

# Mechanical Properties of Geopolymer Concrete with Flyash and Metakaolin



A.Lakshmi Deepak, T.V.S. Vara Lakshmi

**Abstract:** Trials has been made to produce efficient GPC which gives maximum strength. By-Products from industries such as Fly-Ash, Metakaolin and GGBS can be used in concrete replacement which in-turn reduces carbon-di-oxide ( $CO_2$ ) emission affecting to green house. Using the above said products also leads to reduction of water demand in concrete and also shows comparatively no effects on long term effects in concrete, these by-products can effectively be used in concrete production. The high silica content in Fly-Ash and Metakaolin increases the bonding in concrete which in-turn increases the mechanical properties of concrete. Geopolymer concrete of M50 grade was proposed to be produced using fly-ash and Metakaolin instead of cement. Alkali solutions Sodium Hydroxide (NaOH), Sodium Silicate ( $Na_2SiO_3$ ) were replaced with water for better bonding and mixing. Molarity of Sodium Hydroxide with 10M and 12M was considered for this study. Ratio of Alkaline solution were considered as 1:2, 1:2.5 & 1:3 to determine the optimum ratio which gives effective strength. In this experimental study, tests were carried on concrete specimens with percentage replacement of Fly-Ash with Buff Metakaolin in variable percentages of 20, 40, 60, 80 & 100. Mechanical properties of concrete specimens were studied and were compared with control mix results.

**Keywords-** Geo-Polymer Concrete GPC, Fly Ash, Metakaolin, Sodium Hydroxide (NaOH), Sodium Silicate ( $Na_2SiO_3$ ).

## I. INTRODUCTION

The geopolymer concrete technology proposed by Davidovits ensures efficient application of Byproducts as an alternative material to the Portland cement. Use of the geopolymer technology could reduce the  $CO_2$  emission in to the atmosphere, caused by cement and aggregate industries about 80%. Geopolymer concrete has been emerging as an environmental friendly construction material for sustainable development, using Flyash and Metakaolin in place of Portland Cement as the binding agent. The objective of this study, the mechanical properties of Fly-Ash and Metakaolin based GPC mixes with two different molarities by air dry curing method at ambient room temperature.

Geopolymer Concrete of M50 grade was prepared with three alkaline solution ratios. Concrete specimens of 150mm x 150mm x 150mm size were prepared for compressive strength test. Cylindrical specimens of size 150mmx300mm were prepared for split tensile strength tests and beams of size 100mm x 100mm x 500mm were casted for Flexural Strength test of concrete.

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Fig.1 Casting of Concrete Cube Specimens



Fig.2 Casting of Cylindrical and Beam Specimens

## II. LITERATURE REVIEW

Prakash R. Voraa, Urmil V. Dave [1] has evaluated that use of pozzolona materials in the place of cement has enhanced the performance of concrete. Around 20 GPC mix proportions have been casted and were tested to evaluate the mechanical properties and efficiency of Geo Polymer Concrete. Parameters such as solid to alkaline liquid ratio, Alkaline liquid ratio, period of curing, type of curing and percentage of super plasticizer has been considered for variation to study the properties of concrete. Also has been concluded that naphthalene based super plasticiser improves the workability of fresh geopolymer concrete. It was further observed that the water content in the geopolymer concrete mix plays significant role in achieving the desired compressive strength.

Mr.G.Hemanaag, Mr.B.S.R.K.Prasad [2] An inorganic polymer material that uses the by-product materials such as Metakaolin, fly ash etc is known as geo polymer. Instead of cement the above said by products are activated by alkaline liquids such as sodium silicate and sodium hydroxide from 2 Molar to 8 Molar were used in variable of 2M to produce the binder. Type of materials, Mix Ratio and Binding Process were covered in this project. Trial and Error method was used in this study to produce a binder and compressive strength values for various molarities were determined. From the observations it was clear that when the molarity increased, the compressive strength was increased. Compared to fly ash based concrete the compressive strengths of metakaolin based concrete are high, but the cost of metakaolin based concrete is more.

**Siti Noorbaini Sarmin [3]** has reported on the properties of fly ash/metakaolin-based geopolymer lightweight foamed concrete with inclusion of wood particles. Class F fly ash and metakaolin was mixed with an alkaline activator solution (a mixture of sodium silicate;  $\text{Na}_2\text{SiO}_3$  and sodium hydroxide;  $\text{NaOH}$ ), and hydrogen peroxide;  $\text{H}_2\text{O}_2$  was added to the geo polymeric mixture to produce lightweight foamed concrete. The  $\text{NaOH}$  solution was prepared by dilute  $\text{NaOH}$  pellets with distilled water. The ratio of fly ash/metakaolin and alkaline activator used was 2.5:1.0 with addition of 0%, 10%, 20% and 30% of wood particles by volume of the total mix. The reactive were mixed to produce a homogenous mixture sized 50mm and cured at two different curing temperatures (80°C for 24 hours and room temperature for seven days). All the experiments were set up in accordance with International standard methods of testing. In reference to the analysis and discussion, the integration of fly ash/metakaolin and wood particles enhanced the properties of the lightweight foamed concrete. The results showed that the samples which were cured at 80°C produced the maximum compressive strength, (5.71 MPa, 10.2 MPa, 7.62 MPa and 6.3 MPa) for 0%, 10%, 20% and 30% of wood particles respectively. The oven-dry density of samples cured at 80°C was greater than room temperature curing. Heat curing which caused the geo polymerization rate to increase, producing a denser matrix.

### III. MATERIALS AND METHODOLOGY

#### A. Materials Used:

i. *Binder Material:* Class F Fly-Ash and Buff Metakaolin were used instead of cement. Fly-Ash was obtained from Vijayawada Thermal Power Station (VTPS), Vijayawada, India and Buff Metakaolin was purchased from RaniGanj, Secunderabad., India.

ii. *Aggregates:* Coarse Aggregate with an average specific gravity of 2.75 and Fine Aggregate confining to Zone-III with an average specific gravity of 2.67 was considered for this study.

iii. *Alkaline Liquids:* Sodium Hydroxide pellets were purchased in the locally available market and solution of 10M and 12M were prepared. Sodium Silicate Solution (A50) which is directly available in liquid form was considered for this study.

iv. *Super plasticizer:* In this present investigation CONPLAST SP 430 has been used for obtaining workable concrete at low w/c ratio. CONPLAST SP 430 based on NSF condensates is used for this study.

#### B. Mix Design

##### i. Parameters

- Target Strength : M50
- Type of cement : OPC 53 Grade
- Exposure condition : Mild
- Degree of supervision : Good
- Maximum Aggregate size : 20mm

##### ii. Test Data for Materials

- Specific Gravity of cement : 2.96
- Specific Gravity of Fly-Ash: 2.4
- Specific Gravity of Metakaolin: 2.6
- Specific Gravity of Coarse Aggregate: 2.75
- Specific Gravity of Fine Aggregate: 2.67
- Water absorption of Coarse Aggregate: 2.1
- Water absorption of Fine Aggregate: 2.71

##### iii. Mix Proportions for Control Mix

- Cement : 420  $\text{kg}/\text{m}^3$
- Fine Aggregate: 773  $\text{kg}/\text{m}^3$
- Coarse Aggregate: 773  $\text{kg}/\text{m}^3$
- Water : 152  $\text{kg}/\text{m}^3$
- Water Cement Ratio: 0.36
- Admixture: Conplast SP430 (Napthalene based) at 2% of the weight of cement/Geopolymer.
- Mix Ratio: C:F.A:C.A:W/C = 1:1.46:3.1:0.36

##### iv. Mix Proportions for Control Mix

- Binder Content : 420  $\text{kg}/\text{m}^3$
- Fine Aggregate: 773  $\text{kg}/\text{m}^3$
- Coarse Aggregate: 773  $\text{kg}/\text{m}^3$
- Water : 152  $\text{kg}/\text{m}^3$
- Water Cement Ratio: 0.36
- Admixture: Conplast SP430 (Napthalene based) at 2% of the weight of cement/Geopolymer.
- Mix Ratio: C:F.A:C.A:W/C = 1:1.28:3.0:0.43

#### C. Experimentation

##### i. Compressive Strength:

The specimens used for this test were cubes of standard size 150mm x150mm x150mm. for each time period of each molarity, 3 specimens were casted i.e., ( A total of 6 specimens for 10M and 6 specimens for 12M were taken for all time periods i.e., 7 days, 28 days). And from the testing it was observed that 12M specimens yielded good compressive strength compared to that of 10M specimens. Alkaline Solution Ratio of 1:2.5 and 1:3 were considered for testing.

##### ii. Split Tensile Strength

The specimens used for this test were cylinders of standard size 150 mm x 300 mm. for each period of time of each molarity, 3 specimens were casted i.e., a total of 6 specimens for 10M and 6 specimens for 12M were taken for all time periods i.e., 7 days, 28 days. Alkaline Solution Ratio of 1:2.5 and 1:3 were considered for testing.

{ $T = 2P/\pi LD$ } is the formula for calculation of split-tensile strength for 7 and 28 days and the outcomes were tabled and represented beneath .

iii. Flexural Strength

The specimens used for this test were beams of standard size 100 mm x 100 mm x 500 mm .for each period of time of each molarity, 3 specimens were taken i.e., a total of 6 specimens for 10M and 6 specimens for 12M were taken for all time periods ie.,7 days,28 days. Alkaline Solution Ratio of 1:2.5 and 1:3 were considered for testing.  $\{T = 2P/bd^2\}$  is the formula for calculation of flexural strength for 7 and 28 days and the outcomes were tabled and represented beneath

IV. RESULTS AND ANALYSIS

Table: 1

COMPRESSIVE STRENGTH RESULTS OF MIX WITH 10M SOLUTION (1:2.5) NaOH:Na <sub>2</sub> SiO <sub>3</sub>			
Sl. No	Mix Proportion	7 days N/mm <sup>2</sup>	28 days N/mm <sup>2</sup>
1	C.C	31.5	49.7
2	100% F.A	FAILED	
3	100% Metakaolin	50.85	51.4
4	80%MK+20%F.A	52.00	52.80
5	60%MK+40%F.A	44.56	46.40
6	40%MK+60%F.A	37.40	44.12
7	20%MK+80%F.A	34.40	43.51

Table: 2

COMPRESSIVE STRENGTH RESULTS OF MIX WITH 12M SOLUTION (1:2.5) NaOH:Na <sub>2</sub> SiO <sub>3</sub>			
Sl. No	Mix Proportion	7 days N/mm <sup>2</sup>	28 days N/mm <sup>2</sup>
1	C.C	32.2	51.4
2	100% F.A	FAILED	
3	100% Metakaolin	52.23	52.67
4	80%MK+20%F.A	53.26	54.04
5	60%MK+40%F.A	45.28	48.52
6	40%MK+60%F.A	40.17	46.3
7	20%MK+80%F.A	41.23	44.14

Table: 3

COMPRESSIVE STRENGTH RESULTS OF MIX WITH 10M SOLUTION (1:3) NaOH:Na <sub>2</sub> SiO <sub>3</sub>			
Sl. No	Mix Proportion	7 days N/mm <sup>2</sup>	28 days N/mm <sup>2</sup>
1	C.C	31.5	49.7
2	100% F.A	FAILED	
3	100% Metakaolin	52.85	56.52
4	80%MK+20%F.A	54.03	58.09
5	60%MK+40%F.A	46.3	51.04
6	40%MK+60%F.A	38.86	48.53
7	20%MK+80%F.A	35.74	47.87

Table: 4

COMPRESSIVE STRENGTH RESULTS OF MIX WITH 10M SOLUTION (1:3) NaOH:Na <sub>2</sub> SiO <sub>3</sub>			
Sl. No	Mix Proportion	7 days N/mm <sup>2</sup>	28 days N/mm <sup>2</sup>
1	C.C	32.2	51.4
2	100% F.A	FAILED	
3	100% Metakaolin	54.27	57.94
4	80%MK+20%F.A	55.34	59.45
5	60%MK+40%F.A	47.05	53.37
6	40%MK+60%F.A	41.74	50.93
7	20%MK+80%F.A	42.83	48.56

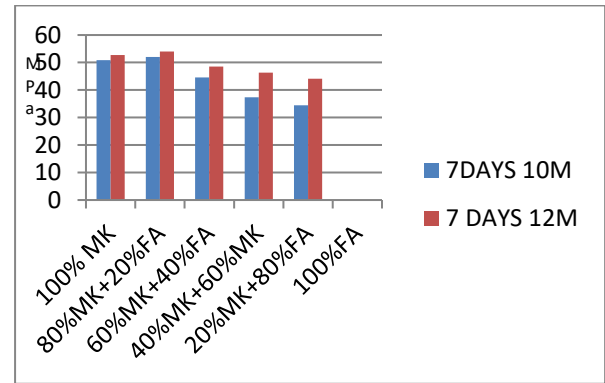


Fig.3: Variation of 7 days compressive strength with variation in % geopolymers for 10M &12M solution with 1:2.5 alkaline liquid ratio

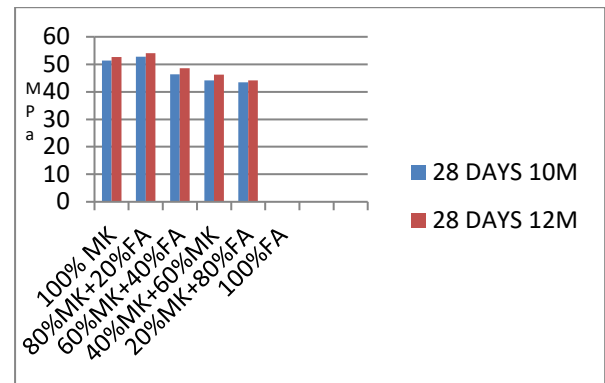


Fig.4: Variation of 28 days compressive strength with variation in % geopolymers for 10M &12M solution with 1:2.5 alkaline liquid ratio

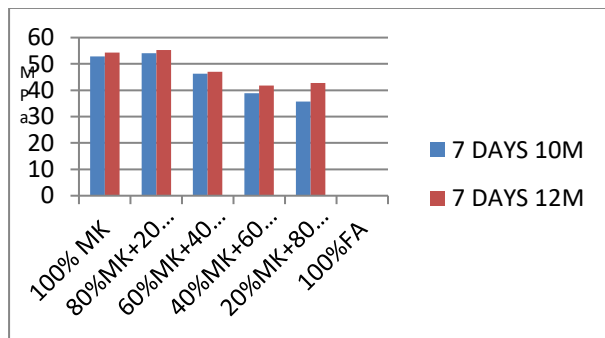


Fig.5: Variation of 7 days compressive strength with variation in % geopolymers for 10M &12M solution with 1:3 alkaline liquid ratio

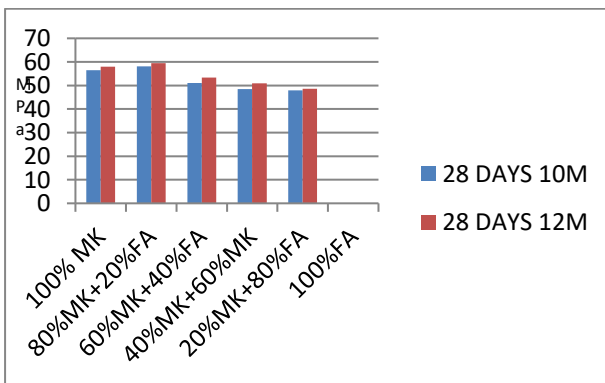


Fig.6: Variation of 28 days compressive strength with variation in % geopolymers for 10M &12M solution with 1:3 alkaline liquid ratio



Table: 5

SPLIT TENSILE STRENGTH RESULTS OF MIX WITH 12 M SOLUTION (1:2.5) NaOH:Na <sub>2</sub> SiO <sub>3</sub>			
Sl. No	Mix Proportion	7 days N/mm <sup>2</sup>	28 days N/mm <sup>2</sup>
1	C.C	4.22	4.87
2	100% F.A	0.571	0.76
3	100% Metakaolin	3.47	4.38
4	80%MK+20%F.A	4.01	5.12
5	60%MK+40%F.A	3.66	3.93
6	40%MK+60%F.A	3.14	3.51
7	20%MK+80%F.A	1.79	2.30

Table:6

SPLIT TENSILE STRENGTH RESULTS OF MIX WITH 12 M SOLUTION (1:3) NaOH:Na <sub>2</sub> SiO <sub>3</sub>			
Sl. No	Mix Proportion	7 days N/mm <sup>2</sup>	28 days N/mm <sup>2</sup>
1	C.C	4.22	4.87
2	100% F.A	0.58	0.93
3	100% Metakaolin	3.57	5.39
4	80%MK+20%F.A	4.13	6.29
5	60%MK+40%F.A	3.77	4.83
6	40%MK+60%F.A	3.24	4.32
7	20%MK+80%F.A	1.85	2.83

Table: 7

SPLIT TENSILE STRENGTH RESULTS OF MIX WITH 10M SOLUTION (1:3) NaOH:Na <sub>2</sub> SiO <sub>3</sub>			
Sl. No	Mix Proportion	7 days N/mm <sup>2</sup>	28 days N/mm <sup>2</sup>
1	C.C	4.22	4.87
2	100% F.A	0.24	0.45
3	100% Metakaolin	2.38	4.64
4	80%MK+20%F.A	3.45	6.25
5	60%MK+40%F.A	2.97	4.72
6	40%MK+60%F.A	3.29	3.01
7	20%MK+80%F.A	0.28	0.74

Table: 8

SPLIT TENSILE STRENGTH RESULTS OF MIX WITH 10 M SOLUTION (1:2.5) NaOH:Na <sub>2</sub> SiO <sub>3</sub>			
Sl. No	Mix Proportion	7 days N/mm <sup>2</sup>	28 days N/mm <sup>2</sup>
1	C.C	4.22	4.87
2	100% F.A	0.23	0.37
3	100% Metakaolin	2.317	3.78
4	80%MK+20%F.A	3.36	5.08
5	60%MK+40%F.A	2.89	3.84
6	40%MK+60%F.A	2.32	2.45
7	20%MK+80%F.A	0.28	0.31

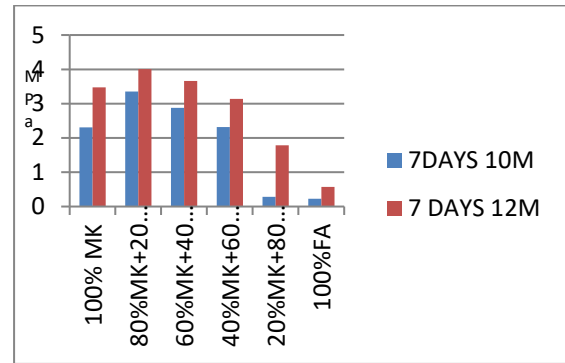


Fig.7: Variation of 7 days Tensile Strength with variation in % geopolymers for 10M &12M solution with 1:2.5 alkaline liquid ratio

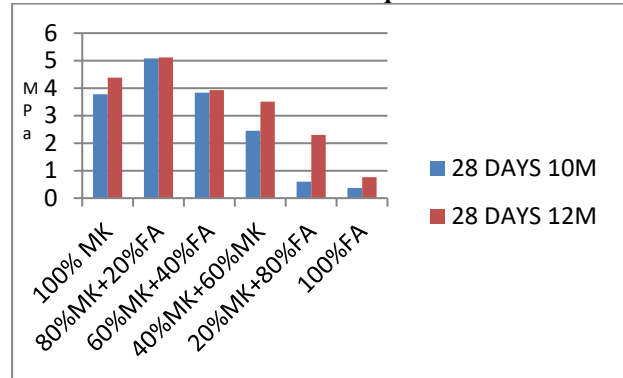


Fig.8: Variation of 28 days Tensile Strength with variation in % geopolymers for 10M &12M solution with 1:2.5 alkaline liquid ratio

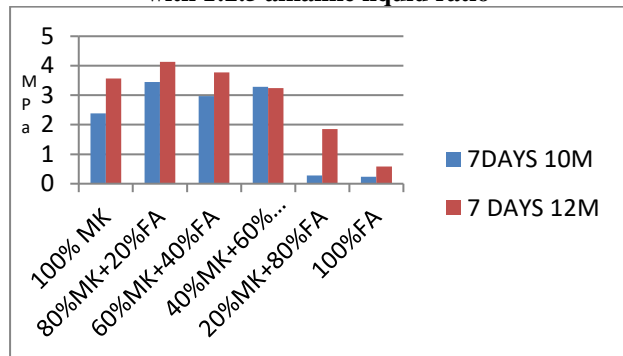


Fig.9: Variation of 7 days Tensile Strength with variation in % geopolymers for 10M &12M solution with 1:3 alkaline liquid ratio

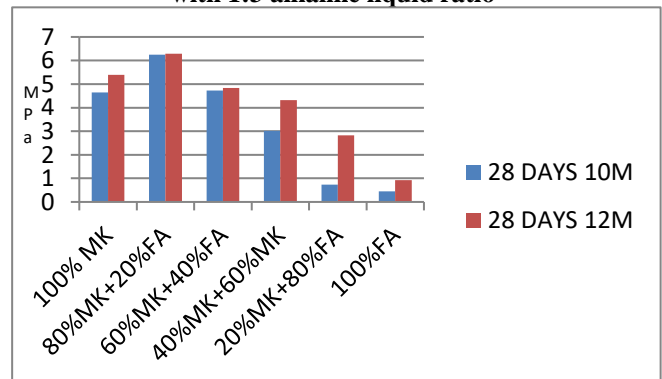


Fig.10: Variation of 28 days Tensile Strength with variation in % geopolymers for 10M &12M solution with 1:3 alkaline liquid ratio.



**Table 9**

FLEXURAL STRENGTH RESULTS OF MIX WITH 10M SOLUTION (1:2) NaOH:Na <sub>2</sub> SiO <sub>3</sub>			
Sl.No	Mix Proportion	7 days N/mm <sup>2</sup>	28 days N/mm <sup>2</sup>
1	C.C		
2	100% F.A	0	0.25
3	100% Metakaolin	2.25	2.44
4	80%MK+20%F.A	3.33	4.76
5	60%MK+40%F.A	1.85	1.96
6	40%MK+60%F.A	0.73	1.04
7	20%MK+80%F.A	0.47	0.61

**Table 10**

FLEXURAL STRENGTH RESULTS OF MIX WITH 12M SOLUTION (1:2) NaOH:Na <sub>2</sub> SiO <sub>3</sub>			
Sl. No	Mix Proportion	7 days N/mm <sup>2</sup>	28 days N/mm <sup>2</sup>
1	C.C		
2	100% F.A	0	0.6
3	100% Metakaolin	2.56	4.01
4	80%MK+20%F.A	3.74	4.94
5	60%MK+40%F.A	2.18	2.74
6	40%MK+60%F.A	0.86	1.56
7	20%MK+80%F.A	0.49	1.41

**Table 11**

FLEXURAL STRENGTH RESULTS OF MIX WITH 10M SOLUTION (1:2.5) NaOH:Na <sub>2</sub> SiO <sub>3</sub>			
Sl.No	Mix Proportion	7 days N/mm <sup>2</sup>	28 days N/mm <sup>2</sup>
1	C.C	2.03	6.13
2	100% F.A	0	0.6
3	100% Metakaolin	0.92	4.06
4	80%MK+20%F.A	1.01	4.64
5	60%MK+40%F.A	0.98	2.77
6	40%MK+60%F.A	0.85	1.58
7	20%MK+80%F.A	0.78	1.43

**Table:12**

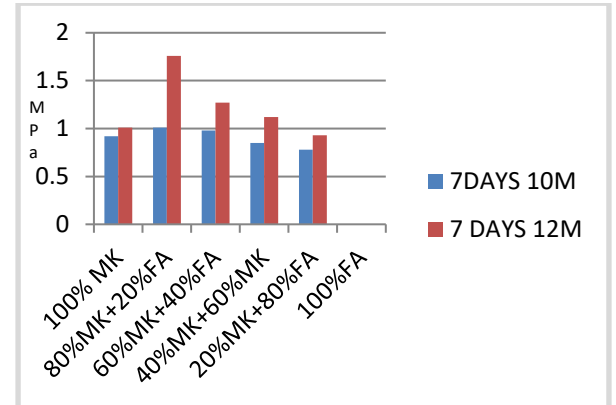
FLEXURAL STRENGTH RESULTS OF MIX WITH 12M SOLUTION (1:2.5) NaOH:Na <sub>2</sub> SiO <sub>3</sub>			
Sl.No	Mix Proportion	7 days N/mm <sup>2</sup>	28 days N/mm <sup>2</sup>
1	C.C	2.03	6.13
2	100% F.A	0	0.65
3	100% Metakaolin	1.01	4.35
4	80%MK+20%F.A	1.76	4.72
5	60%MK+40%F.A	1.27	2.85
6	40%MK+60%F.A	1.12	1.76
7	20%MK+80%F.A	0.93	1.87

**Table:13**

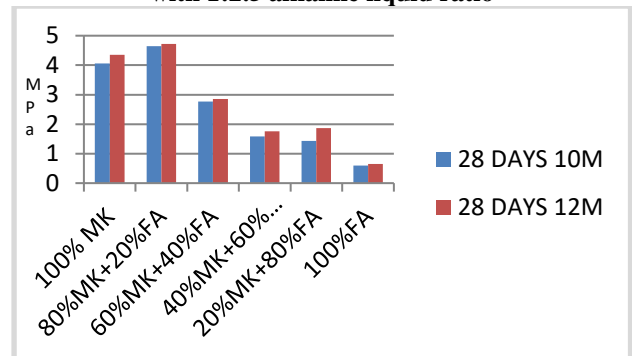
FLEXURAL STRENGTH RESULTS OF MIX WITH 10M SOLUTION (1:3) NaOH:Na <sub>2</sub> SiO <sub>3</sub>			
Sl.No	Mix Proportion	7 days N/mm <sup>2</sup>	28 days N/mm <sup>2</sup>
1	C.C	2.03	6.13
2	100% F.A	0	0.32
3	100% Metakaolin	1.17	3.62
4	80%MK+20%F.A	2.37	5.96
5	60%MK+40%F.A	2.54	2.98
6	40%MK+60%F.A	1.17	1.35
7	20%MK+80%F.A	0.75	0.79

**Table:14**

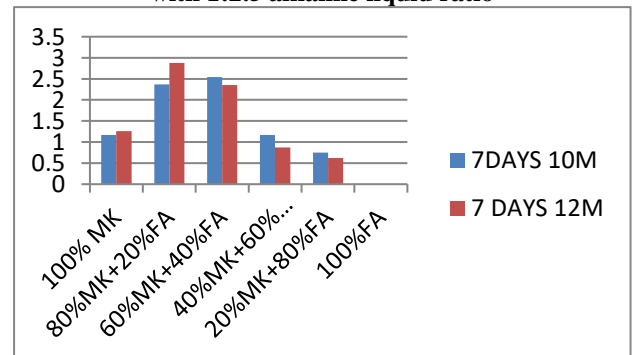
FLEXURAL STRENGTH RESULTS OF MIX WITH 12M SOLUTION (1:3) NaOH:Na <sub>2</sub> SiO <sub>3</sub>			
Sl. No	Mix Proportion	7 days N/mm <sup>2</sup>	28 days N/mm <sup>2</sup>
1	C.C	2.03	6.13
2	100% F.A	0	0.77
3	100% Metakaolin	1.26	5.21
4	80%MK+20%F.A	2.88	6.18
5	60%MK+40%F.A	2.35	3.56
6	40%MK+60%F.A	0.87	2.02
7	20%MK+80%F.A	0.62	1.83



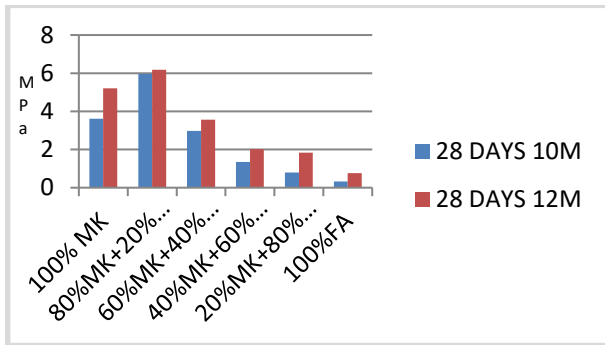
**Fig.13: Variation of 7 days Flexural Strength with variation in % geopolymers for 10M & 12M solution with 1:2.5 alkaline liquid ratio**



**Fig.14: Variation of 28 days Flexural Strength with variation in % geopolymers for 10M & 12M solution with 1:2.5 alkaline liquid ratio**



**Fig.15: Variation of 7 days Flexural Strength with variation in % geopolymers for 10M & 12M solution with 1:3 alkaline liquid ratio**



**Fig.16: Variation of 28 days Flexural Strength with variation in % geopolymers for 10M & 12M solution with 1:3 alkaline liquid ratio**

## V. CONCLUSION

- Optimum mixtures were observed as 80%MK+20%FA.
- Strength properties for GPC with 12 Molar NaOH gives better results compared to 10 Molar solution.
- Compressive Strength of concrete with 1:3 alkaline liquid ratio has been increased compared to 1:2.5.
- Compressive Strength of concrete has been increase by 9% for 12M solution in 1:3 alkaline liquid ratio.
- Split Tensile Strength of concrete has been increase by 18.6% for 12M solution in 1:3 alkaline liquid ratio.
- Flexural Strength of Concrete has been increased by 23.6% for 12M solution in 1:3 alkaline liquid ratio.
- It has been observed that increment in alkaline liquid ration increases the strength of concrete when compared between 1:2.5 and 1:3

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