Effect of Alkaline Solution with Varying Mix Proportion on Geopolymer Mortar

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Abstract: Cement production is attributed by emission of carbon dioxide which causes severe environmental impacts. This has led to the invention of special construction materials which can replace cement. On the other hand, these construction materials (like Fly ash, Metakaolin) also need to be inexpensive and should possess all the characteristics of cementitious materials. In this project, the effect of geopolymerization on the properties of the end product were studied with varying distillation of NaOH solution (10M, 12M and 15M) for different mix proportion (1:1, 1:2 and 1:3). Curing was done for 1 day at a temperature of 60°C and 80°C respectively. The densities, compressive strength, alkalinity, co-efficient of absorption were determined. As a result, the experiments showed the effect of factors such as mix proportion, curing temperature and curing day on the physical and mechanical properties such as mix proportion of the geopolymer concrete. Results of NaOH concentration of 12M concentration cured for 24 hours at 80°C and 60°C showed better mechanical performance than the rest of the concentrations.

Key words: Geopolymer, class ‘F’ fly ash, Temperature, Strength, Alkalinity, Co-efficient of absorption.

1 Introduction

The necessity for Portland cement is increasing as a result of which emission of CO₂ to the atmosphere increases which causes global warming. One tonne of carbon dioxide is emitted with every tonne of cement produced [1]. Nowadays most preferred cement is PPC. Compatibility studies of PPC with different super plasticizers are already studied by many researchers [14]. Devidovits inferred that cement can be replaced completely by fly ash and alkaline solution, as fly ash is generally inert and when it reacts with an alkali it behaves as a cementitious material and this is called as a geopolymer [2]. The fly ash based geopolymer is very eco-friendly as it is a byproduct obtained from thermal power stations and has excellent properties as a cementitious material [3]. In order to achieve expected characteristics (high strength, durability, resistance to fire and it is resistant to alkali aggregate reaction) of rock Geosynthesis was used. It is the skill of built-up non-natural stone at a temperature less than 100°C. Geopolymers can be thus observed as inorganic polymers consequential from geosynthesis[4]. Curing temperature and its duration influences the strength in compression. It was observed that extensive curing period and greater curing temperature resulted in improved compressive strength [5]. It was also observed that there is no significant increase in strength when cured at a temperature above 60°C and curing for times more than 2 days. The strength improvement of fly ash based geopolymer mortar is relying on the temperature and time interval of curing [6]. It is reported that the reaction of class F fly ash in
geopolymerization is not quick at a temperature less than 45°C. It was also observed that there was no strength development at very high temperatures (>115°C) when 8% (Na concentration) activator solution was used. It is also reported that duration of 72 hours is required for low heat curing whereas duration of 24 hours is sufficient for high heat curing [7]. Geopolymer manufactured from fly ash shows excellent performance when exposed to different temperature duration [8]. It has excellent mechanical properties such as compressive strength, modulus of elasticity. Behavior of reinforced geopolymer concrete columns, beams, bond strength of rebar and durability etc. are found to be superior than Portland cement concrete structural components [9].

![Fly ash with alkaline solution](image)

**Figure 1- Fly ash with alkaline solution**

### 2. Material properties:

Present study deals with class ‘F’ fly ash which was taken from Mettur thermal power plant. The material composition of fly ash is shown in Table 1. Since the summation of SiO₂, Al₂O₃ and Fe₂O₃ content is above 70% and CaO content is below 10% in fly ash used, it can be classified as class F type according to ASTM C618 [13]. Fly ash of specific gravity 2.08 was used the residue left on 45 sieve was 17%.

Specific gravity of fly ash was 2.080. The alkaline solution used in this are NaOH pellets of 97% purity and Na₂SiO₃ solution (Na₂O is 9.5% and SiO₂ is 29.1%). NaOH solution of varying molarities of 10M, 12M and 15M are used. The ratio of liquid (alkaline activator solution) to fly ash is 0.5 and that of NaOH to Na₂SiO₃ was 1:1.25. Fine aggregate of specific gravity 2.65 and fineness modulus of 2.73 was used. Varying ratios of fly ash to sand of 1:1, 1:2 and 1:3 were used.

| Oxide   | SiO₂  | Al₂O₃ | Fe₂O₃ | CaO  | MgO  | Na₂O  | SO₃  | LOI  |
|---------|-------|-------|-------|------|------|-------|------|------|
| Fly ash | 54.12 | 23.08 | 1.87  | 3.78 | 2.62 | 2.75  | 0.68 | 2.61 |

Table 1- The material configuration of fly ash (%):
3. Experimental program:

3.1 Mix proportions
Table 2 shows the mix design of mortar which is taken from [8] with some modification including mix proportion and varying molarities of NaOH concentration and curing temperatures.

| Materials       | Mix 1:1 (kg/m³) | Mix 1:2 (kg/m³) | Mix 1:3 (kg/m³) |
|-----------------|-----------------|-----------------|-----------------|
| Fly ash         | 10M 799         | 610             | 495             |
|                 | 12M 815         | 632             | 501             |
|                 | 15M 835         | 659             | 509             |
| Sand            | 10M 799         | 1221            | 1484            |
|                 | 12M 815         | 1239            | 1519            |
|                 | 15M 835         | 1262            | 1525            |
| Sodium hydroxide| 10M 177.5       | 136             | 110             |
|                 | 12M 181         | 138             | 111.5           |
|                 | 15M 186         | 140.5           | 141             |
| Sodium silicate | 10M 222         | 170             | 134.5           |
|                 | 12M 226         | 172             | 140             |
|                 | 15M 232         | 175.5           | 141.2           |
3.2 Compressive strength tests:
The fresh mixes were placed in 70.6 x 70.6 x 70.6mm size cube moulds. Top surface of moulds were covered with wet gunny clothes to prevent moisture loss. The moulds containing mortar mix were oven cured at 60°C and 80°C respectively. Demoulded specimens were kept at room temperature till they were tested. Compressive strength measurements [14] were performed on an UTE-40 with a loading capacity of 40 T and the compression strength was calculated from the applied load at the point of cube failure. A minimum of three cubes were tested for each data point. The specimens were tested at 1 hour after curing. Fig 4.1 shows the mortar specimens for the compressive strength test. The tests procedure followed was in accordance with IS 516-1959.

Figure 2- Over heat curing of cubes

Figure 3- UTE-40
3.3 Alkalinity test:
Test procedure was adopted from Thomas[10] according to which the mortar cubes after testing for compressive strength, the cubes were crushed and passed through IS sieve of 90μm. Subsequently 20 grams of the powdered material was mixed with 200 mL of distilled water in a glass beaker of capacity 500 mL and was stirred for few minutes. The solution after 24 hours was filtered using Whatman paper No.9 and alkalinity of filtered solution was measured using digital pH meter and above.

3.4 Co-efficient of water absorption:
Permeability of water through concrete was determined using coefficient of water absorption [11]. This was measured by determining the rate of water uptake by dry concrete in a period of 1h [11, 12]. There are two method followed by such as absorption by capillary (an under laying substance in contact with water) and ponding action (simulation of water on a pavement or bridge deck). The test procedure was adopted from Dale P. Betz [15] according to which the mortar cubes after testing for co-efficient of water absorption by capillary and ponding. Ponding method allows the measurement of absorption where the surface exposed to the water is the top surface. Thus, gravity will be an additional force to accelerate the penetration of the water into the specimen. This was determined by measuring the amount of water absorbed by oven dried concrete for one hour [12]. After 24 hours of casting the cubes of size 70.6x70.6x70.6mm along with the moulds are kept in oven at 60°C and 80°C, next 24 hours then the moulds are taken out from the oven and kept at room temperature for cooling and weighted (W1). Then it was drowned in water (the level should not be more than 5mm) and the cubes were properly coated with the non-absorbent in order to avoid the flow from the marginal surface. Then proper cleaning of the bottom portion of the sample was done using tissue paper and then the sample was weighted within next 30 seconds (W2). The accuracy of the weighing balance is 0.01g.

\[ K_a = \frac{(Q/A)^2}{t}, \]

Where \( K_a \) is the water absorption (m\(^2\)/s),

\( Q \) is the measure of water absorbed (m\(^3\)) by the oven-dried specimen in time (t),

\( t \) is 3600sec,

\( A \) is the C/S area (m\(^2\)) of specimen through which water infiltrates.

Figure 4- Ponding specimen
4. Results and Discussions

4.1 The effect of concentrations of NaOH on the density of geopolymer mortar:
Increase in the concentration of NaOH has increased the density of geopolymer mortar. The density of the cube cured at 80°C is lesser than the cubes cured at 60°C and fresh mortar. Hence, it was observed that at different mix proportions with different concentrations of NaOH produced different densities at the age of one day. This may be because of increasing the curing temperature increases the degree of reaction of Silica and Aluminum atoms from the fly ash through the action of OH$^-$ ions.

Figure 5- Mix proportions VS Temperatures

4.2 The effect of different concentrations of NaOH on the compressive strength of geopolymer mortar:
Heat cured 70.6x70.6x70.6mm cubes at 60°C and 80°C for a period of 24 hours in an oven were tested for determining its strength in compression. It was inferred that the compressive strength of the cubes prepared by using 12M NaOH concentration shows an increasing compressive strength when compared with 10M and 15M concentrations. However, it is also observed that the strength in compression for the cubes cured at 80°C is higher than the cubes cured at 60°C. Hence, the degree of increase in strength is reliant with the temperature. From the graph, it can be observed that the compressive of 12M concentrations of all the three mix proportions (1:1, 1:2 and 1:3) is higher than other two (10M and 15M) concentrations.
4.3 Effect of different molarities of NaOH on geopolymer alkaline mortar:
From the graph show the effect of different molarities of NaOH solution on geopolymer alkaline mortar with curing temperature of 60°C and 80°C respectively. It is found that the geopolymer alkaline mortar is not much affected with increase in varying of NaOH molarities. The maximum pH value of geopolymer mortar is 11.7. This shows that there is less chance of alkali-aggregate reaction even though highly alkaline solution is used for the preparation of geopolymer mortar.

4.4 Effect of different concentrations of NaOH on the Co-efficient of water absorption of geopolymer mortar:
From the graph it is observed that the water absorption of the cubes prepared by using 12M NaOH concentration shows decreasing water absorption when compared with 10M and 15M concentration. However it is also observed that the water absorption of the cubes cured at 80°C is lesser than the cubes cured at 60°C. And also the water absorption of 12M concentrations of all the three mix proportions (1:1, 1:2 and 1:3) is lesser than the other two (10M and 15M) concentrations. The results prove that the mix proportions with lesser water absorption have a higher compressive strength when
compared with different concentration of NaOH under same temperature. As the mixes with lesser water absorption have low porosity, they have a higher compressive strength.

Figure 8- Coefficient of water absorption VS Mix proportions

5. Conclusions
The present work was done on different mix proportion, NaOH concentrations, curing temperatures, and the following conclusions were established
At 60°C curing, one day compressive strength was found to be in the range of 17 to 22 MPa and for 80°C curing it was between 19 to 31 MPa. Thus, higher curing temperature produces higher strength at increasing sand content. The mixes with 12M concentrations have higher compressive strength due to the low co-efficient of water absorption nature of the mix.
Alkalinity of simulated pore solution measured by pH is in the range of 10.2 to 11.7 which is sufficient for protecting the embedded steel reinforcement. Density of mortar is in the range of 2018 to 2222 kg/m³ at 60°C and for 80°C curing it is 2001 to 2191 kg/m³ which are only marginally less than the Portland cement mortar specimens. Density, compressive strength, alkalinity, co-efficient of water absorption is dependent on the curing temperature.

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