

# “Cost Optimization of Geopolymer Concrete Pavement”

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**Abstract**— In this study, fly ash based geopolymer concrete was prepared using different Cement content (from 0% to 10%) and GGBS content (from 5% to 20%) at same molarity and also at varying molarity of alkaline solution i.e. 3M and 4M in order to evaluate the efficiency of geopolymer concrete. Geopolymer solution was prepared by mixing NaOH and Na<sub>2</sub>SiO<sub>3</sub> in a fixed ratio with water according to the molarity of the solution.

The research encompassed the assessment of compressive strength and flexural strength through.

- (1) Deviation in maturity of alkaline solution
- (2) Deviation in molarity of alkaline solution
- (3) Deviation in percentage of Cement and GGBS. Durability tests like abrasion test and RCPT test were also conducted on geopolymer concrete specimen. The liquid to binder ratio was fixed at .4. However if this ratio was changed in some mix proportions it was noted down in the remarks section.

Test results indicated an increase in compressive as well as flexural strength when mature alkaline solution was used. Higher molarity solution imparted more compressive and flexural strength. However increasing the molarity of alkaline solution leads to an increase in the overall cost of production of geopolymer concrete. It was also found out that compressive and flexural strength decrease with an increase in the cement content. An increase in GGBS content resulted in enhanced compressive and flexural strength. Graphs illustrating these trends are also presented in this thesis document.

After finalizing mix proportions, cost optimization of geopolymer concrete was conducted. The cost per cubic meter of geopolymer concrete was determined to be Rs. 4317, which is comparable to that of conventional concrete at Rs. 4233. The density of geopolymer concrete falls within the range of 2200.

**Keywords**— Geopolymer, Concrete, Compressive strength, Flexural strength, Cost Optimization, Molarity and alkaline solution

## I. INTRODUCTION

We live in a world that is developing very fast. Human, in the search of his basic needs, i.e. food, clothes and shelter has undergone several social, economic and psychological changes which in modern days gave rise to two important global phenomena known as urbanisation and industrialisation. Urbanisation and industrialization are having an impact on this world from the nineteenth century and this process is still going on. One of the major impact of this phenomenon is the conversion of Earth's land cover from natural form to an artificial one. There

is an increase in the built up area due to urbanisation and hence there has always been a need to develop new building materials. The two main aspects of these building materials are strength and durability. As for the proper development of built up areas safety of the residents and life of the structure is important. This lead to the development of the most iconic construction material commonly known as concrete and is being used for most of the construction works. Concrete is so extensively used in modern day world that it is the most widely used man made construction material in the world and is the second most utilized substance in the world only behind water. The concrete consists of coarse aggregates, fine aggregates, cement, plasticizer and water. Concrete is preferred widely due to the ease of availability of its constituents. The only artificial things are cement and admixture. Cement can be easily produced at a minimal cost. India ranks second among the cement producing nations after China with a production of 290 million metric tons in 2018. However the major drawback of cement production is the production of anthropogenic carbon dioxide. Statistically, nearly 8% of the anthropogenic carbon dioxide is produced from the cement kilns.

In India, fly ash has been widely used as an alternative binding material alongside Portland cement for several years. According to estimates, approximately 196.44 million tonnes of fly ash were produced in the country in 2018. The large volume of fly ash posed a significant challenge for sustainability engineers, making its management difficult. However, utilizing fly ash as a supplementary cementitious material in concrete production has not only helped address this issue but has also led to the development of an economical and eco-friendly construction technology, which is now widely adopted in India. Additionally, the depletion of natural resources such as river sand is a growing concern, necessitating the search for viable alternatives. One such solution is geopolymer concrete. As part of this project, cube and beam trials were conducted to assess two critical properties of concrete—compressive strength and flexural strength. Furthermore, mix designs were modified to optimize costs, ensuring the research could be practically implemented in real-world construction practices.

## II. LITRATURE REVIEW

Polymers consists of a large number of small repeating units in order to form a larger molecule. The repeating units can be same or different. This repeating unit in a polymer is called as monomer. The properties of polymer mainly depends upon the properties of this repeating unit. Geopolymer belongs to the family of inorganic polymers. It consists of chain structures whose main components are Al and Si ions. If we check the chemical composition of the geopolymer material, it resembles to that of the natural zeolites.

But on the microscopic level they are amorphous in nature instead of the crystalline structure (Palomo, Grutzeck 1999, Xu & Van Deventer 2000)  $Mn[-(SiO_2)_z-AlO_2]_n \cdot nH_2O$  Here, M is the alkaline element or cation such as sodium, potassium; the symbol - indicates the presence of a bond, n is the degree of polymerisation; z can be 1,2,3 upto 32. The formation of geopolymer can be easily understood in the equations shown below. It clearly indicates that the materials which contains Silica (Si) and Alumina (Al) can be used for the formation of geopolymer. Literature Review 9 Up till now there isn't a clear of reaction kinetics of the geopolymer material i.e regarding the setting of geopolymer material. However some theories have suggested mechanisms for the same. Out of which the most accepted theory is given below (Davidovits 1999, Xu & van Deventer 2000):

The first step involves action of (OH) ions on Si and Al atoms which leads to their dissolution.

- The second step involves condensation or orientation or transportation of precursor ions into monomers.

- The third step involves polymerization i.e. conversion of monomeric unit to a polymeric unit. However all the three steps can overlap with each other and can occur simultaneously. So it is a very tedious to separate and study any one of the following three steps (Palomo, Grutzeck et al 1999). According to (Davidovits 1999) geopolymer material can have one of the three forms as shown below,

- Poly(sialate), having  $[-Si-O-Al-O-]$  as the repeating unit.

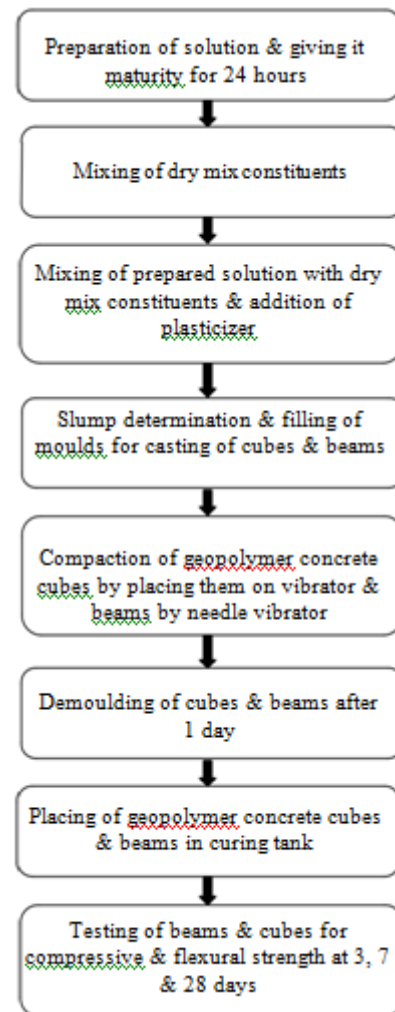
- Poly(sialate-siloxo), having  $[-Si-O-Al-O-Si-O-]$  as a repeating unit.

- Poly(sialate-disiloxo), having  $[-Si-O-Al-O-Si-O-Si-O-]$  as a repeating unit.

Here Sialate means silicon-oxo-aluminate Source Materials Materials that contains a major amount of Silica (Si) and Alumina (Al) can be efficiently used as a source materials for the manufacturing of geopolymer concrete. Investigations were carried out in the past with the different combination of materials in order to manufacture geopolymer concrete. Calcined kaolin commonly called as Metakaolin (Davidovits 1999, Mackenzie, 2000), Class F (Grutzeck & Palomo, 1999), Metakaolin combined with fly ash (Strydom & Swapnepoel, 2002) and GGBS combined with fly ash were experimented as source materials in the past. Fly ash having low calcium content i.e ASTM Class F is given a priority over fly ash having high calcium content i.e. ASTM Class C. Studies show that if calcium is present in large amounts then it interferes with the geopolymerisation process and changes the microstructure (Gourley, 2003). Therefore fly ash having low calcium content i.e. class F was used in the project for the experimentation purpose. As discussed earlier the materials having Al and Si content can be used for manufacturing geopolymer concrete. However one can't predict the suitability to act as a good source material because of the complex reaction kinematics involved in the geopolymerisation process (Xu & Van Deventer 2000). Out of all the materials available only fly ash and GGBS have given positive results to act as good source materials. Due to smaller particle size fly ash is reactive in comparison to GGBS. However their combination gives good results as compared with using fly ash alone. Fly ash having different chemical proportion is available around the globe. Experimentation suggests the most suitable chemical

proportion of fly ash to be used for geopolymerisation (Fernandez & Palomo, 2003). According to them fly ash having low calcium, percentage of unburnt material less than 5%, iron oxide less than 10%, reactive silica in the range of 40% to 50% and 80% to 90% particles having size less than 45  $\mu m$  will give the most appropriate results.

### Process Flowchart



### III. CONCLUSIONS

The prime focus of this study was the development of geopolymer concrete, which is industry-friendly, environment-friendly, offering required properties at minimum material cost, employing a simple method for its preparation and that can be used for the construction of pavements.

In order to achieve this geopolymer concrete specimens were casted using a number of dry materials which are mentioned earlier in this thesis document. After studying the various combinations it was decided to fix the dry constituents as cement, fly ash, GGBS, 10mm aggregates and 20 mm aggregates. After fixing of the dry constituents geopolymer concrete specimens were casted at different cement and GGBS content such as 0% cement and 15% GGBS, 0% cement and 20% GGBS, 5% cement and 15% GGBS and 10% cement and 10% GGBS. Molarity of the alkaline solution was varied keeping the mix proportions

same i.e 3M and 4M. These geopolymer concrete specimens were then tested for workability, compressive strength, flexural strength, abrasion and RCPT test. The variations in compressive and flexural strength with different cement and GGBS content along with changing molarity of alkaline solution were observed and plotted. The effect of maturity to alkaline solution was also observed and plotted.

Based on the observations made in the experimental investigation, the following conclusions could be drawn:

The published literature review has suggested to give 1 day maturity to the prepared alkaline solution. However if geopolymer concrete is to be used in real life projects then it will be a time consuming process. So effects of giving maturity to alkaline solution were studied. The compressive and flexural strength were compared for the same mix proportions with alkaline solution having no maturity, 3 hours maturity and 24 hours maturity. It was observed that there was increase in compressive as well as flexural strength with the maturity of alkaline solution. The 28 days compressive strength values at no maturity, 3 hour maturity and 1 day maturity were 38.6 N/mm<sup>2</sup>, 41.4 N/mm<sup>2</sup> and 45.87 N/mm<sup>2</sup> while that of flexural strength were 4.95 N/mm<sup>2</sup>, 5.07 N/mm<sup>2</sup> and 5.57 N/mm<sup>2</sup> respectively.

With the increase in percentage of cement there was a decrease in the compressive and flexural strength while increase in percentage of GGBS imparted more compressive and flexural strength. It was inferred that the cement interferes with the geopolymerisation process. When the cement content was increased to 10%, 28 days compressive strength was found to be 33.5

N/mm<sup>2</sup>. On the other hand when the GGBS content was increased to 20%, 28 days compressive strength increased to 54.8 N/mm<sup>2</sup>. Similarly in case of 10% cement, 28 days flexural strength was found to be 5.24 N/mm<sup>2</sup>. On the other hand when the GGBS content was increased to 20%, 28 days flexural strength increased to 5.74 N/mm<sup>2</sup>. So it is always preferred to use 0% cement in geopolymer concrete and efforts should be made to increase the pozzolonic material like GGBS in geopolymer concrete.

By experimental investigation it was found that with increase in molarity of alkaline solution i.e. increase in concentration of NaOH and Na<sub>2</sub>SiO<sub>3</sub> in water to make alkaline solution resulted in increased compressive and flexural strength. For the same mix proportions 28 days compressive strength was found to be 43.7 N/mm<sup>2</sup> for a 3M alkaline solution. However in case of 4M alkaline solution the compressive strength increased to 54.8 N/mm<sup>2</sup>. Similarly the 28 days flexural strength increased from 5.2 N/mm<sup>2</sup> in case of 3M alkaline solution to 5.74 N/mm<sup>2</sup> when 4M alkaline solution was used. However increasing the molarity of alkaline solution results in higher cost per cubic meter of geopolymer concrete. So the mix proportions should be designed in such a way that lesser molarity gives the adequate results. When RCPT test was conducted on geopolymer concrete specimen the total charge passed was 135 coulombs. So geopolymer concrete has very low

chloride permeability. Hence it can be used to construct durable structures in corrosive environments like marine regions where chloride ingress can result in corrosion of reinforcement bars.

Geopolymer concrete can maintain the required level of workability by adjusting the dosage of superplasticizers. The source of sodium silicate was changed during the duration of the project. The new silicate was imported from Chennai and it was observed that the source of material plays an important role in designing mix proportions for geopolymer concrete.

The density of geopolymer concrete falls in the range of 2200 to 2300 kg/m<sup>3</sup> which is less than that of the conventional concrete available in the market.

The cost per cubic meter of geopolymer concrete was optimized and it came out to be Rs 4317 which is comparable to that of the conventional M-40 Concrete that is Rs 4233.

After completion of the project it was concluded that geopolymer concrete has adequate compressive and flexural strength. Apart from this the cost per cubic meter of geopolymer concrete is comparable to that of the conventional concrete. So it can be used for the construction of the pavement. Moreover geopolymer concrete utilizes waste materials such as fly ash, GGBS and can be produced without the use of cement. Hence it can play an important role in reducing the CO<sub>2</sub> emission that takes place during the production of cement and reduce the global warming. It does not require natural sand for its production. Hence it is a sustainable construction material and has a great significance in today's era. The day is not far when it will successfully replace the conventional OPC concrete.

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