Effect of Curing Regime on Compressive Strength of Geopolymer Concrete

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Abstract. Advancement of reasonable development materials has been the focal point of exploration globally in recent times. Considering the current scenario, finding options in contrast to Ordinary Portland concrete (OPC) is of incredible importance as a result of high CO₂ emission during its production. Accordingly, supplementary material was acquainted as alternative to cement for concrete production. Utilisation of fly ash is eco-accommodating and furthermore saves cement cost. It is wealthy in silicate and alumina and it responds with alkaline solution to produce alumina silicate gel which helps in fastening the concrete ingredients. The fly ash based geo polymer offers better protection from the forceful condition and elevated temperature than the ordinary cement. Some factors like NaOH Molarity, NaOH/Na₂SiO₃ percentage assume a fundamental element in the development of the geopolymerization reaction became concept of. The investigation on the fly ash based geo polymer profoundly did in the present work, besides the impact of elevated temperature and time are not exceptionally recorded in the available literature. In this study the effect of curing temperature and curing time on the compressive strength (3, 7 and 28 days) of GPC at a constant molarity of NaOH and alkaline solution ratio and compare with controlled concrete. In the present work 10 molars of NaOH and 1:1.5 alkaline solution ratio was considered by varying curing temperature 60⁰, 90⁰ and 120⁰ C and 24, 48 and 72 hours of curing time. M30 grade concrete mix with the equivalent GPC is developed. From the experimental results, it was found that compressive strength was effected by curing temperature and curing time at 3, 7 and 28 days and maximum compressive strength i.e., 53.46 MPa was obtained at higher curing temperature (120⁰ C) and lower curing time (24 hrs). Also, when compared with control concrete, the compressive strength is higher for GPC was observed.

Keywords: Geopolymer concrete, fly ash, NaOH molarity, curing temperature, curing time

1. Introduction

Most concerning issue to the civilization on Earth is ecological contamination, i.e., accumulation of unwanted impurities to the air. Considering the recent time, Ordinary Portland Cement (OPC) and Portland Pozzolana Cement (PPC) are the cements which are used as the binding material as it is widely explored binding constituent of concrete, because of its inevitable accessibility and reasonably minimal expense of the essential raw materials and handling innovation, additionally the adaptability and solid
execution of these materials. Also, Concrete is one of the main constituents of any type of construction project in the world. Since centuries lime stone is used as the main raw material for OPC manufacturing, it resulted into the scarcity lime in many parts of the world. Likewise, during the manufacturing of OPC lot of outflows of carbon dioxide (CO$_2$) gas into the environment takes place. During the concrete production also CO$_2$ outflow takes place in the environment. Because of all these reasons i.e., increase of greenhouse gases like CO$_2$ takes place and which is one of the causes for the present global warming situation. In India consumption of concrete was about 150 million tons in 1995 which continues expanding as much as 390 million tons in 2017. It was also found that 1 ton of CO$_2$ green house is produced when 1 ton of concrete is manufactured. And, this CO$_2$ which is discharged is 65% responsible for depleting the ozone layer of the atmosphere compared to other sources. Many possible alternatives of Portland cements are experimented by various researchers to lessen the use of OPC and PPC in concrete manufacturing without comprising the strength and other properties of conventional concrete, use of materials like fly ash, ground granulated blast furnace slag, metakaolin and so forth are some of the alternative materials. In the previous decade, there has been colossal expansion in the use of fly ash since over 70% of electric power generated in India. In the present scenario, the fly ash production contribute about 160 million-tons by the thermal power plant across the country and this plant are facing decomposition problem of this enormous amount of fly ash. Construction industry is one of the main sectors where fly ash can be consumed in enormous amount. Geopolymer is a light weight, inorganic polymer. It is a fact that by product materials like fly ash act as binder when react with alkaline solution. In this regard, the geopolymer innovation shows extensive guarantee for application in substantial industry as an alternative to the Portland material and it helps in reducing the CO$_2$ discharge to the air brought about by the concrete production. Most of the literature available is three decades back on heat cured regime based fly ash geopolymer concrete. In most parts of India, the temperature difference between summer and winter is greater than 40$^\circ$C.

2. Review of Literature
2.1. Need of Geopolymer
After the industrialization there is lots of changes takes place globally and also many industries are facing problem and challenges. Concrete industry is also had challenges to produce more as day-by-day demand increases but calcined materials reserve is restricted which results in the slow rate of production and also use of it emits CO$_2$ which is a harmful greenhouse gas. India is also facing this global challenge as there is deficit of concrete due to monstrous infra development going on. Endeavors are being made to triumph over this deficiency, substitute resources to OPC are one of the developments to defeat this setback, utilization of waste pozzolana in gigantic quantity with improvement in the properties of concrete. Many supplementary materials such as ‘alkali-activated cement’, ‘calcium sulphaaluminate cement’ etc. are investigated with the benefits of Portland cement[1]. The basic composition of alkaline cement is determined by its phase composition [2]. It is mainly used as a hydration product for concrete. Geopolymer because of its characteristics like early strength, good chemical resistance, low permeability and very high fire resistance attracted many researchers in recent time [3-8].

2.2. Geopolymer Chemistry
Portland cement is first generation and lime is second generation. This material is mainly used as building materials. Amorphous Alkali Aluminosilicate is commonly used as a geopolymer. It is also used as an organic material and as cements [5]. It is made of remanufacturing unit that consists of a sialate silicate monomer (– Si–O–Al–O–). It is commonly used for the development of various polymers. The primary factors that are necessary for creating stable geopolymer are as follows: the source materials should have high reactivity, low water requirement and accumulate aluminum from it without any change. Sodium and potassium-based hydroxides and silicates are used as the alkaline activators for the synthesis of geopolymers. The Properties will be improved by choosing the right mix and design for specific applications [4, 5]. A systematic creation of the before said geopolymer is given in Figure 1.
Figure 1. Systematic creation of fly ash to geoplymer [7]

Under highly alkaline conditions, the reaction between reactants and silicates can cause polymerization and formation of free tetrahedral units like [SiO₄]⁻ and [AlO₄]⁻ in the solution. After the tetrahedral units are connected to the precursor, the resulting into Si–O–Al–O bonds which are formed by the exchange of oxygen atom. During the geopolymerization, following reaction takes place given by [7].

\[
(Si_2O_5Al_2O_2)_n + H_2O + OH^- \rightarrow Si(OH)_4 + Al(OH)^{4-} \\
Si(OH)_4 + Al(OH)^{4-} \rightarrow (-Si - O - Al - O-)_n + 4H_2O
\]

The workability to the geopolymer concrete mix will be obtained by the water which is liberated from the geopolymer reaction. This shows the same reaction of water with metakaolin/fly ash activated as what we get in Portland cement. Also, the zeolite type such as sodium aluminosilicate hydrate gel with varying silica to aluminum ratio is the hydration products of fly ash based geopolymer and in slag based geopolymer it is calcium silicate hydrate with low calcium to silica ratio. Although many of the properties of geopolymers are similar to those of other materials, their chemical and microstructural properties vary significantly. The metakaolin-based geopolymer has a high degree of stability and is easily manufactured. This material has a variety of properties that can be easily adapted to different applications and its plate-shaped particles are known to cause rheological problems due to their shape [8]. Contrary to popular belief, fly ash-based geopolymers are more durable and are more acid-resistant than those made from metakaolin [5]. Also, the former's properties make it a better choice for making geopolymers.

2.3. Geopolymer Concrete

Different mix proportioning of GPC was stated by many researchers, with target strength up to 80 MPa. Some typical properties of GPC mixes by various researchers are stated in table 1.

| Properties | Unit | [10] | [11] | [12] | [13] |
|------------|------|------|------|------|------|
| Density    | kg/m³ | 2330-2430 | 2147-2408 | 1890-2371 | 1876-2555 |
Contrary to popular belief, the ITZ of GPC is not micro concrete because of its varying microstructure. This allows the agents like C to penetrate the concrete structure. When fly ash is taken as source since it has various characteristics that allow the easy penetration of various external agents into a concrete because of its varying microstructure. This allows the agents like Cl, O₂ and SO₄ to penetrate into the concrete structure. Contrary to popular belief, the ITZ of GPC is not micro-structurally distinct

| Molarity | M | 10-16 | Not reported | 14 | 8 |
|----------|---|-------|--------------|----|---|
| Slump    | mm | 60-215 | Not reported | 100-150 | Not reported |
| Compressive strength | MPA | 30-80 | 47-56.5 | 10-80 | 65.1-77.9 |
| Split tensile test | MPA | 3.74-6 | 2.8-4.1 | Not reported | 2.8-5.1 |
| Flexural strength | MPA | 5-12 | 4.9-6.2 | 2.24-6.41 | Not reported |
| Modulus of elasticity | GPa | 23-31 | 23-39 | 1.9-42 | 11.2-41.2 |
| Poisson’s ratio | -- | 0.12-0.16 | 0.23-0.26 | 0.08-0.22 | 0.15-0.19 |
| Activator/Binder ratio | --- | 0.35–0.4 | 0.45–0.59 | 0.4–0.94 | 0.4–0.65 |
| Curing temp. & Curing time | °C | Hrs | 60–80 | 24 | Upto testing | 72 | 24 |

Various parameters were studied to determine the proper mixing for GPC mixes. These included the water/Na₂O ratio, curing period, molarity, and the age of hardening. The molarity, workability, and water content of a GPC mix affect the slump of its mixes. Its effects are evidenced by the various characteristics of the mix [10]. The fresh concrete characteristics such as yield stress help in controlling the flow of liquid materials. The plastic viscosity and yield stress were influenced by the concentration of alkaline solution and the ratio of volume of NaOH and Na₂SiO₃ solution and with alkaline solution strength ranges between 1-20 M [14]. The geopolymer concrete setting time was reported to be about 120 minutes [15]. Considering slag based geopolymer concrete, the setting time may increase to around 180 minutes on addition of admixture which is naphthalene-based and because of this it could be utilized for various mechanical applications [24]. When the ratio of water-geopolymer solid is maintained at 0.18 and temperature 90°C, optimum compressive strength is found, latter's GPC concrete's compressive strength dropped in a similar way to OPC. When tested at elevated temperature for 24 hrs, GPC exhibits no change in its compressive strength with age [10]. The early high strength gain is due to its compact structure, good aggregate-paste bond, and adequate reaction products. OPC exhibits higher modulus of elasticity than that of GPC mix [16]. When fly ash is taken as source material, GPC mix gave better 28 days compressive strength (55 MPA) than OPC concrete mix at elevated temperature ranges between 60-70°C. GPC mix had higher tensile strength and higher flexural values than OPC concrete mix, but it produced less expansion than its concrete counterpart as its modulus of elasticity were 15–29% lower than the controlled OPC concrete [17]. The lower shrinkage of GPC is due to its zeolitic structure, which allows the water to evaporate during casting [16].

Many researchers [10-12, 14-22] have investigated the GPC properties and their relation. The gain in split tensile strength of GPC can be attributed to the denser interfacial zone. The modulus of elasticity increased with the increase in the compressive strength of GPC. The difference between the strength gains and losses of GPC mixes was found to be relatively small, the similarities between the gains was apparent [11]. The equation f = 0.69√f'c MPa and the equation Ec = 580√f'c MPa for GPC was suggested by [12]. The poisson’s ratio value of GPC was lower than OPC. The GPC was brittle due to the cross-linking framework compared to OPC concrete [13, 18, 22]. When compared to OPC concrete, it exhibits low fracture energy because of aggregates stronger bond [21].

The weakest link in OPC concrete is the interfacial zone [23]. The study of ITZ is very important since it has various characteristics that allow the easy penetration of various external agents into a concrete because of its varying microstructure. This allows the agents like Cl, O₂ and SO₄ to penetrate into the concrete structure. Contrary to popular belief, the ITZ of GPC is not micro-structurally distinct.
from that of the bulk binder region [24-25]. At the start of the GPC, many large voids were observed. As the hydration continues, the voids are filled by the products of hydration. The differences in the the ITZ and the matrix microstructure were not significant. Certain elements were higher in the ITZ than that of the matrix [26]. In the field emission scanning electron microscope, a self-compacting GPC with a superplasticizer exhibits a low viscosity and loose and porous ITZ with 3 percent of superplasticizer dose and hard or dense ITZ is formed with 7 percent of superplasticizer dose. The increasing thickness of ITZ decreases the compressive strength and highly depends on dosages of superplasticizer [27].

3. Research significance
The advancement of Fly Ash Geo Polymer Concrete (FGPC) presents direct difficulties to OPCC (Ordinary Portland Cement Concrete) as driving development material. Since 1980s, the examination on mechanical properties of FGPC mortars and cement has been extremely reassuring. A few elements like NaOH Molarity, NaOH/Na₂SiO₃ proportion assume a fundamental part in the improvement of the geopolymerization response was thought of. But the study of curing regime and its effect on compressive strength was not investigated. An attempt was made to examine the variation of compressive strength on both curing temperature and curing time.

4. Experimental program
4.1. Materials
The physical and mechanical properties of materials used in the present experimental is given in table 2.

Table 2. Physical and mechanical properties of Ordinary Portland cement, fly ash, fine aggregate and natural coarse aggregate

| Properties                        | Code Reference     | Test Result | BIS Limits |
|-----------------------------------|--------------------|-------------|------------|
| Test on Ordinary Portland cement  |                    |             |            |
| Normal consistency (%)            | IS: 4031(PART 4)-1988 | 32          | 26 – 33    |
| Initial setting (Min)             | IS: 4031(Part 5)-1988 | 100         | 30-60      |
|                                   | IS 12269:2013       |             |            |
| Final setting (Min)               | IS: 4031(Part 5)-1988 | 435         | 600        |
|                                   | IS 12269:2013       |             |            |
| Fineness (%)                      | IS: 4031(PART3)-1988 | 7.67        | 10         |
|                                   | IS 12269:2013       |             |            |
| Compressive strength (N/mm²)      | IS:4031 (Part-6) 1988 | 3 days      | 29.93      |
|                                   | IS 12269:2013       | 7days       | 39.46      |
|                                   |                     | 28 days     | 55.1       |
|                                   |                     |             | 27         |
|                                   |                     |             | 37         |
|                                   |                     |             | 53         |
| Test on Fly Ash                   |                    |             |            |
| Fineness of the fly-ash           | ---                | 19          | ---        |
| Tests on Fine Aggregate           |                    |             |            |
| Sieve analysis of fine aggregate  | IS 383 1970        | Fineness modulus | 3.16  |
|                                   |                     | Zone        | II         |
| Specific gravity of sand          | IS 2386 (Part-III)1963 | 2.81       | 2.6 - 3.0  |
| Test on Natural Coarse Aggregate  |                    |             |            |
| Sieve analysis of coarse          | IS: 383-1970       | Size        | 20 mm      |
|                                   |                     | Grading     | Single     |
Water absorption | IS 2386 (Part-III)1963 | 0.25% | 0.6 per unit by weight
Specific gravity | IS 2386 (Part-III)1963 | 2.64 | 2.6-3.0
Flakiness index | IS: 2386 (Part-I) 1963 | 20.49 | <30
Elongation index | IS: 2386 (Part-I) 1963 | 22.75 | <45
Impact value | IS: 2386 (Part-IV) 1963 | 9.94 | <20

4.1.1. Proportions
M30 grade concrete was designed in accordance with IS:10262-2009 and is adopted for the design of GPC M30 mix and the mix proportions are represented in Table 3.

Table 3 Mix Design for M30 OPC and GPC (quantities are in kg/m³)

| Grade of Concrete | Cement /Fly ash kg | Fine Agg. | Coarse Agg | Alkaline Solution | Curing Regime |
|-------------------|---------------------|-----------|------------|-------------------|---------------|
| OPC30             | 450                 | 514       | 1119       | NaOH Molarity     | Temperature C |
|                   | Ratio               | 1         | 1.14       | Na₂SiO₃ Molarity | Period or Time Hrs. |
|                   | 1                   | 2.49      | 0.43       | NaOH/Na₂SiO₃ ratio | 24, 48 and 72 |
|                   | kg                  |           |            |                   |               |
| GPC30             | 450                 | 514       | 1119       | 0.43              | 60°, 90° and 120° C |
|                   | Ratio               | 1         | 1.14       | 10                | 24, 48 and 72 |
|                   | kg                  |           |            | 1:1.5             |               |
|                   |                      | 2.49      | 5          |                   |               |

4.2. Preparation of test specimens
The alkaline solution was made by utilizing the technique given in Research report GC-1, Curtin University [28]. At first, the NaOH solution was made by dissolving the NaOH flakes in the water. The mass of NaOH solids in a solution differs dependent on the fixation as communicated in Molarity. For 10M, NaOH arrangement comprises of 10x40 = 200 grams of NaOH solids (in flakes form) per liter of the arrangement, where 40 is the sub-atomic load of NaOH. The mass of NaOH solids was assessed as 360 gm/l of NaOH arrangement for 10 molars of NaOH solution. The alkaline solution was made 24 hrs before the casting, to permit the exothermically warmed fluid to cool to room temperature. First the deliberate measure of fly ash, fine and coarse aggregate were blended in a substantial blender for around 3 min in a dried condition, then, at that point the alkaline solution is added to the dry blend. The blend was properly compacted in three layers utilizing tamping bar and followed by table vibrator compaction for 30 seconds. The cubes of size 100 mm x 100 mm x 100 mm for each blend were casted to track down the compressive strength at 3, 7 and 28 days. Then, at that point the samples were set in the oven for 24 hrs, 48 hrs and 72 hrs with varying temperature 60°, 90° and 120° C and afterward the cubes were taken out from the oven and kept at room temperature until the time of testing. The test was also performed on the GPC samples under ambient condition.

5. Results and discussions
5.1. Compressive strength
The cube compressive strength of OPC M30 concrete at various curing age are tested according to IS:516 (1959) and the outcomes are presented in Figs. 2 to 5. Further, the compressive strength of GPC M30 for 10M NaOH with NaOH/Na₂SiO₃ 1:1.5 with encompassing and distinctive curing temperatures
(ambient, 60°, 90° and 120° C) and curing times (24 hrs, 48 hrs and 72 hrs) are tested and the mean compressive strength results are presented in Figures. 2 to 5.

Figure 2. Shows the variation of compressive strength of GPC M30 for 10M, and NaOH/Na$_2$SiO$_3$ of 1:1.5 under ambient condition at various testing ages. The figures likewise present the compressive strength variation of OPC concrete M30 with various testing age under standard conditions.

![Figure 2](image_url)

It is noticed from the Figure 2. that at alkalinity ratio (1:1.5), the compressive strength of GPC of M30 grades at ambient condition is lower than the M30 OPC concrete at all testing periods. Figure 3. shows the variation of compressive strength of GPC mix M30 for 10M molarity, curing times (24, 48 and 72 hrs) and NaOH/Na$_2$SiO$_3$ of 1:1.5 at 60° C curing temperature at different testing ages. The figures also present the variation of compressive strength of OPC concrete mix of M30 with different testing age under standard curing.
Figure 3. Compressive strengths of OPC and GPC M30 cured at 60°C having 10M with 1:1.5 NaOH / Na$_2$SiO$_3$ ratio after 3, 7 and 28 days of curing

The figure 3. discovers that independent of the ratio of NaOH/Na$_2$SiO$_3$, testing age and molarity of NaOH, there is increase in the compressive strength of M30 GPC mix with the increment in curing time. Comparable outcomes were accounted by [10,29]. This is generally due to longer curing time with lower temperature, which further improve the formation of polymerization chain formation and results in higher compressive strength. After 24 hours of curing time, the 28 days of compressive strength of GPC with alkalinity ratio of 1:1.5 the compressive strength of GPC M30 with 10M of NaOH is 25.92 MPa. The 28 days compressive strength of 10 M of GPC M30 with alkalinity ratio 1:1.5 is enhanced by 2.24%, when the curing time is raised to 48 hrs and increment of 28.82% is observed when curing time is increased to 72 hrs in contrast to 24 hrs of temperature curing.

After 72 hours, the compressive strength of GPC of M30 at 3 and 28 days with 10M NaOH and 1:1.5 alkalinity ratio is 5.14 and 9.85% respectively lower than the corresponding control concrete i.e. M30 concrete with OPC and at 7 days, the compressive strength of M30 GPC is 0.28% higher than corresponding controlled OPC concrete. It is also noticed from the figures that irrespective of the alkalinity ratio (1:1.5), the compressive strength of GPC of M30 grades at 60°C curing temperature increases with increase in curing time at all testing periods. Similar results were reported in the literature [30-38]. The increase in compressive strength with the molarity may be due to increase in the rate of polymerization that takes place with increase in molarity.

Figure 4 show the variation of the compressive strength of M30 GPC mixture for 10 molarity, curing times (24, 48 and 72 hrs) with 1:1.5 NaOH/Na$_2$SiO$_3$ ratio at curing temperature of 90°C. Figure also present the compressive strength of M30 control OPC concrete at 3, 7 and 28 days testing age under standard curing.
The Figure 4 indicate that regardless of the NaOH/Na$_2$SiO$_3$ ratio, testing age and molarity of NaOH, the compressive strength of M30 GPC raised with the raise in curing time. After 24 hours of curing time, the 28 days compressive strength of M30 GPC with 10M of NaOH and with NaOH/Na$_2$SiO$_3$ equal to 1:1.5 is 36.53 MPa. Further, with 10M of NaOH, the compressive strength of GPC M30 improved by 37.28% respectively when the curing time is stretched to 48 hrs and 38.13% when curing time is increased to 72 hrs when compared to 24 hrs of temperature curing. The figure also reveals that irrespective of the alkalinity ratio, molarity and curing time, the compressive strength of GPC M30 with alkalinity ratios 1:1.5 and with 10M NaOH after 72 hours of temperature curing, the 3, 7 and 28 days compressive strength are 77.7%, 79.22% and 36.23% more than the M30 control concrete i.e. concrete with OPC. It is further noticed that irrespective of the molarity of NaOH and alkalinity ratio, GPC M30 have attained target strength within 3days with 48 hours and 72 hours of heat curing. It is noticed from the figures that except at 24 hrs curing time, the compressive strength of GPC M30 is more than the M30 control concrete at all testing ages. It was reported in the literature that the GPC attain the targeted strength before 3 days of testing period and within the first 3 to 4 hours of heat curing, it reached about 70% of 28 days strength [39]. Higher curing time further develops the polymerization interaction and hence increasing the compressive strength further. As observed with 60° C, at 90° C also the compressive strength of GPC M30 grades increases with increase in curing time from 24 to 72 hrs of curing time at all testing periods.

Figure 5 shows the variation of compressive strength of GPC M30 for 1:1.5 alkalinity ratio, 10M of NaOH and 24, 48 and 72 hrs curing times at curing temperature 120° C at various testing age. The figures also present the variation of compressive strength of OPC concrete of M30 with various testing age under standard conditions.
Figure 5. Compressive strengths of OPC and GPC M30 cured at 120° C having 10M with 1:1.5NaOH / Na₂SiO₃ ratio after 3, 7 and 28 days of curing

In contrast to 60° and 90° C curing temperature, Figure 5 reveals that the compressive strength of M30 GPC decreased with increasing curing time at 120° C regardless of the alkalinity ratio, molarity of NaOH and testing age. This is because higher curing temperature with lower curing time the compressive strength of GPC is more than at lower temperature with higher curing time. [40] observed that when higher curing temperature maintained for longer duration, resulted in decrease of moisture content, which inhibits the geopolymerization process taking place. The high alkali concentration in geopolymer concrete may be preventing the concentration of silicate species, resulting in a slight loss in compressive strength. After 24 hours of curing time, the 28 days compressive strength of M30 GPC with 1:1.5 alkalinity ratio and with 10M of NaOH is 53.42 MPa against 37.04 MPa M30 concrete with OPC which is the maximum compressive strength achieved for GPC M30 mix in the present work considering the other parameters. That is the compressive strength of GPC M30 with 1:1.5 alkalinity ratio and with 10M reduced by 12.45% when the curing time is extended to 48 hrs and 29.74% when the curing time is prolonged to 72 hrs in contrast to 24 hrs of temperature curing. Further, it is seen that regardless of the alkalinity ratio, molarity of NaOH, the compressive strength of M30 GPC after 24, 48 and 72 hrs of temperature curing at all testing periods is moderately higher than control concrete i.e. concrete with OPC. After 24 hours of curing time, the compressive strength of M30 GPC with alkaline solution ratio 1:1.5, the raise in compressive strengths of GPC M30 with 10M of NaOH the strengths are 83.71%, 83.43% and 44.22% respectively higher than the corresponding concrete with OPC. Also, rate of increment of compressive strength for M30 GPC reduced by prolonging the curing time at all testing periods. Therefore, it may be concluded that with higher temperature i.e. 120° C with lesser heat curing time (24 hrs) the desired strengths can be attained. This is owing to the fact that a longer curing period at high temperatures impairs the microstructure of fly ash-based geopolymer concrete, causing dehydration and excessive shrinkage due to gel contraction, rather than converting to a more semi-crystalline state [41-42].

[12, 28, 43, 44] were reported that the main component of fly ash is silica and alumina, which are responsible for the development of strength. These elements can be extracted by the use of catalysis of
the alkaline activator. The speed of the reaction was accelerated and the activity of fly ash was also improved at high temperature with low curing time. Also, high temperature accelerates the geopolymerization process and helps in accelerating the hardening time. In addition, when GPC is cured at high temperature, it produces more sodium alumina silicate-hydrate (N-A-S-H) gel than those that are cured at low temperature. This produces high initial strength and ultimate strength.

6. Conclusions

Based on the above experimental results the following concluding remarks can be drawn

- GPC curing at lower temperature i.e. 60\(^{\circ}\)C exhibits lower compressive strength as compared to OPC at all testing ages.
- At lower temperature and medium temperature i.e. 60\(^{\circ}\)C and 90\(^{\circ}\)C by increasing the curing time there is a gain in compressive strength of GPC at all testing ages.
- GPC curing at medium and high temperature (90\(^{\circ}\)C & 120\(^{\circ}\)C) shows higher compressive strength than the control concrete at all testing ages.
- At medium temperature of 90\(^{\circ}\)C there is increase in compressive strength with increase in curing time.
- Compared to lower and medium temperature, at higher temperature higher compressive strength occurs at lower curing time and it decreases with further increase in the curing time.

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