Mechanical properties of GGBSFA Geopolymer concrete with varying Silica Modulus at different curing conditions

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Abstract. Geopolymer concrete is made of waste materials such as Fly ash and ground granulated blast furnace slag (GGBS). The use of this concrete helps to reduce the stock of wastes and also reduces emission of carbon by reducing Portland cement demand. The major constituent of Geopolymer concrete is aluminium and silicon rich materials. These materials are either natural materials that are thermally activated (e.g. kaolinite) or byproducts from industries (e.g. fly ash). These materials are activated using alkaline activating solution which polymerizes the materials and forms into networks creating hard binder. Geopolymer concrete with Fly Ash as precursor gains less strength at low rates in ambient temperature. Fly Ash Geopolymer concrete should be heat cured to improve its strength. In the present investigation effect of Silica Modulus(SiO2/Na2O) and percentage Na2O on the mechanical properties of Geopolymer concrete cured with Plastic Membrane and in ambient temperature are presented. In this alkaline activator which is combination of NaOH(NH) and Na2SiO3(NS) is used to activate the binder. Type of mixes with fixed binder content, varying GGBS, Fly Ash ratio and Silica Modulus of Alkali solution are used to study the strength properties of Hardened concrete. It was found that the strength decreases with increase in Silica Modulus and increased with increase in percentage Na2O. M40 grade concrete is attained for a combination of Silica Modulus of 1.4 and 5.399 percent of Na2O.

Keywords: Flyash, GGBS,Silica Modulus, Plastic Membrane, Ambient Temperature, Alkaline solution

1. Introduction

Due to drastic increase in infrastructure all over the world the need for cement production also increased. Ordinary Portland cement production is playing major role in global warming, it is one of the major contributor for carbon emissions. Around 1.5 billion tonnes per year of greenhouse gases are released due to the production of cement. Production of Cement consumes natural resources and emits around 7 to 10% of the greenhouse gases. There is a wide spread shift to use waste materials by saving natural resources for future generations and make the environment sustainable. Keeping in view the disadvantages involved in the production of conventional concrete there is a need for an alternate binder. Geopolymer cement is a sustainable binder which is introduced by Davidovits [1].

In Geopolymer concrete, cement is completely replaced with by-products of Thermal power plants and iron industries such as GGBS and Fly Ash. India is one of the largest producers of electricity from thermal power plants which produces fly ash as by-product. These waste materials also creates a serious disposal problem that requires large areas of land. Ground water is contaminated when water passes through these waste. Keeping in view the usage of sustainable materials and problems involved in the disposal problems of these materials in construction industry they are used as binders in the present study.

Keeping in view the benefits related with Geopolymer Concrete, in the current research, Fly Ash and GGBS are used as binder materials. Conventional river sand is replaced with Robo sand. River sand is precious natural material which is used in construction industry. River sand dredging causes change in water table level. As per research blended Alkali Activators NaOH and Na2SiO3 give better strength and
performance [2]. Sodium hydroxide initiates the initial reaction and silicate participates in increasing strength.[5]. Combination of NaOH (NH) and Na₂SiO₃ (NS) solutions are used for alkalination of the binders with varying Silica Modulus. It is reported that optimal Silica Modulus of Na₂SiO₃ is between 0.6 to 1.5[6]. It was reported that Silica Modulus of Alkaline solution between 1 to 2 gives optimum strength. In this paper an attempt is made to find the optimum Silica Modulus of Alkaline solution and percentage Na₂O to attain M40 grade concrete. Mechanical properties of the concrete with varying Silica Modulus, cured at ambient temperature and with plastic membrane are studied.

2. Materials used
Fly ash is a by-product obtained from burning pulverized coal in electric power generating plants. Fly Ash conforming to Class F is used as binder which is collected from Ramagundam power plant. Sodium silicate solution has 8.57% Na₂O, 25.88% SiO₂, water 65.55%. Robo-sand is produced by crushing hard granite stone. Robo Sand is an alternative for natural sand in preparation of concrete. In the recent past usage of Robo Sand has been increasing in the construction sector. The Robo Sand was procured from rock crushing unit, Kokapet, Telangana. As per IS 383-1970 sand conforming to Zone-II is used. GGBS in the form of granules is obtained from a blast furnace. These granules are grounded into powder. Coarse aggregate of 20mm nominal size is used in the present investigation. It is collected from local quarry. Specific gravity of coarse aggregate is 2.6. Fineness modulus of Robo Sand obtained is 2.72 as per IS 2386 (Part 1): 1963. This fine aggregate falls under Zone-II type of sand.

### Table 1: Materials Specific Gravity

| Materials      | Specific Gravity |
|----------------|------------------|
| Fly Ash        | 2                |
| GGBS           | 2.4              |
| Fine Aggregate | 2.7              |
| Coarse Aggregate | 2.73           |
| Sodium Silicate | 1.35            |
| Sodium Hydroxide | 1.4            |

### Table 2: Chemical composition of Sodium Silicate.

| S.No. | Characteristic | Value            |
|-------|----------------|------------------|
| 1     | Baume          | 38 Be±1 Be       |
| 2     | Specific gravity | 1.35         |
| 3     | Na₂O           | 8.57%± 0.5%      |
| 4     | SiO₂           | 25.88%± 1.0%     |
| 5     | pH             | 10 to 11         |
| 6     | Insoluble      | 0.2% approximately |

3. Experimental investigations
3.1. Mix proportions
All the mixes are designed with Fixed binder content of 380kg/m³ [3-4,9,11] as per the Literature. Different parameters NS/NH, AI/B, Ms, curing method are taken while designing the mix d of the
concrete. The ratio Sodium silicate to that of hydroxide solution is one of the major factor that influences the compressive strength and economy of Geopolymer Concrete. To get required strength considering the cost, ratio of NS/NH 1.5:1 is used. Alkaline solution to binder ratio (AL/B) is kept constant at 0.45. The GGBS:FlyAsh ratio of 50:50 and 40:60 is considered for mix. Silica Modulus 0.9, 1.1, 1.3, 1.6, were used for various mixes. Two types of curing methods are used, curing in ambient temperature and curing by covering with plastic membrane. As per ASTM C 171 Sheet Materials thickness of sheet covering for curing shall not be less than 0.1 mm. Cubes are completely wrapped with plastic cover of 0.1mm or 100 microns.

Table 3: Mix Proportion

| Mix Id | Binder (kg/m³) | GGB S | Flyas h | FA(Kg) | CA(Kg) | AL/B | NS/NH | NH kg/m³ | NS kg/m³ | Molarty | Ms | Na₂O % |
|--------|----------------|-------|---------|--------|--------|-------|-------|----------|----------|---------|-----|--------|
| GF1    | 380            | 190   | 190     | 650    | 1220   | 0.45  | 1.5   | 68       | 103      | 9.5     | 1   | 7.46   |
| GF2    | 380            | 190   | 190     | 650    | 1220   | 0.45  | 1.5   | 68       | 103      | 7.5     | 1.2 | 6.42   |
| GF3    | 380            | 190   | 190     | 650    | 1220   | 0.45  | 1.5   | 68       | 103      | 6       | 1.4 | 5.399 |
| GF4    | 380            | 190   | 190     | 650    | 1220   | 0.45  | 1.5   | 68       | 103      | 4       | 1.6 | 4.37   |
| GF5    | 380            | 152   | 228     | 650    | 1220   | 0.45  | 1.5   | 68       | 103      | 9.5     | 1   | 7.46   |
| GF6    | 380            | 152   | 228     | 650    | 1220   | 0.45  | 1.5   | 68       | 103      | 7.5     | 1.2 | 6.42   |
| GF7    | 380            | 152   | 228     | 650    | 1220   | 0.45  | 1.5   | 68       | 103      | 6       | 1.4 | 5.399 |
| GF8    | 380            | 152   | 228     | 650    | 1220   | 0.45  | 1.5   | 68       | 103      | 4       | 1.6 | 4.37   |

3.2. Preparation of Concrete Mix
An amalgamation of Sodium Silicate and Sodium Hydroxide at different Silica modulus is used in the present study. The reaction between Sodium hydroxide and water generates heat. To address this problem Sodium Hydroxide solution is prepared and mixed with silicate solution 24hr prior to the casting of cubes. During casting all the dry materials are weighed and placed in pan mixer. These materials are mixed in the mixer for 5 minutes. Then the alkaline solution which is already prepared is added to the mix and mixed for 4 minutes. It is mixed for another 3 minutes by adding super plasticizer with additional water.

Once mix is prepared the fresh concrete is tested for Workability using slump test. Compression, Split and Flexure tests are conducted on hardened concrete. The tests were performed after curing the concrete for 28 days and then few cubes are placed in room temperature for 28 days and few cubes are wrapped with plastic membrane.

4. Results and discussion
4.1. Comparison of Compressive Strength
The cubes casted for different mixes are tested for Compressive strength at 28 days and the results are presented in Table 4.
Table 4: Compressive strength for different mixes with varying Ms Modulus with different curing conditions

| Mix Id | Ms  | Compressive Strength cured at ambient temperature MPa | Compressive Strength cured with plastic membrane MPa |
|--------|-----|-------------------------------------------------------|------------------------------------------------------|
| GF1    | 1   | 62.9                                                  | 74.45                                                |
| GF2    | 1.2 | 60.97                                                 | 69                                                   |
| GF3    | 1.4 | 58.25                                                 | 66.25                                                |
| GF4    | 1.6 | 39.28                                                 | 49.26                                                |
| GF5    | 1   | 60.95                                                 | 71.45                                                |
| GF6    | 1.2 | 57.97                                                 | 67.26                                                |
| GF7    | 1.4 | 53.25                                                 | 64.37                                                |
| GF8    | 1.6 | 34.14                                                 | 44.18                                                |

Table 5: Split Tensile Strength and Flexure for different mixes with Ms Modulus 1.4 with different curing conditions

| Mix Id | Ms  | Tensile Strength cured at ambient Temperature MPa | Flexural Strength at ambient Temperature MPa | Tensile Strength with plastic membrane MPa | Flexural Strength with plastic membrane MPa |
|--------|-----|--------------------------------------------------|---------------------------------------------|--------------------------------------------|---------------------------------------------|
| GF3    | 1.4 | 3.22                                             | 4.42                                        | 3.71                                       | 4.98                                        |
| GF7    | 1.4 | 2.95                                             | 4.02                                        | 3.62                                       | 4.82                                        |
Fig 3: Compressive strength with varying FA:GGBS with different Silica Modulus and curing conditions

Fig 4: Tensile Strength with Ms Modulus 1.4 with different curing conditions

Fig 5: Flexural Strength with Ms Modulus 1.4 with different curing conditions
The trend in Fig 3 shows Compressive Strength increased with increase of GGBS from 40 to 50 percent. Specimens with Mix Id GF1 to GF4 had more compressive strength compared to the specimens GF5 to GF6 with same Silica Modulus. Compressive strength of specimens cured with plastic membrane is 15 to 20% more compared to the same specimen cured in ambient temperature. For mixes with GGBS:FA ratio 50:50, increase in Silica Modulus from 0.9 to 1.6 decreased the Compressive Strength by 35%. For mixes with GGBS:FA ratio of 40:60, decrease in Silica Modulus from 0.9 to 1.6 increased the Compressive Strength by 35 to 40%. Increase in Na2o percent increased compressive strength. It is observed that the compressive strength with 4M NaoH solution decreased drastically compared to other Molarities.

The results of flexural strength and split tensile strength are presented in Table 5. The trend in Fig 4 and Fig 5 shows the Tensile and Flexural strength decreased with increase in GGBS content. Specimens cured with plastic membrane had 15 to 20% more Tensile and Flexural Strength compared to specimen cured at ambient curing.

Decrease in Silica Modulus increased the Compressive strength due to the dissolution of aluminates and silicate present in Flyash and GGBS [7-8, 12]. But Alkaline solution with low Silica Modulus leads to efflorescence in concrete which leads to reduction in polymerisation and reduction in Compressive strength. Alkaline Solution with High Silica Modulus of 1.6 reduced the Strength. So Silica modulus of 1.2 to 1.4 can be adopted to develop optimum mix which ensures strength and reduces efflorescence. In the present study Compressive strength of M40 grade concrete is attained for the GF7 mix with Silica Modulus 1.4. With increase of GGBS percentage it is observed that compressive strength increased due to the dissolution of Calcium present in the GGBS. The geopolymer gel formation is enhanced due to the presence of free calcium ions which prolonged the dissolution of Flyash which added to the later strength of concrete.

5. Conclusions
Based on the above study, the following conclusions are drawn:

1. M40 grade concrete is attained at Silica Modulus 1.4 and 5.399 percent Na2o for an NS/NH ratio of 1.5 cured at ambient curing.
2. Increase in Silica Modulus from 1 to 1.6 decreased the strength of concrete. There is a drastic reduction in compressive strength at 1.6 Silica Modulus.
3. All the mixes cured with Plastic membrane had more strength compared to ambient curing which indicates, this type of curing can be adopted in the field for Geopolymer concrete for attaining more strength economically.

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