Effect of Varying Ratio of Silicon Dioxide to Sodium Oxide on Geopolymer Concrete

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Abstract- Geopolymer concrete is product of reaction between Si and Al rich source material like fly ash, silica fume, rice husk ash with potassium or sodium based alkaline solutions. Geopolymers possess three dimensional alumino silicate networks and is being used as a substitute to Portland cement concrete due to its excellent mechanical properties. In this paper, low calcium class F (ASTM 2001) fly ash and sodium based alkaline solutions i.e. sodium silicate and sodium hydroxide were used as source of Si and Al to produce binder. Different parameters like ratio of Silicon dioxide to sodium oxide (SiO_2/Na_2O), alkaline solution ratio of (Na_2SiO_3/NaOH) and molarity of NaOH were taken. Different ratios of Silicon dioxide to sodium oxide (SiO_2/Na_2O) such as 2.0, 2.25 and 2.35 were taken. In combination with these different ratios, Sodium hydroxide solution having molarities such as 12M, 14M were used. Also ratio of alkaline solution i.e. sodium silicate (Na_2SiO_3) and Sodium hydroxide solution (Na2Sio3/NaOH) was taken as 2.Test results showed that as the ratio of Silicon dioxide to sodium oxide increases compressive strength, flexure strength and split tensile strength decreases. Percentage decrease in silicon dioxide content and percentage increase in sodium oxide content increases compressive strength, flexure strength and split tensile strength.

Keywords – Geopolymer concrete, fly ash, Silicon dioxide, sodium oxide, Compressive strength, Flexural Strength, Spilt Tensile Strength.

I. INTRODUCTION

Concrete is one of the most widely used construction materials with Portland cement as the main component. The demand for concrete as a construction material is on the increase. On the other hand, the climate change due to global warming, one of the greatest environmental issues has become a major concern. Among the greenhouse gases, CO_2 contributes about 65% of global warming. The cement industry is responsible for about 6% of all CO_2 emissions, because the production of one ton of Portland cement emits approximately one ton of CO_2 into the atmosphere[1-2]. Therefore, efforts have been made to promote the use of pozzolans to partially replace Portland cement in concrete production. Other efforts seek to totally replace Portland cement with other forms of cementitious materials such as geopolymers. A geopolymer or alkali-activated cement is an inorganic, alumino-silicate–based material. The strengths of geopolymer mortar and concrete are of the same order as those made with normal Portland cement. Furthermore, it is known that geopolymers possess good mechanical properties as well as fire and acid resistance. A wide range of materials is being used for geopolymerization including materials rich in Si (e.g., fly ash, slag, and rice husk) and materials rich in Al (e.g., clays like kaolin, betonies, and burned Clays). Because of its availability, fly ash is considered among the important sources of geopolymer [3]. As per IS3812 (Part II): 2013, fly Ash is defined as 'pulverized fuel ash extracted from flue gases by any suitable process such as by cyclone separator or electro-static precipitator'. Fly ash is not having any binding property but when it reacts with calcium hydroxide during the hydration process, it forms C-S-H gel. Due to presence of SiO_2 and Al_2O_3 in fly ash, it is very useful in making of special cement. In general terms fly ash is divided into two categories first one is low calcium fly ash Class F and second is high calcium fly ash Class C. It has been shown that low-calcium fly ash-based geopolymer concretes (LCGC) have similar mechanical properties to concretes produced with PC. Although low-calcium fly ash produced by burning bituminous coal is commonly used in fly ash–based geopolymer, high-

calcium fly ash produced by burning lignite and/or subbituminous coal has also been investigated in regard to its use in geopolymer production.
Geo-polymer materials represent an innovative technology that is generating huge amount of interest in the construction industry considering sustainable material. Although geo-polymer concrete is a new technology but the use of this technology has started from the time of pyramids though that time it did not come in the front of the researchers like now to grasp their interest in it. The name “Geo-polymer” was coined by Prof. J. Davidovits in 1978 and he found that the polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals that result in 3D polymeric chain and ring structure consisting of Si-O-Al-O bonds. Geopolymers are three-dimensional networks of alumino silicate molecules that are formed by the dissolution of materials containing reactive alumina and silica and possibly an additional silica source (sodium silicate or amorphous silica) in alkaline-activating solutions (sodium or potassium hydroxide) at temperatures of less than 100°C.The main concept behind this geopolymer is the polymerization of the Si-O-Al-O bond which develops when Al-Si source materials like Fly ash or rice husk is mixed with alkaline activating solution (NaOH or KOH solution with Na2SiO3 or K2SiO3). The geopolymer can be in the form of -Si-O-Al-O- or –Si-O-Al-O-Si-O- or –Si-O-Al-O-Si-O-Si-O- [4].
Geopolymer concrete can be manufactured by using the low-calcium (ASTM Class F) fly ash obtained from coal-burning power stations. Most of the fly ash available globally is low-calcium fly ash formed as a by-product of burning anthracite or bituminous coal. Commercial grade Potassium Hydroxide in pallets form (97%-100% purity) and sodium silicate solution (Na_2O=14-16%, SiO_2=32-35%, Water = 46-49%) were used as the alkali activators. The potassium Hydroxide pallets were dissolved in the required amount of water according to the desired molarity [5].
Use of Geopolymer concrete (GPC) instead of OPC concrete is suitable because CO_2 equivalent emission can be reduced. It is found that GPC is not used everywhere in place of OPC concrete because of some practical limitations. GPC can be used instead of normal concrete by considering the facts that strength can achieve as that of normal concrete [6-7].

II. OBJECTIVES OF WORK

2.1 To study the effect of Silicon dioxide to sodium oxide (SiO_2/Na_2O) ratio on geopolymer concrete.
2.2 To study the effect of Sodium hydroxide solution having 12 and 14 Molarities on geopolymer concrete.

III. SCOPE OF WORK

Geopolymer concrete is a new invention in the world of concrete in which cement is totally replaced by industrial waste which contributes towards the global worming by reducing use of cement and utilization of by products like fly ash. It helps to reduce the utilization of ordinary Portland cement. Scope of present work is to use the optimum ratio of the materials which will enhance the different parameters of the concrete. Mix design procedure for geopolymer concrete suggested by prof. S.V.Patankar is used for M 40 grade of concrete. For each mix, 9 cubes were casted for each trial and tested after curing for 7 days, 14 days and 28 days (3 each). Three beams and three cylinders specimens were casted for each proportion and tested after curing for 28 days. Specimens were cured at 60^0C temperature for 24 hours after giving rest period of 1 day [8-11].

IV. MATERIALS UTILIZED

4.1. Fly Ash -

In the present experimental work, low calcium, Class F (American Society for Testing and Materials 2001) dry fly ash obtained from thermal power station, eklahare, Nashik was used as the base material. Fly ash is a high efficiency class F pozzolanic material confirming to BS 3892, obtained by selection and processing of power station fly ashes resulting from the combustion of pulverized coal[11].

Table 1. General Information

Presentation	Finely divided dry powder
Colour	Light grey
Bulk Weight	Aprox. 0.90 metric ton per cubic meter
Specific density	Aprox. 2.30 metric ton per cubic meter
Specific density	Aprox. 2.30 metric ton per cubic meter
Size	90% < 45 micron

Particle shape	Spherical

4.2. Alkaline Liquid

A combination of sodium silicate solution and sodium hydroxide solution was chosen as the alkaline liquid. Sodium-based solutions were chosen because they were cheaper than Potassium-based solutions. The sodium hydroxide solids were either technical grade in flakes form (3 mm), with a specific gravity of 2.130, 97% purity. Chemical composition of sodium hydroxide is shown in Table No. 2. The sodium hydroxide (NaOH) solution will be prepared by dissolving either the flakes in water. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molar, M. For instance, NaOH solution with a concentration of 12M consisted of 12x40 = 480 grams of NaOH solids per liter of the solution, where 40 is the molecular weight of NaOH.

Table No 2: Chemical composition of sodium hydroxide

Chemical component	Percentage (%)
Sodium hydroxide (min.)	97
Carbonate	2
Chloride	0.01
Sulphate	0.05
Potassium	0.1
Silicate	0.05
Zinc	0.02

Note that the mass of NaOH solids was only a fraction of the mass of the NaOH solution, and water is the major component.

The Sodium silicate consists of silicon dioxide, sodium oxide and water in varying proportions. Chemical composition of sodium silicate is shown in Table No.3.

Table No3. Chemical composition of sodium Silicate ($Na_2 SiO_3$)

Mix	Na_2O	SiO_2	Water Content	Total Solids	Ratio of SiO_2/ Na_2O
Mix 1	16.05%	32.14%	51.81%	48.19%	2.00
Mix 2	15.06%	34.01%	50.93%	49.07%	2.25
Mix 3	14.05%	33.03%	47.08%	52.92%	2.35

4.3. Fine Aggregate: (Natural Sand):

Various tests such as specific gravity, water absorption, impact strength, crushing strength etc. have been conducted on FA to know their quality and grading. All the tests have been carried and results are shown in tables 3.4.Locally available Natural River sand is used confirming to IS 383-1970. Properties of aggregate are as shown in Table No.4.

4.4. Coarse Aggregate:

The nominal maximum size of coarse aggregate should as large as possible within the specified limits but in no case greater than one fourth of the minimum thickness of the member, provided that the concrete can be placed without difficulty so as to surround all reinforcement thoroughly and fill the corners of the form.

The aggregate of size 20mm were used confirming to IS 383-1970.Properties of aggregate are as shown in Table No.4

Table No. 4. Properties of aggregate

Properties	Coarse Aggregate	Fine Aggregate
Type	Crushed angular	Spherical (River sand)
Maximum Size	20mm	4.75 mm
Specific Gravity	2.70	2.63
Material finer than 75 micron	Nil	1.25 %
Water Absorption	0.63%	1.63%
Moisture Content	Nil	Nil

4.5. Concrete Mix Design

As Geopolymer concrete is new invention, the procedure for mix design of conventional concrete as per the procedure of Bureau of Indian Standards IS 10262: 2009 is not applicable. In the present study, Mix design procedure for geopolymer concrete by prof. S.V.Patankar is used for M40 grade of concrete.9 cubes were casted for each proportion and tested after curing for 7 days, 14 days and 28 days (3each). Three beams and three cylinders specimens were casted for each proportion and tested after curing for 28 days [10].

4.6. Water

Potable water available in the laboratory with the pH of 7.0 ± 1 and conforming to the requirement of IS: 456-2000 was used for mixing concrete.

V. GEOPOLYMER CONCRETE MIXES

Geopolymer concrete mixing procedure is same as that of conventional concrete. As per mix design the quantity of coarse aggregate, fine aggregate and fly ash were mixed in dry state. Then the geopolymer solution which was prepared 24-36 hours before was added along with extra water to make the mixture homogenous. Geopolymer mixes were found to be cohesive, viscous and dark gray in colour.

VI.CURING REGIME

Geopolymer concrete cubes were cured at 60^0 C temperatures for 24 hours. These cubes were given 1 day rest period after casting. These cubes were oven cured for 1 day.

VII.RESULTS AND DISCUSSIONS

7.1. Workability of Geopolymer Concrete

Freshly mixed geopolymer concrete is viscous in nature. During polymerization process, water comes out therefore methods like slump cone test is not suitable to measure workability as concrete subside for long time while in compaction factor test, concrete cannot flow freely. So, flow table test is used for workability measurement. The workability of the geopolymer was found medium [10].

7.2 Compressive Strength

Compressive strength tests were conducted after 7, 14 and 28 days on cubes of size 150x150x150mm as shown in Figure No.1.After casting of Geopolymer concrete, these cubes were cured in oven at 60^0 C temperatures for 24 hours. These cubes were given 1 day rest period after casting. Rest period has a considerable effect on compressive strength of concrete [8].

Figure No. 1.Compressive tests on Geopolymer concrete

Results are shown in Table no.5.Results show that maximum compressive strength is obtained for silicon dioxide to sodium oxide having ratio 2 for the trial no. 1 for 12 Molarity.

Table no 5.Compressive Strength Results

Trial	Molarity Of NaOH	Ratio Of Na_2SiO_3/ NaOH	Ratio Of SiO_2/Na_2O	Mean Compressive Strength N/mm^2		
				7	14	28
1	12M	2	2.00	39.11	46.66	54.22
			2.25	32.44	39.11	48
			2.35	34.22	40.44	51.11
2	14M	2	2.00	36	43.11	48.44
			2.25	28.88	36.88	40.88
			2.35	32.88	38.22	44

From Figure No.2 it is observed that maximum strength is 54.22 N/mm^2 which is achieved for ratio of silicon dioxide to sodium oxide having ratio 2.It can also be concluded from figure that early strength gain for 7 days is more. With the increase in duration compressive strength gain is found to be reduced. Minimum compressive strength is achieved for ratio of silicon dioxide to sodium oxide having ratio 2.25.

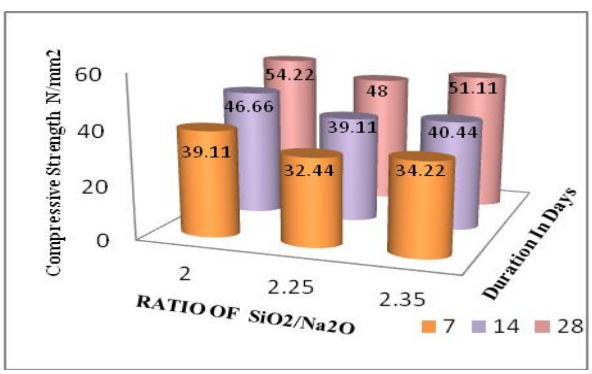

Figure No. 2.Effect of varying ratio of Silicon Dioxide to Sodium Oxide on Geopolymer concrete of 12M for Trial 1

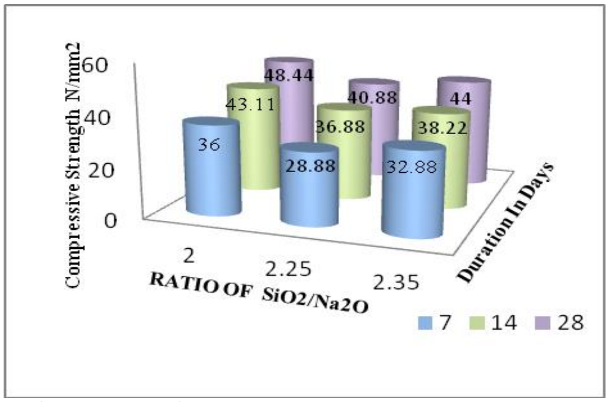

Figure No. 3 Effect of varying ratio of Silicon Dioxide to Sodium Oxide on Geopolymer concrete of 14M for Trial 2

Figure No.3 it is observed that maximum strength is 48.44 N/mm^2 which is achieved for ratio of silicon dioxide to sodium oxide having ratio 2.It can also be concluded from figure that early strength gain for 7 days is more. With the increase in duration compressive strength gain is found to be reduced. Minimum compressive strength is achieved for ratio of silicon dioxide to sodium oxide having ratio 2.25.

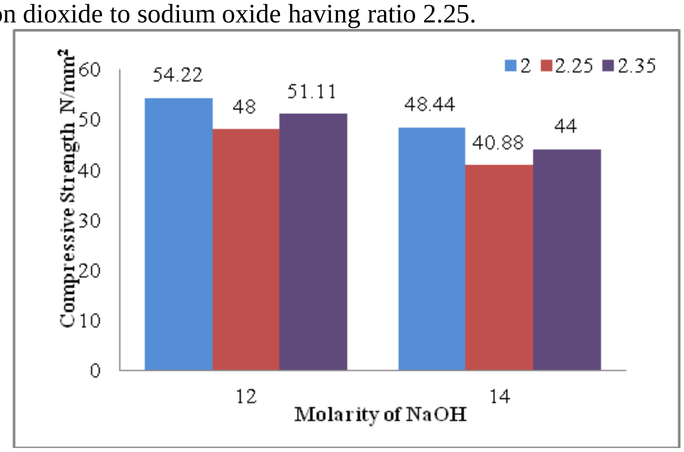

Figure No. 4 Effect of varying molarity on compressive strength at 28 days on Geopolymer concrete for trial 1 & 2.

Figure No.4 shows effect of varying molarity having Na_2SiO_3/NaOH ratio of 2 on compressive strength at 28 days on Geopolymer concrete for trial 1 & 2.With the increase in molarity from 12M to 14M compressive strength found to decrease by 10.66 % for ratio of SiO_2/Na_2O of 2.

Table no 6.Silicon dioxide content and compressive strength of geopolymer

Silicon dioxide content in %	Compressive strength N/mm^2
32.14	54.22
33.03	51.11
34.01	48

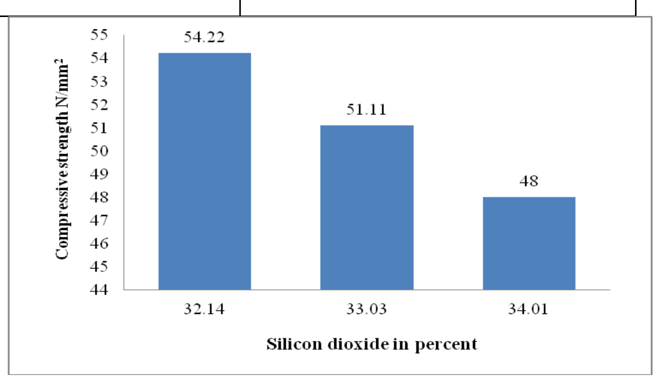

Figure No.5 Effect of silicon dioxide content on compressive strength of geopolymer concrete

As the silicon dioxide content increases compressive strength decreases from 54.22 N/mm^2 to 48 N/mm^2 as shown in Table No. 6 and Figure No.5 .

Table No. 7. Sodium oxide content and compressive strength of geopolymer concrete

sodium oxide content in %	**Compressive strength N/mm^2**
16.05	54.22
15.06	48
14.05	51.11

As the sodium oxide content increases compressive strength decreases from 54.22 N/mm^2 to 48 N/mm^2 and again increases to 51.11 N/mm^2 as shown in Table No.7 and Figure No.6 .

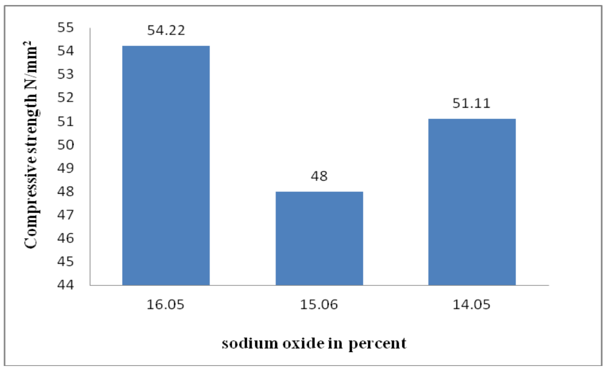

Figure No.6. Effect of Sodium oxide content on compressive strength of geopolymer concrete

7.3 Flexural strength

Three beam section of size 100x100x500 mm were casted and cured for 28 days. All beams were tested under two-point loading in Universal Testing Machine.

Figure No.7. Flexure test on geopolymer concrete

Each beam section was given 1 day rest period. After giving rest period these beams were cured at 60^0C temperature for 24 hours. Testing arrangement for beam sections are shown in Figure No.7.

Table No. 8. Flexure Strength Results

Trial	Molarity Of NaOH	Ratio Of $Na_2SiO_3/NaOH$	Ratio Of SiO_2/Na_2O	Flexure Strength N/mm^2
1	12M	2	2.00	13.875
			2.25	12.075
			2.35	12.85
2	14M	2	2.00	11.42
			2.25	9.725
			2.35	10.40

Beam sections were supported symmetrically over a span of 400mm in the machine. The load was increased until the specimen failed and the failure load was recorded. The results are shown in Table No. 8. Results show that maximum flexure strength is obtained for silicon dioxide to sodium oxide having ratio 2 for the Trial No. 1. The flexural strengths shall be obtained as described in IS 516 and IS 5816 respectively. When the designer wishes to use an estimate of the flexural strength from the compressive strength as per the IS 456:2000 clause 6.2.2.

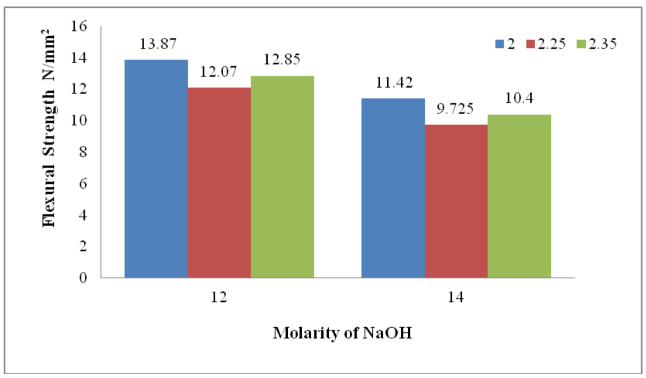

Figure No.8. Effect of varying Molarity on flexural strength of Geopolymer concrete for Trial 1 & 2

Effect of varying molarity having $Na_2SiO_3/NaOH$ ratio of 2 on flexural strength at 28 days on Geopolymer concrete for trial 1 & 2 is shown in Figure No.9.With the increase in molarity from 12M to 14M flexural strength found to decrease by 17.69 % for ratio of SiO_2/Na_2O of 2.

7.4. Split tensile test

The split tensile test is well known indirect test used to determine the tensile strength of concrete.

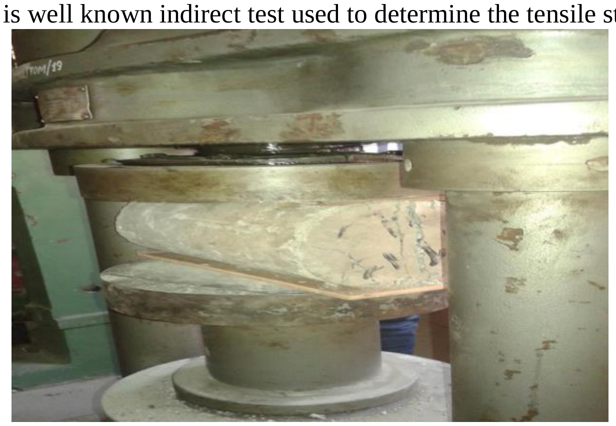

Figure No.9. Split tensile Test on Geopolymer concrete

Three cylindrical sections of diameter 150 mm and length 300 mm were casted and cured for 28 days. Each cylinder section was given 1 day rest period. After giving rest period these cylinders were cured at 60^0C temperature for 24 hours. Testing arrangement for cylinder sections are shown in Figure No.9.

Table 9. Split Tensile Strength Results

Trial	Molarity Of NaOH	Ratio Of $Na_2SiO_3/NaOH$	Ratio Of SiO_2/Na_2O	Split Tensile Strength N/mm^2
1	12M	2	2.00	8.13
			2.25	6.50
			2.35	6.90
2	14M	2	2.00	7.75
			2.25	5.87
			2.35	6.43

The results are shown in Table No.9. Results show that maximum split tensile strength is obtained for silicon dioxide to sodium oxide having ratio 2 for the Trial no. 1. The load was applied at a uniform rate till the specimen failed by a fracture across vertical diameter. When the designer wishes to use an estimate of the tensile strength from the compressive strength as per the IS 456:2000 clause 6.2.2.

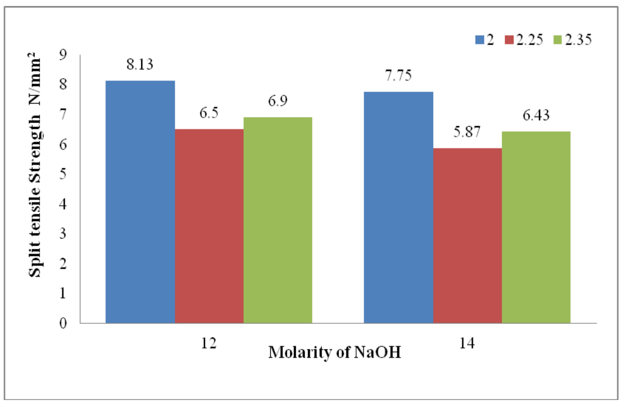

Figure No.10 Effect of varying Molarity on split tensile strength of Geopolymer concrete for Trial 1 & 2

Effect of varying molarity having $Na_2SiO_3/NaOH$ ratio of 2 on split tensile strength at 28 days on Geopolymer concrete for trial 1 & 2 as shown in Figure No.10 .With the increase in molarity from 12M to 14M split tensile strength found to decrease by 4.67 % for ratio of SiO_2/Na_2O of 2.

VIII.CONCLUSION

Test results show that as the ratio of Silicon dioxide to sodium oxide increases compressive strength, flexure strength and split tensile strength decreases. The increase in strength of Geopolymer concrete is due to formation of Si-O-Al-O bond which is formed due to presence of silicate content in fly ash as well as sodium silicate and Al content in fly ash. Also, Percentage decrease in silicon dioxide content and percentage increase in sodium oxide content increases compressive strength. Workability of concrete is affected by the viscosity of the alkaline liquid.As molarity increases from 12M to 14 M compressive strength, flexure strength and split tensile strength decreases. In sodium hydroxide –O-H- plays important role in bonding which is also associated with the Molarity of Geopolymer concrete.

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