International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 7 (2017) pp. 1227-1231


# Study on the Development of Class C Flyash Based GPC by Ambient Curing

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**Abstract**

The fundamental phenomenon of the development of Geopolymer concrete to acheive the early strength is to cure by steam or hot oven curing. As there are practical difficulties in hot curing, few reserchers have tried to cure GPC by exposed or ambient curing methods. Further, most of the works reported on the GPC are based on the low calcium flyash but, only very few on the high calcium flyash. High calcium flyash is more cementitious and less pozzolonic compared to low calcium flyash. Therefore, development of GPC using high calcium flyash as source material is tried, with alkaline solution consisting of the combination of sodium hydroxide and sodium silicate solution having liquid ratio of 2.5. The influence of Molaity of sodium hydroxide in the alkaline solution on the strength properties of three different grades of GPC is studied. Control specimens are cast, cured by ambient curing and tested for compressive strength, splitting tensile strength and modulus of rupture at 28 days of curing. It is observed that the expected 28 day strength of ambient cured GPC can be obtained for specific molarity of NaOH.

**Keywords:** Geopolymer concrete, Class C flyash, alternative binders, activating solution, ambient curing.

## INTRODUCTION

The ecstasy and salient features of geopolymer cements is narrated by Joseph Davidovits (1994). In the review process of GPC, Hardjito and Rangan(2005) have given the development, mixture proportions, and the short-term properties of low-calcium flyash-based geopolymer concrete concluding that the bulk cost of chemicals needed to manufacture this concrete is cheaper than the bulk cost of one ton of Portland cement, excellent compressive strength, suffers very little drying shrinkage and low creep, excellent resistance to sulfate attack, and good acid resistance. Abdul Aleem and Arumairaj (2012) briefly review the constituents of GPC, its strength and potential applications. Sourav et al (2014) give an overall view of the process and parameters which affect the geo-polymer concrete. James and John Day (2012) discussed a wide range of different geopolymer binder systems available, presented data on the engineering properties of GPC and examples of its application. Rangan (2008), Lloyd and Rangan (2009), Anuradha et al (2012), Kolli Ramujee and Potharaju (2014), Jarvis R. Black (2012) presented simple methods for the design of low calcium flyash based GPC mix proportions.

Shankar and Khadiranaikar (2012) presented the performance of class C flyash based GPC subjected to severe environmental conditions and compared with conventional concrete of M30, M40, M50 and M60 grades and reported that that the heat-cured (60°C for 24 hours) GPC had an excellent resistance to Sulphuric acid and magnesium sulphate attack when compared to conventional concrete. Ashley Russell et al (2015) established a relationship between the activator composition and the properties of class C flyash based geopolymer mortar in fresh and hardened states and indicated the potential for the concrete industry to use flyash based geopolymer as an alternative to Portland cement. Prinya Chindaprasirt et al (2013) studied the curing effect of 90W microwave radiation for 5 minutes followed by a shortened heat curing of class C flyash based GPC. Results showed that microwave radiation contributed to the dissolution of flyash in the alkaline solution and numerous gel formations were observed in microscopic scale resulting in a dense composite and strong bonding between the fly ash and the geopolymer matrix leading to high strength gain compared to those of the control pastes cured at 65°C for 24 hours.

Ambient cured conditions have been tried by Kolli Ramujee and Potharaju (2013), Bhosale and Shinde (2012), Krishnan et al (2014) and Kumaravel(2014) and reported that the compressive strength is more for oven drying as compared to specimen left in ambient curing.

Joshi (2014) reviewed and reported that flyash generation is expected to increase to 300 million tons per annum by 2017 and 900 million tons per annum by 2031-32. Neyveli Lignite Corporation (NLC) annually produces 1.20 million tons of high calcium flyash. As the utilization is very low and storing and disposal of ash is also a problem. As the setting characteristics of high calcium flyash is better than the low calcium flyash, an ideal solution is to promote the potential use of the waste flyash as a sorce material and to develop GPC. But the technology is still in the laboratory levels and a data base is to be created on the development process.

## EXPERIMENTATION

The chemical composition of cement and flyash is presented in Table 1. River sand having specific gravity of 2.64 and fineness modulus 2.62ine aggregate is used as fine aggregate and hard granite stone of maximum size 12.5mm having specific gravity of 2.7 and fineness modulus 6.12 is used as coarse aggregate both for OPCC and GPC. The sodium based alkaline solution with liquid ratio 2.5 is considered based on the preliminary studies from literature survey. The ingredients of alkaline solution is shown in figure 1. The molarity of NaOH is varied as 8M, 10M, 12M and 14M for preparing NaOH solution. The mass of the solids obtained based on the Perry's Chemical Engineer's Hand Book (Rajamane and Jeyalakshmi, 2014).

The OPCC grades of M20, M30 and M40 (using 43 grade cement) are designed and considered. Similar equivalent grades of GPC designated as GM20, GM30 and GM40 are designed using a modified method.

The required quantity of NaOH is mixed with water to get required concentrated solution and is prepared and the sodium silicate solution by 2.5 times is added to get the required alkaline solution. The alkaline solution is prepared 24 hours before using for mixing in concrete. For brevity, the constituent details of GPC are given in Table 2.

**Table 1:** Chemical Composition of low calcium flyash and cement

| Material | Mass of elements (%) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | $Na_2O$ | $K_2O$ | $TiO_2$ | MgO | $SO_3$ | LOI |
| Flyash | 47.60 | 21.40 | 07.80 | 11.90 | 00.70 | 00.82 | 01.88 | 01.80 | 02.80 | 03.30 |
| Cement | 22.60 | 04.30 | 02.30 | 64.30 | 00.05 | 00.04 | - | 02.20 | 02.10 | 02.10 |


(a) Sodium Hydroxide (solids) (b)Sodium Silicate solution

**Figure 2:** Ingredients of alkaline solution

## FABRICATION OF SPECIMENS

Twelve different mix ratios are considered for GPC and three for OPCC thus totally 15 mixes are made in batches for determining different strength properties. The constituents for a particular batch of quantity of concrete are got by weigh batching. OPCC is prepared in the standard way of mixing and GPC also is prepared conventionally. Flyash and the aggregates are first mixed together dry for about three minutes. The alkaline liquid prepared 24 hours in advance is then added to the dry materials and the mixing continued for four minutes. With the part of the mixed concrete, slump test is conducted for checking with the assumed value.The concrete specimens are cast using cube, cylinder and prism moulds and compacted over table vibrator.

As the maximum size of coarse aggregate considered is 12.5mm, specimens like 100mm cubes for compression, 100×200mm cylinders for splitting tension and 100×100×500mm prisms for flexure (moulus of rupture) are cast respectively. The cast OPCC specimens are made to have pond curing for 28 days. The GPC specimens are cast and kept inside a polythene coverage. After 3 days of casting, the specimens are demoulded and kept for ambient curing in the laboratory.

**Table 2:** Constituent quantities of GPC at a glance

| | | Constituent quantities per m$^3$ of GPC | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Grade | M | NaOH | | | $Na_2SiO_3$ | | | Fly ash | Aggregates | |
| | | Solid-Water-Solution | | | Solid – Water- Solution | | | | Fine/Coarse | |
| GM20 | 8M | 09.41 | 27.50 | 36.91 | 40.70 | 51.59 | 92.29 | 230.8 (1) | 612 (2.65) | 1428 (6.19) |
| | 10M | 11.29 | 25.62 | | | | | | | |
| | 12M | 13.07 | 23.85 | | | | | | | |
| | 14M | 14.77 | 22.15 | | | | | | | |
| GM30 | 8M | 13.39 | 39.11 | 52.50 | 57.86 | 73.35 | 131.21 | 296.3 (1) | 576 (1.95) | 1344 (4.54) |
| | 10M | 16.07 | 36.43 | | | | | | | |
| | 12M | 18.59 | 33.91 | | | | | | | |
| | 14M | 20.99 | 32.50 | | | | | | | |
| GM40 | 8M | 17.23 | 50.32 | 67.55 | 74.47 | 94.39 | 168.86 | 363.6 (1) | 540 (1.49) | 1260 (3.47) |
| | 10M | 20.67 | 46.87 | | | | | | | |
| | 12M | 23.91 | 43.63 | | | | | | | |
| | 14M | 27.02 | 40.52 | | | | | | | |

## STRENGTH PROPERTIES

After 28 days of casting, the specimens are tested for their appropriate properties in a standard manner. As the 28 day strength is the deciding factor for conventional concrete, the same concept is followed for GPCC also. The compressive strength of concrete specimens is determined as per IS specification. The splitting tensile strength and the test for modulus of rupture (two point load system) are also conducted in a standard manner. The test results are compared in figures 2, 3 and 4 respectively for their variation.

## ANALYSIS OF RESULTS

The 28 day compressive strength of GPC increases for increase in the molarity of NaOH for all the three grades of GPC and also it increases as the grade value rises for the liquid ratio of 2.5. Equal strength of GPC is reached incase of GM20 for 8 molarity as 27.3MPa which is almost equal to that of M20 concrete (27.7MPa) and grater than the target strength of M20 concrete(26.6 MPa). The strength for 10M, 12M and 14M based concrete are 15%, 25%, 26% respectively grater than 8M based concrete.

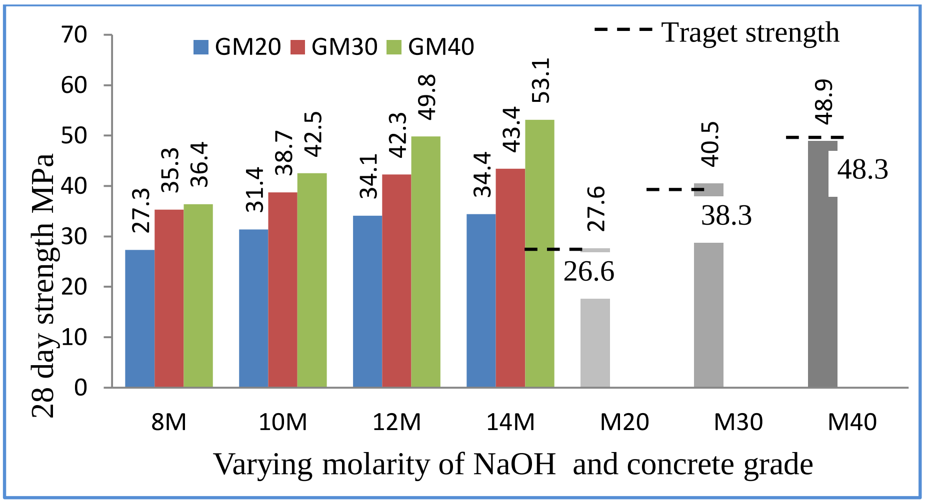


**Figure 2.** Comparison of cube compressive strength

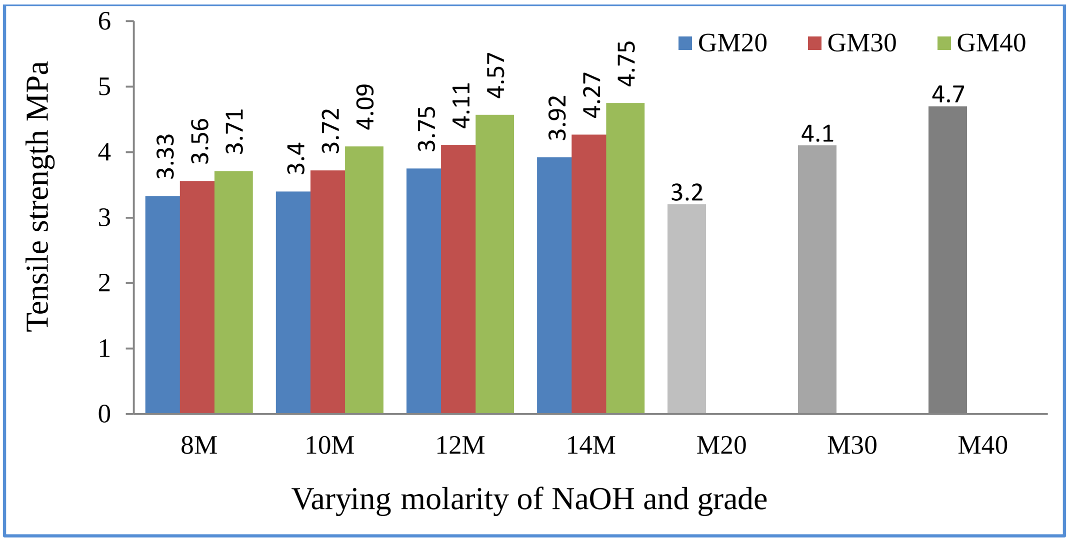


**Figure 3.** Comparison of Splitting tensile strength

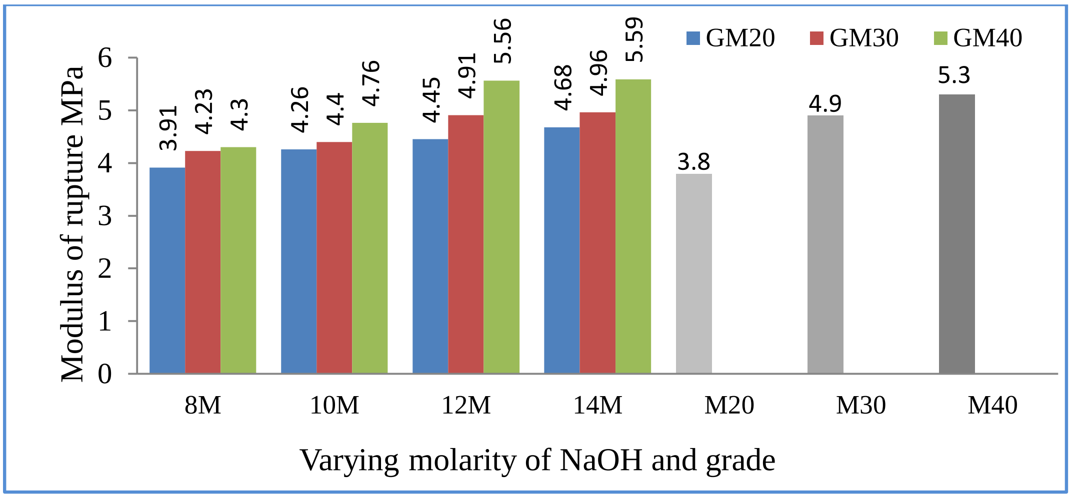


**Figure 4.** Comparison of flexural strength

Equal strength of GPC is reached in GM30 for 10 molarity as 38.7 MPa which is almost equal to target strength(38.3MPa) but 5% less than that of the OPCC of M30 concrete (40.5 MPa). The strength for 12M and 14M based are 9% and 12% more than that of 10M based concrete.

Incase of GM40, the equal grade strength of GPC is reached for 12 molarity of NaOH as 49.8 MPa which is 2% more than the target strength (48.9MPa) but almost equal to the strength of conventional M40 concrete (48.9MPa). The strength for 14M based GM40 concrete is 6% grater than 12M based concrete.

The 28 day strength in spilitting tension as well as the modulus of rupture of GPC increase for increase in the molarity of NaOH for all the three grades of GPC and also it increases as the grade value rises. Further, the modulus of rupture is grater than the splitting tensile strength for all the fifteen different concrete mixes.

Ambient curing is observed to be adequate to develop required compressive strength in 28 days and hot curing is not necessary for GPC. But, 28 days of curing is a must as applied to conventional cement concrete. This is also applicable for splitting tensile strength as well as modulus of rupture.

## CONCLUSIONS

- The strength development is possible for GPC similar to OPCC without hot curing.
- The expected grade strength of GPC can be reached for specimic molarities of NaOH.
- Equal grade strength of GPC is reached incase of GM20 for 8 molarity, GM30 for 10 molarity and GM40 for12 molarity of NaOH.
- The same trend like compressive strength is also observed for splitting tensile strength as well as modulus of rupture of GPC.

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