Performance studies on Geo polymer concrete

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Abstract. Geo polymer concrete, an eco-friendly concrete produced without addition of cement. Though cement is a basic material in the production of concrete; however in global carbon dioxide emission 5 to 8% contribution is from the production of concrete. In geo polymer concrete the absence of cement is replaced by an inorganic alumina silicate compound synthesized using fly ash as a binder. Fly ash involves in reduction of high energy consumption and offers solutions for utilizing waste by products from industries. This paper describes the experimental investigation on fly ash based Geo polymer concrete to evaluate the effects of workability, compressive and split tensile strength in order to ensure the overall performance of the concrete mix. The various parameters has been analysed based on the ratio of liquid to binder, molarity of sodium hydroxide solution, ratio of sodium silicate to sodium hydroxide and alkaline to fly ash ratio. The test results indicate that the compressive strength gradually increases with increase in molarity of NaOH solutions for two different alkaline to fly ash ratios of 0.35 and 0.5 respectively. The split tensile strength of geo polymer concrete is very low and not increases significantly. The workability of mix improves by adding 2% superplasticizer. Further overall performance is greatly influenced by the molarity of NaOH solution and the ratio of alkaline to fly ash to evaluate the early age strength of concrete.

Keywords: Flyash, Geopolymer, strength.

1. Introduction. Concrete manufactured using the primary binder of ordinary Portland cement consumes large amount of natural resources and energy with substantial emission of carbon-dioxide [1]. Besides the Portland cement, other materials such as fine aggregate and coarse aggregate in concrete also require more amount of energy during its quarrying operations. The undesirable impact on environmental is reduced efficiently by reduction in utilization of Portland cement. However, the utilisation of pozzolanic materials such as Fly ash, silica fume and ground granulated blast furnace slag (GGBS) can also be used as replacement alternative for Portland cement, to reduce the probable emission of CO₂ gases [2]. Geo polymer is a kind of alternate binder over conventional binder which can be made economical and sustainable with alumina silicate materials activated with high alkali solutions to eliminate cement [3-8].The naturally available materials such as metakaolin, clay, red mud and the by-product materials such as ground granulated blast furnace slag (GGBFS), flyash, bagasse ash and rice-husk ash can also be used as geo polymer binders by several researchers [4]. The Geo polymer concrete is inorganic chemical compound synthesized by addition of aluminium and silicate
materials with alkali reagent. Several researchers suggest that the performance of geo polymer is better than OPC and PPC. The efficiency in producing geo polymer concrete is highly reliant on the activators as well as types of alumina silicates [5]. Geo-polymerization is a chemical reaction that integrates minerals that are naturally having silico-aluminates [9-10]. Geo-polymerization reaction is best perceived in presence of alkaline medium of sodium hydroxide solution with addition of silicon molecules for appropriate ionic composition to enhance better bonding properties. The consistency of the concrete mix reduces with increase in the concentration of solution during mixing that initiates faster polymeric chain reaction [13-19]. The polymerisation process initiates the gel formation at faster rate due to higher silicate content by inclusion of sodium silicate in sodium hydroxide solution. The studies done on geo polymer concrete is considerably limited before 2001 whereas, numerous research studies increased probably from the year 2016, stipulating growth towards sustainable environment [5]. This research aimed to investigate the workability, compressive strength of geo polymer concrete, ratio of liquid to binder, percentage of water content, molarity of sodium hydroxide solution, ratio of sodium silicate to sodium hydroxide solution.

2. Materials and Methods
2.1 Materials
Fly ash used in this study was low calcium fly ash conforming to grade 1 of IS 3812. The particle size distribution of the fly-ash is very significant during the binding process in geo-polymer concrete. With fineness of the fly-ash the strength of the concrete will increase. Chemical compositions of the fly ash used along with the specifications are given in Table 1.

| Component | Percentage % |
|-----------|--------------|
| SiO₂      | 57.30        |
| Al₂O₃     | 22.87        |
| Fe₂O₃     | 8.06         |
| MgO       | 1.55         |
| SO₃       | 1.05         |
| Na₂O      | 0.73         |
| CaO       | 0.03         |
| LOI       | 1.60         |

M sand is used for making geo polymer concrete and it is confirming to IS 2386 standards. The specific gravity of M sand is 2.68. The coarse aggregates of size 12.5mm are used for mixing geo polymer concrete. The compressive strength of geo polymer concrete is studied for the varies mix of having different molarities of sodium hydroxide (10M, 11M, 12M and 13M). The molecular weight of sodium hydroxide (NaOH) is 40g/mol. To prepare 10M sodium hydroxide solution, 400g of sodium hydroxide pellets were weighed and they are dissolved in distilled water to form 1 litre solution. After the pellets dissolved fully in the water, add the remaining water to make 1 liter solution. The weights of pellets added for other molarity of solutions are as given in Table 2.
Table.2. Molarity of alkaline activator solutions

| Molarity | Molecular weight (g/mol) | Weight of NaOH pellets (g) |
|----------|--------------------------|---------------------------|
| 10M      | 40                       | 400                       |
| 11M      | 40                       | 440                       |
| 12M      | 40                       | 480                       |
| 13M      | 40                       | 520                       |

2.2 Mix proportions

The basic difference in preparing geo polymer concrete and Portland cement concrete is the binder and its solutions. The major quantities of silicon dioxide and aluminium oxide in the fly ash reacts with the alkaline liquid to form the geo polymer paste that binds the loose coarse aggregates, fine aggregates, and un-reacted materials together to form the geo polymer concrete. The geo polymer concrete is prepared using fly ash, fine aggregate, Coarse aggregate and alkaline liquid with the mix ratio of 1:1.5:3.3 and its formulations are presented in Table.3. The alkaline liquids are Sodium hydroxide (NAOH) and Sodium Silicate (Na$_2$SiO$_3$) solutions. To meet the performance criteria, the alkaline liquid-to-fly ash ratio by mass, water-to binder ratio by mass, water to geo polymer solids ratio by mass, the wet-mixing time, the heat-curing temperature, and the heat-curing time are selected as parameters. The super plasticizers are added of about 1 to 3% for each mix ratio to enhance the retarder capability. After making the homogeneous mix, workability test by slump cone method is determined. Then, the cubes of size 150 mm X 150 mm X 150 mm and cylinders of size 300mm x 150mm were used to cast specimens in three layers as per standard procedures. After 24 hours of casting cubes were demoulded and kept for rest period before and after curing stages. The rest period is the time taken after casting of specimens and before curing process [11-12]. The steam Curing process was done at temperatures like 600$^\circ$C. These cubes were placed at room temperature after curing up to the testing age. The testing at the age 7 days and 28 days were done. The compressive strength and the workability of geo polymer concrete are influenced by the proportions and properties of the binder materials that make the geo polymer paste. To predict the performance criteria the compressive strength of hardened concrete and the workability of fresh concrete are been selected.

Table.3. Mix ratio formulation

| Mix ratio | NaOH Molarity | Water binder ratio | Alkaline to fly ash Ratio | M sand to fly ash ratio | Superplasticizer % |
|-----------|---------------|--------------------|---------------------------|------------------------|-------------------|
| M11       | 10M           | 0.3                | 0.35                      | 1.6                    | 2                 |
| M12       | 10M           | 0.3                | 0.50                      | 1.6                    | 2                 |
| M21       | 11M           | 0.3                | 0.35                      | 1.6                    | 2                 |
| M22       | 11M           | 0.3                | 0.50                      | 1.6                    | 2                 |
| M31       | 12M           | 0.3                | 0.35                      | 1.6                    | 2                 |
| M32       | 12M           | 0.3                | 0.50                      | 1.6                    | 2                 |
| M41       | 13M           | 0.3                | 0.35                      | 1.6                    | 2                 |
| M42       | 13M           | 0.3                | 0.50                      | 1.6                    | 2                 |
3. Results and Discussion

3.1 Test for Workability on Geo polymer Concrete

To measure the workability of the geo polymer concrete slump cone method is employed for all the sample specimens are measured and presented in table 4. The test is employed to measure the slump degradation and the diameter of spread concrete that are affected by molarity of NaOH solutions based on different alkaline to fly ash ratios presented in Figure 1. The usage of superplasticizer improves the slump value has proved effective enough to improve the poor workability of geo polymer concrete [20]. The difference in slump value is lesser than 10 mm which shows that the usage of super plasticizer will have an impact on workability of the geo polymer concrete at initial stages. Therefore, the M22 mix can be taken as suitable mix in terms of workability.

| Slump Value, mm | M11 | M12 | M21 | M22 | M31 | M32 |
|-----------------|-----|-----|-----|-----|-----|-----|
| Without Super plasticizer | 89  | 91  | 85  | 90  | 89  | 98  |
| 2% super plasticizer added | 100 | 105 | 98  | 100 | 100 | 110 |

3.2 Test on Hardened Concrete

3.2.1 Test on Compressive strength

The average compressive strength of hardened concrete is obtained by testing the concrete cubes specimens after 7 days and 28 days for different Molarity solutions of NaOH and for alkaline to fly ash ratios. The cubes are allowed for the rest period of 24, 48 hours and it is placed under steam curing of 600°C. The comparison of average compressive strength for M32 mix shows 15.9 N/mm² and 20.13 N/mm² for 7 and 28 days of steam curing respectively. The compressive strength is greatly influenced by the amount of calcium oxide content in fly ash that increases the strength considerably [14]. The inclusion of 2% superplasticizer does not significant to the cube compressive strength [20]. The increase in molarity of NaOH solutions increases the compressive strength considerably as shown in figure 2 and 3.
Figure 2. Effect on different molarity of NaOH solutions to compressive strength at 0.5 alkaline to fly ash ratio.

Figure 3. Effect on different molarity of NaOH solutions to compressive strength at 0.35 alkaline to fly ash ratio.

3.2.2 Test on Split tensile strength
The average split tensile strength of 7 days and 28 days are tested for different Molarity solutions of NaOH and for alkaline to fly ash ratio are presented in figure 4 and 5. The cylinder specimens are allowed for the rest period of 24, 48 hours and it is placed under steam curing of 600°C. The result shows that the split tensile strength increases with increase in molarity of NaOH solutions. For 13M mix sample the split tensile strength is higher for both 0.35 and 0.5 alkaline to fly ash ratio.

Figure 4. Effect on different molarity of NaOH solutions to Split Tensile strength at 28days for different alkaline to fly ash ratio.
Figure 5. Effect on different molarity of NaOH solutions to Split Tensile strength at 7 days for different alkaline to fly ash ratio.

4. Conclusions

The study reveals the performance of geopolymer concrete based on various parameters. The ratio of alkaline to fly ash, by mass does not affect the compressive strength of the geopolymer concrete. The addition of superplasticizer improves the workability of geopolymer concrete. The compressive strength of the geopolymer concrete increases with increase in concentration of molarities of sodium hydroxide. The split tensile strength of concrete is very low when compared to control concrete but gradually increases with increase in molarity of NaOH solutions. Increase in strength beyond 24 and 48 hours is observed and the compressive strength of the geopolymer concrete increases with increase in the curing temperature of about 600°C. It has been observed that wide number of parameters affect the compressive strength and split tensile strength of the geopolymer concrete. The amount of water meant for curing geopolymer concrete is very less compared to conventional concrete.

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