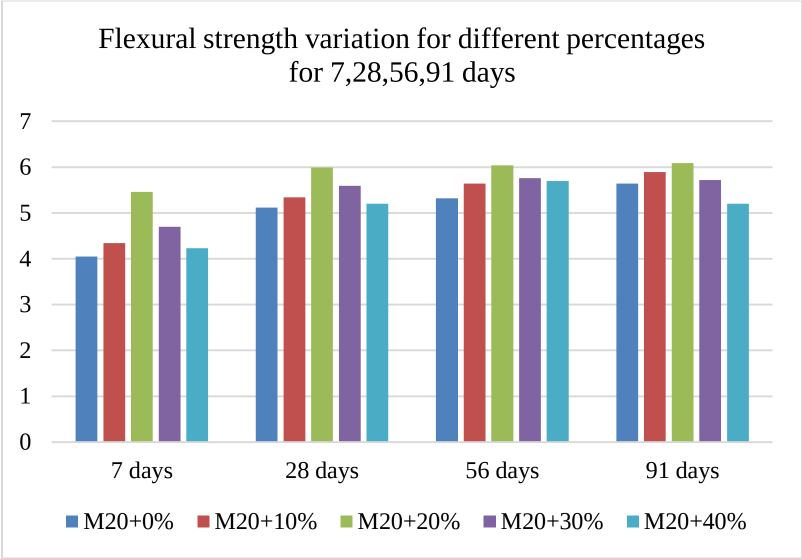

Fig 3. Flexural strength (N/mm^2)

5.5 Compressive Strength of Acid treated Specimens

The comparison of 28 days compressive strength with 91 days acid treated compressive strength with the increase in GGBS content for M20 grade concrete was tabulated in Table 11 and shown in figure 4.

Table 11. Compressive strength of acid treated cubes

Compressive strength at the age (days)	M20+0% GGBS (MPa)	M20+10% GGBS (MPa)	M20+20% GGBS (MPa)	M20+30% GGBS (MPa)	M20+40% GGBS (MPa)
Before acid treatment	28.12	30.14	32.94	30.96	29.14
After acid treatment	27.12	28.96	31.85	29.14	27.33

It is observed that 20% replacement of cement with GGBS is giving better resistance to acid attack for M20 grade concrete compared to other proportions of mixes. The decrease in compressive strength is of order 3.56%, 3.92%, 3.31%, 5.88%, 6.21% for 0%, 10%, 20%, 30%, 40% replacement with GGBS respectively.

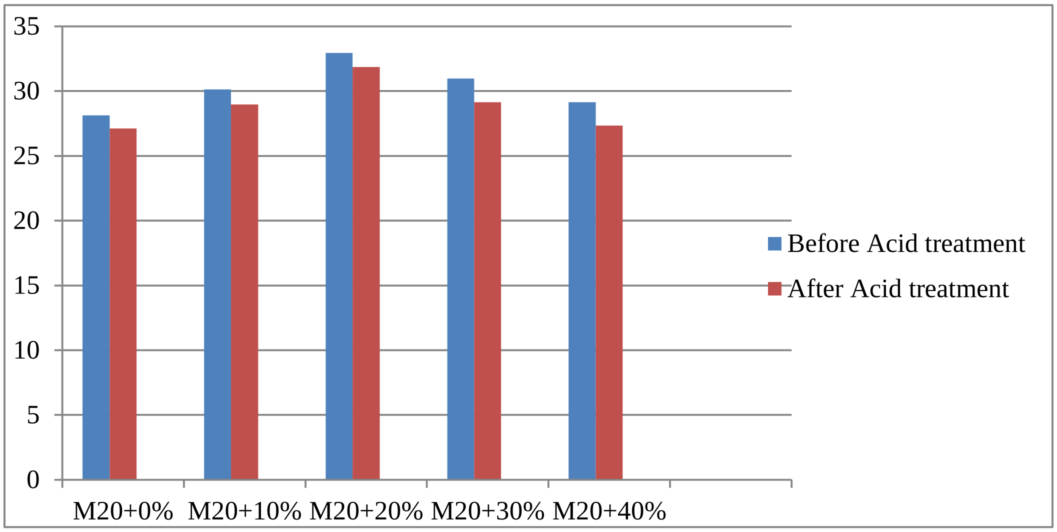

Fig 4. 91 days acid treated cubes

5.6 Split tensile strength of Acid treated Specimens

The comparison of 28 days split tensile strength with 91 days acid treated split tensile strength with the increase in GGBS content for M20 grade concrete was tabulated in Table 12 and shown in figure 5.

Table 12. Split Tensile strength of acid treated cylinder

Description	M20+0% GGBS (MPa)	M20+10% GGBS (MPa)	M20+20% GGBS (MPa)	M20+30% GGBS (MPa)	M20+40% GGBS (MPa)
Before acid treatment	2.73	2.92	3.06	2.66	1.91
After acid treatment	2.54	2.78	2.99	2.50	2.43

It is observed that 20% replacement of cement with GGBS is giving better resistance to acid attack for M20 grade concrete compared to other proportions of mixes. The decrease in split tensile strength is of order 6.96%, 4.79%, 2.28%, 6.01%, 4.33% for 0%, 10%, 20%, 30%, 40% replacement with GGBS respectively.

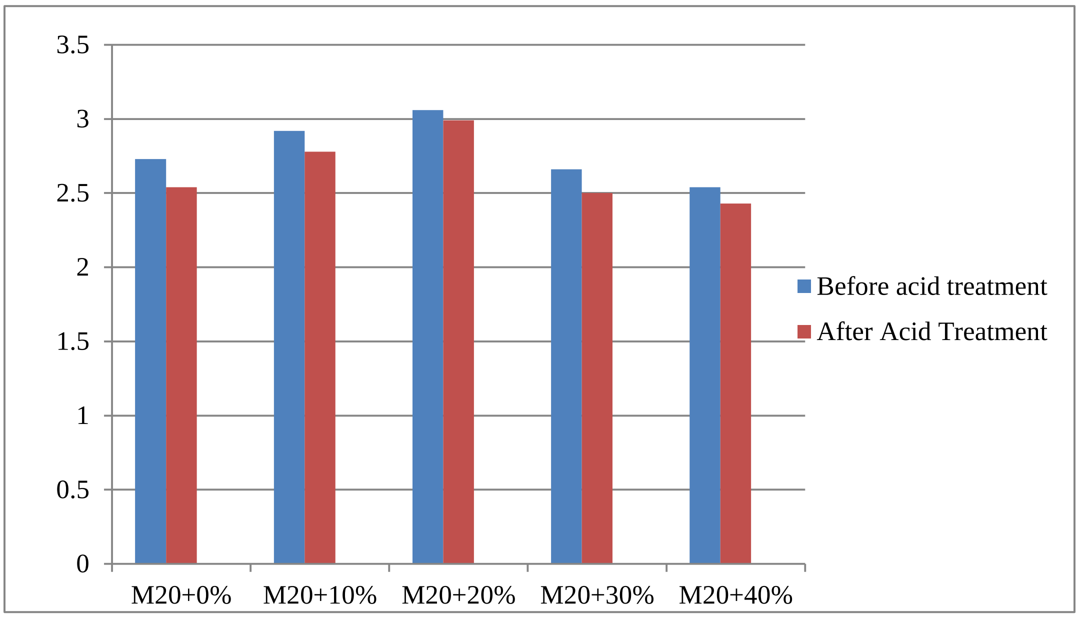

Fig 5. 91 days acid treated cylinders

5.7 Flexural Strength of Acid Treated Specimens

The comparison of 28 days flexural strength with 91 days acid treated flexural strength with the increase in GGBS content for M20 grade concrete was tabulated in Table 13 and shown in figure 6.

Table 13. Flexural Strength of acid treated prisms

Description	M20+0% GGBS (MPa)	M20+10% GGBS (MPa)	M20+20% GGBS (MPa)	M20+30% GGBS (MPa)	M20+40% GGBS (MPa)
Before acid treatment	5.12	5.34	5.99	5.59	5.20
After acid treatment	5.02	5.26	5.90	5.42	5.00

It is observed that 20% replacement of cement with GGBS is giving better resistance to acid attack for M20 grade concrete compared to other proportions of mixes. The decrease in flexural strength is of order 1.95%, 1.49%, 1.33%, 3.04%, 3.85% for 0%, 10%, 20%, 30%, 40% replacement with GGBS respectively.

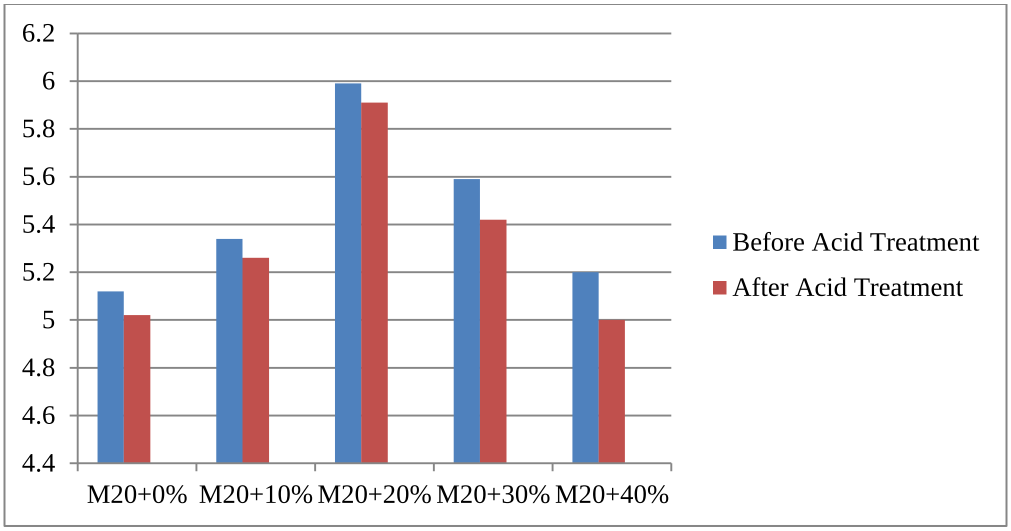

Fig 6. 91 days acid treated prisms

6. Conclusions

Results were analyzed to derive useful conclusions regarding the workability, strength characteristics of concrete with replacement of cement in different proportions for M20 grade concrete. The following conclusions were drawn from the study.

1. The GGBS can be used as a best alternative material for partial replacement of cement and gives more compressive strength in order of 3.63% to 17.14% for M20 grade concrete than conventional concrete.
2. The slump values of concrete with GGBS were observed to be relatively higher when compared to conventional concrete.
3. As the percentage of replacement of GGBS increases the slump increases and compaction factor increases which shows increase in workability.
4. The slump in terms of Vee-Bee time decreases with increase in percentage replacement of GGBS.
5. It is observed that 20% replacement of cement by GGBS is giving better compressive strength for M20 grade concrete compared to other proportions of mixes.
6. It is observed that 20% replacement of cement by GGBS is giving better split tensile strength for M20 grade concrete compared to other proportions of mixes.
7. It is observed that 20% replacement of cement by GGBS is giving better flexural strength for M20 grade concrete compared to other proportions of mixes.
8. The increase in compressive strength for M20 grade concrete is of order 0%, 7.18%, 17.14% 10.09%, 3.63% for 0%, 10%, 20%, 30%, 40% replacement with GGBS.
9. The increase in split tensile strength for M20 grade concrete is of order 0%, 6.96%, 12.09%, 2.56%, 6.96% for 0%, 10%, 20%, 30%, 40% replacement with GGBS.
10. The increase in flexural strength for M20 grade concrete is of order 0%, 4.29%, 16.99%, 9.17%, 1.56% for 0%, 10%, 20%, 30%, 40% replacement with GGBS.
11. It is observed that 20% replacement of cement with GGBS is giving better resistance to acid attack for M20 grade concrete compared to other proportions of mixes.
12. The decrease in compressive strength for M20 grade concrete is of order 3.56%, 3.92%, 3.31%, 5.88%, 6.21% for 0%, 10%, 20%, 30%, 40% replacement with GGBS.
13. The decrease in split tensile strength for M20 grade concrete is of order 6.96%, 4.79%, 2.28%, 6.01%, 4.33% for 0%, 10%, 20%, 30%, 40% replacement with GGBS.
14. The decrease in flexural strength for M20 grade concrete is of order 1.95%, 1.49%, 1.33%, 3.04%, 3.85% for 0%, 10%, 20%, 30%, 40% replacement with GGBS.

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