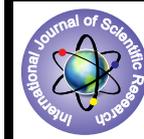


Performance Of Geopolymer Concrete Under Various Curing Conditions



Engineering

KEYWORDS : geopolymer concrete, molarity, sodium hydroxide, sodium silicate, compressive strength, split tensile strength

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ABSTRACT

This paper presents the study done on development of strength for various grades of geopolymer concrete with various types of curing conditions (ambient, steam and oven curing). The grades chosen for the investigation were M-40, M-50 and M-60, the mixes were designed for molarity of 12 M. The test specimens were 150x150x150 mm cubes, 100x200 mm cylinders, for hot air oven and steam curing the specimens were cured at 60°C. The alkaline solution used for experimental study is a combination of sodium silicate and sodium hydroxide solution with the ratio of 2.5. Out of these three curing conditions heat curing gave better results. Since it utilizes the industrial wastes such as fly ash for producing the binding system in concrete, it can be considered as eco-friendly materials.

Introduction

Portland cement is widely used in concrete industry since many decades ago, however it releases green house gases, i.e. carbon dioxide (CO₂), into the atmosphere during its manufacture [1]. Geopolymer technology is one of the new technologies attempted to reduce the use of Portland cement in concrete. Geopolymers are amorphous to semi-crystalline three-dimensional aluminosilicate polymers similar to zeolites [2].

Geopolymers are environmental friendly materials which do not emit green house gases during polymerisation process. Besides, they need only moderate energy to produce. Geopolymers are made from source materials with silicon (Si) and Aluminium (Al) content, thus they can be made using fly ash, waste-product of coal-fired power station, as the source materials [3].

The geopolymer technology was first introduced by Davidovits in 1978. His work considerably shows that the adoption of the geopolymer technology could reduce the CO₂, Na₂SiO₃, kg/m³ emission caused due to cement industries. Davidovits proposed that an alkaline liquid could be used to react with aluminosilicate in a source material of geological origin or in by-product materials such as fly ash to make a binder [4].

Fly ash is the most common source material for making geopolymers. Normally, good high-strength geopolymers can be made from class F fly ash [5]. Geopolymer is synthesized by mixing aluminosilicate-reactive material with strong alkaline solutions, such as sodium hydroxide (NaOH), potassium hydroxide (KOH), sodium silicate or potassium silicate. The mixture can be cured at room temperature or temperature cured [6]. The Alkaline activating solution is important for dissolving of Si and Al atoms to form geopolymer precursors and finally aluminosilicate material. The most commonly used alkaline activators are NaOH and KOH.

Experimental Investigations

Materials:

The following materials have been used in the experimental study [9]

- Fly Ash (Class F) collected from Raichur Thermal power plant having specific gravity 2.00.
- Fine aggregate: Sand conforming to Zone-III of IS:383-1970 [13] having
- Fly Ash (Class F) collected from Raichur Thermal power plant having specific gravity 2.00.
- Fine aggregate: Sand conforming to Zone-III of IS:383-1970 [13] having specific gravity 2.51 and fineness modulus of 2.70.
- Coarse aggregate: Crushed granite metal conforming to IS:383-1970 [13] having specific gravity 2.70 and fineness modulus of 5.90.
- Water : Clean Potable water for mixing
- Alkaline liquids: Specific gravity of
 - Sodium Hydroxide (NaOH) = 1.16
 - Sodium Silicate (Na₂SiO₃) = 1.57

Tests were conducted on specimen of standard size as per IS: 516-1959 and IS:5816-1999 [15 and 16]. Details of tests conducted and specimens used are given in Table 1.

Table 1: Details of specimen used and tests conducted

| Type of test conducted | Size of specimen | No. of specimen cast for different grades |
|------------------------|------------------|---|
| Compressive strength | 150x150x150mm | 5 |
| Split tensile strength | 100x200mm | 5 |

Mix design of geopolymer concrete

In the design of geopolymer concrete mix, coarse and fine aggregates together were taken as 77% of entire mixture by mass. This value is similar to that used in OPC concrete in which it will be in the range of 75 to 80% of the entire mixture by mass. Fine aggregate was taken as 30% of the total aggregates. The density of geopolymer concrete is taken similar to that of OPC as 2400 kg/m³ [7]. The details of mix design and its proportions for different grades of GPC are given in Table 2.

Mixing, Casting, Compaction and Curing of Geopolymer Concrete

GPC can be manufactured by adopting the conventional techniques used in the manufacture of Portland cement concrete. In the laboratory, the fly ash and the aggregates were first mixed together dry on pan for about three minutes. The liquid component of the mixture is then added to the dry materials and the mixing continued usually for another four minutes [Fig.1]. In preparation of NaOH solution, NaOH pellets were dissolved in one litre of water in a volumetric flask for concentration of NaOH (12M). Alkaline activator with the combination of NaOH and Na₂SiO₃ was prepared just before the mixing with fly ash. The ratio of alkaline liquid to fly ash by mass varies with the grade of concrete [8]. The alkaline liquid (Na₂SiO₃ / NaOH) used in the current study was 2.5 for all the mixes. The fly ash and alkaline activator were mixed together in the mixer until homogeneous paste was obtained. This mixing process can be handled within 5 minutes for each mixture with different molarity of NaOH. Fresh fly ash based geopolymer concrete was usually cohesive [Fig. 2]. The workability of the fresh concrete was measured by means of conventional slump test [Fig. 3]. For easy working of fresh GPC mixes, superplasticizer Conplast SP-430 was used. After casting the specimens, they were kept in rest period for two days and then they were demoulded. The demoulded specimens were kept accordingly to the various curing conditions namely ambient room temperature, steam curing and hot air oven curing both maintained at 60°C for 24 hours [Fig. 4 to 6].

Results and Discussions

Workability

Fresh GPC mixes were found to be highly viscous and cohesive with medium to high slump. The workability of the geopolymer concrete decreases with increase in the grade of the concrete as presented in Fig. 7, this is because of the decrease in the ratio of water to geopolymer solids. Hence we can say that as the grade

of the concrete increases, the mix becomes stiffer decreasing the workability.



Sodium hydroxide pellets Sodium silicate pellets Mixing of NaOH and Na₂SiO₃

Fig. 1 Stages of preparation of alkaline solution



Fig. 2: Mixing of GPC



Fig. 3: Slump cone test



Fig. 4: Specimens in ambient curing conditions



Fig. 5 Hot air oven



Fig. 6: Steam curing chamber

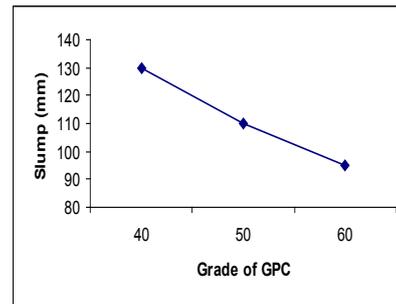


Fig. 7: Workability of GPC mixes

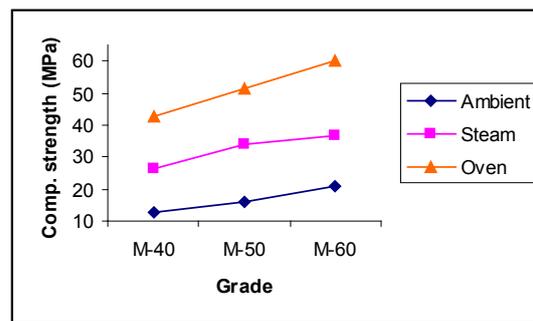


Fig. 8 Comp. strength Vs Grade of GPC (7 days)

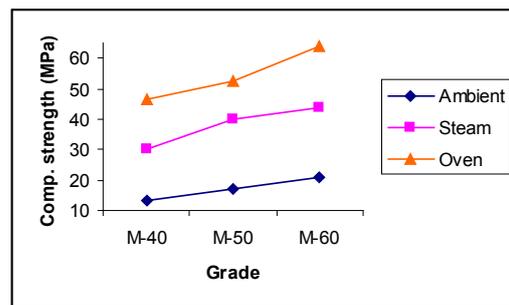


Fig. 9 Comp. strength Vs Grade of GPC (28 days)

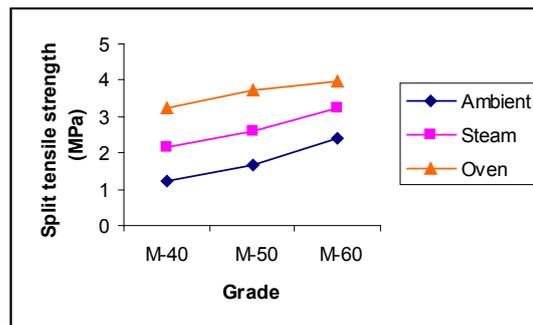


Fig. 10 Split tensile strength Vs Grade of GPC (7 days)

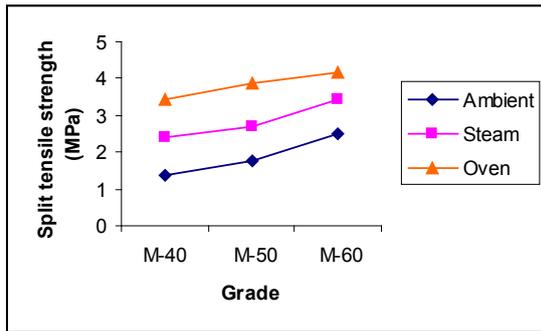


Fig. 11 Split tensile strength Vs Grade of GPC (28 days)

Table 2: Mix proportions of GPC mix with molarity of 12M (Na₂SiO₃/ NaOH as 2.5)

| Materials | | Mass (kg/m ³) | | |
|---|-------|---------------------------|--------|--------|
| | | M-40 | M-50 | M-60 |
| Coarse aggregates | 20 mm | 277.20 | 277.20 | 277.20 |
| | 14 mm | 369.60 | 369.60 | 369.60 |
| | 7 mm | 646.80 | 646.80 | 646.80 |
| Fine sand | | 554.40 | 554.40 | 554.40 |
| Fly ash | | 394.29 | 408.89 | 424.62 |
| Na ₂ SiO ₃ / NaOH | | 2.50 | 2.50 | 2.50 |
| SiO ₂ /Na ₂ O | | 2.00 | 2.00 | 2.00 |
| Sodium hydroxide solution | | 45.06 | 40.89 | 36.4 |
| Sodium silicate solution | | 112.65 | 102.22 | 91 |
| Super Plasticizer | | 5.91 | 6.13 | 6.37 |
| Extra water | | 39.42 | 40.88 | 42.46 |

Compressive strength

The compressive strength of the GPC specimens synthesized at three different regimes of curing are as shown in Fig. 8 and 9. The condensation polymerization that takes place is endothermic in nature therefore supply of heat need to be consistently present. This process is different from OPC concrete as geopolymer concrete does not utilize water in its polymeric reaction. This in turn helps the mixing and casting process to increase the fresh concrete workability.

From the graphs it is clear that hot air oven resulted in maximum strength. The 7 and 28 days average compressive strength of hot air oven specimens were 34% and 68% higher than that of steam and ambient cured specimens respectively, which indicates that heat curing is necessary for achieving strength for geopolymer concrete. It was also observed that the critical period of geopolymer concrete strength development is within the first week from mixing process. Lack of polymeric reaction during this period reduced the compressive strength.

Split tensile strength

The split tensile strength of geopolymer concrete is only a fraction of compressive strength, as in case of Ordinary Portland cement concrete. The variation of results are presented in Fig. 10-11. From those graphs it is clear that hot air oven resulted in maximum strength. The 7 and 28 days average split tensile strength of hot air oven specimens was 27% and 52% higher more than that of ambient cured and steam cured specimens respectively.

Conclusions

Based on the experimental investigations done the following conclusions can be drawn:

- The compressive strength development of geopolymer concrete was much affected by the curing condition during maturing period. Therefore proper curing method was important to obtain acceptable geopolymer structures.
- As grade of geopolymer concrete increases the workability of mix goes on decreasing.
- The average compressive strength of heat cured specimens were 34% and 68% higher than that of steam and ambient air curing respectively.
- The average split tensile strength of heat cured specimens were 27% and 52% higher than that of steam and ambient air curing respectively.
- The reaction of fly ash was extremely slow during ambient temperature, hence initial curing was necessary that can improve the geopolymerization, which led to high strength of geopolymer concrete.
- Geopolymer concrete is more environmental friendly and has the potential to replace ordinary Portland cement concrete.

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