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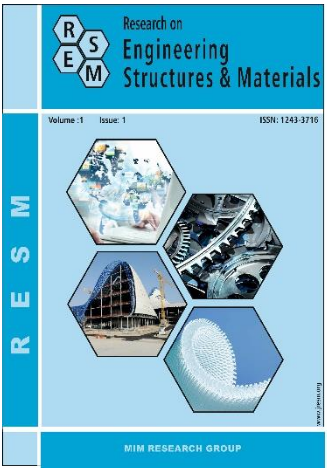


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*Research Article*

# Investigation on effects of fineness of flyash and alkaline ratio on mechanical properties of geopolymer concrete

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## Abstract

Geopolymer is a new development in the world of concrete in which cement is totally replace by pozzolanic material like fly ash and activated by highly alkaline solutions to act as a binder in the concrete mix. Experimental investigation has been carried out to find the effect of fineness of fly ash and alkaline solutions ratio on the mechanical properties of fly ash based geopolymer concrete. Geopolymer concrete is produced by activating fly ash with a highly alkaline solution of sodium silicate containing 16.32% $Na_2O$, 32.75% $SiO_2$ and 50.93% $H_2O$ and sodium hydroxide solution having 13 molar concentrations is maintained constant throughout the study. Compressive strength, split-tensile strength and flexural strength are obtained using three samples of fly ash with fineness of 364, 442 and 610 $m^2/kg$. Alkaline ratio (i.e., $Na_2SiO_3/NaOH$ ratio) of 1, 1.5, 2, 2.5, 3 and solution to fly ash ratio of 0.35 is considered. The specimens are cured in an oven for 110 °C for 7 hrs and tested after 7 and 28 days rest period. It is observed that the fineness of fly ash in terms of specific surface area ($m^2/kg$) increases the strength of geopolymer concrete and optimize at alkaline solution ratio at 1.5.



## 1. Introduction

Use of concrete in the world is second after water and it is globally accepted due to ease in operation, mechanical properties and low cost of production as compared to other construction materials. An important ingredient in the conventional concrete is the Portland cement. Production of Portland cement is increasing due to the increasing demand of construction industries. Therefore the rate of production of carbon dioxide released to the atmosphere during the production of Portland cement is also increasing. Generally for each ton of Portland cement production, releases a ton of carbon dioxide in the atmosphere [1]. The greenhouse gas emission from the production of Portland cement is about 1.35 billion tons annually, which is about 7 % of the total greenhouse gas emissions [2].

The environmental issues associated with the production of ordinary Portland concrete are too many, out of which global warming is the main concerned. Efforts are being made in the construction industry to address this issue by utilizing supplementary materials and developing alternative binders in concrete; the application of geopolymer technology [3] is one such alternative.

Fly ash is a byproduct of pulverized coal blown into fire furnace of electricity generated thermal power plant. According to survey, total fly ash production in the world is about 780 million tons per year but utilization is only 17-20% [2, 4]. In India the production of fly ash is 220 million tons annually [4] out of which utilization is only 35% which creates

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disposal problem. Several hectares of valuable land are acquired by thermal power plant for disposal of fly ash. Aleem and Arumairaj [5] studied geopolymer concrete produced by chemical action of inorganic molecules. Fly ash rich in silica and alumina reacted with alkaline solution produced with alumina-silica gel that acted as binder material for concrete.

Malhotra [6, 7] recommended replacement of cement by fly ash is up to 60 % known as high volume fly ash concrete. But it was observed that the pozzolanic action of fly ash with calcium hydroxide formed during the hydration of cement is very slow. The particles of size less than 45 µm are responsible for pozzolanic reaction. Higher size particles present in fly ash acts as filler. Therefore for complete replacement of cement by fly ash and to achieve the higher strength within a short period of curing, Davodavits [8, 9] suggested activation process of pozzolanic material like fly ash that is rich in silica and alumina. Fly ash when comes in contact with highly alkaline solutions forms inorganic alumino–silicate polymer product yielding polymeric Si–O–Al–O bonds known as geopolymer [8-10].It is an excellent alternative construction material to the existing plain cement concrete. Geopolymer concrete shall be produced without using any amount of ordinary Portland cement.

Davidovits [10, 11] proposed that an alkaline liquid could be used to react with the Silicon (Si) and Aluminium (Al) in source material of geological origin or in byproduct material such as Fly ash, Metakaolin, Ground granulated blast furnace slag (GGBS) Rice husk ash (RHA) etc. to produce binders. Lloyd and Rangan[12] proved that geopolymer concrete result from the reaction of a source material that is rich in silica and alumina with alkaline liquid. The compressive strength of geopolymer mortar increases with increase in duration of heating at constant temperature. Patankar *et al.* [13] proved that the flow of geopolymer concrete increases with increase in water-to-geopolymer binder ratio but the compressive strength decreases with increase in water-to-geopolymer binder ratio similar to water/cement ratio in cement concrete. Jamkar *et al.* [14] investigated on the effect of fineness of fly ash. It is observed that the both workability and compressive strength increases with increase in the fineness of fly. Finer particles resulted in increasing the rate of reaction needing less heating time to achieve desired strength. Patil and Allouche [15] proved that the extent of alkali silica reaction due to the presence of reactive aggregates in fly ash-based geopolymer concretes is substantially lower than in the case of ordinary Portland cement-based concrete, and well below the ASTM specified threshold. Aamer *et al.* [16] Investigated the performance of geopolymer concrete prepared using blended ash of pulverized fuel ash and palm oil fuel ash from agro-industrial waste along with alkaline activators when exposed to a 5% sodium sulphate solution. Patankar *et al.* [17] developed the mix design procedure for fly ash based geopolymer concrete which is used to design normal and standard geopolymer concrete. Sanni and Khadiranaikar [18] presented performance of alkaline solution on grades of geopolymer concrete. Vijai*et al.* [19-21] studied the effect of glass fibres and steel fibres on various strengths of geopolymer concrete. Kumar *et al.* [22] also studied the properties of glass fibre reinforced geopolymer concrete. Sayyad and Patankar [23] studied the effect of steel fibers and low calcium fly ash on mechanical and elastic properties of geopolymer concrete composites (GPCC)

In the present study experimental investigation has been carried out to find effect of fineness of fly ash and alkaline ratio on mechanical properties of fly ash based Geopolymer concrete.

## 2. Experimental Investigation

In the present investigation, following materials were used for the development of fly ash based geopolymer concrete;

### 2.1 Materials

Fly Ash: Low calcium processed fly ash is used as source material. The physical properties and chemical compositions of fly ash samples are shown in Table 1 and 2 respectively.

GCF1: geopolymer concrete with fly ash of grade 364 $m^2/kg$.

GCF2: geopolymer concrete with fly ash of grade 442 $m^2/kg$.

GCF3: geopolymer concrete with fly ash of grade 610 $m^2/kg$.

Table 1. Physical properties of fly ash

| Physical properties | Processed fly ash grade | | | Specification as per IS 3812:1981 |
|---|---|---|---|---|
| | GCF1 | GCF2 | GCF3 | |
| Residue retained on 45μm, % | 15.34 | 7.84 | Nil | 34 |
| Specific surface area, ($m^2/kg$) | 364 | 442 | 610 | 320 |
| Moisture content, % | 0.27 | 0.29 | 0.32 | 2 |
| Autoclave expansion, % | 0.033 | 0.023 | 0.025 | 0.8 |

Table 2. Chemical properties of fly ash

| Chemical composition, % | Processed fly ash grade (F) | | | Specification as per IS 3812:1981 |
|---|---|---|---|---|
| | GCF1 | GCF2 | GCF3 | |
| $SiO_2+Al_2O_3+Fe_2O_3$ | 92.20 | 93.16 | 93.26 | 70(Min. By mass) |
| $SiO_2$ | 58.90 | 59.40 | 60.35 | 35(Min. By mass) |
| MgO | 1.23 | 1.96 | 2.04 | 5 (Max. By mass) |
| $SO_3$ | 0.91 | 0.69 | 0.96 | 3 (Max. By mass) |
| $Na_2O$ | 0.53 | 0.55 | 0.58 | 1.5 (Max. By mass) |
| Total Chlorides | 0.028 | 0.032 | 0.028 | 0.05 (Max. By mass) |
| Loss on ignition | 1.00 | 1.10 | 0.70 | 5 (Max. By mass) |

a) Fine Aggregate: Locally available Godavari river sand confirming to grading Zone-I as per IS 383-1970[24] having specific gravity 2.57 and fineness modulus 3.741 is used as fine aggregate.

b) Coarse aggregate: Crushed angular basalt rock aggregates confirming to IS 383-1970 having specific gravity 2.65 and fineness modulus 6.58 is used as coarse aggregate. The properties of fine aggregate and coarse aggregate are given in table 3.

c) Alkaline activators: Sodium Silicate ($Na_2SiO_3$) solution and prepared 13 molar Sodium Hydroxide (NaOH) solutions were used as alkaline activators. The chemical composition of Sodium Silicate solution was maintained constant throughout the investigation. It contains $N_{a2}O$ of 16.32%, $Si_{O2}$ of 32.75% and $H_2O$ of 50.93%.

## 2.2 Preparation of sodium hydroxide solution

For the preparation of one mole sodium hydroxide solution, flakes of sodium hydroxide weighing 40 grams were added in distilled water so as to make one-liter solution, where 40 is the molecular weight of NaOH. After dissolving the flakes of NaOH, the temperature of solution rise up to 70 to 80$^0$C, therefore solution was prepared two days before casting of concrete so as to avoid any contamination during the mixing of ingredients of geopolymer concrete. For preparation of 13M NaOH solution, 520 Gms of NaOH flakes were added in distilled water so as to make a liter of NaOH solution.

Table 3. Physical properties of fine and coarse aggregate [24]

| Properties | Fine aggregate | Coarse Aggregate |
|---|---|---|
| Particle Shape/Type | Rounded / Natural | Angular/ Crushed Stone |
| Nominal size | 4.75mm | 20mm |
| Fineness Modulus | 3.7406 | 6.58 |
| Silt content | 2% | Nil |
| Specific Gravity | 2.57 | 2.65 |
| Bulking of sand | 4.16% | --- |
| Surface moisture | Nil | Nil |
| Crushing Value | --- | 18.115 % |
| Impact Value | --- | 11.167% |

## 2.3 Preparation of geopolymer concrete mixes

The grade of geopolymer concrete mix was considered as $M_{25}$ and quantities of ingredients of geopolymer concrete were calculated by considering solution-to-fly ash ratio of 0.35, sodium silicate-to-sodium hydroxide ratio by mass of 1, concentration of Sodium silicate solution with $Na_2O$ of 16.37%, $SiO_2$ of34.35% and $H_2O$ of 49.28%, and concentration of NaOH solution maintained at 13 M as per past research [17].

Preparation of geopolymer concrete is similar to that of cement concrete. Two types of coarse aggregates, sand and fly ash were mixed in dry state. Then add prepared mixture solution of sodium hydroxide and sodium silicate along with extra water based on water-to-geopolymer binder ratio and mix thoroughly so as to give homogeneous mix. After making the homogeneous mix, workability of fresh geopolymer concrete was measured by slump similar to cement concrete as per IS: 1199-1959. Then concrete cubes of side 150 mm were cast in three layers. After 24 hours of casting, all cubes were demoulded and then placed in an oven for thermal curing at 110$^0$C temperature for 7 hours. Three cubes were cast for each mix and tested for compressive strength after 7 and 28 days of rest period. The quantities of materials required for different fineness of fly ash are shown in Table 4 while Table 5 shows the quantities of materials required at different alkaline ratios by maintaining constant fineness of fly ash of 442$m^2$/kg .

Table 4. Materials required per Cu.M for M25 grade of GPC for different fineness of fly ash

| Sr. | Identification | Fineness of | Ingredients of Geopolymer concrete, kg/m$^3$ | | | | | |
|---|---|---|---|---|---|---|---|---|
| No. | Mark | Flyash | Fly | NaOH | $Na_2SiO_3$ | Sand | Coarse | Extra |

| | | | Ash | | | | aggregate | water |
|---|---|---|---|---|---|---|---|---|
| 01 | GCF1 | 364 $m^2/kg$ | 460 | 80.5 | 80.5 | 679.79 | 1158.98 | 18.85 |
| 02 | GCF2 | 442 $m^2/kg$ | 385 | 67.375 | 67.375 | 728.49 | 1240.80 | 46.692 |
| 03 | GCF3 | 610 $m^2/kg$ | 260 | 45.5 | 45.5 | 821.42 | 1398.62 | 86.425 |

Table 5. Materials required for per Cu.M for $M_{25}$ grade of GPC for different alkaline ratio

| **Sr. No.** | **Identification Mark** | **Alkaline Ratio** | **Ingredients of Geopolymer concrete, kg/m³** | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Fly Ash | NaOH | $Na_2SiO_3$ | Sand | Coarse aggregate | Extra water |
| 01 | GCF2AL1.5 | 1.5 | 385 | 53.9 | 80.85 | 727.52 | 1239.27 | 48.485 |
| 02 | GCF2AL2.0 | 2.0 | 385 | 44.91 | 89.84 | 727.43 | 1238.60 | 49.548 |
| 03 | GCF2AL2.5 | 2.5 | 385 | 38.5 | 96.25 | 727.15 | 1238.12 | 50.305 |
| 04 | GCF2AL3.0 | 3.0 | 385 | 33.687 | 101.062 | 727.94 | 1237.77 | 50.874 |

## 3. Results and Discussion

The results of workability in terms of slump and effect of different fineness of fly ash and alkaline ratio on compressive strength of geopolymer concrete are presented in the following section.

### 3.1 Effect of fineness of fly ash and alkaline ratio on workability of geopolymer concrete

The workability of fresh geopolymer concrete was measured by slump cone test apparatus. Figure 1 shows the effect of finesse of flyash on workability of freshly mixed fly ash based geopolymer concrete. It is observed that the workability increases with increase in fineness of fly ash. It might be due to finer particles are more spherical effective in reducing friction between aggregate particles.

Figure 2 shows the effect of alkaline solution ratio of sodium silicate and sodium hydroxide by mass on workability in terms of slump using fly ash sample with fineness of 442 $m^2/kg$. It is observed that the workability increases with increase in solution-to-fly ash ratio. As sodium silicate–to-sodium hydroxide ratio increases, the mix was more and more viscous which reduces the rate of gain of workability after solution-to-fly ash ratio of 2.0which creates compaction problem during casting.

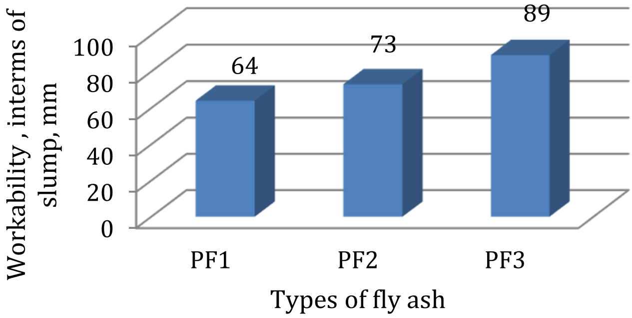


Fig.1. Effect of finesse of flyash on workability (slump value) of geopolymer concrete.

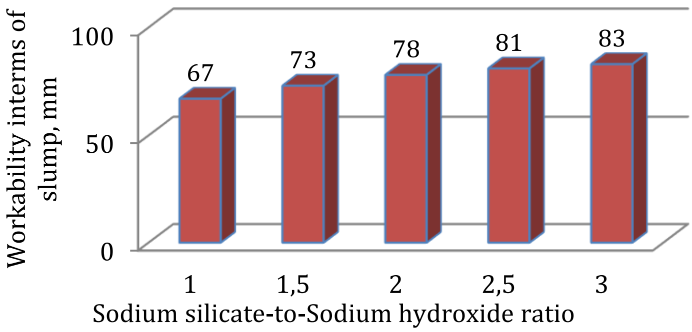


Fig. 2. Effect of alkaline ratio on workability (slump value) of geopolymer concrete

### 3.2 Compressive strength of geopolymer concrete

The cubes were tested for effect of finesse of fly ash as well as effect of alkaline ratio on compressive strength of fly ash based geopolymer concrete. Cubes were demoulded after 24 hours of casting and then place in an oven at 110$^0$C temperature for heat curing for 7 hours. Then after 24 hours, cubes were removed from oven so as to avoid sudden variation in temperature and then tested [25] three cubes for each mix after 7 and 28 days of heating. Table 6 shows the result of mass density and compressive strength of geopolymer concrete for different fineness of fly ash. It is observed that the mass density of hardened geopolymer concrete increases with increase in fineness of fly ash. It might be due to finer particles fill ups the voids within coarser particle as to give more compact concrete. Table 7 shows the effect of alkaline ratio on compressive strength of geopolymer concrete tested after 7 and 28 days of rest period.

Table 6 Compressive strength of geopolymer concrete for different fineness of fly ash

| Sr. No. | Identification mark | Fineness of fly ash ($m^2/kg$) | Rest period (Days) | Mass density of specimen ($kg/m^3$) | Comp. strength ($N/mm^2$) | Remarks |
|---|---|---|---|---|---|---|
| 1 | GCF1 | 364 | 07 | 2395.56 | 20.67 | No surface cracks developed |
| | | | 28 | 2395.80 | 21.85 | |
| 3 | GCF1 | 442 | 07 | 2459.26 | 26.37 | |
| 4 | | | 28 | 2450.62 | 29.70 | |
| 5 | GCF1 | 610 | 07 | 2502.72 | 41.74 | |
| 5 | | | 28 | 2050.12 | 42.296 | |

Table 7 Compressive strength of geopolymer concrete for various alkaline ratios.

| Sr. No. | Identification mark | Alkaline ratio | Mass density of specimen ($kg/m^3$) | | Comp. strength ($N/mm^2$) | | Remarks |
|---|---|---|---|---|---|---|---|
| | | | 7 Days | 28 Days | 7 Days | 28 Days | |
| 1 | GCF2AL1.0 | 1.0 | 2501.7283 | 2295.8025 | 26.370 | 29.704 | No surface cracks developed |
| 2 | GCF2AL1.5 | 1.5 | 2475.5555 | 2440.4938 | 37.778 | 38.815 | |
| 3 | GCF2AL2.0 | 2.0 | 2526.4190 | 2407.9012 | 36.741 | 38.296 | |
| 4 | GCF2AL2.5 | 2.5 | 2507.1605 | 2404.4444 | 32.000 | 33.407 | Surface cracks developed |
| 5 | GCF2AL3.0 | 3.0 | 2509.62 | 2436.5432 | 30.889 | 31.037 | |

### *3.2.1 Effect of fineness of fly ash on compressive strength of geopolymer concrete*

Figure 3 shows the effect of fineness of fly ash on compressive strength of fly ash based geopolymer concrete with all other test parameters were kept constant. It is observed that the compressive strength of geopolymer concrete increases with increase in fineness of fly ash. It might be due to most of the particle of fly ash goes under polymerisation and smaller particles fill up the voids present in fine aggregate. Also it is seen that there is no abrupt change in strength of geopolymer concrete for 7 and 28 days test after curing. It clearly shows that the fineness of fly ash plays vital role in developing strength of geopolymer concrete in a short period of time.

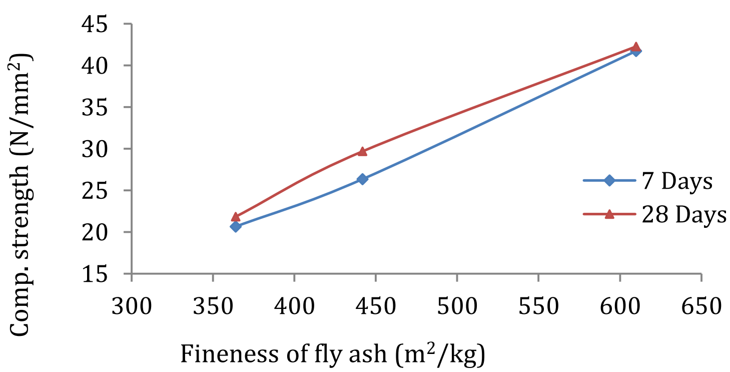


Fig. 3. Effect of various fineness of fly ash on compressive strength of geopolymer concrete

#### 3.2.2. Effect of alkaline ratio on compressive strength of geopolymer concrete

Figure 4 shows the effect of ratio of Sodium Silicate-to-Sodium Hydroxide by mass on compressive strength of geopolymer concrete. For these grades the concentration of Sodium Silicate solution and Sodium Hydroxide solution (in terms of molarity), the fly ash content and the temperature of curing. The ratio was varied from 1.0 to 3.0, in increment of 0.5. The average maximum strength was obtained when the ratio was 1.5.

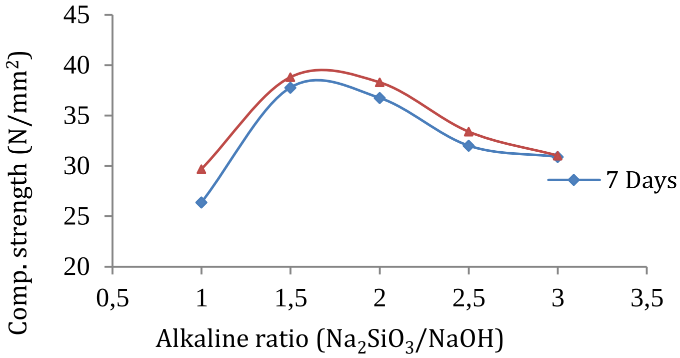


Fig.4. Effect of various alkaline ratios on compressive strength of geopolymer concrete

### 3.3 Indirect split tensile test and flexural test

Cylindrical specimens of size 150mm diameter by 300mm long is used to find split tensile strength while beam specimens of size 100mm X 100mm X 500mm are cast for testing flexural strength of fly ash based geopolymer concrete by maintaining constant alkaline ratio of 1.5. Figure 5 shows the effect of fineness of fly ash on split tensile strength of geopolymer concrete cured in oven at 110$^0$C for 7 hours and tested after 7 and 28 days of rest period. As fineness increases indirect tensile strength of geopolymer concrete also increase. Same trend is observed in flexural strength test as shown in figure 6. The variation is linear that means indirect tensile strength of geopolymer concrete is directly proportional to fineness of fly ash (i.e. particle size).

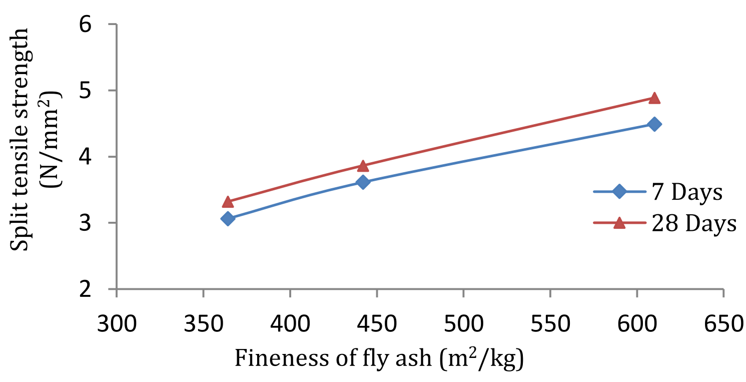


Fig.5. Effect of various fineness of fly ash on indirect split tensile strength of geopolymer concrete

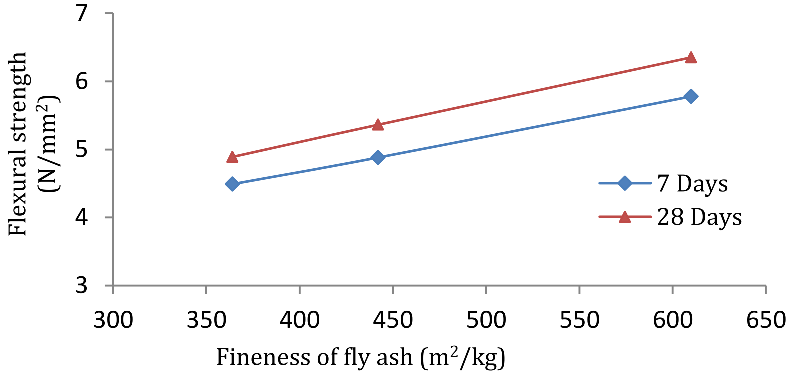


Fig.6. Effect of various fineness of fly ash on flexural strength of geopolymer concrete

Table 8 Indirect split tensile strength and flexural strength of geopolymer concrete:

| Sr. No. | Identification mark | Fineness of flyash ($m^2/kg$) | Indirect split tensile strength ($N/mm^2$) | | Flexural strength ($N/mm^2$) | |
|---|---|---|---|---|---|---|
| | | | 7 Days | 28 Days | 7 Days | 28 Days |
| 1 | GCF1AL1.5 | 364 | 2501.7283 | 2295.8025 | 26.370 | 29.704 |
| 2 | GCF2AL1.5 | 442 | 2475.5555 | 2440.4938 | 37.778 | 38.815 |
| 3 | GCF3AL1.5 | 610 | 2526.4190 | 2407.9012 | 36.741 | 38.296 |

## 4. Conclusions

This paper presented the effect of fineness of fly ash and alkaline ratio on workability and mechanical strength of geopolymer concrete. Following are the conclusions of present investigation;

- Geopolymer concrete is more environmental friendly and has the potential to completely replace ordinary portland cement concrete in many applications such as precast units and green building technology
- The workability of freshly mixed geopolymer concrete increases with increasing fineness of fly ash due to reduction in internal friction between aggregates.
- Workability can also be increase by increasing alkaline ratio. But beyond alkaline ratio of 1.5, the mix was more and more viscous which creates compaction problem.
- As the fineness of fly Ash in terms of specific surface area ($m^2/kg$) increases the strengths of geopolymer concrete increases because most of the part of particle of fly ash goes under polymerization and less voids content in the concrete.
- It is also seen from the densities of geopolymer concrete that higher fineness of fly ash gives more dense concrete because voids get filled by finer particles of fly ash.
- There is no large variation in compressive strength
- Maximum strength achieved at alkaline solution ratio of 1.5, but beyond that there is no large variation in strength. This is due to more and more viscous mix obtained at higher alkaline ratio which creates lack of compaction.

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