An Experimental Investigation on Role of Geopolymer Concrete with GGBS in Rigid Pavements

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ABSTRACT
In this Era, Concrete is one of the most used construction material due to its durability and economy. India uses tonnes of ready-mixed concrete each year. It is in Streets, Buildings, Highways, Bridges, tunnels, Dams, Railway. It was an average that 3 tonne of concrete is used by each person on earth. CO₂ leads to global warming and it has a major part of green-house gases. Contribution of CO₂ is 65% and out of this 7% is only from cement industry. India, China & USA generally consuming most of concrete produced. It was estimated that cement manufacturing was rising 2.5%. On the other hand plenty of materials are available with which cement can be replaced (Wikipedia). It is helping a lot in reduction of emission of CO₂. Fly ash, slag, rise husk, GGBS are the things which are used for replacement. This concrete prepared is known as Geopolymer concrete. GPC is considered now complete replacement of cement. A lot of studies has been carried out by researcher that use of GGBS in Geopolymer concrete has improved the strength properties but its excess amount may reduce the strength. It has a history since 1940 but it is not so common till now[1].

Keywords:-GGBS, Molarity, Alkaline Activator Solutions, Rigid pavements, safety measures.

INTRODUCTION TO GGBS AND GGBS BASED GEOPOLYMER CONCRETE
GGBS is generally produced during the production of steel. Generally limestone, iron ore, coke are put into a kiln for the production of iron. At a temperature of 1600°C slag is produced approximately 40%-CaO & 30-40%-SiO₂ it is cementitious in nature. It hydrates like cement. It can also resist some chemical attacks. Molten iron is removed and slag contains residue have siliceous and aluminous properties. Now molten iron slag in water produces granulate slag. Rapid cooling is done to get granulated Slag. It is then dried and ground into fine powder to get GGBS. It was first introduced by Joseph Davidovits. In the year 1972 as an alternative of OPC. Geopolymer concrete have a good strength and it is quite suitable for various works such as Rigid pavements, buildings etc.

MATERIALS
The material used for making Geopolymer concrete were GGBS as source material aggregates(CA+FA), Alkaline solution and potable water.

Ground Granulated Blast Furnace Slag
It is a byproduct of steel industry and it includes all the constituents that an OPC has but the concentration is different. GGBS on GPC increases the strength of the concrete and it also makes the concrete curable at room temperature[2].

| Table1:-Chemical Composition of GGBS |
|--------------------------------------|
| Material (%) | Quantity present |
| CaO         | 0.31            |
| SiO₂        | 5.89            |
| Al₂O₃       | 0.25            |
| Glassy Content | 93.55       |
Table 2: Physical properties of GGBS

| Test performed          | Result | Method         |
|-------------------------|--------|----------------|
| Fineness                | 3.12   | IS 1727-1967   |
| Specific gravity        | 2.86   | IS 1727-1967   |
| Residue 45micron        | 2.97   | IS 1727-1967   |
| Residue 90micron        | 7.01   | IS 1727-1967   |

Table 3: Physical Properties of Fine Aggregates

| Physical properties of fine aggregates |
|---------------------------------------|
| Specific gravity                      | 2.56   |
| FM                                    | 3.16   |

Table 3: Properties of Course Aggregates

| Properties          | 10mm Result | 20mm Result |
|---------------------|-------------|-------------|
| Type                | Crushed     | Crushed     |
| Max. Size           | 10          | 20          |
| Specific Gravity    | 2.62        | 2.69        |
| FM                  | 1.25        | 1.97        |

Table 4: L-Sieve analysis of FA

| Sieve | Wt. Retained(kg) | % Retained | % passing | CWR |
|-------|------------------|------------|-----------|-----|
| 10mm  | 0.00             | 100        | 0.00      |     |
| 4.75mm| 652              | 21.70      | 78.30     | 21.70|
| 2.36mm| 247              | 8.23       | 70.07     | 29.3 |
| 1.18mm| 405              | 13.50      | 57.02     | 42.98|
| 600µ  | 198              | 6.60       | 50.42     | 49.58|
| 300µ  | 856              | 28.53      | 71.89     | 78.11|
| 150µ  | 543              | 18.10      | 3.97      | 95.29|
| Pan   | 99               | 3.30       | -         | -    |
| Total | 3000             | -          | -         | 316.96|

Sodium Hydroxide and Sodium Silicate

In this investigation commercial grade is adopted 97%-99% pure [2]. Generally Sodium Hydroxide was available in the form of pellets, flakes. All these things are used to make the solution of required molarity. If we talk about the sodium silicate, this is available in solution form and it was 98% pure.

These solutions taken in different fractions with sodium hydroxide to make good Alkaline Activator Solution. This is considered as alkaline activator solution and we are taking AAS ratio 2.5 for our study[3].

Table 5: Sodium hydroxide properties (Science sale Sonipat)

| S.NO | Properties               | Amount |
|------|--------------------------|--------|
| 1.   | Na₂CO₃ By mass           | 0.32   |
| 2.   | NaOH by mass(%)          | 99.52  |
| 3.   | NaCl(%)                  | 0.12   |

Table 6: Sodium silicate properties (Er. Manish DCRUST)

| S. No | Characteristics | Actual Value | Specified Value |
|-------|-----------------|--------------|-----------------|
| 1.    | Color           | Light gray   | Clean           |
| 2.    | Water           | 55.36%       | 55-57%          |
| 3.    | Density         | 51.76        | 51-54           |
| 4.    | SiO₂            | 31.2%        | 30-33           |
| 5.    | Na₂O            | 14.23        | 13-15           |
| 6.    | Total Solids    | 44.56        | 44%min          |

Table 7: Geopolymer Concrete mix

| Material (kg/m³) | Amount TM-1 | Amount TM-2 |
|-----------------|-------------|-------------|
| GGBS            | 391         | 413.79      |
| FA              | 554         | 420         |
| CA 10mm         | 620         | 617.40      |
| CA 20 mm        | 672         | 642.60      |
| Steel Fibres    | 120         | 120         |
| NaOH            | 46          | 53.20       |
| Na₂SiO₃         | 115         | 133         |
| Extra water     | 49          | 52          |
| Steel Fibres    | -           | 120         |

AAS

It has a vital role in the reaction. Silica and alumina present in this mix helps in binding. We are using 10Mto prepare
solution $10 \times 40 = 400$ Grams. It is prepared in 1L of water to prepare a solution of 1.32 in 1 kg of solution $= 400/1.32 = 303.033$ Grams. AAS sodium silicate was mixed with the sodium hydroxide solution. Sodium silicate helps to increase the reaction. We prepared the solution 5 hours before the cube casting. But the recommendation were 3-24 hours. Molarity from 8-16[5].

**Table 8:-Mix proportion of ingredients per cubic meter of GPC**

| GGBS (kg/m$^3$) | FA (kg/m$^3$) | CA 10mm (kg/m$^3$) | CA 20mm (kg/m$^3$) | Na$\text{}_2\text{SiO}_3$ (kg/m$^3$) | NaOH SOLUTION (kg/m$^3$) |
|-----------------|---------------|---------------------|--------------------|-----------------------------------|--------------------------|
| 413.79          | 420           | 617.40              | 642.60             | 133                               | 53.20                    |
| 413.79          | 420           | 617.40              | 642.60             | 133                               | 53.20                    |
| 413.79          | 420           | 617.40              | 642.60             | 133                               | 53.20                    |

**RESULTS & ANALYSIS**

Here we have discussed the results obtained by experimental investigation on GPC. The variation of properties and suitability of GPC for pavements has been discussed.

**Workability**

This test helps to find out the how efficiently you can use the mixture for work. Generally this is performed on fresh concrete. This is performed as per IS: 1199-1959. We have tested the slump for different moralities of sodium hydroxide and presented as.

**Table 9:-Slump value**

| Mix no | Molarity | Slump value (mm) |
|--------|----------|------------------|
| Mix 1  | 8        | 132              |
| Mix 2  | 10       | 109              |
| Mix 3  | 12       | 82               |
| Mix 4  | 14       | 65               |
| Mix 5  | 16       | 58               |

From this table it was concluded that as the molarity of the NaOH increases the slump value decreases. It simply means workability of mix decreases when quantity of sodium hydroxide increases. After sometime of preparation it will be less workable. We found that it was workable up to 10 minutes. In between 10-15 minutes working with this was difficult as compare to first one and at 20 minutes it was very difficult to work with GPC.

**Strength Results**

Now further Compressive strength, flexural strength and split tensile strength are tabulated and graphs have been plotted. We are tabulating compressive strength, flexural strength and split tensile strength of 12M, 14M and 16M.

We have used AAR= 1:2.5

**Table 10:-Compressive strength of 12M**

| Age in Days | Average Strength (MPa) |
|-------------|------------------------|
| 3Days       | 52.4                   |
| 7Days       | 61.48                  |
| 28Days      | 64.53                  |

**Table 11:-Compressive strength of 14M**

| Age in Days | Average Strength (MPa) |
|-------------|------------------------|
| 3Days       | 58.17                  |
| 7Days       | 62.48                  |
| 28Days      | 67.70                  |
DURABILITY OF GGBS BASED GPC

To check the durability of the Specimens we need some utensils which are resistant to acid attack. For this we need polyester flask. Here we have checked sulphate attack, acid attack and chloride attack. For this we need solution about 2% with 98% amount of distilled water[5].

Table 19: Gain in compressive strength after Curing with MgSO₄

| 28 days Avg comp. Strength(Mpa) | B.curing | A.curing | % gain in strength |
|--------------------------------|----------|----------|--------------------|
| 65.51                          | 66.29    | 1.19     |
| 67.70                          | 68.45    | 1.12     |
| 69.04                          | 70.09    | 1.51     |
ECONOMIC ANALYSIS
GGBS based geopolymer concrete has several advantages over conventional concrete. We found the price of the alkaline solution high but overall cost of the Geopolymer concrete is 10% less than conventional concrete in 8m and 10 M but when the AAS amount increases price of mix also increases somehow we can use cheap AAS to reduce the cost of concrete. According tom this it can be said that it will help us to reduce the price in construction and also help in cutting the amount of emission of the CO₂.

CONCLUSION
This report presents a little bit understanding to the geopolymer concrete based on GGBS, higher the amount of the alkaline activator higher will be the strength.
1. We found marginal improvement in the workability of concrete with the addition of GGBS in place of cement.
2. The compressive strength of Geo polymer concrete cube increases up to a molarity of 16.
3. GGBS shows a pozzolanic behavior.
4. The increment in molarity resulting in higher compressive strength in the concrete mix.
5. Mixture becomes hard after 18 minutes so better to use it within 12-14 minutes.
6. We found strength maximum of 16M but some other Molarity have also good

Table 20:- Loss in compressive strength after Curing with H₂SO₄

| 28 days Avg comp. Strength(Mpa) | % loss in strength |
|---------------------------------|-------------------|
| B. curing                       | A. curing         |
| 65.51                           | 64.32             | 1.81 |
| 67.70                           | 66.88             | 1.21 |
| 69.04                           | 67.97             | 1.55 |

Table 21:- Gain in compressive strength after Curing with NaCl

| 28 days Avg comp. Strength(Mpa) | % gain in strength |
|---------------------------------|-------------------|
| B. curing                       | A. curing         |
| 65.51                           | 66.18             | 1.01 |
| 67.70                           | 68.42             | 1.06 |
| 69.04                           | 69.76             | 1.04 |
results. As per the requirement we can use them.
7. If we talk about the strength it generally gains strength in first week then increment in strength slowly and slowly tasks place.

The influence of replacement of cement by GGBS has been studied. Based on the experimental work conducted, the following conclusions are drawn.

Strength is 23% of 28 days and 7 days strength is 77.43 % of 28 days strength. Also for the 3 days strength of 12M, 14m, 16m are 29.76%, 34%, 37%. Further the strength of 7 days concrete 86% 86.0. The Compressive strength we found in 8M is 81.62% at 3 days of 28 days strength and at 7 days it is 96.39% of 28 days strength. In 10m 3 days strength is 86.85% of 28 days and 7 days strength is 94.32%. Also for the 3 days strength of 12M, 14m, 16m are 81.20%, 85.29%, 88.35%. Further the strength of 7 days concrete are 95.27%, 92.28%, 95 % of the 28 days strength. We found the maximum strength in 16M.

The split tensile strength we found in 8M is 81% at 3 days of 28 days strength and at 7 days it is 92% OF 28 days strength. In 10M 3 days strength is 86% of 28 days and 7 days strength is 94 % of 28 days strength. Also for the 3 days strength of 12M, 14m, 16M are 84%, 83%, 86%. Further the strength of 7 days concrete is 92%, 93.32%, 93.70 % of the 28 days strength.

The Flexural strength we found in 8M is 17.8% at 3 days of 28 days strength and at 7 days it is 84% OF 28 days strength. In 10M 3 days 8%, 88.08% of the 28 days strength respectively.

The concrete has good compressive strength but we found a poor flexural strength for 8M and 10M. For making of road pavements min flexural strength requirement is 45 Kg/cm² but the strength we found is very less than this in 8M and 10M. So we do not recommend the concrete to be used for pavements directly. We need to improve the flexural strength for better use in pavements. It can be used for local streets and parking areas where VDF is very less but for the 12M-16M we suggest this can be used for pavement construction but some more studies like soundness need to be analysed. As we found the slump value very high we need to reduce the slump by reducing amount of water as recommended slump value for road making is 30-40mm.

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