# Strength and Durability Studies on GGBS Concrete

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**Abstract** *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 the extraction of raw material and $CO_2$ emission during cement manufacture. This brought pressures on researchers for the reduction of cement consumption by partial replacement of cement by supplementary materials. These materials may be naturally occurring, industrial wastes or by-products that are less energy intensive. These materials (called pozzalonas) when combined with calcium hydroxide, exhibits cementetious properties. Most commonly used pozzalonas are fly ash, silica fume, metakaolin, ground granulated blast furnace slag (GGBS). This needs to examine the admixtures performance when blended with concrete so as to ensure a reduced life cycle cost. The present paper focuses on investigating characteristics of M20 and M40 grade concrete with partial replacement of cement with ground granulated blast furnace slag (GGBS) by replacing cement via 30%, 40%, 50%. The cubes, cylinders and prisms are tested for compressive strength, split tensile strength, flexural strength. Durability studies with sulphuric acid and hydrochloric acid were also conducted.*

**Keywords —** *GGBS blended concrete, strength, Put your keywords here, keywords are separated by comma.*

## I INTRODUCTION

### 1.1 General

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 the extraction of raw material and $CO_2$ emission during cement manufacture. This brought pressures on researchers for the reduction of cement consumption by partial replacement of cement by supplementary materials. These materials may be naturally occurring, industrial wastes or by-products that are less energy intensive. These materials (called pozzalonas) when combined with calcium hydroxide, exhibits cementetious properties. Most commonly used pozzalonas are fly ash, silica fume, metakaolin, ground granulated blast furnace slag (GGBS). This needs to examine the admixtures performance when blended with concrete so as to ensure a reduced life cycle cost. There are competing reasons, in the long term, to extend the practice of partially replacing cement with waste by products and processed materials possessing pozzolanic properties. Lately some attention has been given to the use of natural pozzolans like GGBS as a possible partial replacement for cement. Amongst the various methods used to improve the durability of concrete, and to achieve high performance concrete, the use of GGBS is a relatively new approach, the chief problem is with its extreme finesse and high water requirement when mixed with Ordinary Portland cement.

The present paper focuses on investigating characteristics of M20 and M40 grade concrete with partial replacement of cement with GGBS by replacing cement via 30%, 40%, 50%. The cubes, cylinders and prisms are tested for compressive strength, split tensile strength, flexural strength. Durability studies with sulphuric acid and hydro chloric acid were also conducted.

Numerous works have been done researchers across the globe and some of the important contributions are presented here.

## II REVIEW OF LITERATURE

**Venu Malagavelli et al.** [1] studied on high performance concrete with GGBS and robo sand nd concluded that the percentage increase of compressive strength of concrete is 11.06 and 17.6% at the age of 7 and 28 days by replacing 50% of cement with GGBS and 25% of sand with ROBO sand. **Luo et al.** [2] experimentally studied the chloride diffusion coefficient and the chloride binding capacity of Portland cement or blended cement made of Portland cement and 70 % GGBS replacement with or without 5 % sulphate. They found that (i) chloride diffusion coefficient decreased; (ii) chloride ion binding capacity improved in samples of blended cement. **Clear** [3] concluded that higher the proportion of GGBS, the slower the early age strength development. **Oner and Akyuz** [4] studied on optimum level of GGBS on compressive strength of concreteand concluded that the optimum level of GGBS content for maximizing strength is at about 55–59% of the total binder content. **Qian Jueshi and Shi Caijun** [5] studied on high performance cementing materials from industrial slag and reviewed the recent progresses in the activation of latent cementitious properties of different slag. They opined that Alkali-activated slag, such as blast furnace slag, steel slag, copper slag and phosphorus slag should be a prime topic for construction materials researchers. **Ganesh Babu and Sree Rama Kumar** [6] studied on efficiency of GGBS in Concrete. **Wainwright** [7] conducted Bleed tests in accordance with

ASTM C232-92 on concretes in which up to 85% of the cement was replaced with ground granulated blastfurnace slag (GGBS) obtained from different sources. They observed that delaying the start of the bleed test from 30 to 120 min reduced the bleed capacity of the OPC mix by more than 55% compared with 32% for the slag mixes. The reduction in bleed rate was similar for all mixes at about 45%. **Tamilarasan et al.** [7] studied on Chloride diffusion of concrete on using GGBS as a partial replacement material for cement and without and with Superplasticiser. The study results showed that, with the increase in percentage of GGBS, the Chloride diffusion of concrete decreases. Also it is found that the Chloride diffusion in the M25 concrete is less than M20 concrete. **Soutsos et al.** [8] studied on fast track construction with high-strength concrete mixes containing Ground Granulated Blast Furnace Slag. They showed that the existing maturity functions like the Nurse-Saul and the Arrhenius equation may not be suitable for GGBS concretes. **Pavia and Condren** [9] studied the durability of OPC versus GGBS Concrete on Exposure to Silage Effluent. This research concluded that PC composites incorporating GGBS are more durable than those made with PC alone in aggressive environments under the action of acids and salts such as those produced by silage. **Ashish kumar dash et al.** [10] researched on different materials like rice husk ash, GGBS, silica fume to obtain the desired needs. **Higgins** [11] discussed on the effect of addition of a small percentage of calcium carbonate or calcium sulfate on the sulfate resistance of concrete containing GGBS. **Pazhani and Jeyaraj** [12] conducted experimental investigation to assess the durability parameters of high performance concrete with the industrial wastes. **Shariq Prasad et al.** [13] studied the effect of curing procedure on the compressive strength development of cement mortar and concrete incorporating ground granulated blast furnace slag is studied. The compressive strength of OPC concrete shows higher strength as compare to the GGBFS based concrete for all percent replacement and at all ages. Incorporating 40% GGBFS is highly significant to increase the compressive strength of concrete after 56 days than the 20 and 60% replacement. Among GGBFS based concrete 40% replacement is found to be optimum. **Stanley** [14] studied on the use of iron blast-furnace slag as a constituent of concrete, either as an aggregate or as a cementing material. **Hanifi Binici et al.** [15] studied on blended cements containing corncob ash (CA) and GGBS. They concluded that The CA and GGBFS containing cements, immersed in sulfate solution showed 15% lower average compressive strength than that of the control cement specimens at the end of 24 months. Greater resistances of blended cements against sodium sulfate were achieved with higher percentage of additives. **Puertas et al.** [16] analyzed the behaviour of water glass- or NaOH-activated slag mortars after carbonation. The results obtained indicate that alkali-activated slag mortars were more intensely and deeply carbonated than Portland cement mortars. **Barnett et al.** [17] studied on the strength development of mortars containing GGBS and portland cement. They concluded that the early age strength development of mixtures containing GGBS is highly dependent on temperature. **Wang Ling et al.** [18] studied the application of GGBS in China. **An Cheng, Ran Huang et al.** [19] investigated on the durability of GGBS concretes and the corrosion behavior of reinforced concrete beams under various loading ratios. **Olorunsogo et al.** [20] investigated the influence of particle size distribution (PSD) of GGBS on the bleeding characteristics of slag cement mortars. The results showed that for the slag samples with similar size range distribution (i.e., having a constant slope, *n*), the bleeding capacity increased with increases in $x_o$, except the 30% slag mixes, which were made to 0.35 w/c. **Huiwen Wan et. al.** [21] investigated the geometric characteristics of different GGBS, including particle size distribution (PSD), shape and their influences on cement properties.

All the above results are based on the properties of ingredients used. The optimum % replacement may vary based on the properties of GGBS and ingredients used. The main objective of this paper is to study the strength and durability characteristics of GGBS concrete with locally available fine and course aggregate.

## III EXPERIMENTAL PROGRAM

### 3.1 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 Mix proportions of OPC concrete for M20 and M40 by IS method (10262-2009).
3. To calculate the mix proportion with partial replacement such as 0%,30%, 40% and 50%of GGBS with OPC.
4. To prepare the concrete specimens such as cubes for compressive strength, cylinders for split tensile test, prisms for flexural strength and also cubes for durability studies in laboratory with 0%, 10%, 20% and 30% replacement of GGBS with OPC for M20 and M40 grade concrete.
5. To cure the specimens for 28 days and 90 days.
6. To evaluate the mechanical characteristics of concrete such as compressive strength, split tensile test, flexural strength.
7. To evaluate the durability studies of M20 and M40 grade GGBS replacement concrete, with 1% and 5% concentrations of Hydro chloric acid (HCl) and Sulphuric acid ($H_2So_4$).
8. To evaluate and compare the results.
9. To check the economic viability of the usage of GGBS, Keeping in view of the safety measures.

### 3.2 Properties of ingredients of concrete

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

CEMENT

Ordinary Portland cement of43 grade (Parashakthi) was used in this investigation. The properties of cement are as follows.

Specific gravity: 3.15 (Density bottle method)
Fineness test: 8% (Sieve test)
Initial setting time: 90 min. (Vicat's apparatus)
Final setting time: 3 hrs 30 min. (Vicat's apparatus)
Standard consistency: 33% (Vicats apparatus)

FINE AGGREGATE

Aggregates smaller than 4.75 mm and up to 0.075 mm are considered as fine aggregate. The properties of fine aggregate are as follows.

Specific gravity: 2.52 (Density bottle method)
Fineness modulus: 2.25 (Sieve analysis)
Water Absorption of Sand: 1.0%
Free (Surface) Moisture of Sand: Nil
Sieve Analysis of Fine Aggregate: Conforming to Zone III of table 4 of IS 383

COARSE AGGREGATES

Aggregates greater than 4.75 mm are considered as coarse aggregates. The properties of course aggregate are as follows.

Specific gravity: 2.71
Fineness modulus: 7.27
Water Absorption of 20 mm Aggregate: 0.5%
Free (Surface) Moisture of 20 mm Aggregate: Nil
Sieve Analysis of Coarse Aggregate: Confirming to Table II of IS: 383

GGBS

In the present investigation GGBS marketed by Gajapathi Cements is used. The results furnished by the manufacturer are presented in Table 1.

**Table 1**
**Physical and Chemical properties of GGBS**

| CHEMICAL COMPOSITION | | PHYSICAL PROPERTIES | |
|---|---|---|---|
| Calcium oxide | 40% | Colour | off-white |
| Silica | 35% | Specific gravity | 2.9 |
| Alumina | 13% | Bulk density | 1200 kg/m3 |
| Magnesia | 8% | Fineness | >350m2/kg |

### 3.3 Mix Design (as per IS 10262: 2009)

The following specifications were considered for Mix design.

| | |
|---|---|
| Type of Cement | OPC 43 grade |
| Maximum Nominal Aggregate Size | 20 mm |
| Minimum Cement Content | 310 kg/m$^3$ |
| Maximum Water Cement Ratio | 0.55 |
| Workability (Slump) | 25-50 mm |
| Exposure Condition | Mild |
| Degree of Supervision | Good |
| Type of Aggregate | Crushed Angular Aggregate |
| Maximum Cement Content | 540 kg/m$^3$ |
| Chemical admixture type | No |
| Type of fine aggregate | Normal river sand |
| Type of vibration | Mechanical |

The mix proportions for One m$^3$ of concrete are presented in Table 2.

**Table 2**
**Mix Proportions for One m$^3$ of concrete**

| Grade | Cement | Fine aggregate | Course aggregate | Water | w/c ratio |
|---|---|---|---|---|---|
| Units | kg/m$^3$ | kg/m$^3$ | kg/m$^3$ | kg/m$^3$ | |
| M20 | 338.2 | 641.07 | 1226 | 186 | 0.55 |
| M40 | 442.85 | 610.54 | 1167.54 | 186 | 0.42 |

The designed ratio for M20 is 1:1.9: 3.62: 0.55 and for M40 is 1:1.38: 2.64: 0.42.

Among the trail mix conducted, the above mix gave required workability and required strength.

### 3.4 Replacement of Cement with GGBS

The mix proportions with partial replacement of OPC with 0%, 30%, 40% and 50% of GGBS are calculated.

**Mix Proportions for M20 grade concrete**

Conventional Concrete – 1:1.9: 3.62: 0.55
30% replacement- 0.7:1.9: 3.62: 0.55
40% replacement – 0.6:1.9: 3.62: 0.55
50% replacement – 0.5:1.9: 3.62: 0.55

**Mix Proportions for M40 grade concrete**

Conventional Concrete – 1:1.38: 2.64: 0.42
30% replacement- 0.7:1.38: 2.64: 0.42
40% replacement – 0.6:1.38: 2.64: 0.42
50% replacement – 0.5:1.38: 2.64: 0.42

### 3.5 Casting and curing of test specimens

The specimens of standard cubes (l50 mm X 150 mm X 150 mm) 9 No.'s, Standard prisms (100 mm x 100 mm x 500 mm) 3 No.'s and Standard cylinders of (150 mm diameter 300 mm height) 3 No.'s are cast for each cycle. In all 240 specimens the cement was replaced by GGBS by (0%, 30%, 40% and 50%) with M20 case and M40 mix case were cast for 28 days and 90 days curing.

### 3.6 Curing

24 hours after casting the test specimens, cubes, cylinders and prisms are de-moulded and immediately immersed in clean and fresh water tank and allow it for curing for 28 days and for 90 days in potable water. Specimens were also cured in 1% $H_2SO_4$ acid and 1% HCl acid for 90 days and 5% $H_2So_4$ acid curing, 5% HCl acid curing for 28 days.

## IV RESULTS AND DISCUSSION

### 4.1 Tests for Workability

The results on tests for workability are shown in Table 3 and Table 4.

**Table 3**
**Slump and Compaction Factor Values for M20**

| Sl. No. | Description | Compaction Factor | Slump (mm) |
|---|---|---|---|
| 1 | Plain Concrete | 0.87 | 40 |
| 2 | 30% GGBS | 0.89 | 43 |
| 3 | 40 % GGBS | 0.89 | 49 |
| 4 | 50 % GGBS | 0.9 | 52 |

**Table 4**
**Slump and Compaction Factor Values for M40**

| Sl. No. | Description | Compaction Factor | Slump (mm) |
|---|---|---|---|
| 1 | Plain Concrete | 0.85 | 22 |
| 2 | 30% GGBS | 0.852 | 34 |
| 3 | 40 % GGBS | 0.87 | 41 |
| 4 | 50 % GGBS | 0.883 | 44 |

### 4.2 Compressive Strength of Concrete

CTM of 2000 kN capacity was used with load rate of approximately 140 kg/cm /min until failure for Compressive strength test. The test results for compressive strength are presented in Tables 5 and Table 6 (0%, 30%, 40% and 50% of GGBS concrete) for M20 and M40 grades of concrete at room temperature for 28 and 90 days respectively.

**Table 5**
**Compressive Strength of concrete for M20**

| Sl. No. | % of GGBS | Compressive Strength ($N/mm^2$) | |
|---|---|---|---|
| | | 28 days | 90 days |
| 1 | 0 | 33.3 | 46.2 |
| 2 | 30 | 35 | 50.11 |
| 3 | 40 | 36.42 | 52.49 |
| 4 | 50 | 32.2 | 48.12 |

**Table 6**
**Compressive Strength of concrete for M40**

| Sl. No. | % of GGBS | Compressive Strength ($N/mm^2$) | |
|---|---|---|---|
| | | 28 days | 90 days |
| 1 | 0 | 49.99 | 54.22 |
| 2 | 30 | 51.12 | 55.02 |
| 3 | 40 | 53.6 | 57.46 |
| 4 | 50 | 50.12 | 54.27 |

### 4.3 Split tensile strength of concrete

For split tensile strength, the load was applied without shock and increased continuously at a nominal rate within the range 1.2 $N/mm^2$/min to 2.4 $N/mm^2$/min until failure of the specimen. The test results for split tensile strength are presented in Tables 7 and Table 8 (0%, 30%, 40% and 50% of GGBS concrete) for M20 and M40 grades of concrete at room temperature for 28 and 90 days respectively.

**Table 7**
**Split tensile strength of M20 grade concrete**

| Sl. No. | % of GGBS | Split tensile Strength ($N/mm^2$) | |
|---|---|---|---|
| | | 28 days | 90 days |
| 1 | 0 | 2.69 | 3.5 |
| 2 | 30 | 2.85 | 3.6 |
| 3 | 40 | 3.05 | 3.85 |
| 4 | 50 | 2.75 | 3.57 |

**Table 8**
**Split tensile strength of M40 grade concrete**

| Sl. No. | % of GGBS | Split tensile Strength ($N/mm^2$) | |
|---|---|---|---|
| | | 28 days | 90 days |
| 1 | 0 | 3.11 | 3.67 |
| 2 | 30 | 3.33 | 3.85 |
| 3 | 40 | 3.74 | 4.15 |
| 4 | 50 | 3.18 | 3.71 |

Figure 1 and 2 show the specimens under testing for compressive strength and Split tensile strength.

**Figure 2 Compressive Strength testing**

**Figure 5 Split Tensile Strength testing**

### 4.4 Flexural strength of concrete

The prism specimens was placed in the machine in such a manner that the load was applied to the uppermost surface as cast in the mould, along two lines spaced 13.33cm 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, 38mm in diameter, mounted at the third points of the supporting span that is spaced at 13.33cm center 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 presented in Tables 9 and 10 for 0%, 30%, 40% and 50% of GGBS concrete for M20 and M40 grades of concrete at room temperature for 28 and 90 days respectively.

**Table 9**
**Flexural tensile strength of M20 grade concrete**

| Sl. No. | % of GGBS | Flexural tensile Strength ($N/mm^2$) | |
|---|---|---|---|
| | | 28 days | 90 days |
| 1 | 0 | 5.21 | 6.51 |
| 2 | 30 | 5.60 | 7.05 |
| 3 | 40 | 5.82 | 7.77 |
| 4 | 50 | 5.3 | 6.8 |

**Table 10**
**Flexural tensile strength of M40 grade concrete**

| Sl. No. | % of GGBS | Flexural tensile Strength ($N/mm^2$) | |
|---|---|---|---|
| | | 28 days | 90 days |
| 1 | 0 | 6.1 | 7.02 |
| 2 | 30 | 6.42 | 7.42 |
| 3 | 40 | 7.02 | 7.9 |
| 4 | 50 | 6.25 | 7.1 |

### 4.5 Durability Studies with $H_2SO_4$ and HCl

Concrete cubes of 150 x 150 x 150 $mm^3$ size were cast for durability studies for 2 grades (M20 and M40) of concrete.

1% $H_2SO_4$, 1% HCl concentration for 90 days curing and 5% $H_2SO_4$, 5% HCl concentration for 28 days curing were considered for durability studies. Each grade consists of 4 series 0%, 20%, 30% and 40% and hence each grade contains 96 cubes placed in individual tubs for each concentration. The normality of the solution was checked for every 2 days. The Compressive strength of cubes exposed to $H_2SO_4$ and HCl are tested for compressive strength and results were presented from Tables 11, 12, 13 and 14 for 0%, 30%, 40% and 50% of GGBS concrete for M20 and M40 grades of concrete at room temperature for 28 and 90 days respectively. Figure 3 shows acid affected concrete cubes.

**Table 11**
**Compressive strength for M20 grade concrete after $H_2SO_4$ Acid curing.**

| Sl. No. | % of GGBS | Compressive Strength (N/mm$^2$) | |
|---|---|---|---|
| | | 28 days (5% $H_2SO_4$) | 90 days (1% $H_2SO_4$) |
| 1 | 0 | 26.2 | 36.5 |
| 2 | 30 | 29.29 | 42.12 |
| 3 | 40 | 32.8 | 46.52 |
| 4 | 50 | 28.4 | 38.26 |

**Table 12**
**Compressive strength for M40 grade concrete after $H_2SO_4$ Acid curing.**

| Sl. No. | % of GGBS | Compressive Strength (N/mm$^2$) | |
|---|---|---|---|
| | | 28 days (5% $H_2SO_4$) | 90 days (1% $H_2SO_4$) |
| 1 | 0 | 39.26 | 43.22 |
| 2 | 30 | 41.44 | 46.7 |
| 3 | 40 | 45.81 | 51.28 |
| 4 | 50 | 41.62 | 46.47 |

**Table 13**
**Compressive strength for M20 grade concrete after HCl Acid curing.**

| Sl. No. | % of GGBS | Compressive Strength (N/mm$^2$) | |
|---|---|---|---|
| | | 28 days (5% HCl) | 90 days (1% HCl) |
| 1 | 0 | 26.4 | 37.62 |
| 2 | 30 | 29.58 | 42.5 |
| 3 | 40 | 33.2 | 47.25 |
| 4 | 50 | 29.12 | 43.49 |

**Table 14**
**Compressive strength for M40 grade concrete after HCl Acid curing.**

| Sl. No. | % of GGBS | Compressive Strength (N/mm$^2$) | |
|---|---|---|---|
| | | 28 days (5% HCl) | 90 days (1% HCl) |
| 1 | 0 | 40.44 | 44.52 |
| 2 | 30 | 42.77 | 47.27 |
| 3 | 40 | 47.24 | 53.2 |
| 4 | 50 | 43.64 | 48.2 |

**Figure 3 Acid effected concrete cubes**

## V DISCUSSION ON RESULTS

### 5.1 Effect of variation of GGBS on compressive strength

The compressive strength of concrete for 28 days, 90 days for 0%, 30%, 40% and 50% replacement of GGBS and the values are presented in Figure 4 and 5.

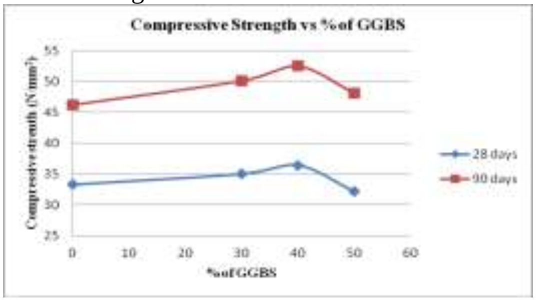


**Figure 4 Compressive Strength of concrete for M20 vs % of GGBS**

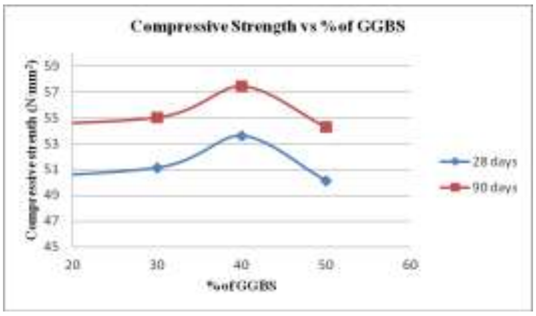


**Figure 5 Compressive Strength of concrete for M40 vs % of GGBS**

From Figure 4 and 5, it is observed that at about 40% replacement of cement with GGBS, concrete attains its maximum compressive strength for both M20 and M40 grade concretes, when the replacement exceeds 40%, the compressive is found to be decreasing slightly. And 30% replacement of GGBS is greater than the 50% replacement of GGBS.

### 5.2 Effect of Variation of GGBS on Split Tensile Strength

The split tensile strength of concrete is tested for 28 days, 90 days for 0%, 30%, 40% and 50% replacement of GGBS and the values are presented Figure 6 and 7.

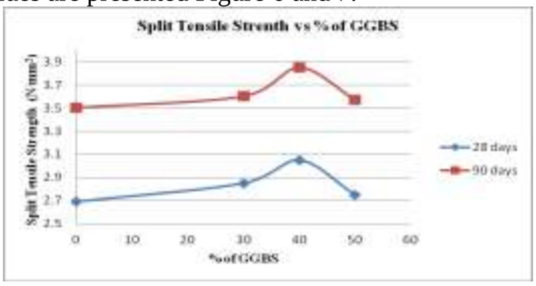


**Figure 6 Split Tensile Strength of concrete for M20 vs % of GGBS**

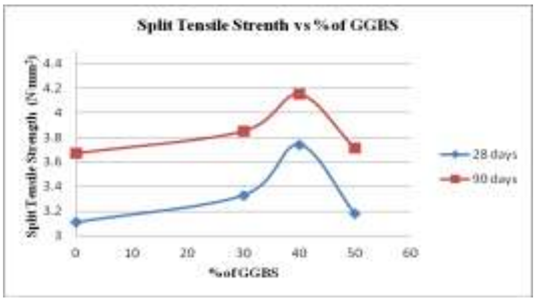


**Figure 7 Split Tensile Strength of concrete for M40 vs % of GGBS**

From Figure 6 and 7, it is observed that at about 40% replacement of cement with GGBS, concrete attains its maximum split tensile strength for both M20 and M40 grade concretes, when the replacement exceeds 40%, the compressive is found to be decreasing slightly. And 30% replacement of GGBS is greater than the 50% replacement of GGBS.

### 5.3 Effect of Variation of GGBS on Flexural Strength

The flexural strength of concrete is tested for 28 days, 90 days for 0%, 30%, 40% and 50% replacement of GGBS and the values are presented in Figure 8 and 9.

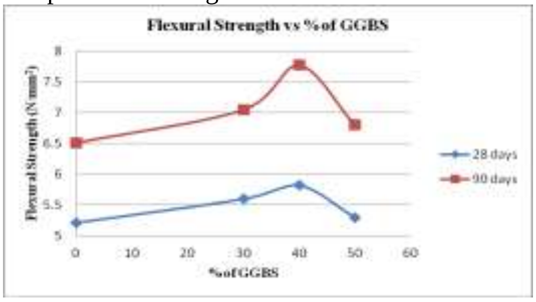


**Figure 8 Flexural Strength of concrete for M20 vs % of GGBS**

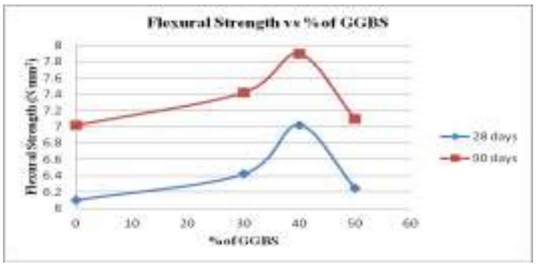


**Figure 9 Flexural Strength of concrete for M40 vs % of GGBS**

From Figure 8 and 9, it is observed that at about 40% replacement of cement with GGBS, concrete attains its maximum flexural strength for both M20 and M40 grade concretes, when the replacement exceeds 40%, the compressive is found to be decreasing slightly. And 30% replacement of GGBS is greater than the 50% replacement of GGBS.

### 5.4 Effect of $H_2SO_4$ and HCl acids on durability of Concrete

Concrete cubes of 0%, 30%, 40% and 50% of GGBS concrete of M20 and M40 grade concrete exposed to $H_2SO_4$ and HCl of 1% and 5% concentrations are tested for compressive strength for 90 days and 28 days respectively. The results are presented in Figure 10, 11, 12 and 13.

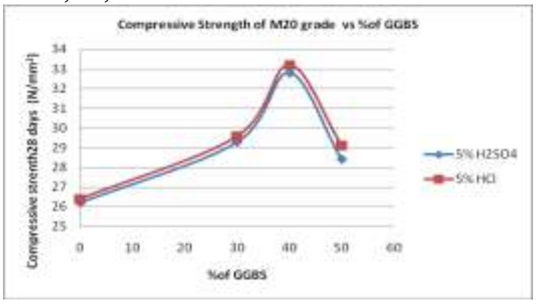


**Figure 10 Compressive Strength of concrete for M20 vs % of GGBS**

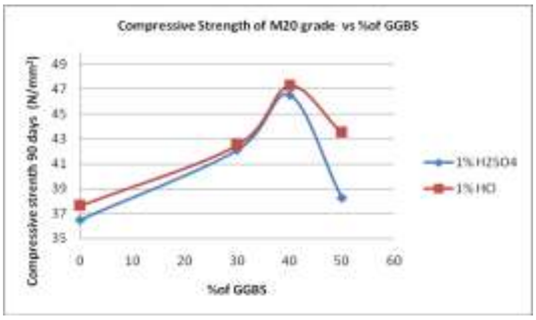


**Figure 11 Compressive Strength of concrete for M20 vs % of GGBS**

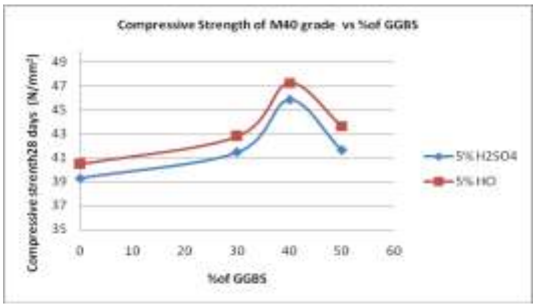


**Figure 12 Compressive Strength of concrete for M40 vs % of GGBS**

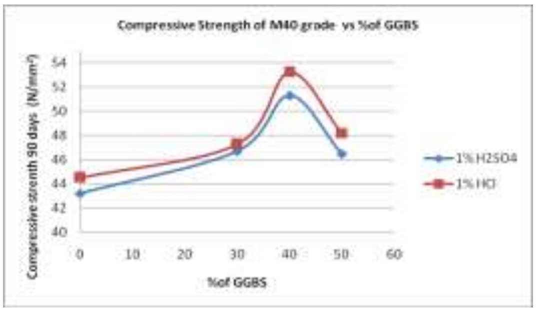


**Figure 13 Compressive Strength of concrete for M40 vs % of GGBS**

The following observations can be made from Figure 10, 11, 12 and 13.

**Effect of $H_2SO_4$**

The compressive strength values of 5% (28 days) and 1% (90 days) concentration $H_2SO_4$ containing M20 and M40 grade concrete decreases, but resistance power of concrete increases with replacement of GGBS against to $H_2SO_4$, up to 40% replacement resistance power increases beyond that resistance power decreases, but at 40% replacement of GGBS the resistance power of concrete is more.

**Effect of HCl**

The compressive strength values of 5% (28 days) and 1% (90 days) concentration HCl containing M20 and M40 grade concrete decreases, but resistance power of concrete increases with replacement of GGBS against to HCl, up to 40% replacement resistance power increases beyond that resistance power decreases, but at 40% replacement of GGBS the resistance power of concrete is more.

So the compressive strength values of acid effected concrete decreases on comparison with of normal concrete, but the effect of acid on concrete decreases with the increase of percentage of GGBS. At 40% replacement of GGBS the resistance power of concrete is more.

**Comparison of $H_2SO_4$ and HCl**

The compressive strength values of GGBS concrete effected to HCl were greater than the GGBS concrete effected to $H_2SO_4$. The effect of HCl on strength of the concrete is lower than the effect of $H_2SO_4$ on strength of the concrete

## VI CONCLUSIONS

Based on the analysis of experimental results and discussion there upon the following conclusions can be drawn.

1. Workability of concrete increases with the increase in GGBS replacement level.
2. The compressive strength of concrete increased when cement is replaced by GGBS for both M20 and M40 grade of concrete. At 40% replacement of cement by GGBS the concrete attained maximum compressive strength for both M20 and M40 grade of concrete.
3. The split tensile strength of concrete is increased when cement is replaced with GGBS. The split tensile strength is maximum at 40% of replacement.
4. The flexural strength of concrete is also increased when the cement is replaced by GGBS. At 40% replacement, the flexural strength is maximum.
5. The compressive strength values of acid effected concrete decreases on comparison with of normal concrete, but the effect of acid on concrete decreases with the increase of percentage of GGBS. At 40% replacement of GGBS the resistance power of concrete is more.
6. The compressive strength values of GGBS concrete effected to HCl were greater than the GGBS concrete effected to $H_2SO_4$. The effect of HCl on strength of the concrete is lower than the effect of $H_2SO_4$ on strength of the concrete

## SCOPE FOR FURTHER STUDY

1. Other levels of replacement with GGBS can be researched.
2. Combination of GGBS with different other admixture can be carried out.
3. Studies on replacements levels of high grade concrete can be carried out.
4. Beams with different shear span to effective depth ratios, varying percentages of tensile reinforcement and varying percentages of GGBS, may be investigated.
5. For use of GGBS concrete as a structural material, it is necessary to investigate the behavior of reinforced GGBS concrete under flexure, shear, torsion and compression.
6. Some tests relating to durability aspects such as water permeability, resistance to penetration of chloride ions, corrosion of steel reinforcement, durability in marine environment etc. need investigation.
7. The study may further be extended to know the behavior of concrete whether it is suitable for pumping purpose or not as present day technology is involved in ready mix concrete where pumping of concrete is being done to large heights.

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