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EXPERIMENTAL INVESTIGATION ON GEO POLYMER CONCRETE

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ABSTRACT

Based on the results obtained from this study, the following Conclusions seems to be valid. The increase in percentage replacement of Fly Ash with Metakaoline from 0% to 10.00% causes increase in Slump value up to 5% and beyond that slump is decreased. This shows workability is reducing as percentage of Metakaoline increased beyond 5%. Hence, 5% replacement of Fly ash with Metakaoline is suitable from workability point of view. The increase in percentage replacement of Fly ash with Metakaoline from 0% to 5% causes increase in compressive strength of concrete from 17.6MPa to 22.6MPa. Further increase in percentage replacement of Fly ash with Metakaoline from 5% to 10% causes decrease in the compressive strength from 22.6MPa to 18.7MPa. Hence, 5.00% replacement of Fly Ash with Metakaoline is advisable from compressive strength point of view .The increase in percentage replacement of Fly ash with Metakaoline from 0% to 5% causes increase in Split Tensile strength of concrete from 3.72MPa to 4.68MPa. Further increase in percentage replacement of Fly ash with Metakaoline from 5% to 10% causes decrease in the split Tensile strength from 4.68MPa to 3.94MPa. Hence, 5.00% replacement of Fly Ash with Metakaoline is advisable from Split Tensile strength point of view. The increase in percentage replacement of Fly ash with Metakaoline from 0% to 5% causes increase in flexural strength of concrete from 3.0 MPa to 3.36 MPa. Further increase in percentage replacement of Fly ash with Metakaoline from 5% to 10% causes decrease in the flexural strength from 3.36MPa to 3.2MPa. Hence, 5.00% replacement of Fly Ash with Metakaoline is advisable from flexural strength point of view. Finally, it can conclude Keeping in view of the workability, compressive strength, Split Tensile Strength and flexural strength in mind, 5% replacement of Fly ash with Metakaoline is recommended for use in GEO POLYMER CONCRETE (GPC).

This paper presents test data on fly ash-based geopolymer concrete. The paper covers the material and the mixture proportions, the manufacturing process, the fresh and hardened state characteristics, the influence of various parameters on the fresh and hardened state concrete, the utilization of the material in structural members, and the Short -term behavior .

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1. INTRODUCTION

1.1 GENERAL

Concrete, artificial engineering material made from a mixture of Portland cement, water, fine and coarse aggregates and a small amount of air. It is the most widely used construction material in the world. Concrete is the only major building material that can be delivered to the job site in a plastic state. This unique quality makes concrete desirable as a building material because it can be molded to virtually to any form or a shape. Concrete provides wide latitude in surface textures and colors and can be used to construct a wide variety of structures such as highways and streets, bridges, dams, large buildings, airport runways, irrigation structure, break waters, piers and docks, sidewalks, soils and farm building homes and even barges and ship. Other desirable qualities of concrete as a building material are its strength, economy and durability. Depending on the mixture of materials used, concrete will support, in compression, 700 or more kg/sq cm, (10,000 or more 1b/sq cm). The tensile strength of concrete is much lower when compared to compressive strength of concrete, but by using properly designed steel reinforcing, the structural members can be made that are as strong as in compression. The durability of concrete is evidenced by the fact that concrete columns built by the Egyptians more than 3600 years ago are still standing.

Concrete is the premier construction material around the world and is most widely used in all types of construction works, including infrastructure, low and high-rise buildings, and domestic developments. It is a man-made product, essentially consisting of a mixture of cement, aggregates, water and admixture(s). Inert granular materials such as sand, crushed stone or gravel form the major part of the aggregate. These materials are blended in required proportions according to the strength parameter and Grade of concrete.

1.2 DEVELOPMENT OF GEO POLYMER CONCRETE: A MODERN INNOVATION

In the context of increased awareness regarding the ill-effects of the over exploitation of natural resources, eco-friendly technologies are to be developed for effective management of these resources. Construction industry is one of the major users of the natural resources like cement, sand, rocks, clays and other soils. The ever increasing unit cost of the usual ingredients of concrete have forced the construction engineer to think of ways and means of reducing the unit const of its production. At the same time, increased industrial activity in the core sectors like energy, steel and transportation has been responsible for the production of large amounts like fly ash, blast furnace slag, silica fume and quarry dust with consequent disposal problem.

The geopolymer technology was first introduced by Davidovits in 1978. His work considerably shows that the adoption of the geopolymer technology could reduce the CO2 emission caused due to cement industries. Geopolymers are members of the family of inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous. Any material that contains mostly silicon (Si) and aluminium (Al) in amorphous form is a possible source material for the manufacture of geopolymer. Metakaolin or calcined Kaolin, low calcium ASTM Class F fly ash, natural Al-Si minerals, combination of calcined minerals and non-calcined minerals, combination of fly ash and metakolin, combination of granulated blast furnace slag and metakaolin have been studied as source materials. The most common alkaline liquid used in geopolymerisation is a combination of sodium hydroxide or potassium hydroxide and sodium silicate or potassium silicate.

Unlike ordinary Portland pozzolanic cements, geopolymers do not form calcium-silicate-hydrates (CSHs) for matrix formation and strength, but the alumino-silicate gel formed by geopolymerization binds the aggregates and provides the strength to geopolymer concrete. Source materials and alkaline liquids are the two main constituents of geopolymers, the strengths of which depend on the nature of the materials and the types of liquids.

Materials containing silicon (Si) and aluminium (Al) in amorphous form, which come from natural minerals or by-product materials, could be used as source materials for geopolymers. Kaolinite, clays, etc., are included in the natural minerals group whereas fly ash, silica fume, slag, rice-husk ash, red mud, etc., are by-product materials. For the manufacture of geopolymers, the choice of source materials depends mainly on their availability and cost, the type of application and the specific demand of the users. Metallurgical slag was also used as a raw material to make geopolymer and it was found that the addition of slag enhanced the properties of the geopolymer.

From the awareness of reduction in the cement content in concrete many countries tried different combinations of replacing cement with pozzoloniac materials. These are some of the countries which took initiative for the production of GPC.

Table 1: Worldwide status of GPC

Country	Production yield in Tons	% of World Production
UK	21565700	34.9
Australia	15667600	25.4
India	10148000	16.4
Brazil	1973370	3.2
China	1380980	2.2
Vietnam	1128500	1.8
Mexico	1004710	1.6
Japan	2099000	3.4

Geopolymer Concrete (GPC) is a new class of concrete based on an inorganic alumino- silicate binder system compared to the hydrated calcium silicate binder system of concrete. It possesses the advantages of rapid strength gain, good mechanical and durability properties and is eco- friendly and sustainable alternative to Ordinary Portland Cement (OPC) based concrete.

Davidovits in 1988 proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminum (Al) in a source material of geological origin or in by-product materials such as fly ash and rice husk ash to produce binders. Because the chemical reaction that takes place in this case is a polymerization process, he coined the term "Geopolymer" to represent these binders. Geopolymer concrete is concrete which does not utilize any Portland cement in its production. Geopolymer concrete is being studied extensively and shows promise as a substitute to Portland cement concrete. Research is shifting from the chemistry domain to engineering applications and commercial production of geopolymer concrete.

Geo-polymer materials represent an innovative technology that is generating huge amount of interest in the construction industry considering sustainable material. Although geopolymer 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. Prof. J. Davidovits 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. 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-SiO-Si-O-.

The geopolymer concrete mix was prepared as follows

NaOH (in water) + Na2SiO3 → Alkaline Liquid

Alkaline Liquid + Super plasticizer + Extra water + Aggregate + silica fume → Geopolymer Concrete

1.3 OBJECTIVE AND SCOPE:

The objective of this study is to assess the utility and efficacy of silica fume and alkaline liquids as a geopolymer concrete as an alternative to ordinary Portland cement concrete. The properties of materials have to be known before it can be used as an alternative of ordinary concrete. This study focuses on replacement of normal cement with silica fume as termed to be geopolymer concrete.

If geopolymer concrete emerges successfully and attain the properties as normal concrete, it would be a milestone achievement for the local construction industries. Therefore, the main objective of this research is to determine the feasibility of pozzolanoic materials as in geopolymer concrete. The objectives of the study are briefly summarized below.

- To make a concrete without using cement (i.e. Geopolymer concrete).
- To evaluate the optimum mix proportion of Geo-polymer concrete with fly ash replaced of cement and also the mix proportion of OPC.
- To study the different Strength properties of Geo-polymer concrete.
- To make the study of the concrete this has been casted in different moulds and cured.

2. REVIEW OF LITERATURE

This Chapter presents a brief review of the terminology and chemistry of geopolymers, and past studies on geopolymers. Additional review of Geopolymer technology is available.

Davidovits (1988; 1994) proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminum (Al) in a source material of geological origin or in by-product materials such as fly ash and rice husk ash to produce binders. Because the chemical reaction that takes place in this case is a polymerization process, he coined the term 'Geopolymer' to represent these binders. Geopolymers are members of the family of inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals, those results in a three-dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds (Davidovits, 1994).

The schematic Formation of Geopolymer Material

The schematic formation of geopolymer material can be shown as described by Equations (1) and (2)(Davidovits, 1994; van Jaarsveld et al., 1997):

Geopolymers include three classifications of inorganic polymers which depend on the ratio of Si/Al in their structures:

a) Poly (sialite) (-Si-O-AL-O-)

b) Poly (sialate-siloxo) (-Si-O-Al-O-Si-O-)

c) Poly (sialate-disiloxo) (-Si-O-Al-O-Si-O-Si-O-)

Source Materials and Alkaline Liquids

There are two main constituents of geopolymers, namely the source materials and the alkaline liquids. The source materials for geopolymers based on alumino-silicate should be rich in silicon (Si) and aluminum (Al). These could be natural minerals such as kaolinite, clays, micas, and alousite, spinel, etc whose empirical formula contains Si, Al, and oxygen (O) (Davidovits, 1988c). Alternatively, by-product materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc could be used as source materials. The choice of the source materials for making geopolymers depends on factors such as availability, cost, and type of application and specific demand of the end users. The alkaline liquids are from soluble alkali metals that are usually Sodium or Potassium based. Since 1972, Davidovits (1988c; 1988d) worked with kaolinite source material with alkalis (NaOH, KOH) to produce geopolymers. The technology for making the geopolmers has been disclosed in various patents issued on the applications of the so called" SILIFACE-Process" Later, Davidovits (1999) also introduced a pure calcined kaolinite called KANDOXI (KAolinite, Nacrite, Dickite Oxide) which is calcined for 6 hours at 750oC. This calcined kaolinite like other calcined materials performed better in making geopolymers compared to the natural ones.

Xu and Van Deventer (1999; 2000) have also studied a wide range of aluminosilicate minerals to make geopolymers. Their study involved sixteen natural Si-Al minerals which covered the ring, chain, sheet, and framework crystal structure groups, as well as the garnet, mica, clay, feldspar, sodalite and zeolite mineral groups. It was found that a wide range of natural alumino-silicate minerals provided potential sources for synthesis of geopolymers. For alkaline solutions, they used sodium or potassium hydroxide. The test results have shown that potassium hydroxide (KOH) gave better results in terms of the compressive strength and the extent of dissolution.

Among the waste or by-product materials, fly ash and slag are the most potential source of geopolymers. Several studies have been reported related to the use of these source materials. Cheng and Chiu (2003) reported the study of making fire-resistant geopolymer using granulated blast furnace slag combined with metakaolinite. The combination of potassium hydroxide and sodium silicate was used as alkaline liquids. Van Jaarsveld et. al., (1997; 1999) identified the potential use of waste materials such as fly ash, contaminated soil, mine tailings and building waste to immobilize toxic metals. Palomo et. al., (1999) reported the study of fly ash-based geopolymers. They used combinations of sodium hydroxide with sodium silicate and potassium hydroxide with potassium silicate as alkaline liquids. It was found that the type of alkaline liquid is a significant factor affecting the mechanical strength, and that the combination of sodium silicate and sodium hydroxide gave the highest compressive strength. Van Jaarsveld et. al. (2003) reported that the particle size, calcium content, alkali metal content, amorphous content, and morphology and origin of the fly ash affected the properties of geopolymers. It was also revealed that the calcium content in fly ash played a significant role in strength development and final compressive strength as the higher the calcium content resulted in faster strength development and higher compressive strength. However, in order to obtain the optimal binding properties of the material, fly ash as a source material should have low calcium content and other Characteristics such as unburned material lower than 5%, Fe_2O_3 content not higher than 10%, 40-50% of reactive silica content, 80-90% particles with size lower than 45 m and high content of vitreous phase (Fernández-Jiménez & Palomo, 2003). Gourley (2003) also stated that the presence of calcium in fly ash in significant quantities could interfere with the polymerization setting rate and alters the microstructure. Therefore, it appears that the use of Low Calcium (ASTM Class F) fly ash is more preferable than High Calcium (ASTM Class C) fly ash as a source material to make geopolymers..Swanepoel and Strydom (2002), Phair and Van Deventer (2001; 2002), VanJaarsveld (2002a; 2002b) and Bakharev (2005a; 2005b; 2005c) also presented studies on fly ash as the source material to make geopolymers. Davidovits (2005) reported results of his preliminary study on fly ash-based geopolymer as a part of a EU sponsored project entitled 'Understanding and mastering coal fired ashes geo polymerisation process in order turn potential into profit' , known under the acronym of GEOASH.

Every source material has advantages and disadvantages. For example, metokaolin as a source material has high dissolvability in the reactant solution, produces a controlled Si/Al ratio in the geopolymer, and is white in colour (Gourley, 2003).However; metakaolin is expensive to produce in large volumes because it has to be calcined at temperatures around 500oC – 700oC for few hours. In this respect using waste materials such as fly ash are economically advantageous.

3. MATERIAL AND METHODOLOGY

3.1 Ordinary Portland Cement

Cement used in the experimental work is Ordinary Portland Cement (OPC) of 53grade (ZUARI brand) conforming to IS: 12269-1987.

3.2 Coarse aggregate

The coarse aggregate is obtained from a local quarry. The coarse aggregate with size less than 20mm and greater than 12.5 mm having a specific gravity 2.76 and fineness modulus of 7.36 is used in the present study. The rodded and loose bulk density values obtained are 1605 kg/m3 and 1477 kg/m3 respectively and the water absorption is 0.41%.

3.3 Fly-Ash

Fly ash, also known as flue-ash, is one of the residues generated in combustion, and comprises the fine particles that rise with the flue gases. Ash which does not rise is termed bottom ash. In an industrial context, fly ash usually refers to ash produced during combustion of coal. Fly ash is generally captured by electrostatic precipitators or other particle filtration equipment before the flue gases reach the chimneys of coal-fired power plants and together with bottom ash removed from the bottom of the furnace is in this case jointly known as coal ash. Depending upon the source and makeup of the coal being burned, the components of fly ash vary considerably, but all fly ash includes substantial amounts of silicon dioxide (SiO_2) (both amorphous and crystalline) and calcium oxide (CaO), both being endemic ingredients in many coal-bearing rock strata.

In the past, fly ash was generally released into the atmosphere, but pollution control equipment mandated in recent decades now requires that it be captured prior to release. In the US, fly ash is generally stored at coal power plants or placed in landfills. About 43% is recycled, often used as a pozzolan to produce hydraulic cement or hydraulic plaster or a partial replacement for Portland cement in concrete production.

Fig-1: Fly-Ash

3.4 *Ground Granulated Blast Furnace Slag:*

Ground Granulated Blast furnace slag (GGBS) is a by-product for manufacture of pig iron and obtained through rapid cooling by water or quenching molten slag. Here the molten slag is produced which is instantaneously tapped and quenched by water. This rapid quenching of molten slag facilitates formation of "Granulated slag". Ground Granulated Blast furnace Slag (GGBS) is processed from Granulated slag. If slag is properly processed then it develops hydraulic property and it can be effectively used as a pozzolanic material. However, if slag is slowly air cooled then it is hydraulically inert and such crystallized slag cannot be used as pozzolanic material. Though the use of Ground Granulated Blast furnace slag (GGBS) in the form of Portland slag cement is not a common in India, experience of using Ground Granulated Blast furnace slag (GGBS) as partial replacement of cement in concrete in India is very less quantity. Ground Granulated Blast furnace slag (GGBS) essentially consists of silicates and alumina silicates of calcium and other bases that is developed in a molten condition simultaneously with iron in a blast furnace. The chemical compositions of oxides in ground granulated blast furnace slag (GGBS) are similar to that of Portland cement but the proportions may vary.

The four major factors, which influence the hydraulic activity of slag, are as follows.

- Glass content
- Chemical composition
- Mineralogical composition
- Fineness.

The glass content of Ground Granulated Blast furnace slag (GGBS) affects the hydraulic property, chemical composition determines the alkalinity of the slag and the structure of glass. The compressive strength of concrete varies with the fineness of Ground Granulated Blast furnace slag.

Ground granulated blast furnace slag now a days mostly used in India. Recently for marine out fall work at Bandra, Mumbai. It has used to replace cement up to 70%. So it has become more popular now a days in India also.

3.5 METHODOLOGY

The primary difference between geopolymer concrete and Portland cement concrete is the binder. The silicon and aluminum oxides in the low-calcium fly ash reacts with the alkaline liquid to form the geopolymer paste that binds the loose coarse aggregates, fine aggregates, and other un-reacted materials together to form the geopolymer concrete.

As in the case of Portland cement concrete, the coarse and fine aggregates occupy about 75 to 80% of the mass of geopolymer concrete. This component of geopolymer concrete mixtures can be designed using the tools currently available for Portland cement concrete.

Mix design of geopolymer concrete is calculated from the density of geopolymer concrete. Generally, in the design of geopolymer concrete mix, coarse and fine aggregates have been taken as 75% of entire mix by mass. This value is similar to that used in OPC concrete in which they have been in the range of 75% to 80% of the concrete mix by mass. Fine aggregate has been taken as 30% of the total aggregate. The average density of geopolymer concrete has been considered similar to that of OPC concrete of 2400 kg/m3 based on literature survey. The combined mass of fly ash and alkaline liquid arrived from the density of geopolymer concrete. From the combined mass, using ratio of fly ash to alkaline liquid the amount of fly ash e and alkaline solution is determined. By taking the ratio of sodium silicate solution to sodium hydroxide solution, find out the mass of sodium silicate solution and sodium hydroxide solution is calculated by above procedure and issued for mix design.

Step-1: Making the Parameters Constant in Mix Design

Density of concrete 2400Kg/m3

Alkaline liquid to fly ash ratio =0.35

Sodium Silicate to Sodium Hydroxide ratio =2.5

Molarity= 8 M

Rest Period = 1day

Admixture Dosage = 3 %

Step 2. Calculation of Aggregates

Assume mass of coarse aggregate [0.75- 0.8]

Consider = 0.77

= 2400 * 0.77

= 1848 Kg/m3 (Aggregates = Coarse + Fine Aggregates)

Step 3. Calculation of fly ash And Alkaline Liquid Content

= 2400 – 1848

= 552 Kg/m3

Step 4. Calculation of values

Mass of fly ash = 552/(1+0.35) = 408.88 Kg/m3 mass of alkaline liquid = 552 – 408.88 = 143.11 Kg/m3

Step 5. Calculation of values of alkaline liquid

Mass of NaOH = 143.11/(1+2.5) = 40.8 Kg/m3

Sodium Hydroxide pillets wt for 8 Molarity is 26.2% of

Sodium hydroxide solution i.e; 26.2/100X41= 10.74 kg/cum

And water in this solution is 41-10.74=30.26 kg /cum

Mass of Na2SiO3 = 143.11- 40.8 = 102.22 Kg/m3

Water to Fly Ash Ratio as =0.33

Water to geo polymer solids Ratio as =0.30

Commercial Available super plasticizer is adopted as 1.5% of Fly ash by wt

Step 6. Calculation of mass of aggregates:

F.A = 35% of 1848

= 0.35 * 1848

= 646.80 Kg/m3

C.A = 65 % of 1848

= 0.65 * 1848

= 1201 Kg/m3

Table-2: Mix Proportions of GPC

	Fly ash	F.A	C.A	Water	NaOH	Na_2SiO_3	Super plasticizer
Ratio	1	1.36	3.16	0.04	0.1	0.25	0.03

4. RESULTS AND DISCUSSION

Table-3: Workability Values Of Green Concrete (Geo Polymer Concrete) Mixes

S.No	Percentage of Metakaoline in Fly ash	Slump in mm
1	0%	40
2	2.5%	42
3	5%	45
4	7.5%	45
5	10%	45

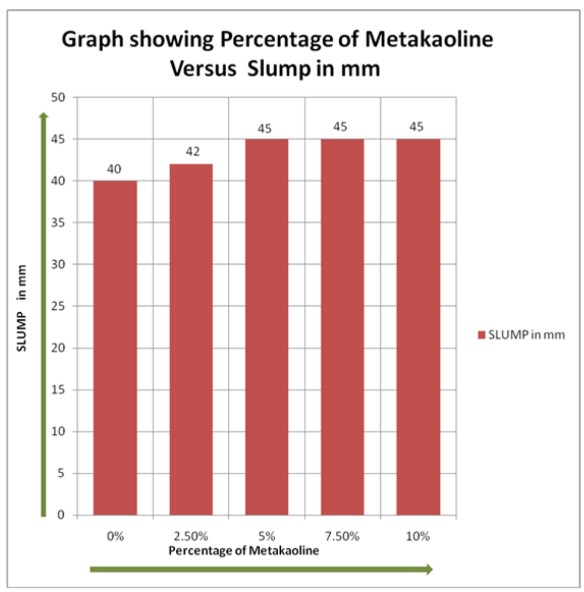

Fig.2: Slump of Geopolymer Concrete with Metakoline

4.1 Compressive Strength:

Table-4: Compressive Strength with variation of Metakaoline percentage

S.No	Percentage of Metakaolin in Fly ash	Compressive Strength N/mm²
1	0%	17.6
2	2.5%	19.8
3	5%	22.6
4	7.5%	19.2
5	10%	18.7

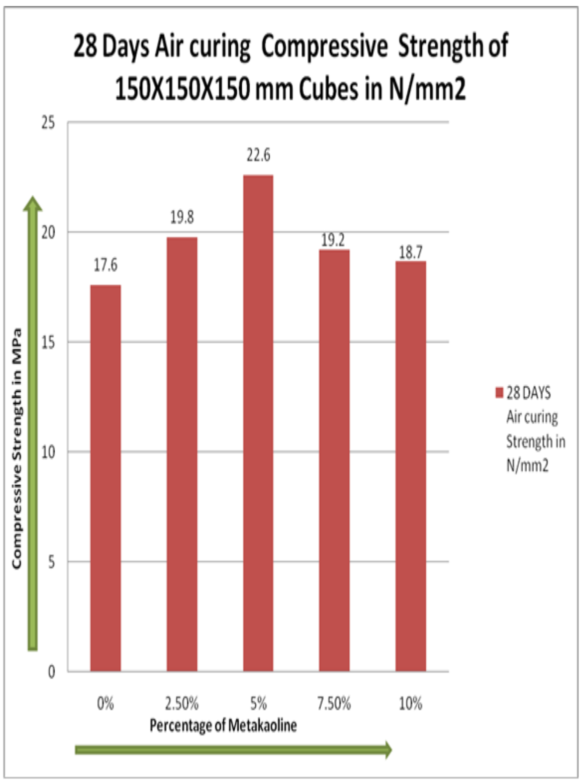

Fig.3: Compressive Strength of Geopolymer Concrete with Metakoline

4.2 Split Tensile Strength:

Table-4: Split tensile Strength with Metakaoline

S.No	Percentage of Metakaoline in Fly ash	Split tensile Strength N/Sqmm
1	0%	3.72
2	2.5%	4.18
3	5%	4.68
4	7.5%	4.07
5	10%	3.94

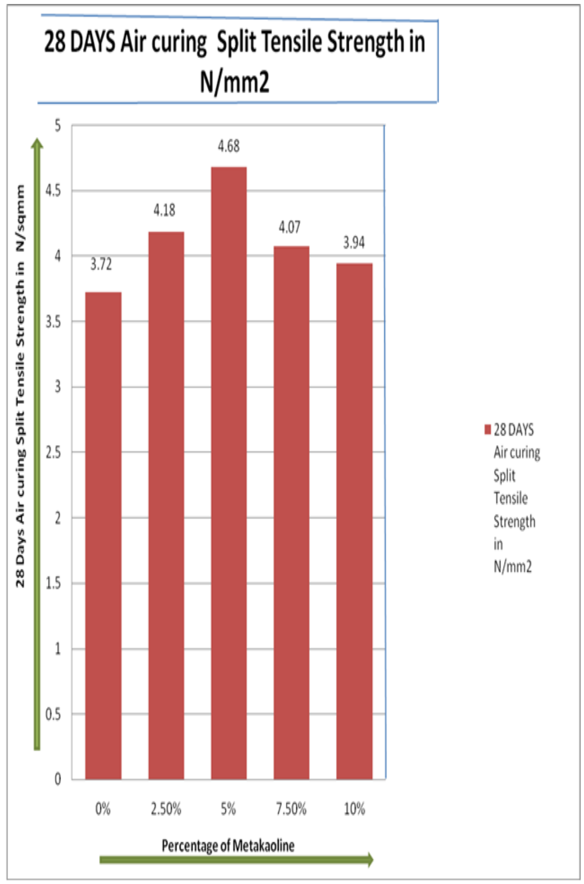

Fig.4: Split Tensile Strength of Geopolymer Concrete with Metakoline

4.3 Flexural Strength:

Table-5: Flexural Strength with variation of Metakaoline percentage

S.No	Percentage of Metakaoline in Fly ash	Flexural Strength N/Sqmm
1	0%	3.0
2	2.5%	3.2
3	5%	3.36
4	7.5%	3.25
5	10%	3.2

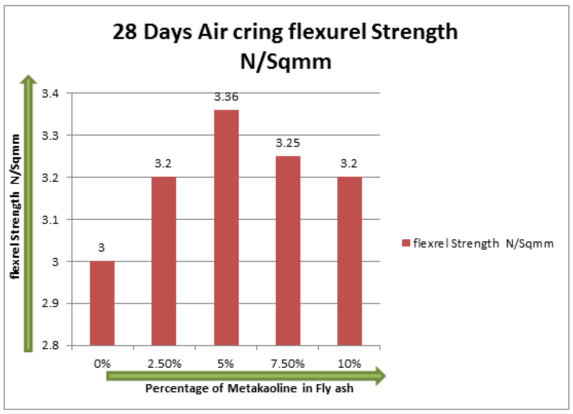

Fig.5:Flexural Strength of Geopolymer Concrete with Metakoline

5. CONCLUSION

Based on the results obtained from this study, the following Conclusions seems to be valid.

- The increase in percentage replacement of Fly Ash with Metakaoline from 0% to 10.00% causes increase in Slump value up to 5% and beyond that slump is decreased.. This shows workability is reducing as percentage of Metakaoline increased beyond 5%. Hence, 5% replacement of Fly ash with Metakaoline is suitable from workability point of view.
- The increase in percentage replacement of Fly ash with Metakaoline from 0% to 5% causes increase in compressive strength of concrete from 17.6MPa to 22.6MPa. Further increase in percentage replacement of Fly ash with Metakaoline from 5% to 10% causes decrease in the compressive strength from 22.6MPa to 18.7MPa. Hence, 5.00% replacement of Fly Ash with Metakaoline is advisable from compressive strength point of view.
- The increase in percentage replacement of Fly ash with Metakaoline from 0% to 5% causes increase in Split Tensile strength of concrete from 3.72MPa to 4.68MPa. Further increase in percentage replacement of Fly ash with Metakaoline from 5% to 10% causes decrease in the split Tensile strength from 4.68MPa to 3.94MPa. Hence, 5.00% replacement of Fly Ash with Metakaoline is advisable from Split Tensile strength point of view.
- The increase in percentage replacement of Fly ash with Metakaoline from 0% to 5% causes increase in flexural Strength of concrete from 3.0MPa to 3.36 MPa. Further increase in percentage replacement of Fly ash with Metakaoline from 5% to 10% causes decrease in the flexural Strength from 3.36MPa to 3.2MPa. Hence, 5.00% replacement of Fly Ash with Metakaoline is advisable from flexural strength point of view.
- Finally, it can conclude Keeping in view of the workability and compressive strength Split Tensile Strength and flexural Strength in mind, 5% replacement of Fly ash with Metakaoline is recommended for use in GEO POLYMER CONCRETE.

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