Seasonal effect on compressive strength of ambient cured, nominal mix proportioned alkali-activated slag concrete

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Abstract. Strength of the concrete is a very important factor for the safe design of concrete and safe construction. Nowadays high strength concrete has an important role in the construction of different structures. It is difficult to enhance the strength of the concrete and enhancing strength requires a lot of changes in the mix design. The present study is to develop Geopolymer concrete to increase the compressive strength of low nominal mix proportions using alkali activators like NaOH and Na₂SiO₃ solutions. Geopolymer concrete is one of the best alternative concrete for conventional and other cement concretes for many reasons. The Geopolymer concrete is prepared with ground granulated blast furnace slag (GGBS) and silica fume (SF) as a binder. NaOH and Na₂SiO₃ solutions are adopted as alkali activators. Quartz sand is used as fine aggregate along with normally used coarse aggregate. Cubes are prepared with different combinations of ingredients and after 28 days of ambient curing conditions, the cubes are tested for compressive strength. And this study is conducted in summer, monsoon and winter seasons to study the effect of seasons on ambient curing of the Geopolymer concrete.

1. Introduction
Concrete plays a significant role in the development of infrastructure that is taking place all over the world. In past decades so many varieties of concretes were developed based on the requirements in construction. High strength concrete is one of the most needed concrete for structures which are affected to heavy loads and the need for high strength Cement increasing day by day. Strength is the most important property of concrete. It is difficult to enhance the strength concrete with low conventional concrete mix proportions. Generally, the characteristic compressive strength up to 20 N/mm² the concrete is called ordinary concrete, 25 to 55 N/mm² is called standard concrete and 60 to 80 N/mm² is called high strength concrete. Generally, with conventional mix and ingredients, it is difficult to increase the concrete strength. Another important problem with the conventional ingredient is pollution. The process of producing cement not only consumes a significant amount of natural resources but is also highly internal energy-intensive. About 3 billion tons of raw materials are needed for cement manufacture every year. It is also responsible for large emission of CO₂. On average, approximately one Ton of cement is being produced each year by every human being in the world. Hence to protect the environment, the main concern of minimizing CO₂ emission can be realized by reducing the percentage...
of cement used in making concrete. To mitigate these environmental problems, Civil Engineers have strived to produce many alternatives and more eco-friendly concretes. In this concrete, the methodology is to replace the ingredients with industrial by-product materials and still possesses excellent mechanical properties. Every year millions of tons of industrial waste are generated of which is no correct process to dispose of them environmentally friendly. Many efforts are being made to reduce the use of Portland cement in concrete by replacing these industrial wastes [2].

Normal water curing is required for any structure which is constructed with concrete. The requirement of water is so high that the concrete industry uses over one trillion gallons of water each year globally excluding wash water. This becomes a problem in that region where the freshwater is not easily available. So, if we use concrete which can be cured in ambient air, the problem in many regions can be solved. So, there is a need to replace concrete with such a material which is environmentally friendly and can be cured in ambient air condition.

1.1 Geopolymer concrete
Producing Geopolymer by a polymerization (it involves a chemical reaction of aluminosilicate minerals under the alkaline condition that results in a three-dimensional polymeric chain [5]) reaction of alkaline liquid with the source of industrial by-product materials rich in silica and alumina. It exhibits many excellent properties such as low creep, low shrinkage, good acid resistance and high compressive strength [3, 4]. The theoretical basis of Geopolymerization as a major reaction mechanism of cementless concrete was established for the first time by the French researcher JOSEPH DAVIDOVITS in 1978. In Geopolymer concrete, alkali activator solution plays a major role in the dissolution of Si and Al oxides. Hence, Geopolymers are synthesized by mixing the most common alkaline activators that are strong alkaline solutions such as Sodium Hydroxide (NaOH), Potassium Hydroxide (KOH), Potassium Silicate or Sodium Silicate with aluminosilicate reactive materials [8]. The compressive strength of the Geopolymer is significantly affected by the concentration of the activator that increases the strength of Geopolymer.

1.2 Materials for Geopolymer concrete
Supplementary Cementitious materials are used as a partial or full replacement of ordinary Portland cement. These are industrial by-products and are environmentally friendly. Some of the supplementary cementitious materials are Fly ash, GGBFS, Silica Fume, Rice husk ash, Metakaolin etc., In the preparation of geopolymer concrete adopted in this study, GGBS and Silica Fume are used as a replacement of cement. The main ingredients with which Geopolymer mortar is made up of in this study are Binder (GGBS, silica fume), Alkali activators (Sodium hydroxide and Sodium silicate), Coarse aggregate, Fine aggregate (quartz sand) and Admixture (Gypsum).

2. Methodology
2.1 Principle steps involved in the Step-by-step methodology
The following methodology was adopted to conduct the experimental program.
1. Procuring the required materials for Geopolymer concrete and study their physical and chemical properties to establish their suitability in making Geopolymer concrete.
2. The mix proportion and alkali binder ratios are determined by conducting trail mixes to obtain an ideal mix proportion of maximum strength.
3. Three types of nominal mix proportions were considered that is 1:1:2, 1:1.5:3 and 1:2:4 with different combinations of NaOH and to Na2SiO3. Three sets of concrete cubes were prepared in summer, monsoon and winter to check the effect of weather in ambient air curing.
4. Alkali solutions are prepared one hour before their use in Geopolymer concrete. From the ideal mix proportion and alkali binder ratios, cubes of size 150mm³ are cast in moulds and demolded after 24 hours by keeping them at room temperature. Compressive strength at 28 days is determined for ambient air-cured concrete cubes using the compressive testing machine.

2.2 Modal mix calculation.
The following details are modal mix proportion for a Nominal mix of 1:2:4 of Geopolymer concrete mix for one cube of size (150 mm ×150 mm × 150 mm) with A/B ratio of 0.8
For the different mixes consider

Mass of NaOH = 0.8 × 1.2053 = 0.9642 kg

The ratio of NaOH to Na₂SiO₃ = 2: 5

Mass of NaOH solution = (2/7) × (0.9642) = 0.2754 kg

Mass of Na₂SiO₃ solution = (5/7) × (0.9642) = 0.6887 kg

2.3 Quantities of different mix proportions

For the different mixes considered in this study, the are calculated and presented in table 1

| Mix | Mix Code | GGBS | Silica fume | Gypsum | Quartz sand | Coarse Aggregate | Mass of NaOH | Mass of Na₂SiO₃ |
|-----|----------|------|-------------|--------|-------------|----------------|-------------|----------------|
|     |          |      |             |        |             | 20 mm | 10 mm | W_{wate r} | W_{Shr} | W_{wate r} | W_{ss} |
| Z1  | 500      | 125  | 31          | 625    |             | 750   | 500   | 102      | 40     | 285      | 71    |
| Z2  | 500      | 125  | 31          | 625    |             | 750   | 500   | 102      | 40     | 232      | 125   |
| Z3  | 500      | 125  | 31          | 625    |             | 750   | 500   | 102      | 40     | 178      | 178   |
| Z4  | 500      | 125  | 31          | 625    |             | 750   | 500   | 85       | 57     | 285      | 71    |
| Z5  | 500      | 125  | 31          | 625    |             | 750   | 500   | 85       | 57     | 232      | 125   |
| Z6  | 500      | 125  | 31          | 625    |             | 750   | 500   | 85       | 57     | 178      | 178   |
| Z7  | 500      | 125  | 31          | 625    |             | 750   | 500   | 72       | 70     | 285      | 71    |
| Z8  | 500      | 125  | 31          | 625    |             | 750   | 500   | 72       | 70     | 232      | 125   |
| Z9  | 500      | 125  | 31          | 625    |             | 750   | 500   | 72       | 70     | 178      | 178   |
| Y1  | 363      | 90   | 22          | 681    |             | 818   | 545   | 75       | 29     | 207      | 52    |
| Y2  | 363      | 90   | 22          | 681    |             | 818   | 545   | 75       | 29     | 168      | 91    |
| Y3  | 363      | 90   | 22          | 681    |             | 818   | 545   | 75       | 29     | 130      | 130   |
| Y4  | 363      | 90   | 22          | 681    |             | 818   | 545   | 62       | 41     | 207      | 52    |
| Y5  | 363      | 90   | 22          | 681    |             | 818   | 545   | 62       | 41     | 168      | 91    |
| Y6  | 363      | 90   | 22          | 681    |             | 818   | 545   | 62       | 41     | 130      | 130   |
| Y7  | 363      | 90   | 22          | 681    |             | 818   | 545   | 52       | 51     | 207      | 52    |
| Y8  | 363      | 90   | 22          | 681    |             | 818   | 545   | 52       | 51     | 168      | 91    |
| Y9  | 363      | 90   | 22          | 681    |             | 818   | 545   | 52       | 51     | 130      | 130   |
| X1  | 285      | 71   | 17          | 714    |             | 857   | 571   | 58       | 23     | 163      | 41    |
| X2  | 285      | 71   | 17          | 714    |             | 857   | 571   | 58       | 23     | 132      | 71    |
| X3  | 285      | 71   | 17          | 714    |             | 857   | 571   | 58       | 23     | 102      | 102   |
| X4  | 285      | 71   | 17          | 714    |             | 857   | 571   | 49       | 32     | 163      | 41    |
| X5  | 285      | 71   | 17          | 714    |             | 857   | 571   | 49       | 32     | 132      | 71    |
| X6  | 285      | 71   | 17          | 714    |             | 857   | 571   | 49       | 32     | 102      | 102   |
| X7  | 285      | 71   | 17          | 714    |             | 857   | 571   | 41       | 40     | 163      | 41    |
| X8  | 285      | 71   | 17          | 714    |             | 857   | 571   | 41       | 40     | 132      | 71    |
| X9  | 285      | 71   | 17          | 714    |             | 857   | 571   | 41       | 40     | 102      | 102   |

2.4 Preparation of concrete specimens

1. The alkali solutions made of required Sodium hydroxide and required Sodium silicate solution, are prepared one hour before for making Geopolymer concrete.
2. The binder materials are mixed in sequence i.e. GGBS, silica fume and gypsum respectively. Next, the quartz sand and coarse aggregate are added to the mix and all the materials are combined by electrical mixer for 2-3 minutes.

3. After proper mixing of materials, alkali activators like sodium hydroxide and sodium silicate are added in required proportions.

4. After proper mixing of Geopolymer concrete, the concrete mix is filled into moulds and each layer is compacted by 25 blows using tamping rod having specifications of diameter 16mm & length 610 mm length. After filling the moulds and proper compaction, place the moulds on a vibration table for better compaction.

5. After completion of casting placed the specimens are demolded after 24 hours from cast time after keeping the specimens in ambient curing for 28 days.

3. Results
As per IS 516 (1959), the compressive strength of concrete was performed on the compressive testing machine having a capacity of 3000 kN. For testing, an average of three cube specimens of each size 150 mm³ that were cast and tested under compressive load is considered. 28 days compressive strength results are presented in Table 2 for ambient cured cube specimens in summer, monsoon and winter.

Table 2. Compressive Strengths of different mix proportions in different seasons

| Mix | Code | NaOH | Na$_2$SiO$_3$ | Compressive strength (MPa) in Summer | Monsoon | Winter |
|-----|------|------|---------------|--------------------------------------|---------|--------|
| 1:1:2 | Z1  | 9M   | 20%           | 21.6                                 | 23.8    | 24.9    |
|     | Z2  |      | 35%           | 29.8                                 | 29.4    | 30.7    |
|     | Z3  |      | 50%           | 25.5                                 | 31.8    | 33.6    |
|     | Z4  | 14M  | 20%           | 25.9                                 | 22.4    | 23.7    |
|     | Z5  |      | 35%           | 33.3                                 | 30.1    | 30.5    |
|     | Z6  |      | 50%           | 33.1                                 | 33.3    | 36.8    |
|     | Z7  | 19M  | 20%           | 25.1                                 | 20.8    | 26.2    |
|     | Z8  |      | 35%           | 42.2                                 | 32.8    | 32.8    |
|     | Z9  |      | 50%           | 44.3                                 | 38.6    | 39.4    |
| 1:1.5:3 | Y1 | 9M   | 20%           | 20.9                                 | 26.2    | 27.3    |
|      | Y2  |      | 35%           | 22.6                                 | 24.7    | 25.8    |
|      | Y3  |      | 50%           | 25.6                                 | 33.8    | 35.4    |
|      | Y4  | 14M  | 20%           | 35.5                                 | 24.3    | 25.6    |
|      | Y5  |      | 35%           | 40.5                                 | 33.7    | 36.1    |
|      | Y6  |      | 50%           | 38.7                                 | 39.0    | 41.0    |
|      | Y7  | 19M  | 20%           | 25.6                                 | 25.3    | 26.5    |
|      | Y8  |      | 35%           | 39.8                                 | 29.1    | 30.9    |
|      | Y9  |      | 50%           | 44.2                                 | 40.0    | 38.1    |
| 1:2:4 | X1  | 9M   | 20%           | 17.5                                 | 22.5    | 23.5    |
|      | X2  |      | 35%           | 28.9                                 | 27.8    | 30.9    |
|      | X3  |      | 50%           | 30.9                                 | 35.7    | 36.3    |
|      | X4  | 14M  | 20%           | 25.6                                 | 28.7    | 28.6    |
|      | X5  |      | 35%           | 43.9                                 | 36.5    | 38.3    |
|      | X6  |      | 50%           | 39.5                                 | 36.5    | 36.5    |
|      | X7  | 19M  | 20%           | 26.9                                 | 27.5    | 28.7    |
|      | X8  |      | 35%           | 43.2                                 | 43.0    | 43.2    |
|      | X9  |      | 50%           | 46.9                                 | 45.8    | 45.6    |
4. Discussion of results: Effect of alkali activators and seasons on compressive strength

For conventional concrete, the mix proportion 1:1:2 represents M25 concrete. The Geopolymer concrete developed with mix proportion of 1:1:2 with different combinations of NaOH and Na$_2$SiO$_3$ produced higher compressive strength values than conventional concrete. The effect of alkali solution and seasons on compressive strength is represented in figure 1. Highest compressive strength value 44.3 MPa has obtained for 19M NaOH solution and 50% Na$_2$SiO$_3$ concentration in the summer season. Out of three seasons summer season exhibit good compressive strength values at higher concentration of alkali solution. Monsoon and winter seasons exhibit approximately equal strengths for all concentrations of alkali solution.

![Figure 1](image1.png)

**Figure 1.** Effect of seasons on Compressive Strength of 1:1:2 mix Geopolymer concrete

![Figure 2](image2.png)

**Figure 2.** Effect of seasons on Compressive Strength of 1:1.5:3 mix Geopolymer concrete
For conventional concrete, the mix proportion 1:1.5:3 represents M20 concrete. The Geopolymer concrete developed with mix proportion of 1:1.5:3 with different combinations of NaOH and Na$_2$SiO$_3$ produced higher compressive strength values than conventional concrete. The effect of alkali solution and seasons on compressive strength is represented in figure 2. Highest compressive strength value 44.2 MPa has obtained for 19M NaOH solution and 50% Na$_2$SiO$_3$ concentration in the summer season. Out of three seasons summer season exhibit good compressive strength values at higher concentration of alkali solution. Monsoon and winter seasons exhibit approximately equal strengths for all concentrations of alkali solution.

![Figure 2. Effect of seasons on Compressive Strength of 1:1.5:3 mix geopolymer concrete](image)

For conventional concrete, the mix proportion 1:2:4 represents M15 concrete. The Geopolymer concrete developed with mix proportion of 1:2:4 with different combinations of NaOH and Na$_2$SiO$_3$ produced higher compressive strength values than conventional concrete. The effect of alkali solution and seasons on compressive strength is represented in figure 3. Highest compressive strength value 46.9 MPa has obtained for 19M NaOH solution and 50% Na$_2$SiO$_3$ concentration in the summer season. Out of three seasons summer season exhibit good compressive strength values at higher concentration of alkali solution. Monsoon and winter seasons exhibit approximately equal strengths for all concentrations of alkali solution.

![Figure 3. Effect of seasons on Compressive Strength of 1:2:4 mix Geopolymer concrete](image)

5. Conclusions
From the experimental results, the following conclusions are acquired
1. The experimental study is conducted for different mix proportions, they are 1:1:2, 1:2:4 and 1:1.5:3 and all these mix proportions produces good compressive strength results out of these 1:2:4 mix produces higher results.
2. Compressive strength of Geopolymer concrete increases with the increasing of sodium silicate concentration and maximum results obtain at 50 % concentration.
3. Compressive strength of geopolymer concrete also increases with the increasing of molarities of sodium hydroxide and maximum results obtain at 19M solution.
4. 9M and 14M sodium hydroxide mixes produce the same results in all mix proportions. But 19M varies very highly in every mix proportion.
5. Compressive strength of Geopolymer concrete will not depend on the mix proportion. It depends on the Alkali activators only.
6. Summer, monsoon and winter seasons also affect the Ambient curing of the Geopolymer concrete which leads to changes in compressive strength.
7. Summer season exhibits good compressive strength values at higher concentration of alkali solution. Monsoon and winter seasons exhibit approximately equal strengths for all concentrations of alkali solution.
8. Maximum compressive strength value 44.3 MPa is obtained for 1:1:2 mix proportion of 19M NaOH solution and 50% Na₂SiO₃ concentration in the summer season.
9. Maximum compressive strength value 44.2 MPa is obtained for 1:1.5:3 mix proportion of 19M NaOH solution and 50% Na₂SiO₃ concentration in the summer season.
10. Out of all condition’s highest compressive strength value, 46.9 MPa is obtained for 1:2:4 mix proportion of 19M NaOH solution and 50% Na₂SiO₃ concentration in the summer season.
11. With 1:2:4 low nominal mix proportions higher compressive strength Geopolymer concrete is achieved.

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