IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

# EXPERIMENTAL STUDY ON FLY ASH BASED GEOPOLYMER CONCRETE

Mohd Faisaluddin[1], Dr Shaik Kamal Mohd Azam[2]

Ph.D Student, Department of Civil Engineering, Mewar University, Rajasthan, India[1]
Professor, KBN College of Engineering, Department of Civil Engineering, Karnatka, India[2]

***Abstract:*** Environmental and economic reasons require the revision of present concrete making materials. Fortunately within this scenario a new player has emerged that can help in mitigating the problem and the player is Geopolymer Concrete. This paper provides the details of development of the process of making fly ash-based geopolymer concrete. Due to the lack of knowledge and know-how of making of fly ash based geopolymer concrete in the published literature, this study adopted a rigorous trial and error process to develop the technology of making, and to identify the salient parameters affecting the properties of fresh and hardened concrete. The main parameters affecting the compressive strength of hardened fly ash-based geopolymer concrete are the curing temperature and curing time, the molar H2O-to-Na2O ratio, and mixing time.

Fresh fly ash-based geopolymer concrete has been able to remain workable up to at least 120 minutes without any sign of setting and without any degradation in the compressive strength. Providing a rest period for fresh concrete after casting before the start of curing up to five days increased the compressive strength of hardened concrete.

***Index Terms* - Geopolymer Concrete, Modulus of Elasticity, Poisson's ratio, Fly ash**

## I. INTRODUCTION

After wood, concrete is the most often used material by the community. Concrete is conventionally produced by using the ordinary Portland cement (OPC) as the primary binder. The environmental issues associated with the production of OPC are well known. The amount of the carbon dioxide released during the manufacture of OPC due to the calcinations of limestone and combustion of fossil fuel is in the order of one ton for every ton of OPC produced. In addition, the amount of energy required to produce OPC is only next to steel and aluminum.

Geopolymer concrete is a 'new' material that does not need the presence of Portland cement as a binder. Instead, the source of materials such as fly ash, that are rich in Silicon (Si) and Aluminum (Al), are activated by alkaline liquids to produce the binder. Hence concrete with no Portland cement.

## II. LITERATURE REVIEW

A well known example of the first model is the activation of blast furnace slag, which has a long history in the former Soviet Union, Scandinavia and Eastern Europe (Roy 1999). On the other hand, studies on the second model are limited (Palomo, Grutzeck et al. 1999). Many aspects of the material characteristics and reaction mechanisms are still not clear. For the second model, Davidovits (1999) coined the term Geopolymer in 1978 to describe the alkali activated material from geological origin or by-product materials such as fly ash and rice husk ash. Davidovits (1994) also revealed the fact that very few scientific literatures on geopolymer material available was caused by the patent oriented schemes of research works. Only from the late 1990s scientific information were becoming available in the published literature.

## III. OBJECTIVES OF THE RESEARCH

1. To develop a mixture proportioning process of making fly ash-based geopolymer concrete.
2. To identify and study the effect of salient parameters that affects the properties of fly ash-based geopolymer concrete.
3. To study the short-term engineering properties of fresh and hardened fly ash based geopolymer concrete.

# IV. EXPERIMENTAL PROGRAMM WITH RESULTS AND DISCUSSION

Based on the limited past research on geopolymer pastes available in the literature and the experience gained during the preliminary experimental work, the following ranges were selected for the constituents of the mixtures used in further studies
• Low calcium (ASTM Class F) fly ash
• Alkaline activators
Ratio of sodium silicate solution-to-sodium hydroxide solution, by mass, of 0.4 to 2.5.
This ratio was fixed at 2.5 for most of the mixtures because the sodium silicate solution is considerably cheaper than the sodium hydroxide solution.
Molarity of sodium hydroxide (NaOH) solution in the range of 8M to 16M.
Ratio of activator solution-to-fly ash, by mass, in the range of 0.3 and 0.40.

The compressive and tensile strength tests on hardened fly ash-based geopolymer concrete were performed on a 2000 kN capacity Farnell hydraulic testing machine in accordance to the relevant Standards (1999; 2000). Five 100x200 mm concrete cylinders were tested for every compressive strength test. Three 150x300 mm concrete cylinders were tested for each tensile splitting strength test. The results given in the various Figures and Tables are the mean of these values.

**Table 4.1: Details of Mixtures 1 to 13**

| Mixture No | Aggregate | | | | | Fly Ash | NaOH Solution | | Sodium Silicate | Added Water | Super-plasticiser |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 20 mm (kg) | 14 mm (kg) | 10 mm (kg) | 7 mm (kg) | Fine Sand (kg) | (kg) | Mass (kg) | Molarity | (kg) | (kg) | (kg) |
| 1 | 277 | 370 | - | 647 | 554 | $476^{a)}$ | 120 | $8M^{*)}$ | 48 | - | - |
| 2 | 277 | 370 | - | 647 | 554 | $476^{a)}$ | 48 | $8M^{*)}$ | 120 | - | - |
| 3 | 277 | 370 | - | 647 | 554 | $476^{a)}$ | 120 | $14M^{*)}$ | 48 | - | - |
| 4 | 277 | 370 | - | 647 | 554 | $476^{a)}$ | 48 | $14M^{*)}$ | 120 | - | - |
| 5 | - | - | - | 1294 | 554 | $408^{c)}$ | 51.5 | $14M^{**)}$ | 103 | $16.5^{x)}$ | - |
| 6 | - | - | - | 1294 | 554 | $408^{c)}$ | 51.5 | $14M^{**)}$ | 103 | $16.5^{x)}$ | 4.1 |
| 7 | - | - | - | 1294 | 554 | $408^{c)}$ | 51.5 | $14M^{**)}$ | 103 | $16.5^{x)}$ | 8.2 |
| 8 | - | - | - | 1294 | 554 | $408^{c)}$ | 51.5 | $14M^{**)}$ | 103 | $16.5^{x)}$ | 16.3 |
| 9 | - | - | 554 | 647 | 647 | $408^{b)}$ | 41 | $12M^{**)}$ | 103 | $14.3^{y)}$ | 6.1 |
| 10 | - | - | 554 | 647 | 647 | $408^{b)}$ | 41 | $14M^{**)}$ | 103 | $17.6^{y)}$ | 6.1 |
| 11 | - | - | 554 | 647 | 647 | $408^{b)}$ | 41 | $12M^{*)}$ | 103 | $14.3^{y)}$ | 6.1 |
| 12 | - | - | 554 | 647 | 647 | $408^{b)}$ | 41 | $8M^{*)}$ | 103 | - | 6.1 |
| 13 | 277 | 370 | - | 647 | 554 | $408^{a)}$ | 41 | $14M^{*)}$ | 103 | - | 8.2 |

Note:
*) Technical Grade
**) Commercial Grade
a) Fly Ash: Batch I
b) Fly Ash: Batch II
c) Fly Ash: Batch III
x) Tap water
y) Distilled water

**Table 4.2: Details of Mixtures 14 to 26**

| Mixture No | Aggregate 20 mm (kg) | Aggregate 14 mm (kg) | Aggregate 10 mm (kg) | Aggregate 7 mm (kg) | Aggregate Fine Sand (kg) | Fly Ash (kg) | NaOH Solution Mass (kg) | NaOH Solution Molarity | Sodium Silicate (kg) | Added Water (kg) | Super-plasticiser (kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 | 277 | 370 | - | 647 | 554 | 408 [a)] | 41 | 14M [*)] | 103 | 10.7 [y)] | 8.2 |
| 15 | 277 | 370 | - | 647 | 554 | 408 [a)] | 41 | 14M [*)] | 103 | 21.3 [y)] | 8.2 |
| 16 | - | - | 554 | 647 | 647 | 408 [b)] | 41 | 8M [*)] | 103 | - | 6.1 |
| 17 | - | - | 554 | 647 | 647 | 408 [b)] | 41 | 10M [*)] | 103 | 7.5 [y)] | 6.1 |
| 18 | - | - | 554 | 647 | 647 | 408 [b)] | 41 | 12M [*)] | 103 | 14.4 [y)] | 6.1 |
| 19 | - | - | 554 | 647 | 647 | 408 [b)] | 41 | 14M [*)] | 103 | 20.7 [y)] | 6.1 |
| 20 | - | - | 554 | 647 | 647 | 408 [b)] | 41 | 16M [*)] | 103 | 26.5 [y)] | 6.1 |
| 21 | - | - | 554 | 647 | 647 | 408 [b)] | 41 | 14M [**)] | 103 | 20.7 [y)] | 6.1 |
| 22 | - | - | - | 1294 | 554 | 408 [c)] | 41 | 14M [**)] | 103 | 16.5 [x)] | 6.1 |
| 23 | - | - | 554 | 647 | 647 | 408 [b)] | 41 | 14M *) | 103 | - | 8.2 |
| 24 | - | - | 554 | 647 | 647 | 408 [b)] | 41 | 8M [*)] | 103 | - | 6.1 |
| 25 | - | - | 554 | 647 | 647 | 408 [b)] | 55.4 | 8M [*)] | 103 | - | 6.1 |
| 26 | - | - | 554 | 647 | 647 | 408 [b)] | 55.4 | 8M [*)] | 103 | - | 6.1 |

Note:
*) Technical Grade
**) Commercial Grade
a) Fly Ash: Batch I
b) Fly Ash: Batch II
c) Fly Ash: Batch III
x) Tap water
y) Distilled water

**Table 4.3: Properties of Mixtures 1 to 9**

| Mixture No | Curing Time (hours) | Curing Temp. (°C) | Curing Method | Age at Test (days) | Slump (mm) | Density (kg/m³) | Compressive Strength (MPa) | Standard Deviation | Special Features |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 24 | 60 | Oven | 7 | na | 2365 | 17 | 0.91 | - |
| 2 | 4 | 30 | Oven | 7 | na | 2376 | 8 | 0.27 | - |
| | 4 | 60 | Oven | 7 | na | 2378 | 24 | 0.47 | - |
| | 4 | 90 | Oven | 7 | na | 2341 | 37 | 4.39 | - |
| | 24 | 30 | Oven | 7 | na | 2364 | 20 | 1.13 | - |
| | 24 | 60 | Oven | 7 | na | 2377 | 57 | 2.51 | - |
| | 24 | 90 | Oven | 7 | na | 2341 | 66 | 5.46 | - |
| 3 | 24 | 60 | Oven | 7 | na | 2386 | 48 | 1.62 | - |
| 4 | 48 | 30 | Oven | 7 | na | 2367 | 49 | 1.6 | - |
| | 4 | 60 | Oven | 7 | na | 2320 | 25 | 2.57 | - |
| | 4 | 90 | Oven | 7 | na | 2376 | 30 | 3.71 | - |
| | 24 | 30 | Oven | 7 | na | 2367 | 29 | 1.46 | - |
| | 24 | 60 | Oven | 7 | na | 2386 | 68 | 4.09 | - |
| | 24 | 90 | Oven | 7 | na | 2385 | 70 | 2.68 | - |
| 5 | 24 | 60 | Steam | 3 | 39 | 2340 | 42 | 0.8 | Superplasticiser 0% |
| 6 | 24 | 60 | Steam | 3 | 59 | 2375 | 41 | 0.5 | Superplasticiser 1% |
| 7 | 24 | 60 | Steam | 3 | 80 | 2347 | 41 | 2.7 | Superplasticiser 2% |
| 8 | 24 | 60 | Steam | 3 | 93 | 2336 | 36 | 1.3 | Superplasticiser 4% |
| 9 | 24 | 60 | Steam | 7 | 209 | - | 40 | 2.9 | Rest Period = 0 day |
| | 24 | 60 | Steam | 7 | 209 | - | 41 | 2.1 | Rest Period = 1 day |
| | 24 | 60 | Steam | 7 | 209 | - | 48 | 1.9 | Rest Period = 2 days |
| | 24 | 60 | Steam | 7 | 209 | - | 50 | 1.2 | Rest Period = 3 days |
| | 24 | 60 | Steam | 7 | 209 | - | 49 | 1.8 | Rest Period = 4 days |

Table 4.4: Properties of Mixtures 10 to 13

| Mixture No | Curing | | | Age at Test (days) | Slump (mm) | Density ($kg/m^3$) | Compressive Strength (MPa) | Standard Deviation | Special Features |
|---|---|---|---|---|---|---|---|---|---|
| | Time (hours) | Temp. (°C) | Method | | | | | | |
| 10 | 24 | 60 | Steam | 7 | 215 | 2298 | 43 | 1.1 | Rest Period = 0 day |
| | 24 | 60 | Steam | 7 | 215 | 2299 | 53 | 1.5 | Rest Period = 1 day |
| | 24 | 60 | Steam | 7 | 215 | 2298 | 56 | 1.3 | Rest Period = 2 days |
| | 24 | 60 | Steam | 7 | 215 | 2305 | 57 | 2.3 | Rest Period = 3 days |
| | 24 | 60 | Steam | 7 | 215 | 2306 | 57 | 1.6 | Rest Period = 4 days |
| | 24 | 60 | Steam | 7 | 215 | 2303 | 58 | 5.0 | Rest Period = 5 days |
| 11 | 24 | 60 | Steam | 7 | 225 | 2305 | 38 | 2.8 | Rest Period = 0 day |
| | 24 | 60 | Steam | 7 | 225 | 2309 | 53 | 2.2 | Rest Period = 1 day |
| | 24 | 60 | Steam | 7 | 225 | 2314 | 56 | 1.9 | Rest Period = 2 days |
| | 24 | 60 | Steam | 7 | 225 | 2318 | 59 | 2.5 | Rest Period = 3 days |
| | 24 | 60 | Steam | 7 | 225 | 2318 | 59 | 2.3 | Rest Period = 4 days |
| | 24 | 60 | Steam | 7 | 225 | 2314 | 59 | 3.0 | Rest Period = 5 days |
| 12 | 24 | 60 | Oven | 7 | 60 | 2357 | 63 | 4.2 | Rest Period = 0 day |
| | 24 | 60 | Oven | 7 | 60 | 2364 | 74 | 4.1 | Rest Period = 1 day |
| | 24 | 60 | Oven | 7 | 60 | 2363 | 73 | 2.7 | Rest Period = 2 days |
| | 24 | 60 | Oven | 7 | 60 | 2361 | 76 | 3.5 | Rest Period = 3 days |
| | 24 | 60 | Oven | 7 | 60 | 2369 | 75 | 3.2 | Rest Period = 4 days |
| | 24 | 60 | Oven | 7 | 60 | 2368 | 77 | 5.3 | Rest Period = 5 days |
| 13 | 24 | 30 | Oven | 7 | na | 2387 | 44 | 0.51 | $H_2O/Na_2O$=10.00 |
| | 24 | 45 | Oven | 7 | na | 2377 | 55 | 1.69 | |
| | 24 | 60 | Oven | 7 | na | 2375 | 59 | 2.52 | |
| | 24 | 75 | Oven | 7 | na | 2375 | 65 | 4.81 | |
| | 24 | 90 | Oven | 7 | na | 2376 | 71 | 4.69 | |

Table 4.5: Details of Mixtures 14 to 20

| Mixture No | Curing | | | Age at Test (days) | Slump (mm) | Density ($kg/m^3$) | Compressive Strength (MPa) | Standard Deviation | Special Features |
|---|---|---|---|---|---|---|---|---|---|
| | Time (hours) | Temp. (°C) | Method | | | | | | |
| 14 | 24 | 30 | Oven | 7 | na | 2338 | 35 | 1.79 | $H_2O/Na_2O$=11.25 |
| | 24 | 45 | Oven | 7 | na | 2336 | 42 | 4.17 | |
| | 24 | 60 | Oven | 7 | na | na | na | na | |
| | 24 | 75 | Oven | 7 | na | 2337 | 60 | 2.04 | |
| | 24 | 90 | Oven | 7 | na | 2334 | 59 | 3.13 | |
| 15 | 24 | 30 | Oven | 7 | na | 2326 | 32 | 1.02 | $H_2O/Na_2O$=12.50 |
| | 24 | 45 | Oven | 7 | na | 2322 | 37 | 0.73 | |
| | 24 | 60 | Oven | 7 | na | 2321 | 44 | 2.49 | |
| | 24 | 75 | Oven | 7 | na | 2301 | 44 | 0.63 | |
| | 24 | 90 | Oven | 7 | na | 2318 | 44 | 3.35 | |
| 16 | 24 | 60 | Oven | 7 | 32 | 2381 | 55 | 1.50 | $Na_2O/SiO_2$=0.097 |
| | 24 | 60 | Steam | 7 | 32 | 2385 | 47 | 1.24 | |
| 17 | 24 | 60 | Oven | 7 | 113 | 2352 | 53 | 3.00 | $Na_2O/SiO_2$=0.103 |
| | 24 | 60 | Steam | 7 | 113 | 2362 | 45 | 0.82 | |
| 18 | 24 | 60 | Oven | 7 | 162 | 2361 | 51 | 1.70 | $Na_2O/SiO_2$=0.109 |
| | 24 | 60 | Steam | 7 | 162 | 2364 | 42 | 1.55 | |
| 19 | 24 | 60 | Oven | 7 | 214 | 2343 | 45 | 2.17 | $Na_2O/SiO_2$=0.115 |
| | 24 | 60 | Steam | 7 | 214 | 2341 | 40 | 1.16 | |
| 20 | 24 | 60 | Oven | 7 | 240 | 2341 | 47 | 1.93 | $Na_2O/SiO_2$=0.120 |
| | 24 | 60 | Steam | 7 | 240 | 2342 | 40 | 2.30 | |

.

Table 4.6: Properties of Mixtures 21 to 26

| Mixture No | Curing Time (hours) | Curing Temp. (°C) | Curing Method | Age at Test (days) | Slump (mm) | Density (kg/m³) | Compressive Strength (MPa) | Standard Deviation | Special Features |
|---|---|---|---|---|---|---|---|---|---|
| 21 | 24 | 60 | Steam | 21 | 234 | 2345 | 37 | 1.44 | Mixing time 2 min |
| | 24 | 60 | Steam | 21 | 234 | 2367 | 40 | 1.92 | Mixing time 4 min |
| | 24 | 60 | Steam | 21 | 226 | 2373 | 45 | 3.36 | Mixing time 6 min |
| | 24 | 60 | Steam | 21 | 219 | 2378 | 45 | 3.06 | Mixing time 8 min |
| | 24 | 60 | Steam | 21 | 219 | 2387 | 47 | 0.25 | Mixing time 10 min |
| | 24 | 60 | Steam | 21 | 206 | 2397 | 49 | 2.08 | Mixing time 13 min |
| | 24 | 60 | Steam | 21 | 206 | 2399 | 52 | 1.01 | Mixing time 16 min |
| 22 a | 4 | 90 | Steam | 3 | 91 | 2331 | 40 | 0.78 | Mixing time 4 min |
| b | 4 | 90 | Steam | 3 | 67 | 2344 | 47 | 1.24 | Mixing time 8 min |
| c | 4 | 90 | Steam | 3 | 49 | 2368 | 56 | 4.28 | Mixing time 16 min |
| 23 | 24 | 90 | Oven | 90 | 46 | - | 89 | 4.45 | |
| 24 | 24 | 90 | Oven | 90 | 135 | - | 68 | 4.56 | |
| 25 | 24 | 60 | Oven | 90 | 207 | - | 55 | 1.80 | |
| 26 | 24 | 60 | Steam | 90 | 219 | - | 44 | 1.20 | |

Table 4.7: Data from Additional Studies for Mixture 2 (1)

| Super-plasticiser (kg) | Curing Time (hours) | Curing Temp. (°C) | Curing Method | Age at Test (days) | Density (kg/m³) | Compressive Strength (MPa) | Standard Deviation | Special Feature/s |
|---|---|---|---|---|---|---|---|---|
| - | 24 | 60 | Oven | 3 | 2404 | 61 | 5.49 | Age at test 3 days |
| - | 24 | 60 | Oven | 7 | 2401 | 58 | 4 | Age at test 7 days |
| - | 24 | 60 | Oven | 14 | 2387 | 64 | 3.65 | Age at test 14 days |
| - | 24 | 60 | Oven | 28 | 2373 | 60 | 5.16 | Age at test 28 days |
| - | 24 | 60 | Oven | 56 | 2362 | 61 | 1.95 | Age at test 56 days |
| - | 24 | 60 | Oven | 91 | 2362 | 63 | 3.02 | Age at test 91 days |
| - | 4 | 60 | Oven | 7 | 2396 | 25 | 0.46 | Curing time 4 hrs |
| - | 8 | 60 | Oven | 7 | 2398 | 31 | 3.67 | Curing time 8 hrs |
| - | 12 | 60 | Oven | 7 | 2394 | 41 | 2.31 | Curing time 12 hrs |
| - | 24 | 60 | Oven | 7 | 2391 | 61 | 5.52 | Curing time 16 hrs |
| - | 48 | 60 | Oven | 7 | 2387 | 72 | 10.03 | Curing time 24 hrs |
| - | 72 | 60 | Oven | 7 | 2403 | 77 | 2.7 | Curing time 72 hrs |
| - | 96 | 60 | Oven | 7 | 2400 | 82 | 6.2 | Curing time 96 hrs |
| 4.1 | 24 | 60 | Oven | 7 | 2379 | 56 | 1.86 | Superplasticiser 1.0%, No Rest Period |
| 6.1 | 24 | 60 | Oven | 7 | 2374 | 58 | 3.02 | Superplasticiser 1.5%, No Rest Period |
| 8.2 | 24 | 60 | Oven | 7 | 2362 | 57 | 2.33 | Superplasticiser 2.0%, No Rest Period |
| 10.2 | 24 | 60 | Oven | 7 | 2354 | 50 | 3.28 | Superplasticiser 2.5%, No Rest Period |
| 12.2 | 24 | 60 | Oven | 7 | 2364 | 50 | 0.76 | Superplasticiser 3.0%, No Rest Period |
| 14.3 | 24 | 60 | Oven | 7 | 2335 | 46 | 2.82 | Superplasticiser 3.5%, No Rest Period |
| 4.1 | 24 | 60 | Oven | 7 | 2379 | 56 | 1.86 | Superplasticiser 1.0%, 1 hr Rest Period |
| 6.1 | 24 | 60 | Oven | 7 | 2374 | 58 | 3.02 | Superplasticiser 1.5%, 1 hr Rest Period |
| 8.2 | 24 | 60 | Oven | 7 | 2362 | 57 | 2.33 | Superplasticiser 2.0%, 1 hr Rest Period |

Table 4.8: Data from Additional Studies for Mixture 2 (2)

| Super plasticiser (kg) | Curing | | | Age at Test (days) | Density (kg/m³) | Compressive Strength (MPa) | Standard Deviation | Special Feature/s |
|---|---|---|---|---|---|---|---|---|
| | Time (hours) | Temp. (°C) | Method | | | | | |
| 10.2 | 24 | 60 | Oven | 7 | 2354 | 50 | 3.28 | Superplasticiser 2.5%, 1 hr Rest Period |
| 12.2 | 24 | 60 | Oven | 7 | 2364 | 50 | 0.76 | Superplasticiser 3.0%, 1 hr Rest Period |
| 14.3 | 24 | 60 | Oven | 7 | 2335 | 40 | 2.82 | Superplasticiser 3.5%, 1 hr Rest Period |
| 6.1 | 24 | 60 | Oven | 7 | 2363 | 59 | 2.32 | Handling time = 0 Mnts |
| 6.1 | 24 | 60 | Oven | 7 | 2376 | 59 | 2.36 | Handling time = 30 Mnts |
| 6.1 | 24 | 60 | Oven | 7 | 2365 | 61 | 4.26 | Handling time = 45 Mnts |
| 6.1 | 24 | 60 | Oven | 7 | 2366 | 65 | 1.46 | Handling time = 60 Mnts |
| 6.1 | 24 | 60 | Oven | 7 | 2374 | 64 | 1.49 | Handling time = 75 Mnts |
| 6.1 | 24 | 60 | Oven | 7 | 2370 | 65 | 1.15 | Handling time = 90 Mnts |
| 6.1 | 24 | 60 | Oven | 7 | 2370 | 62 | 4.06 | Handling time = 120 Mnts |
| 6.1 | 24 | 30 | Oven | 7 | - | 35 | 1.22 | Curing Temperature = 30 °C |
| 6.1 | 24 | 45 | Oven | 7 | - | 41 | 2.11 | Curing Temperature = 45 °C |
| 6.1 | 24 | 60 | Oven | 7 | - | 63 | 1.17 | Curing Temperature = 60 °C |
| 6.1 | 24 | 75 | Oven | 7 | - | 64 | 3.42 | Curing Temperature = 75 °C |
| 6.1 | 24 | 90 | Oven | 7 | - | 63 | 3.75 | Curing Temperature = 90 °C |
| 6.1 | 6 | 45 | Oven | 7 | 2378 | 33 | 1.01 | Curing Temperature = 45 °C |
| 6.1 | 6 | 60 | Oven | 7 | 2386 | 42 | 1.07 | Curing Temperature = 60 °C |
| 6.1 | 6 | 75 | Oven | 7 | 2303 | 48 | 2.68 | Curing Temperature = 75 °C |
| 6.1 | 6 | 90 | Oven | 7 | 2369 | 51 | 2.73 | Curing Temperature = 90 °C |
| 4.1 [1)] | 24 | 60 | Oven | 7 | 2388 | 61 | 4.08 | Rest Period 1 hr |
| 4.1 [1)] | 24 | 60 | Oven | 7 | 2393 | 61 | 3.84 | No Rest Period |

[1)] Polycarboxylic ether hyperplasticiser

## V.CONCLUSIONS

1. Higher concentration (in terms of molar) of sodium hydroxide solution results in higher compressive strength of fly ash-based geopolymer concrete (Table 4.9).
2. Higher the ratio of sodium silicate-to-sodium hydroxide ratio by mass, higher is the compressive strength of fly ash-based geopolymer concrete (Table 4.9).
3. As the curing temperature in the range of 30 deg C to 90 deg C increases, the compressive strength of fly ash-based geopolymer concrete also increases (Figures 4.1 and 4.2).
4. Longer curing time, in the range of 4 to 96 hours (4 days), produces higher compressive strength of fly ash-based geopolymer concrete (Figure 4.3). However, the increase in strength beyond 24 hours is not significant.
5. The addition of naphthalene sulphonate-based super plasticiser up to
approximately 4% of fly ash by mass, improves the workability of the fresh fly ash-based geopolymer concrete with very little effect on the compressive strength of hardened concrete (Figure 4.5, 4.6 and 4.7).
6. The slump value of the fresh fly-ash-based geopolymer concrete increases with the increase of extra water added to the mixture (Figure 4.13).
7. The Rest Period, defined as the time taken between casting of specimens and the commencement of curing, of up to 5 days increases the compressive strength of hardened fly ash-based geopolymer concrete. The increase in strength is substantial in the first 3 days of Rest Period (Figure 4.8 and 4.9).
8. The fresh fly ash-based geopolymer concrete is easily handled up to 120 minutes without any sign of setting and without any degradation in the compressive strength (Figure 4.4).

## REFERENCES

[1]. Davidovits, J., (1994). “Properties of geopolymer cements”, 1st International Conference on Alkaline Cements and Concretes (Krivenko, ed.). Kiev, Ukraine, 1: 131-149.

[2]. Davidovits, J., (1994). “Global Warming Impact on the Cement and Aggregates Industries”, World Resource Review, 6(2), 263-278.

[3]. Davidovits .J. (1999) “Chemistry of Geopolymeric systems, Terminology” Geopolymers International Conference France.

[4]. Robert Mccaffrey., (2002). “Climate Change And The Cement Industry”, Conference On Market And Economic Trends Influencing The Global Cement Industry.

[5]. Davidovits, J., (1988). “Soft Mineralogy and Geopolymers”, Proceedings of the of Geopolymer 88 International Conference, the Université de Technologie, Compiègne, France.

[6]. Palomo A, Grutzek MW, Blanco MT., (1999) "Alkali-activated fly ashes. A cement for the future", Cem Concretre Research ;29:1323–9.

[7]. Davidovits, J. (1994) "High-Alkali Cements for 21st Century Concretes. In Concrete Technology, Past, Present and Future", Proceedings of V. Mohan Malhotra Symposium, Editor: P. Kumar Metha, ACI SP- 144, 383-397.

[8]. Sofi, M., van Deventer, J. S. J., Mendis, P. A. and Lukey, G. C., (2007a). "Engineering Properties of Inorganic Polymer Concretes (IPCs)", Cement and Concrete Research, 37(2), 251- 257

[9]. B. Vijaya Rangan., (2008). "Studies On Fly Ash-Based Geopolymer Concrete", Malaysian Construction Research Journal, Vol. 03 [No. 2].

[10]. Gourley, J. T., & Johnson, G. B. (2005) "Developments in Geopolymer Precast Concrete", Paper presented at the International Workshop on Geopolymers and Geopolymer Concrete, Perth, Australia.