# An Experimental Study on Setting Characteristics of Geopolymer Paste, Optimizationof Geopolymer Mortar and Microstructural Analysis to Correlate the Compressivestrength of Geopolymer Mortar

**B S Girish**
*Architecture, VTU, Assistant Professor*
*R V College of Architecture, India*

**Dr. H R Manjunath**
*Architecture, VTU, Associate Professor*
*R V College of Architecture, India*

## Abstract

Consumption of cement as a major construction material is a global phenomenon. Cement manufacturing unit have been observed as one of the most imperative users of carbon based fuels that considerably contribute to greenhouse gas emissions. Hence there is a need to produce an essentially cement free binding material called Geopolymer.

In the present research, an experimental study on setting characteristics of geopolymer paste, optimization of geopolymer mortar and microstructural analysis to correlate the compressive strength of geopolymer mortar wasstudied. The test results showed that initial and final setting time of Set1 and Set2 ranges from 15-320minutes and 40-640minutes respectively which was more than that of setting time of standard cement paste 65and 270minutes.This shows that increase in molarity makes the paste to set at a faster rate, whereas in increase of sodium silicate delays the setting time. The 28days compressive strength of Set1 and Set2 geopolymer specimens at ambient conditions was in the range 5.49-23MPa and 28days with one day oven curing was in the range 9.42-30MPa.Comparing the results of Set1 and Set2, 14M with activator ratio 1:2.5 gave the highest strength of 23MPa and 30MPa at ambient and oven curing conditions respectively. Geopolymer mortar at ambient conditions gave 10% less and oven cured samples gave 10% more strength than standard cement mortar. But there is still room for increase in strength as observed from microstructural analysis.

From microstructural analysis, it was observed that the rate of reaction of geopolymer mortarincreases with the increase of NaOH concentration resulting in higher compressive strength and rate of reaction decreases with the increase of sodium silicatewhich results in lower compressive strength. The bonding at the age of 28 days (oven cured for 24 hours) samples was more when it was compared with 28 days ambient cured sample which indicates that the greater compressive strength. Also the bonding was more for the optimum activator ratio of 1:2.5 compared to all other activator ratios. Therefore the optimum dosage of alkali solution is 14M NaOH with activator ratio of 1:2.5. According to many literature papers the compressive strength gained in geopolymer mortar up to 28 daysis only around 75% – 80%, after 28 days there is possibility for improvement in the strength around 10% – 15 %.

**Keywords: Geopolymer, Setting Time, Compressive Strength, Micro Structural Analysis**

---

## I. INTRODUCTION

Ordinary Portland Cement (OPC) is an important material in the production of concrete which acts as binder. Portland cement concrete (PCC) is the most popular and widely used building material, due to the availability of the raw materials and its easy preparation. Due to growing environmental concerns of the cement industry, alternative cement technologies have become an area of increasing interest. Another form of cementitious materials geopolymers has many advantages.

Mortar is a combination of cementitious materials, water and fine aggregate. Water enables the mixing of the fine aggregate and cementitious materials. The important properties of hardened mortar are bond, and compressive strength. Tensile stress measures the bond strength and breaks the bond between the materials of the mortar and the compressive strength is singled out as a selection principle as it can be measured easily. Mortars provide uniform performance characteristics in the field. Each ingredient has its own standard, which requires chemical and physical properties that are desirable for mortar. Whereas, geopolymer mortar consists of alkaline solutions, fine aggregates and alternate binders. Geopolymer mortar has become indispensable as because construction is one of the fast growing fields worldwide.

## II. LITERATURE REVIEW

Van Riessen et.al [1]explained the physical and mechanical properties of geopolymer mortars with altering levels of sand aggregate. The sand to geopolymer binder weight ratio varied from 0.11 to 1. 60 MPa was the obtained compressive strength of the fly ash based geopolymer paste. Provis.J.L et.al [2]explainedthat thegeopolymer technology is evidently an area of importance as the world attempts to move towards a sustainable worldwide economy, because it provides the opening for both waste beneficiation and immobilization, while providing an alternative to a highly polluting existing technology. Both the papers investigates on how the raw materials of geopolymers such as alkali content and greater proportions of aggregates affects the strength of the geopolymers. Simultaneously, larger-scale commercialization of geopolymer technology is beginning to show that aluminosilicate alternatives to Portland cement are in fact practicable in precast and ready-mix concrete making.

Mohd Mustafa Al Bakri et.al [3] outlines that The fly ash fineness affects the compressive strength of mortar and the decreased porosity can be obtained. But according toVilla.C et.al[4]the influence of activator ratio, curing time and temperature affects the compressive strength of geopolymers.

KushalGhosh et.al [7]explained thatsetting time of geopolymers pastes depends on the alkali content and silica content respectively. By varying the percentage of Na2O from 4.25 to 10.25percentage, the initial and final setting time decreased with a constant ratio of silica content and was carried out at ambient temperature. This outlines that at higher alkali content geopolymerisation gets accelerated and setting time is reduced. But Djwantorohardjito et.al [8]explained that if Water to binder ratio is 0.325 and setting time test is subjected to temperature of 650C and keeping the NaOH molarity constant, then the initial and final setting time were 230 and 270minutes respectively. This was continued by varying the temperatures upto 800C and setting time was noted down. Also, Tanakorn Phoo-ngernkhan et.al [9]carried out the studies on different geopolymer mix by replacing the percentage of ordinary Portland cement upto 15percentage.

A.M.Mustafa Al Bakriet.al [12]and V.Sreevidya et.al [13]revealed that highest strength was obtained for the ratio of 0.4 of activator/flyash ratio. As the Sio2/Al2O3 ratio increased, the number of Si-O-Si bonds increased with increase in compressive strength. The curing temperatures were ranged from 65ºC to 80ºC. They maintained the NaOH concentration to 15M to prepare a GP mortar, which was cured at 70ºC for 1 day and the strength obtained, was 8.6MPa. Whereas, V.Sreevidya et.al [13]explained that if NaOH concentration is 16M then GP mortar gives the strength of 26MPa, and also outlines that the geopolymer mix has a higher compressive strength than conventional mix which is 8% to be accurate. Ubolluk Rattanasak et.al [20]studied the microstructure of specimen having the highest compressive Strength with 10M and NaOH: Na2SiO3=1.5 and in addition admixtures like sucrose was used andmicroFigures revealed that paste forms a continuous mass of aluminosilicate and partly reacted fly ash particles. M S Morsy et.al [11] and RadomirZejaket.al [12]studied the microstructural properties of theFly-Ash based geopolymer paste and mortar. The research by them was on hardened specimens having 10M and NaOH: Na2SiO3=1.5respectively. MicroFigure from both the papers revealed that the sample was not homogenous and is characterized by the presence of sand grains and geopolymer paste.

Xueying Li et.al [15]studied aboutthe microstructure of class C flyash based geopolymers and they revealed that the formation of a relatively dense reacted product of paste and mortar was independent of the water-to-fly ash. The SEM images were taken for the samples having highest strength of paste and mortar having 58MPa and 85MPA respectively which was cured at 70oc for 24hours.According to Anupam Bhowmick et.al [19]parameters such as workability and compressive strength on Geopolymer mortar was studied.From the microfigureshe observed that geopolymer matrix comprises of gel phase and unreacted /partially reacted fly ash particles.

## III. OBJECTIVE

Most of the experiments discussed above are done either by changing mole concentration or by changing the ratios of activators solution for the geopolymer mortar. Hence, this motivates the proposed study.

The objectives of the research are

1) To Characterize the materials like flyash, Ground granulated blast furnace slag etc.
2) To Proportion the geopolymers using binders and various alkali activators ratios.
3) Standard paste and mortar of Ordinary Portland Cement(OPC) was prepared and tests are done for the comparison purpose.
4) To study the setting time and compressive strength development of geopolymer paste and mortar respectively.
5) To study the morphological characteristics of hardened geopolymer mortar using SEM (Scanned Electron Microscopy) and to co-relate the compressive strength of geopolymer mortar with its microstructure.

## IV. METHODOLOGY

Basic tests will be conducted on all the materials such as cement, Flyash, ground granulated blast furnace slag (GGBS), and fine aggregate etc. It is important to know their properties like specific gravity, setting time test, water absorption test, gradation density, water absorption capacity, and chemical compositions. The setting time test will be conducted using Vicat apparatus.

The materials chosen for setting time test are Flyash and ground granulated blast furnace slag with their ratios 80% and 20% respectively, with different molarities(8, 10, 12, 14 and 16M) and with constant alkali activator ratio (NaOH solution:Na2 SiO3 solution 1:2.5 ). The initial and final setting time test will be done at ambient temperatures only.

Later, the Geopolymer cubes of size 70.60mm will be prepared and is subjected to ambient curing. After curing, all the Geopolymer mortar specimens will be tested for compressive strength at 3, 7, 28 and 28 days (24hours oven curing at 800 C immediately after casting). This is the first set of experiment.

By comparing the results of the first set experiments, in the second set the molarity(M)will be fixed to 14M and activator ratio (1:1.5, 1:2, 1:2:5, 1:3 and 1:3.5) is varied. The setting time and compressive strength will be determined as mentioned in the first set of experiment.Both the first set and second set results will be correlated with standard ordinary Portland cement.

Using SEM (Scanned Electron Microscopy), the morphological characteristics of hardened geopolymers mortar samples will be studied. The geopolymer samples chosen for microstructural analysis will be the samples having least and highest compressive strength and co-relation will be done between the compressive strength of geopolymer mortar and microstructure.

## V. EXPERIMENTAL WORK

The experimental work involves the following steps.

1) Procurement and characterization of material
2) Determining and comparing the physical and chemical properties of the materials with the standard requirements.
3) Preparation of alkaline solution
4) Finalising the mix proportion
5) Preparation of geopolymer paste and mortar.
6) Conducting the standard test on paste and mortar and finally micro-structural analysis of mortar.

Alkaline solution was prepared using Sodium hydroxide, Sodium silicate and distilled water as represented in the figure 3.1. To the known requisite quantities, sodium hydroxide pellets were added to a beaker containing distilled water and stirred well until it gets dissolved completely and this solution was used after 24 hours of its preparation. The following day Sodium hydroxide solution is mixed with Sodium silicate solution and stirred once in an hour for five to six times to avoid deposits.

The mix proportion consisting of activator solution is defined under two sets and is tabulated,

Table – I

| *MIX PROPORTION for SET 1.* | |
|---|---|
| *Binder : aggregate ratio* | *1:2* |
| *Binder = Flyash : GGBS* | *80% : 20%* |
| *Activator solution* | *NaOH solution + Sodium Silicate* |
| *Molarities* | *8M, 10M, 12M, 14M and 16M* |
| *NaOH solution : sodium silicate* | *1:2.5* |

Table – II

| *MIX PROPORTION for SET 2.* | |
|---|---|
| *Binder : aggregate ratio* | *1:2* |
| *Binder = Flyash : GGBS* | *80% : 20%* |
| *Activator solution* | *NaOH solution + Sodium Silicate* |
| *Molarities* | *14M* |
| *NaOH solution : sodium silicate* | *1:1.5, 1:2, 1:2.5, 1:3 and 1:3.5* |

The geopolymer paste was prepared by adding required quantity of alkaline solution to a mixture of binding material consisting of flyash and GGBS. To determine the optimum ratio of flyash to GGBS, various trial mixes was performed. To establish the normal consistency and setting time of geopolymer paste, calculated amount of activator solution was added based on the above proportions, to the dry mix of binder and was mixed thoroughly to get the uniform mix for different molarities (8M,10M,12M,14M and 16M).

The geopolymer mortar is used to indicate a paste prepared by adding required quantity of alkaline solution to a mixture of binding material and fine aggregate. The binder used in the preparation of GP mortar is Flyash, GGBS (Ground Granulated Blast furnace Slag). To determine the optimum ratio of flyash to GGBS proportion, various trial mixes were performed. The aggregate used is fine aggregate (river sand) passing through 4.75mm sieve.The GP mortar was prepared using binder to sand ratio of 1:2 and are mixed in the dry condition. Based on the above mentioned proportions, activator solution is addedto the binder and is mixed thoroughly to get a uniform wet mix. The geopolymer mortar cubes were molded to size of 70.6mm for compressive strength.

After casting, the specimens were placed for curing. Geopolymer mortar specimens should be wrapped by placing a lid on the mould,during curing at elevated temperatures in a dry environment (in the oven) to prevent excessive evaporation. Geopolymer mortar requires dry curing. So these specimens were kept for ambient curing.

# VI. RESULTS AND DISCUSSION

Table – III

| Weight of sand (grams) | % of water added | Weight of water added in (grams) | Height of sand ($h_1$in cm) | Bulking(%) ($h_1$-h)/h X100 |
|---|---|---|---|---|
| 500 | 2 | 10 | 16.5 | 43.48 |
| 500 | 4 | 20 | 15.5 | 34.78 |
| 500 | 6 | 30 | 15.2 | 32.174 |
| 500 | 8 | 40 | 14.8 | 28.696 |
| 500 | 10 | 50 | 14.5 | 26.089 |
| 500 | 12 | 60 | 14.00 | 21.739 |
| 500 | 14 | 70 | 13.7 | 19.13 |
| 500 | 16 | 80 | 13.5 | 17.39 |
| 500 | 18 | 90 | 13.30 | 15.65 |
| 500 | 20 | 100 | 13.00 | 13.04 |
| 500 | 22 | 110 | 11.5 | 0 |

110 grams of water is added to sand, bulking of fine aggregates is zero. The % of bulking for the initial water content (W) of the sample is 43.48%

Table – IV

| | Trial 1 | Trial 2 | Trial 3 |
|---|---|---|---|
| Mass of empty pycnometer ($M_1$)g | 646.5 | 647 | 647 |
| Mass of pycnometer + given sample ($M_2$)g | 1130.5 | 1129.0 | 1122.0 |
| Mass of pycnometer + given sample + water ($M_3$)g | 1813.5 | 1812.0 | 1807.5 |
| Mass of pycnometer + water ($M_4$)g | 1510.5 | 1510.5 | 1510.5 |

Specific gravity of sand and the value obtained after conducting experiment using pycnometer for 3 trials was 2.67.

Table – V

| SL.NO | IS sieve no | Weight retained in grams | %retained | % passing | Cumulative % retained (F) |
|---|---|---|---|---|---|
| 1 | 4.75 | 60 | 3.0 | 97.0 | 3.0 |
| 2 | 2.36 | 70 | 3.5 | 93.5 | 6.5 |
| 3 | 1.18 | 332 | 16.6 | 76.9 | 23.1 |
| 4 | 600μ | 513 | 25.65 | 51.25 | 48.75 |
| 5 | 300μ | 692 | 34.60 | 16.65 | 83.35 |
| 6 | 150μ | 282 | 14.10 | 2.55 | 97.45 |
| 7 | Pan | 50 | 2.5 | 0.05 | 99.95 |

The fineness modulus of sand is 2.65 and is represented in the figure 4.2 and belongs to Zone 2.

The specific gravity results of cement, flyash and GGBS which are 2.994, 1.94 and 2.754 respectively.

Table – VI

| Molarity | Consistency (%) |
|---|---|
| Cement(Standard) | 29 |
| 8M | 36 |
| 10M | 38 |
| 12M | 39 |
| 14M | 39 |
| 16M | 42 |

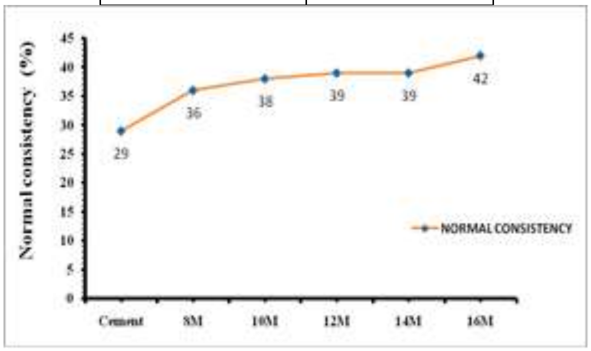


Fig. 1: Normal consistency of cement paste and geopolymer paste of 14M with variation of NaOH: Na2SiO3 ratios

Table VII

| Molarity | Initial Setting Time (Minutes) | Final Setting Tim(minutes) |
|---|---|---|
| Cement | 65 | 270 |
| 8M | 225 | 420 |
| 10M | 220 | 416 |

| | | |
|---|---|---|
| 12M | 215 | 410 |
| 14M | 190 | 400 |
| 16M | 160 | 350 |

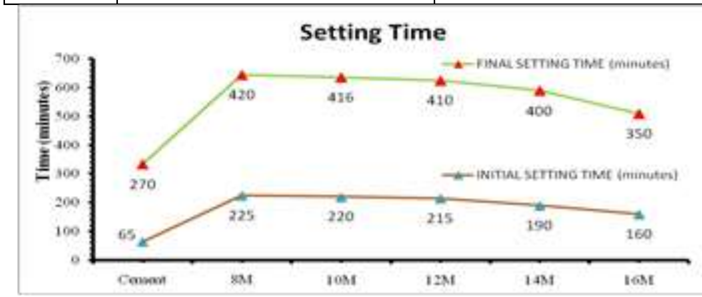

Fig. 2: Setting time of cement paste and different molarities of geopolymer paste with NaOH: Na2SiO3= 1:2.5

Normal Consistency of Geopolymer paste for different molarities (8M, 10M, 12M, 14M and 16M) with NaOH: Na2SiO3 of 1: 2.5 have minor variations which ranges from 36% to 42% and which is slightly higher than the Standard Cement paste which have a consistency of 29%. When compared to the initial and final setting time of standard cement paste, the geopolymer paste requires 15% -20% more time to set. The initial setting time of geopolymer paste ranges from 160-240minutes and the final setting time range from 350 – 420 minutes respectively. As shown in the figure 4.4, it can be conclude that the time availability for mixing, handling, transportation and compaction is more; hence complete replacement of cement with geopolymers is beneficial and economical.

It was observed that the normal consistency performed on geopolymer paste of 14M with NaOH: Na2SiO3 ratio as 1:1 and 1:1.5 and keeping the other parameters constant was harden quickly within a fraction of second. Hence the mix was discarded and later consistency was determined for geopolymers of 14M with activator ratios1:2, 1:2.5, 1:3 and 1:3.5.

The NaOH:Na2SiO3 ratio of 1:2 sets at a faster rate and increase of activator ratio to 1:2.5, 1:3 and 1:3.5increases the setting time and this explains that with increase in concentration of sodium silicate the paste sets at a slower rate and is high than that of the standard cement paste.

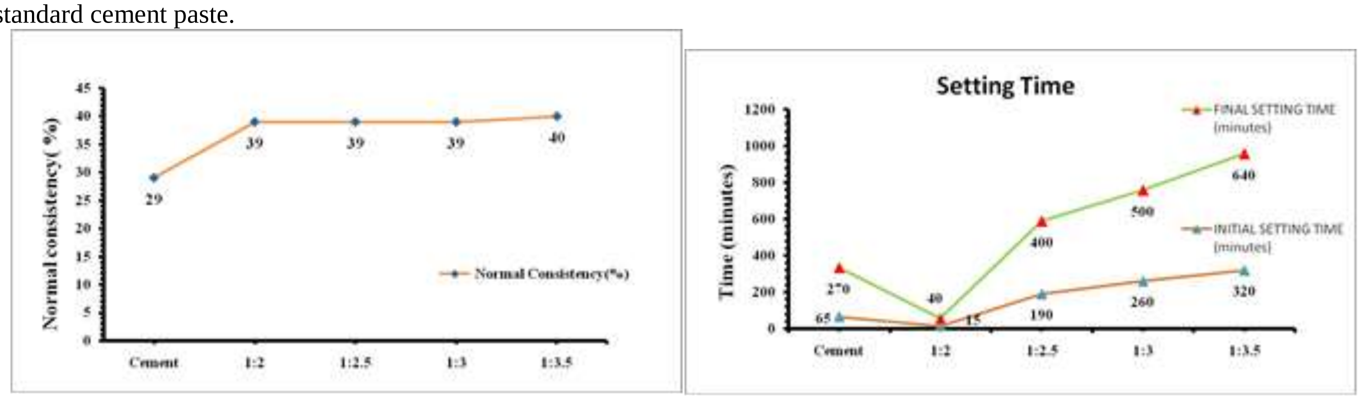

Fig. 3 & 4: Setting time of cement paste and geopolymer paste of 14M with variation of NaOH: $Na_2SiO_3$ ratios

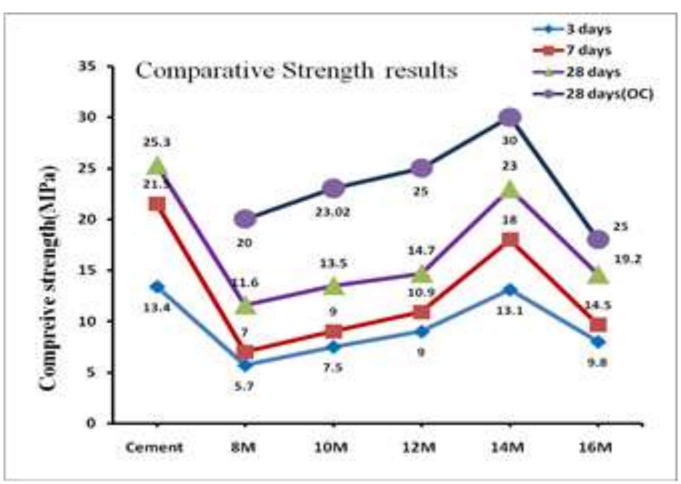

Fig. 5: Comparison of compressive strength of cement/geopolymer mortar different molarities

 

Figure 5 shows the compressive strength of cement, geopolymer mortar with 8,10,12,14 and 16M solution. This interprets that molar solution concentration of NaOH (14M) with activator ratio 1:2.5 yielded more strength. Further increase of NaOH concentration beyond 14M decreases the compressive strength significantly. Hence, from figure 4.13 conclusions can be made that the to optimize the geopolymer mortar mix the NaOH concentration should be 14M, and this strength is analogous to cement mortar 28days strength.

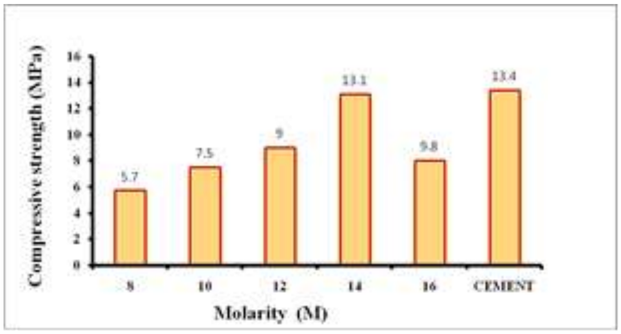

Fig. 6: Variation of 3days Compressive strength

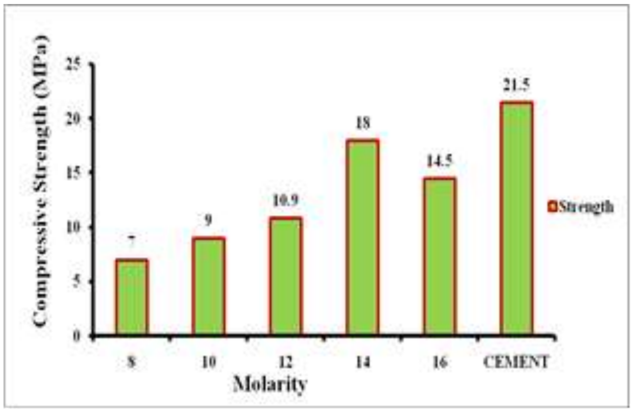

Figure 7 Variation of 7days Compressive strength

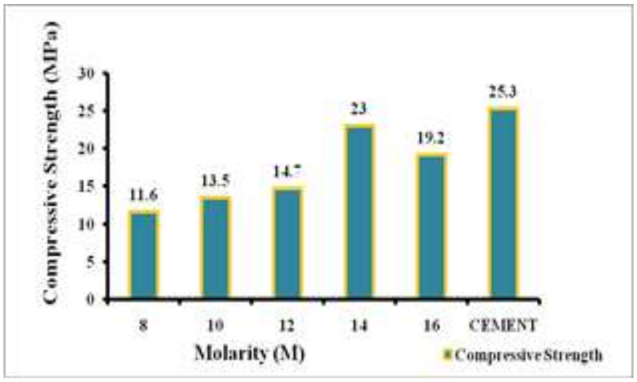

Figure 8 Variation of 28days Compressive strength

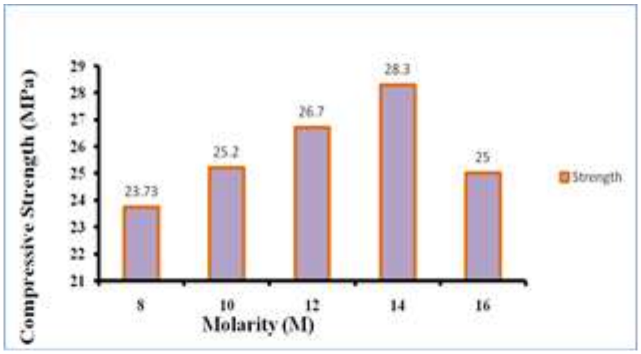

Figure 9 Variation of 28days (Oven cured for 24hours at 800C immediately after casting) Compressive strength

The compressive strength of 14M with NaOH:Na2SiO3as 1:2.5 at ambient conditions gives the highest strength at all the ages of curing and its 28days strength is analogous to cement mortar 28 days compressive strength. But
It is also observed that 14M, NaOH: Na2SiO3as1:2.5oven cured sample gives more strength than that of cement mortar 28days strength.

Hence, to optimise the mix proportion of geopolymer mortar at ambient conditions, the molar concentration was fixed to 14M. Keeping in this view, the present research was extended further by preparing geopolymer mortar cubes with constant sodium hydroxide concentration expressed in terms of molarity as 14M and with varied NaOH: Na2SiO3ratios as 1:2, 1:2.5, 1:3 and 1:3.5. For the above mortar preparation, the binder/aggregate ratio was 1:2, procedure of casting and curing was followed same as the former case and the compressive strength results highlighted in the tables below

Table – VIII

| *Molarity* | *NaOH:$Na_2SiO_3$* | *Compressive strength ( MPa)* | | | |
|---|---|---|---|---|---|
| | | *3 days* | *7 days* | *28 days* | *28 days (OC)* |
| *14M* | *1:2* | *5.75* | *9.2* | *15.1* | *20.1* |
| | *1:2.5* | *13.1* | *18* | *23* | *13.8* |
| | *1:3* | *5.9* | *7.8* | *13.8* | *16.2* |
| | *1:3.5* | *3.83* | *4.74* | *5.49* | *9.42* |
| *Cement* | | *13.4* | *21.5* | *25.3* | |

The compressive strength of ambient cured geo-polymer mortar continuously increases with age for the given set of parameters. The compressive strength of ambient cured geopolymer mortar at 28days ranged from 5.49MPa - 23MPa. The maximum compressive strength of 23MPa was obtained for 14M, NaOH:Na2SiO3 ratio=1:2.5 and minimum compressive strength of 5.49MPa was for 14M, NaOH:Na2SiO3 ratio=1:3.5 and also the compressive strength for 14M, NaOH:Na2SiO3 ratio=1:2 was 15.1MPa.

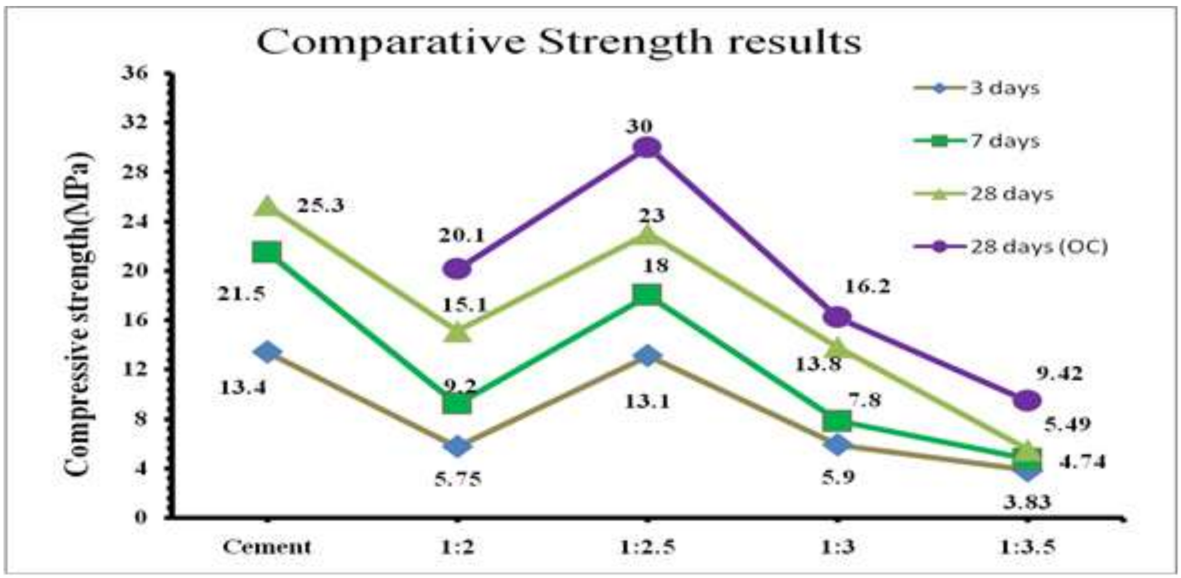


Fig. 10: Variation of Compressive Strength results of cement/ geopolymer mortar of 14M with different NaOH: $Na_2SiO_3$ ratios

The compressive strength of geopolymer mortar and cement mortar at different ages. When compared to standard cement mortar strength, the 14M with alkali ratio 1:2.5 of geopolymer mortar gives the similar strength. The least strength is observed for 14M with alkali ratio 1:3.5. This shows that optimum dosage of activator ratios is 1:2.5 and increase or decreases of sodium hydroxide and sodium silicate proportion beyond 1:2.5 decreases the strength drastically. The strength increases as the ambient curing age proceeds and the maximum strength is obtained for 28days sample. It is noticed that 14M with NaOH:$Na_2SiO_3$ ratio 1:2.5 at the age of 28daysas shown in the Figure 4.25 gives the highest compressive strength and later the strength decreases considerably for the ratios of 1:3 and 1:3.5. This shows that as the sodium silicate concentration rises up, the compressive strength of geopolymers lowers significantly. Therefore to optimise the mix proportion, the best ratio suitable for making geopolymer mortar with strength of 23MPa is14M with NaOH:$Na_2SiO_3$ ratio as 1:2.5 at ambient curing conditions which is comparable to cement mortar 28 days strength of 25.3MPa. Hence geopolymer mortar fulfils the building material properties and replaces the cement completely and thus finds its applications in making of compressed blocks, pavers etc.

### A. *Micro stuctural analysis*

3 Days (8M) (a) 3 Days (14M) (b)

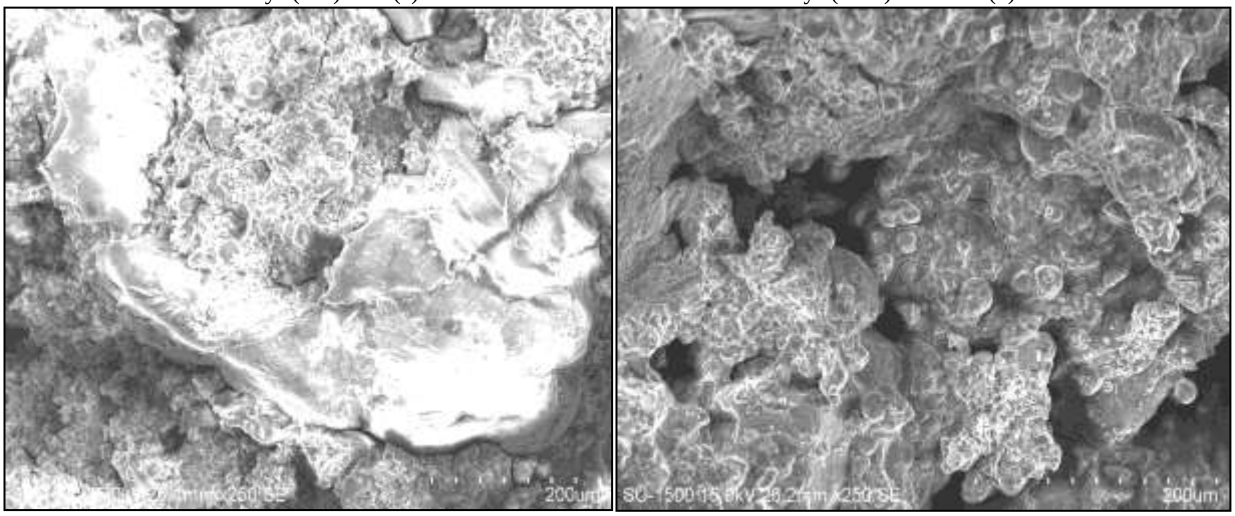


Fig. 11: 3Days Comparative SEM Images with NaOH: Na2SiO3 ratio of 1:2.5

7 Days (8M) (c) 7 Days (14M) (d)

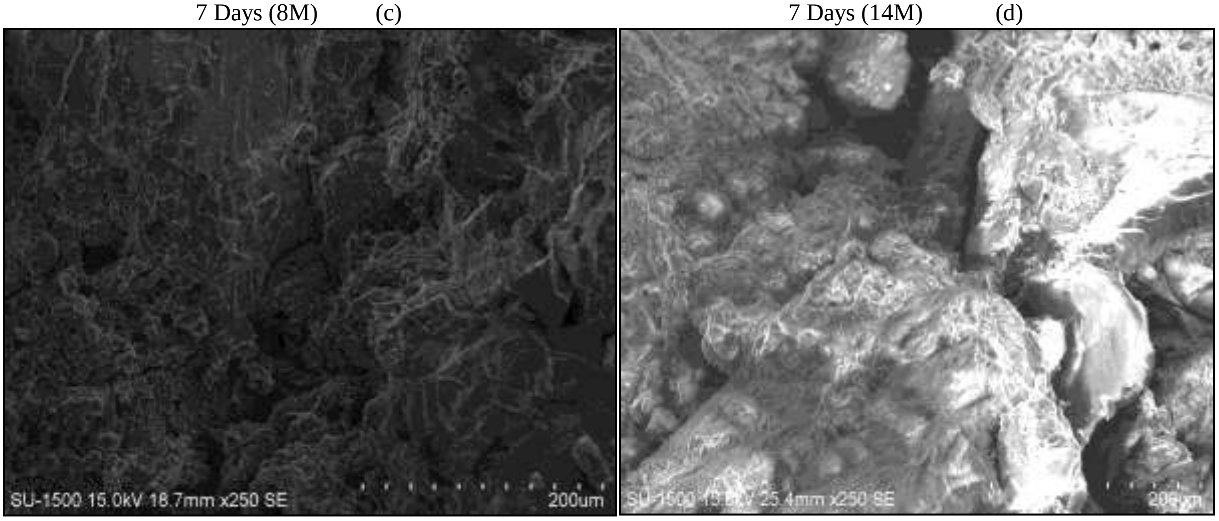


Fig. 12: 7 Days Comparative SEM Images with NaOH: $Na_2SiO_3$ ratio of 1:2.5

28 Days (8M) (e) 28 Days (14M) (f)

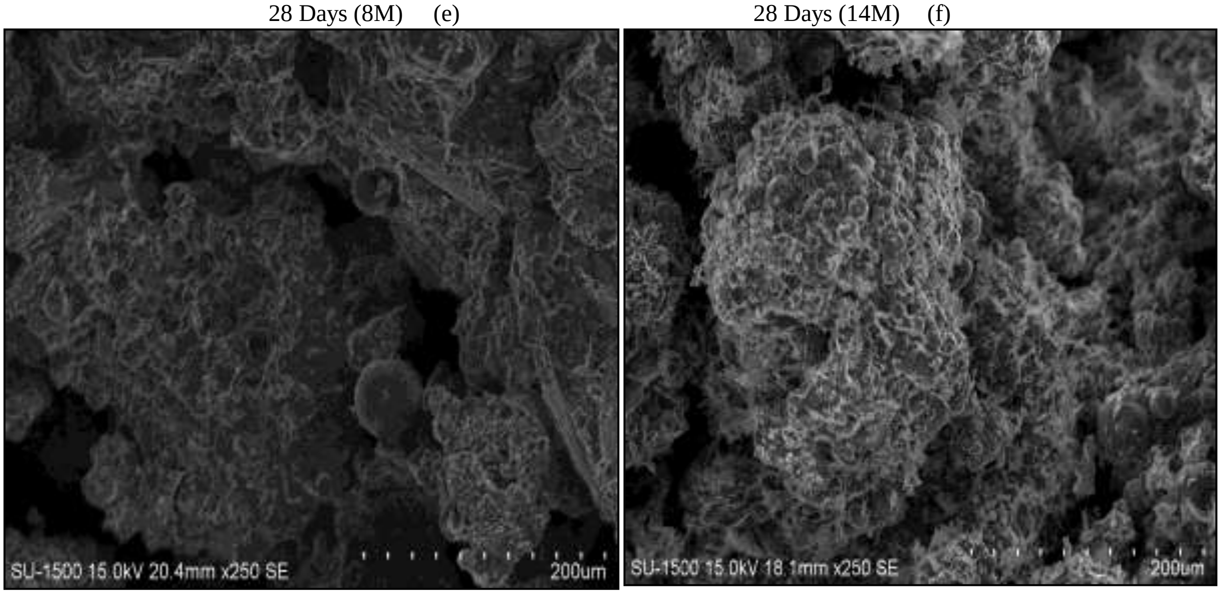


Figure 13: 28 Days Comparative SEM Images with NaOH: $Na_2SiO_3$ ratio of 1:2.5

28 Days (OC) (8M) (g) 28 Days(OC) (14M) (h)

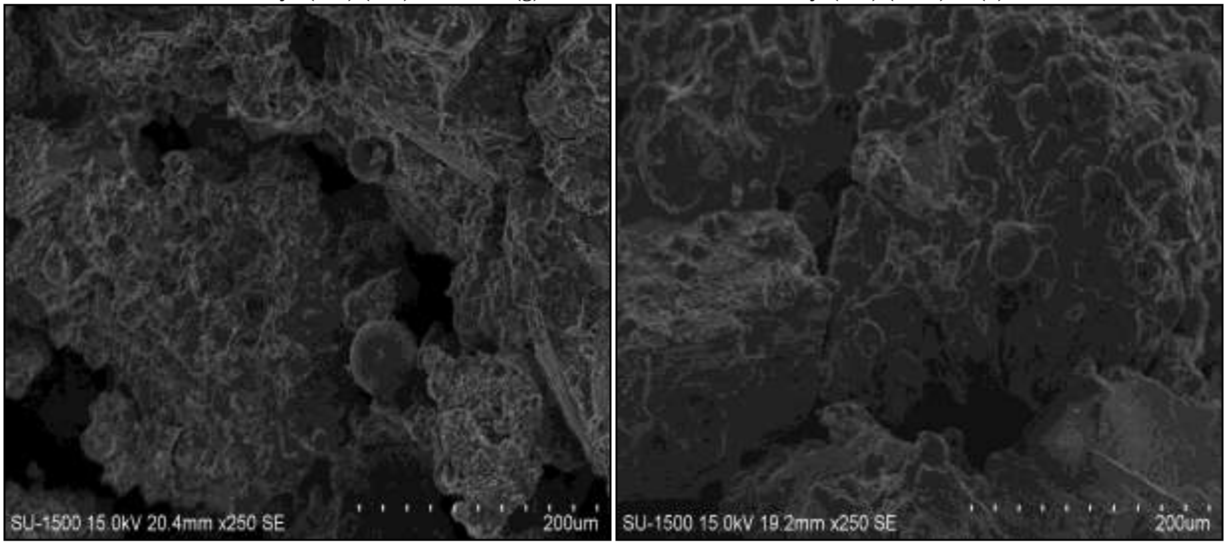


Fig. 14: 28 Days (OC) Comparative SEM Images with NaOH: $Na_2SiO_3$ ratio of1:2.5

The above SEM Images shows that

- The samples were not homogeneous.
- Changes in morphology was observed as a consequence of activators and type of curing.
- As the molarity of NaOH increases from 8M to 14 M the microstructure of the resulted geopolymer appeared to contain relatively lesser reacted flyash and slag particles.
- Least unreacted particles were observed when the molarity was 14M with oven curing for 24 hours at $80^0$C immediately after cast.
- The cracks were present in the SEM Images because of testing the cubes for compressive strength.
- From the compressive strength results it is observed that 8M showed least compressive strength of 5.7MPa, 7MPa, 11.6MPa, 20MPa for 3, 7, 28 and 28days (Oven Cured for 24 hours) respectively where it can be observed in SEM Images and the compressive strength of 14M showed the highest compressive strength of13.1MPa, 18MPa, 23MPa and 30MPa for 3, 7, 28 and 28days (Oven Cured) respectively observed in SEM Images.
- As the concentration of NaOH increases there is an increase in compressive strength up to 14M this can be justified by observing the SEM Images of mortar sample. The SEM Images of mortar sample made out of 8M solution, more unreacted particles at all the ages compare to mortar sample made out of 14 M solution
- This shows rate of reaction depends mainly on NaOH concentration. From the SEM image it can be observed the bonding of material is better and strong in sample with 14M solution when compared to sample with 8M.
- In both samples made out of 8M and 14M oven cured samples shows less unreacted particles than ambient cured samples at 28 days. Therefore rate of reaction depends on type of curing; the rate of reaction is faster at elevated temperature.
- It is clearly observed that the amount of concentrated particles reduces as the age increases and also it can be observed the amounts of unreacted particles are least at the elevated temperature.The amount of bonding is improved because of age of the sample and elevated curing.
- At the age of 28 days ambient curing, the SEM image shows that the unreacted particles are less.
- It is observed that as the curing age proceeds, the volumes of unreacted particles was decreased considerably and were least in the samples which were oven cured i.e. at the age of 28 days (oven cured for 24 hours immediately after cast Also the bonding in oven cured samples was more justifying the highest strength gain.

## VII. CONCLUSION

1) The material characterizes viz. Fly ash, Ground granular blast furnaces slag, Sand, Cement etc. are suitable to use in the present work.
2) It was observed that the Normal Consistency of Geopolymer paste for different molarities (8M, 10M, 12M, 14M and 16M) with NaOH : $Na_2SiO_3$ of (1 : 2.5 ) has minor variations which ranged from 36% to 42% and which is slightly higher than the Standard Cement paste which had a consistency of 29%. Whereas, for 14M geopolymer pastes with different alkali ratios (1:2, 1:2.5, 1:3 and 1:3.5), the normal consistency observed was 39% which remained constant with slight variations.
3) The initial setting time of cement obtained was 65 min and geopolymer paste for different molarities (8M to 16M) with alkali ratio of 1:2.5 ranged from 160–225min and initial setting time of GP paste of 14M with different alkali ratios ranged from 15-

320min which was comparable to standard Cement paste whereas final setting time of geopolymer paste ranged from 40–640 min.

4) The setting time decreased as the molarity increased because the amount of NaOH concentration increased. Also the setting time of geopolymer paste increased with the increase of sodium silicate concentration.
5) The compressive strength results of cement mortar obtained was 13.43MPa, 21.5MPa and 25.3MPa at the age of 3, 7 and 28 days respectively. It shows that the aging of cement mortar samples affect the compressive strength significantly. The compressive strength of 8M obtained 5.7MPa, 7MPa, 11.6MPa and 20MPa at the age of 3, 7, 28 and 28 days (oven cured for 24hours at $80^0$C immediately after casting) respectively which showed the least strength. The compressive strength of 14M with alkali ratio 1:2.5 obtained was 13.1MPa, 18MPa, 23MPa and 30MPa at the age of 3, 7, 28 and 28days (Oven Cured for 24 hours immediately after cast) respectively which showed the highest strength.
6) The compressive strength increased with the increase of molarity up to 14M, later the strength decreased for 16M, where the strength obtained was 9.8MPa, 14.5MPa, 19.2MPa and 25MPa at the age of 3, 7, 28 and 28days (Oven Cured for 24 hours immediately after cast) respectively.
7) The results demonstrated that an increase in the molarity as well as that of curing time uplifts the strength in the material only up to certain limit (14M) later it decreases drastically.
8) The compressive strength results of 14M with different alkali ratios (1:2, 1:2.5, 1:3 and 1:3.5) ranged from 3.83-30MPa at the age of 3, 7, 28 and 28 days (oven cured for 24hours at $80^0$C immediately after casting). The compressive strength of 14M with alkali ratio 1:2 was 5.75, 9.2, 15.1 and 20.1MPa and for 1:3.5 ratio the strength was 3.83MPa, 4.74MPa, 5.49MPa and 9.42MPa at the age of 3, 7, 28 and 28days (Oven Cured for 24 hours immediately after cast) respectively which showed the least strengths respectively. The compressive strength of 14M with alkali ratio 1:2.5 obtained was 13.1MPa, 18MPa, 23MPa and 30MPa at the age of 3, 7, 28 and 28days (Oven Cured for 24 hours immediately after cast) respectively which showed the highest strength.
9) Thisconcludes that either increase or decrease of sodium silicate concentration the compressive strength decreases significantly. Hence, the optimum mix proportion for making the geopolymer mortar should be 14M with alkali ratio 1:2.5.
10) Geopolymer mortar of 14M with alkali ratio 1:2.5 gave 10% lesser strength than OPC at ambient curing conditions and at oven cured conditions geopolymersof 14M with alkali ratio 1:2.5 gave 10% more strength when compared to cement mortar.
11) From microstructural analysis, it was observed that rate of reaction for 3 and 7days strength sample was slow, because the amount of unreacted particles were more compared to 28days strength samples.
12) The material bonding is strong and unreacted particles content is very less in oven cured samples compared with ambient cured samples this shows oven curing uplifts the rate of reaction.
13) The 28 days strength of geopolymer mortar at ambient curing conditions is very close to that of OPC mortar of 28 days, but from microstructure analysis we observe that the reaction is still in progress and unreacted particles will react further and hence there is possibility for increase in strength beyond 28 days.
14) The strength of geopolymer mortar at ambient condition may become more than the strength of OPC mortar.
15) It can be concluded that geopolymer mortar as an ecofriendly construction material and can be used for can be successively used for manufacturing of compressed blocks / pavers.

## VIII. FUTURE WORK

1) The same should be adopted for preparing geopolymer blocks and conducting relevant tests on blocks.
2) Suitability of using geopolymers for structural use.

## REFERENCES

[1] A. Van Riessen,J. Temuujin K.J.D. Mackenzie -Preparation And Characterisation Of Fly Ash Based Geopolymer Mortars-Construction And Building Materials 24,pp.1906–1910,2010.
[2] J.L.Provis,P.Duxson,R.M.Harrex,C-Z.Yong,J.S.J. Van Deventer-Valorisation Of Fly Ashes By Geopolymerisation-Global Nest Journal, Vol 11, No 2, pp 147-154, 2009
[3] Mohd Mustafa Al Bakri1, H.Mohammed, H.Kamarudin, I.KhairulNizaand Y.Zarina1-Review on fly ash-based geopolymer concrete without Portland Cement-Research Vol. 3(1), pp1-4, 2011.
[4] Villa, E.T.Pecina, R.Torres, L.Gómez-Geopolymer synthesis using alkaline activation of natural zeolite-Construction and Building Materials 24, pp2084–2090,2010.
[5] D.Bondar, C.J.Lynsdale, N.B.Milestone, N.Hassani, and A.A.Ramezanianpour-Engineering Properties of Alkali Activated Natural Pozzolan Concrete,2010.
[6] Zongjin Li, Zhu Ding, and Yunsheng Zhang-Development of sustainable cementitious materials,2010.
[7] KushalGhosh and Dr. ParthaGhosh-Effect of synthesizing parameters on compressive strength of flyash based geopolymer paste, India International Journal of Structural and Civil Engineering ISSN: 2277-7032 Volume1, 2012.
[8] Djwantoro Hardjito, Chua Chung Cheak& Carrie Ho Lee Ing- Strength and Setting Times of Low Calcium Fly Ash-based Geopolymer Mortar, Modern applied science, vol2, No.4, july 2008.
[9] TanakornPhoo-ngernkhan, prinyachindaprastri, vanchaisata, saengsureepandaeng and Theerawatsinsiri, Properties of high calcium flyash geopolymer pastes with portland cement as an additive, International journal of minerals, Metallurgy and materials,Volume 20, No.2,Page 214, 2013.
[10] Ubolluk Rattanasak, KanokwanPankhet, and PrinyaChindaprasirt- Effect of chemical admixtures on properties of high-calcium fly ash geopolymer,International Journal of Minerals, Metallurgy and Materials. Volume 18, No.3, Page 364,Mechanics, vol. 65, pp. 231-246, 1974 ,June 2011.

[11] Chengxu Wu, HuajunZeng- The Role of Fly Ash in the Granulated Blast Furnace Slag-based Geopolymer, Applied Mechanics and Materials, Vol. 405-408, pp.2760-2766, 2013
[12] A.M.Mustafa Al Bakri, H.Kamarudin& Omar A.K.A Karem, C.M.Ruzaidi& A.R. Rafiza and M.N.Norazian- Optimization of Alkaline Activator/fly ASH Ratio on The Compressive Strength of Manufacturing Flyash-Based Geopolymer,Applied Mechanics and Materials Vols.110-116, pp734-739, 2012.
[13] V.Sreevidya, R.AnuradhaAnd R.Venkatasubramani- Strength Study on Fly Ash-Based Geopolymer Mortar,Asian Journal of Chemistry- Vol. 24, No.7, 2012.
[14] Zhu Pan, Jay G. Sanjayan,B.V.Rangan An investigation of the mechanisms for strength gain or loss of geopolymer mortar after exposure to elevated temperature,Springer Science+Business Media, LLC, 2012.
[15] Xueying Li, Zheng Wang and ZhenzhenJia-Mechanical Properties and Microstructure of Class C FlyAsh-Based Geopolymer Paste. Mortar Institute of Technology, Harbin 150006,2013.
[16] M.S.Morsy, S.H.Alsayed,Y.Al-Salloum and T.Almusallam- Effect of Sodium Silicate to Sodium Hydroxide Ratios on Strength and Microstructure of Fly Ash Geopolymer Binder,Arab J SciEng39:4333–4339 DOI 10.1007/s13369-014-1093-8,2013.