Nile Higher Institute
fo Engineering and Technology

Department of Civil Engineering

"Properties and Strength of Materials Project"

Effect of Sodium Hydroxide molarity on Performance Of Fly Ash Geopolymer Concrete.

Supervised by:

Assoc. Prof. Dr. Hany Ibrahim Ahmed Awad

"Professor at Civil Department, Nile Higher Institute for Engineering

Presented by :

Name	Code
Mahmoud moawad Ibrahim salah.	180124
mohamed hossam younes mohamed	180187
Omar mohamad elbakry ahmed	180185
Ahmed khaled ibrahim eldesouqy	180018
Ahmed Mohamed Al-Basioni Al-Shkibiy	180206
Ahmed Elshahat mohamed Mustafa	180175
Ahmed Ibrahim abd-elfattah dawood	180212
Amr osama Mohamed	180188

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Abstract

This paper presents the results of an experimental program that was tested to examine the geopolymer (GP) mortar mixtures subjected to elevated temperatures. The main parameters investigated were the molarity levels of NaOH (8 M, 10 M, and 12 M), the ratios of sodium silicate to NaOH solution (1), the ratio of alkali liquid to fly ash (0.45), centralization temperatures (70 °C), and rest 9 hours), a high temperature mortar of 70°C was worked for 9 hours.

This project comply with Egyptian code ECP: 203 (2020), Egyptian standard specification ES requirements (4756-1/2005) (Appendix A). The results showed that the mechanical properties of geopolymer concrete improved by increasing the molarity ratio of the activator solution. By adding the fresh properties of concrete improved by increasing the dose of sodium hydroxide.

Chapter 1: Introduction to Geopolymer Concrete .

1.1 Project Definition

Considering the high consumption of concrete and the increasing necessity for cement production, high attention to the environmental degradation effects of this substance is needed geopolymer concrete. These effects include 7% of CO2 emission and the considerable consumption of energy such as electricity and fossil fuels. Hence the provision of alternative products in order to move towards sustainable development is essential. Therefore, the use of an eco-friendly concrete enables the reduction of consumption of ordinary Portland cement (OPC) with activated pozzolanic binders as a replacement, leading to lower emission of CO2 in the atmosphere.

Geopolymers are in the family of mineral polymers, in which their chemical combinations are similar to zeolite materials, whereas their microscopic structure is amorphous rather than crystalline. The use of polymers such as concrete adhesives result in the production of geopolymer concrete (GPC) that can be a suitable substitute for OPC.

1.2 Definition of concrete:

Geopolymer concrete is a type of concrete that is made by reacting aluminate and silicate bearing materials with a caustic activator, such as fly ash or slag from iron and metal production. It can be a suitable substitute for ordinary Portland cement .

1.3 Types of concrete:

1.Geopolymer concrete: is an innovative and eco-friendly construction material and an alternative to Portland cement concrete. Use of geopolymer reduces the demand of Portland cement which is responsible for high CO_2 emission.

2. Cement concrete: It is a mixture of cement, fine aggregates, coarse aggregates and water in a definite proportion.

3. Lime concrete: Here binding material is lime (CaO)

4. RCC: Steel reinforcing is done in the CementConcrete.

5. Prestressed cement concrete:This concrete is a form of concrete used in construction which is "pre-stressed" by being placed under compression prior to supporting any loads beyond its own dead weight. This compression is produced by

the tensioning of high-strength "tendons" located within or adjacent to the concrete volume, and is done to improve the performance of the concrete in service.

1.4 Uses of concrete:

Polymers are used in construction projects where there is a need to resist types of corrosion and are supported to be durable i.e. long lasting. It can be used similarly to regular concrete. Polymeric is used in the following works:

- Repair data damaged by corrosion.
- Prestressed concrete.
- Nuclear power plants.
- Electrical or industrial constructions.
- marine business.
- Prefabricated structural components such as acid tanks, manhole, table, highway barriers, etc.
- Waterproofing of structures.
- Sewage works and desalination plants.

Polymeric concrete is also used in electrolytic cells to recover base metals. It is particularly suitable for the construction and repair of manholes because of its ability to resist toxic and corrosive sewage gases and bacteria, which are commonly found in sewage systems.

Unlike traditional concrete structures, PVC pipes do not need any coating and welding, because the polymeric concrete itself acts as a welding material.

1.5 Benefits of concrete:

There are numerous positive aspects of concrete:

1. It is a relatively cheap material and has a relatively long life with few. maintenance requirements .

2. It is strong in compression.

3. Before it hardens it is a very pliable substance that can easily be shaped.

4. It is non-combustible.

1.6 Limitations of concrete:

The large-scale production and real-world application; Thermal treatment required for curing (typically > 70 ◦C for 24 H); Economic feasibility, Particularly, alkali activators are responsible for the majority of the cost (≈80%), and cheaper alternatives are encouraged; The activators are highly alkali and corrosive, and it can be a drawback in replacing the OPC which is less likely to cause workplace hazards; Lack of control over the rheology and setting; Material selection, conventional geopolymer concrete can be made from an overwhelming range of precursors and activators, and therefore, the selection of the best raw materials should be the first step, and it requires expertise.

1.7 Main Objectives of geoploymer concrete:

1- to identify the mechanical properties of fly ash geopolymern concrete.
2- to study the effect of activator solution of fly ash geopolymer concrete.
3- To study the effect of change in molarities of NaOH on strength of cement concrete.
4- To study the effect of curing temperature & curing period on geoploymer concrete.
5- To determine strength & workability by adding Admixtures in it.
6- To compare properties with conventional concrete.
7- Conserve land ,used for disposal of coal combustion products.
8- Durable infrastructures with design life of hundred of years (resistance against chemical attack).
9- Alternative to OPC concrete.

Chapter 2: Literature Review :

2.1 Introduction

Geopolymer concrete is an innovative and environmentally friendly building material and alternative to Portland cement concrete. The use of geopolymer reduces the demand for Portland cement, which is responsible for high carbon dioxide emissions. Geopolymer is the name that engineer Daidovits gave in 1978 to materials that are characterized by chains, networks, or inorganic molecules. Geopolymer cement concrete is made from the use of waste materials such as fly ash and granulated blast furnace slag.

Several geopolymer concrete mixtures have been prepared and tested for the strength properties of concrete and concrete durability and compared with the control mixture of ordinary Portland cement. Based on the mechanical properties of the different admixtures, an optimal geopolymer concrete mix was determined. The control and geopolymer mixture optimized for microstructural properties were studied by scanning electron microscopy.

2.2 Report items :

1- Properties of Portland Cement Concrete with Geopolymer Materials as Partial or Entire Replacement.

2- Geopolymers as Construction Materials

3- Composition of geopolymer concrete.

4- Mechanical properties of geopolymer concrete.

5- Other properties of geopolymer concrete.

6- geopolymer concrete applications.

2.3 Properties of Portland Cement Concrete with Geopolymer Materials as Partial or Entire Replacement.

In experimental tests, the 28-day compressive strength is typically examined at the laboratory, however, considering the acquired results from geopolymer compressive strength, it seems that there is a slight increase over the period from 28 to 90 days; hence it is deeply suggested that the compressive strength would be measured for this type of concrete at age of 90 days as well. Despite the slight increment in the compressive strength of GPC observed at 28 days, most of its compressive strength was developed at seven days due to heat curing accelerating the geopolymerization reaction, resulting in the increase of compressive strength.

Direct comparison of GPM and PCM mixes prepared with the same paste amount and two different classes (normal of 37.5 MPa and high of 60 MPa) exhibited that workable GPC mixes could be provided by minimum water value compared to PC mixes. Thus, GPCs have much shorter initial and final setting times than those obtained by PC, which causes GPCs to obtain very rapid enhancement for compressive strength which is 55–66% of their entire strength at 28 days in comparison with PCs which achieved 18–28% over this time period

Fly ash class and superplasticizer type are the key factors in the improvement of workability for GPC. The type of activator, such as simple or multi-compound, has a notable role in the workability and the compressive strength of fly ash. The experimental test with multi-compound activator and the ratio of Na2SiO3/NaOH = 2.5 and has higher slump and compressive strength compared to fly ash activated by NaOH. With regard to the better performance of PC for FA class C (low silicate, high calcium), this phenomenon is probably due to the high dispersive capability that appeared in class C, which is strongly related to the presence of positively charged calcium cations leading to the stiffness reduction and fluidity enhancement in concrete mixes .

The specific reason that PC was the most effective SP in AAMs, especially where w/b is 0.4, could be due to the presence of several lateral chains on PC molecules causing steric repulsion improving the plasticizing effect of PC Besides the effect of N-based SP in workability, it can drastically decrease the alkaline activator to slage ratio resulting in notable improvements for compressive strength, provided that FA-based GPC is activated by only NaOH solution . This can be justified due to the fact that N-based SP is the unique type of SP which is chemically compatible with NaOH solution

According to the investigation by Mehta and Siddique .it is clear that the values of compressive strength at all ages were gradually increased due to OPC replacement by 20%, and exceeding that, this trend was reduced. Based on this study, the highest value of 66.81 MPa compressive strength was obtained for the specimens with 20% OPC at 365 days due to further reaction occurring between OPC and the use of alkaline solutions in this research. C-A-S-H and C-S-H were achieved as an additional hydrated product which has coexistence with N-A-S-H as additional phases .The extra heat increased the effective curing temperature for polymerization and further enhanced the formation of N-A-S-H because of the exothermic nature of the hydration reaction. The additional calcium also accelerated hardening and dissolution by preparing extra nucleation sites. On the other hand, the enhancement of OPC beyond 20% led to an increase in calcium content and consequently, a reduction of silica and alumina values, which was due to high calcium amount and low silica and alumina in OPC. On the contrary, in the chemical combination of fly ash, less calcium and high amount of silica and alumina are available. Thus, this led to the lack of sufficient alumina and silica in order to produce N-A-S-H polymerization in this concrete mix design. Also, higher calcium increased the water demand for hydration, which was released from water-filled pores resulting in extra void spaces. Therefore, it can be concluded that the optimal amount of OPC that would be effective for the high compressive strength of this type of concrete is 20% based on the findings achieved in this research.

Based on the study by Moon et al. it is known that the compressive strength is directly associated with porosity and water absorption. This means that an increase in compressive strength resulted in the reduction of porosity and water absorption up to 20% OPC, whereas there was a slight increase for the rate of water absorption and porosity while increasing the value of OPC by 30% in this attempt. Other obtained observations from the specimens at ages of 90 and 365 days are in accordance with the previous test (28 days). The main significant reason for this phenomenon is the fact that the addition of OPC co-existed with GPC products (N-A-S-H, C-A-S-H) due to the additional hydration products. This resulted in incremental concrete strength and the reduction of water absorption in a concurrent manner. As discussed above, there is a substantial increase in the compressive strength of concrete with the high amount of fly ash after seven days more than that of OPC due to pozzolanic reactions. The difference of approximately 10% can be seen in the mean values of compressive strength of fly ash.

Type V cement plays the main role in terms of the sulfate attack as it contains limited values of C3A (tricalcium aluminate) and C4AF participating in the process of chemical sulfate attack, however most companies are struggling to find a more comprehensive solution which resists against sulfate attack better than this type of cement. Some literature in recent years have proved that the use of fly ash, particularly low-calcium or class F, effectively enables an increase in concrete resistance against sulfate attacks . However, the improvement of concrete resistance to sulfate attack by the use of class C fly ash containing a high value of calcium is suspected as the materials with rich lime have the ability to produce their own calcium hydration independently. Therefore, the concrete containing fly ash with a high value of calcium is to be exposed against sulfate attack. It also can be realized that class F fly ash is quite effective on the permeability reduction of concrete, however, the optimum percentage of fly ash as the major factor should be considered to obtain more appropriate results

It was noted that a 50% cement replacement ratio has the highest value of mechanical properties such as compressive strength comparable to other concrete mixtures produced by the replacement ratio of 0%, 25%, 75%, and 100% . Furthermore, "Does this cement replacement have similar effects on other concrete mixtures produced from other Portland types (Portland type 2)?" is arguably an important question to be investigated, however other significant factors such as binder materials and activator solution ratio can be considered towards a more profound understanding of the chemical solution role in different concrete mixtures in the near future.

Workability is typically attributed to liquid-to-solid ratio in most concrete mixtures such as natural pozzolan-based alkali-activated concrete. In laboratory schedule by Ibrahim et al. very low slumps were measured for concrete mixtures composed of different binder content and alkaline material, which revealed a number of gaps and shortcoming in this case. Based on the outcomes of this research, it seems that the higher binder content is beneficial for the concrete mixtures containing the low ratio of water-to-solid compared to those with lower values of binder content and sufficient workability, which was achieved from the mixtures including high concrete binder in spite of the low ratio of water to solid.

Generally, the improvement of compressive strength in the concrete mixtures thoroughly consisted of pozzolanic additives (100% natural pozzolan) as the replacement of cement Portland is associated with the following factors:

- Binder content (fly ash quantity) -
- Sodium silicate-to-sodium hydroxide (SS/SH) ratio-
- Alkaline solution-to-binder ratio-

2.4 Geopolymers as Construction Materials :

Utilising geopolymer as a construction material has gained institutional and commercial interest over the past decade, due to its favourable emissions profile as an alternative to carbon-intensive Ordinary Portland Cement-based concrete, which currently accounts for around 7% of global carbon emissions.

Keywords: geopolymer concrete; commercialisation; material properties; economic factors; social attitudes; regulatory environment.

Industrial processes are one of the main sources of greenhouse gas (GHG) emissions, burning significant quantities of fossil fuels and producing huge amounts of mass in situ GHGs in their operations. The cement industry is a major source of GHGs, being responsible for 26% of industrial and 7% of global carbon emissions . Cement substitution in concrete with alternative materials is a promising approach to reduce carbon emissions produced by the cement and concrete industry. Various materials with pozzolanic property can replace cement in concrete, among them geopolymers, a material first coined by Davidovits.

The term geopolymer refers to the formation of a structural material made through the dissolution and polymerisation of source material high in reactive silica and alumina . These materials are commonly precipitated through highly alkaline activating solutions such as sodium/potassium hydroxides and silicates. When combined with aggregates, a structural material with properties similar to concrete can be manufactured, with added advantages over carbon emissions-intensive construction materials such as Ordinary Portland Cement (OPC) . That is because geopolymer binders can be produced exclusively of recycled waste materials such as fly ash, which is a by-product of coal-fired power plants with associated environmental and health hazards in several countries due to the large waste stockpiles deposited into landfill. Increasing the application of geopolymer, and specifically fly ash, could have significant environmental and societal benefits through a reduction in cement reliance and subsequent emissions savings, as geopolymer technology can produce 10–64% less GHG emissions when compared to OPC concrete of the same strength.

Geopolymerisation process for the fabrication of geopolymer cement/concrete. Different sources of siliceous and aluminous materials are used for the production of geopolymers, the most common including fly ash, metakaolin, silica fume, ground granulate blast slag, and other ashes such as volcanic and biomass ashes. Reprinted with permission from ref.

Australia is currently one of the international leaders in geopolymer innovation. Research in Australian universities and institutes focusing on the strength and durability properties of the material has been ongoing since the turn of the millennium through studies undertaken by Van Jaarsveld [13] and Van Deventer [14]. Furthermore, the market presence of companies producing geopolymer indicates that Australia continues to be a global innovator in this field . Nevertheless, despite the abundance of geopolymer research undertaken in Australia, there persists a significant underutilisation of fly ash, in particular, low-quality fly ash from sub-bituminous and brown coal, in the Australian market when compared to other developed and developing countries. This poses a significant environmental issue when coupled with Australia's rising demand for concrete , as increased consumption of concrete without supplementary or substitutional use of geopolymer will further increase the carbon footprint of Australia's construction industry .

The commercialisation of the product is the key approach to increasing the utilisation of geopolymer. Nevertheless, there are several challenges for the adoption of geopolymers in the construction industry such as (1) the material properties (i.e., strength and durability), (2) economic factors, (3) social attitudes to the relatively unknown technology, and (4) the regulatory environment. These factors are interconnected and can pose significant barriers to widespread adoption.

This article aims to provide a perspective of the current body of research in each of these four areas to identify the key gaps in research and to determine barriers against the commercialisation of geopolymer in Australia. Based on these analyses, effective and practical recommendations are proposed for future investigation avenues that may aid the industry adoption of geopolymer. Although focused on Australia due to the significant research initiative but yet low utilisation of fly ash and commercialisation of geopolymer concrete, this review is also applicable to other countries with low levels of fly ash utilisation or where low-quality fly ash is abundant, such as China, as well as many international markets where the substitution of OPC concrete with geopolymer could aid attainment of emissions reduction targets.

2.5 Composition of geopolymer concrete:

The following materials are required for the production of geopolymer concrete :

Alkaline Activator Solution: The catalytic liquid system is used as an alkaline activator solution. It is a mixture of alkali silicate solutions and hydroxides along with distilled water. The role of the alkaline activator solution is to activate geopolymer source materials containing silicon and aluminum such as fly ash and granulated blast furnace slag.

-Fly Ash: It is a by-product of thermal power plant.

-Granulated blast furnace slag: a by-product of the iron plant.

-Aggregates: fine and coarse aggregates as required for normal concrete .

Geopolymer concrete - one of the new environmentally friendly materials. Almost all substances that are included in its composition are of natural origin.

Production technology without a twinge of conscience can be called innovative. And although this material was first used in ancient Egypt during the construction of the pyramids, now it has been possible to restore and improve production technology.

Buying it instead of the usual concrete, you can save. Low cost due to the characteristics of production technology. To prepare the right mixture, you need to be very careful with the selection of ingredients.

The special ingredient is fly ash. Ash itself has high physical and technological properties.Its use allows you to end up with such a material that is not only not inferior to Portland cement, but in some indicators surpasses it. So, lime concrete has strength comparable to granite. It is resistant to abrasion, high temperature, low permeability, and less shrinkage.

- Gain maximum strength quickly. Temporary indicators significantly exceed those of conventional concrete. Already on the second day it reaches sufficient strength. For a set of maximum strength, he needs only one week, not a month, as usual.
- It mainly consists of waste from economic activity, which has not been previously processed and not used. That is, there is already a decent raw material base for production.
- In manufacturing you get rid of waste that harms the environment.

- Simple production technology.
- Continuous improvement of the configuration in order to improve performance. In this case, for the most part, experiments are carried out with the ratio of components, and the initial composition remains almost unchanged.

Recent years have seen a great development in a novel family of building materials—geopolymer cement around the world. Geopolymer cement is a type of three-dimensional CaO-free aluminosilicate binder, which was developed by J. Davidovits in the late 1970s (Davidovits, 1988). Geopolymer cement can be synthesized by mixing calcined kaolin and strongly alkaline solutions (such as NaOH or KOH), then curing at room temperature. Under a strongly alkaline solution, calcined kaolin is rapidly dissolved to form free SiO4 and AlO4 tetrahedral units. With the development of reaction, water is gradually split out and the SiO4 and AlO4 tetrahedral units are linked alternatively to yield three types of geopolymer products: poly-sialate [–SiO4–AlO4–] (PS type), poly-sialate-siloxo [–SiO4–AlO4–SiO4–] (PSS type), or poly-sialate-disiloxo [–SiO4–AlO4–SiO4–SiO4–] (PSDS type) by sharing all oxygen atoms between two tetrahedral units (Davidovits, 1989). Compared to Portland cement, geopolymer requires less energy consumption, has less CO2 emission, high early strength, less shrinkage, low permeability, good fire and acid resistance and excellent durability (Davidovits, 1988, Davidovits, 1989, Davidovits et al., 1990, Duxson et al., 2007, Hongling et al., 2005, Nowak, 2008, Sofi et al., 2007, Van Jaarsveld and Van Deventer, 1999, Bakharev, 2005, Lyon et al., 1997) These merits make geopolymers promising potentials in the fields of civil, bridge, pavement, hydraulic, underground and militia engineering (Davidovits, 1994a).

Geopolymer cement is different from Portland cement. However, very little scientific literature is available on the subject until now, which seriously influence the commercial development and application of geopolymer cement. In this study, a three key parameters composition design method was proposed based on the chemical characteristics analysis of geopolymer cement. Taking Na-PSDS geopolymer cement as an example, a total of 9 geopolymer cement pastes were designated to investigate the influence of the three key ratios on mechanical properties and microstructure in accordance with orthogonal design. The compressive strength and microstructure of the hardened cement pastes were evaluated as a function of the three ratios. The influencing extent of each ratio on the compressive strength was quantitatively determined on basis of the gradation analysis. The microstructural changes as a function of ratios were also investigated by using Fourier transform infrared spectroscopy (FTIR) technique. Based on the macroscopic and microscopic experiments, almost fully reacted geopolymer cements with the highest strength and optimum microstructure could be obtained by properly adjusting the three mole ratios. Subsequently, the coordination status of two main construction elements (Al and Si), micrographics and chemical compositions of the fully reacted Na-PSDS geopolymer cement were examined by X-ray Diffraction Analysis (XRD), Environment Scanning Electron Microscope equipped with Energy Dispersion X-ray Analysis (ESEM-EDXA), highly sensitive Magic Angle Spinning-Nuclear Magnetic Resonance Spectroscopy (MAS-NMR) techniques.

2.6 Materials:

Kaolin from China Kaolin Clay Company, Su Zhou, P.R. China, was calcined at 700 °C for 12 h. NaOH and sodium silicate solution with the mole ratio of SiO2/Na2O of 3.2 and a solid content of 37% were used as alkaline reagents. The silicon content was increased by the addition of fumed silica with 95% or higher SiO2 content to compensate for the shortage of silicon in calcined kaolin. Distilled water was used throughout the experiments.

2.7 Specimen preparation :

NaOH, sodium silicate solution and water were mixed in a beaker

2.8 Chemical composition characteristics of geopolymer cement:

Al2O3 and SiO2 are the main components of geopolymer cement. The mole ratio of Si to Al directly determines the molecular configuration types of the products: PS type at Si/Al = 2, PSS type at Si/Al = 4, or PSDS type at Si/Al = 6. There are obvious differences amongst different types of geopolymer cements: good thermal insulation for PS; high strength and good toxic wastes solidification for PSS; excellent fire-resistance and high bonding for PSDS (Davidovits, 1988, Davidovits, 1989). Thus, the mole

2.9 Preparation of the calcined kaolin-based geopolymer cements:

In this study, a total of 9 geopolymer cement pastes were designated to investigate the influence of the three key ratios: SiO2/Al2O3 (Factor A), Na2O/Al2O3 (Factor B) and H2O/Na2O (Factor C). The three mole ratios were varied: 5.5 ≤ SiO2/Al2O3

≤ 6.5, 0.8 ≤ Na_2O/Al_2O_3 ≤ 1.2, 7.0 ≤ H_2O/Na_2O ≤ 10. The levels for each of the factors were set at three grades (low, intermediate, and high). The experimental program corresponded to three-factor-experiments with three levels of each factor. Based on the

2.9.1 XRD analysis

The XRD pattern showed that a large diffuse halo at about 20–40°(2θmaxCuKα) diffractogram for the fully reacted cement, i.e. Na-PSDS2 (Fig. 2). This indicates that Na-PSDS products were mainly X-ray amorphous consisting of randomly orientated Si–Al tetrahedra.

2.9.2 ESEM-EDXA

Fig. 3 shows ESEM micrograph of the sponge-like hardened Na-PSDS. Crystals with regular shape were not observed. EDXA was also performed on the whole region shown in the above ESEM micrograph to determine its chemical composition after

2.9.3 Conclusions

The influence of the three key parameters SiO_2/Al_2O_3, M_2O/Al_2O_3, H_2O/M_2O on the synthesis of calcined kaolin-based geopolymer cement was systematically investigated. A total of 9 cement pastes with different mole ratios SiO_2/Al_2O_3, Na_2O/Al_2O_3, H_2O/Na_2O were designated to investigate the effects on mechanical strength and microstructure in accordance with an orthogonal design. The gradation analysis of experimental results revealed that Na_2O/Al_2O_3 and H_2O/Na_2O had significant impact on the

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2.11 Mechanical properties of geopolymer concrete:

The compressive strength of geopolymer concrete has been found to be as high as 70 MPa (Newtons per mm2). Concrete gains compressive strength faster and faster than ordinary Portland cement concrete. The strength of concrete after 24 hours was found to be more than 25 MPa. The compressive strength after 28 days was found to be 60 to 70 MPa.

The increasing demand of environment friendly construction has been the driving force for developing sustainable and economical building materials. The critical aspects influencing the development are performance of the materials under different and special user conditions, economic aspects as well as environmental impact aspects. Cement is an energy consuming and high green house gas emitting product. Geopolymers are gaining increased interest as binders with low CO2-emission in comparison to Portland cement. In the present investigation, the mechanical properties of flyash based geopolymer concrete(GPC) were studied. Experimentally measured values of the compressive strength and split tensile strength of GPC specimens made from low, medium and higher grades compared with reference to the control mixes(OPC).The regression model analysis was carried out to study the relationship between the Compressive strength and Split tensile strength and It was found that the mechanical behaviour of GPC is similar to that of ordinary Portland cement(OPC) concrete.

Initial research on geopolymers carried out by Davidovits was on the linear organic polymer, which is a branch of organic chemistry. Later, this topic was extended beyond this scope and research conducted in the early 1970s was focused on developing nonflammable inorganic polymer materials suitable for fire resistance. This attempt was because of the fact that the used organic polymers at that time were of low heat resistance. The work was ended to develop an amorphous to semi-crystalline three-dimensional silico-aluminate composite called geopolymer. This invention was followed by the manufacturing of fire-resistant chipboard panels, different geopolymeric ceramics, and later, geopolymeric binders including high strength cement and fireproof geopolymer fiber reinforced composites.

Geopolymer is essentially different from the conventional concrete which consists of hydraulic cement as a binder. Instead, there is an alkali-activated mineral admixture as a binding medium holding an inert aggregate to form a compact mass. This new type of concrete can offer many benefits including high early strength , high temperature resistance , and good chemical resistance for aggressive environments , as compared with normal concrete. In particular, durability of ordinary Portland cement concrete is under examination, as many concrete structures, especially those built in corrosive environments, start to deteriorate after 20 to 30 years . Other reasons for using geopolymer concrete (GPC) include the vital need to save the natural environment and to use cleaner construction material since there is a global warning against the use of Portland cement-based composite. It is clear that the production of Portland cement accompanies the use of natural resources including gravel, water, and raw materials required for manufacturing of cement, leading to destroying the surrounding environment. Reports showed that about 2.7 billion tonnes of the raw materials needed every year for cement manufacturing . Other reports indicate that in order to manufacture one ton of Portland cement there is a need for about 2.8 tons of raw materials, including fuel. Another problem to be considered is the environmental pollution encountered with production of Portland cement. During the manufacturing of Portland cement, large amounts of greenhouse gas (CO2) will be released into the atmosphere, and the related reports indicate that the cement industry contributes around 8% of the worldwide yearly CO2 emission .

Based on the above-mentioned facts, the problem-related use of concrete must be well addressed, and there is a vital need to reduce Portland cement concrete consuming or searching for the alternatives for construction purposes. In a recent paper , the performance of composite concrete-timber section for roof construction was investigated, and the authors concluded that there is a chance to reduce concrete thickness by one half if populous nigari joist is used to make a composite section. Geopolymers seem to be a good solution to produce a clean concrete, since the Portland cement can be totally replaced, and instead there is a special concrete depending on an alkali-activated pozzolanic material, such as fly ash and blast furnace slag, to provide a binding medium. Physical and mechanical properties of fly ash (FA)-based geopolymer concrete (GPC), compared to those of Portland cement concrete (PCC), were investigated by Nikoloutsopoulos et al. through testing three GPCs with different FA content and three appropriate PCC. It was shown that in some cases, minor adjustments of the regulations are needed, while in other cases complete revision is required. GPC indicated competitive compressive strength compared to PCC, while modulus of elasticity was about 50% less than that of PCC. GPC shows a higher mid-span deflection during flexural test up to 35% compared with that of PCC. Furthermore, ultrasonic pulse velocity of GPC was found quite different from that of PCC, even for the same strength level. They concluded that the quality of GPC cannot be assessed using the classification table used for PCC. The ratio of binder (FA) to aggregates seems to have a significant effect on the properties of GPC, in which GPC with 750 kg/m3 FA seems to be the best choice with regard engineering and environmental criteria.

It was reported that the frost resistance of alkali-activated materials (AAM) is very good . This was confirmed by investigating mechanical properties of GPC and frost resistance of different compositions of alkali activators made of sodium water glass with a silicate modulus modified with potassium hydroxide. Bilek et al. found that the strengths of AAMs are significantly affected by the curing method, while the frost resistance depends on the method of curing and on the composition of the activator. As a conclusion, good frost resistance can be achieved if: (a) the optimal ratio between the alkalis and silica in the activator, in which activation with hydroxide or with the water glass with a high silicate modulus (low (Na_2O + K_2O)/SiO_2 (R/S) mass ratios, was found not suitable. The optimal R/S was recommended to be between 50/50 to 70/30; (b) the optimal amount of activator—dry mass of the activator higher than 15% seems to be deleterious from the point of view of frost resistance, knowing that the strengths of these materials are very high.

2.12 State-of-the-Art Review of Mechanical Properties of Geopolymer Concrete:

Understanding mechanical properties of GPC is an important step toward producing large quantities of GPC with reasonably consistent and predictive engineering properties. These properties were the subject of numerous investigations in the past 20 years. The authors have been reviewed more than 250 research works on this topic and found that there are many ways to produce the geopolymers of different properties. Below, reviewing of important mechanical properties have been done and those parameters governing each property and relation among them are briefly investigated. Important parameters governing the performance of geopolymer binder are (a) activator solution-to-source material (fly ash, slag, etc.) ratio, (b) concentration of NaOH solution (molarity), (c) sodium silicate solution-to-sodium hydroxide solution ratio (Na_2SiO_3/NaOH), and this parameter depends on the composition of the sodium silicate solution, (d) curing temperature, (e) curing period, and (f) water content . Indeed, if the basic pozzolanic material is partially replaced with other materials, there is a chance to adjust the binding characteristics

Different properties of geopolymer paste , mortar , and concrete were experimentally investigated. If the density of concrete is considered, there are two types of geopolymer concrete, normal weight and lightweight, and the latter may be foamed concrete , or others based on lightweight aggregate. Properties of self-compacting geopolymer concrete were experimentally investigated by Memon et al. Ushaa et al. and Saini and Vattifalli . Behavior of GPC with nanomaterials was investigated by Phoo-ngernkham et al. Pozzolanic materials used for GPC mixes were mostly class F fly ash; however, class C fly ash , Phoo-ngernkham et al. , natural Pozzolan ground granulated blast furnace slag (GGBS) metakaolin [rice husk ash a mixture of two or more Pozzolanic materials and ceramic dust waste were also examined. Some special ashes or compounds were used by some investigators such as palm oil fuel ash (POFA) waste bottle glass (WBG) and sugarcane bagasse ash (SCBA) . With regard to the curing of GPC, several methods of curing were attempted by the researchers, including oven heating, membrane curing, steam curing, hot gunny curing, hydrothermal curing, room temperature, and water curing. Among them, oven curing proved to be the most efficient .Heat curing regime of GPC depending on both temperature and duration, and initial temperature for curing varied between 30 °C and 120 °C or normally cured at the ambient temperature while curing time up to 110 h was attempted. Below, important mechanical properties of GPC are mentioned and discussed.

2.13 Compressive Strength :

This property was extensively investigated in the laboratory and majority of research works on geopolymer concrete contained data on this property. Those parameters governing compressive strength of GPC are briefly discussed herein. Shehab et al. observed that the values of compressive strength, bond strength, splitting tensile strength and flexural strength are the highest at 50% ordinary Portland cement (OPC) replacement with fly ash, while Vijai et al. found that replacement of 10% of fly ash by OPC in GPC mix resulted in an enhanced compressive strength, split tensile strength and flexural strength. Tests by Lloyd and Rangan showed that the inclusion of a 24 h period before curing increased the compressive strength of GPC. Curing at ambient condition will produce low early strength concrete, while there is a significant strength improvement on using high temperature. It should be noted that extended curing time able to enhance the geopolymerization mechanism and consequently the strength; however, longer duration of curing at an elevated temperature results in failure of the concrete In general, higher initial curing temperature and duration resulted in higher compressive strength . Experimental tests by Adam and Horianto showed that both temperature and duration of initial heat curing plays a major role for the strength development of fly ash-based geopolymer mortar. The optimum heat curing regime was found to be at 120° for 20 h. Tests by Joseph and Mathew indicate 100 °C as the best temperature, while the optimum time of curing at 60 °C observed by Chindaprasirt et al. was 3 h. These researchers found that the optimum curing temperature is 75 °C. The reaction was completed at 7 days to obtain the maximum strength and no further strength was observed. The importance of initial heat curing was also observed by Vijai et al. Abdullah et al. and Almuhsin et al. The latter researchers found an increase of 56% in the compressive strength for concrete subjected to one hour of oven curing at 90 °C. Increasing heat curing time to 90 h , and 110 h resulted in an increase in compressive strength. Duration of heat curing was also investigated in which they found that there is an increase in compressive strength when heat curing (65 °C and 85 °C) increased from 5 to 24 h. Curing time more than 24 h was found has no appreciable effect on the strength.

2.14 Other properties of geopolymer concrete:

- Dry shrinkage is much less compared to cement concrete. This makes them well suited for thick, heavily constrained concrete structural members.
- It has a lower heat of water when compared to cementitious concrete.
- The fire resistance is much better than the traditional cement-based concrete.
- Classification of the chloride permeability of concrete plaster from low to very low according to the standard test method for the electrical indication of the ability of concrete to resist penetration of chloride ions. It provides better corrosion protection for steel reinforcement compared to conventional cement concret.
- This concrete was found to have extremely high acid resistance when tested under exposure to 2% and 10% sulfuric acids.

Geopolymer concretes (geocretes) are considered as eco-friendly materials for various building applications. Geocrete has high early strength, less consumption of natural resources, cost-effectiveness, capacity to form different structural configurations and to remain intact for extended periods without repair works. Meanwhile, geocretes have still exhibited an unstable behavior over time compared to traditional cementitious composites. To overcome this disadvantage, hundreds of studies have focused on the improvement of the microstructure of geocretes with a wide range of improved durability characteristics. Therefore, the review paper has an objective to make available an inclusive review on the production of supplemental-cementing-materials (SCMs), their economic returns, environmental and durability impacts, the conceptual model for geopolymerization, durability affecting factors, and function and long-term durability properties of geocrete. It is concluded that geocrete demonstrated a better resistance against aggressive environment compared to normal concrete, due to its less porous structures. Moreover, it is found that the strength of alkali-activated concrete was found to improve in chloride environment, unlike OPC based concrete. It is also concluded that, the presence of GGBS and MK in alkali-activated materials reduces its alkali-silica reactivity while it is recommended to use high calcium FA in geocrete production for durable concrete and geopolymerization. The higher the molarity of NaOH solution for a given quantity of $Na2SiO3$ the faster the geopolymerization process and the higher the compressive strength of concrete corrosion current than the OPC concrete. Further long-term durability studies are required to provide test methods and validation techniques since most studies focus on the 28-day curing regime.

Geopolymer concrete (geocrete) is an innovative and environmentally friendly-engineered material that is regarded as a potential replacement of ordinary Portland cement (OPC) Portland cement has been used for the construction of various infrastructures like transport infrastructure, road construction, buildings, and offshore applications Geopolymers are regarded as a subset of alkali-activated materials. The use of a geopolymer alleviates the large emission of $CO2$ during the manufacturing of OPC. Geocretes has been reported as a very durable material, which is expected to mitigate the durability issues related to traditional concretes . This is achieved using natural or industrial by-products, which are minimally processed. Binders of thermally activated materials or industrial by-products generally supply silicon and aluminum. Then, an alkaline solution is employed to activate them into molecular chains and networks, which are the main components of geocrete, sometimes referred to as inorganic polymer cement or alkaline-activated cement . Some other binder materials are metakaolin (MK) , fly ash (FA) , red mud , rice husk ash (RHA) , silica fume ash (SFA) , ground granulated blast furnace slag (GGBS) , and palm oil fuel ash (POFA) . All these mineral materials were used as supplemental-cementing-materials (SCMs) .Because of the environmental footprint, including resource extraction, the shift from waste material to by-product status has a significant effect. Alkali-activated materials uses SCMs, and are regarded to exhibit better durability compared to OPC based concrete . This means that using geocrete can help reduce industrial waste and quickly increase strength, making geocrete an excellent choice for quick construction . Geocrete has also high tensile strength, less brittle than OPC, and can withstand more movement compare to conventional concrete.

2.15 ENVIRONMENT AND CONCRETE

Cement manufacturing industry annually produces about 1.35 billion tons of the greenhouse gas emissions which is about 7% of the total man-made greenhouse gas emissions to the atmosphere With the industrial development in India and China, the installation of new cement plants substantially increasing the CO_2 emission and also huge amount of fly ash produced by thermal power plants were not being recycled properly.McCaffrey proposed three options to decrease the release of CO_2 by the cement industries into the atmosphere, that is, (a) lessening the amount of calcined material in cement, (b) reduce the amount of cement in concrete by using higher strength cement, and (c) use cement in less number of buildings. Hardjito et al. reported that Mehta had also proposed environmental friendly concrete which is in two phases namely: industrial ecology, which is an effort of using lesser amount of natural resources, consume less energy, reduce the emission of CO_2 and reduce the material consumption rate to decrease the effect of undesirable industrial by-products. Further, use of less OPC, incorporation of more auxiliary cementitious materials, using less water by using more super-plasticizers and water reducers, inclusion of recycled aggregates in concrete, usage of lightweight concrete at possible situations, and so on are some of the methods through which the cement and concrete industry can contribute toward reducing CO_2 emissions for sustainable construction.

2.16 GEOPOLYMER CHEMISTRY

During the ancient days, by mixing dolomite, kaolinite or limestone with K_2CO_3 or Na_2CO_3 (acquired from waste plant product or salt lakes) and silica, yields the formation of synthetic rocks. When water added to KOH and NaOH (obtained from the above mixture), some of the silica dissolves and strongly reacts with other additives to produce a geopolymeric binder.**9** Considering the developments of concrete, lime and ordinary Portland concrete are considered as the first- and second-generation concretes, respectively, and geopolymer is considered as the third-generation cement. Geopolymer is an amorphous alkali alumina-silicate has variety of nomenclature like “geocements,” “alkali-activated cements,” “hydroceramics,” alkali-bonded ceramics,” “inorganic polymers,” and so on, all these terms describes the materials synthesized utilizing the same chemistry. The process of geopolymerization contains a substantively fast chemical reaction under highly alkaline conditions between alumino-silicate oxides and silicates, that results polymeric Si─O─Al─O bonds.10-12 The schematic formation of geopolymer material is described in Equations (1) and (2)

$$n\,(Si_2O_5,Al_2O_2) + 2n\,SiO_2 + 4nH_2O + NaOH \text{ or } KaOH \rightarrow Na^+, K^+ + n(OH)_3 - Si - O - \underset{\underset{(OH)_2}{|}}{Al^-} - O - Si - (OH)_3 \quad (1)$$

(Si-Al Materials) (geopolymer precursor)

$$n(OH)_3 - Si - O - Al^- - O - Si - (OH)_3 + NaOH \text{ or } KOH\ (Na^+,K^+) - (-\underset{\underset{O}{|}}{\overset{|}{Si}} - O - \underset{\underset{O}{|}}{\overset{|}{Al^-}} - O - \underset{\underset{O}{|}}{\overset{|}{Si}} - O -) + 4nH_2O \quad (2)$$

(geopolymer backbone)

.

During curing from the geopolymer matrix water is released and leaves the intermittent nano-pores on further drying. This does not show any role in the chemical reaction process that take place except it helps in improving the workability, Whereas, the water play an important role during the process of hydration in OPC mixture.13 Geopolymerization is exothermic, under highly alkaline conditions on Al-Si minerals yields a three-dimensional polymeric chain and ring structure which is on the basis of Si/Al ratio. Poly (sialate) Si/Al = 1, Poly (sialate-siloxo) Si: Al = 2, and Poly (sialate-disiloxo) Si: Al = 3.14 Based on the Si/Al ratio, various geoplymer applications are categorized and is presented in Table 1.

Table 2.1. Geopolymeric materials applications based on Si:Al ratio

Si:Al ratio	Applications
1	• Bricks • Ceramics • Fire protection
2	• Low CO_2 cements and concretes • Radioactive and toxic waste encapsulation
3	• Fire protection fiber glass composite • Foundry equipment • Heat resistant composites, 200–1,000°C • Tooling for aeronautics titanium process
>3	• Sealants for industry, 200–600°C • Tooling for aeronautics SPF aluminium
20–35	• Fire resistant and heat resistant fiber composites

It was found that if clay and fly ash were used, the dissolution of the starting materials was not completed before the final hardened structure was formed. In most cases, only small amount of the silica and alumina present on particle surfaces had to take part in the reaction for the whole mixture to solidify. Therefore, it was believed that surface reaction was responsible for bonding the undissolved waste particle into final geopolymeric structure.

2.17 PARAMETERS INFLUENCING THE PROPERTIES OF GOEPOLYMER CONCRETE

The source materials and alkaline solutions are the two main constituents of geopolymers and these source materials should be rich in silicon (Si) and aluminium (Al) for aluminate-silicate based geopolymers. These geopolymer binders can be made from different natural materials such as metakaolin, clays, and so on, or alternatively the by-product materials such as ground granulated blast furnace slag (GGBFS), FA, mine waste, red mud, rice-husk ash, and so on. -The cost, availability, application type, and the end user demand are the factors which to be considered for the selection of source materials for making geopolymers. As the FA is cheaper, easily available, rich in silica and alumina and larger potential for making geopolymers, FA was the most commonly used source material among these materials. Curing temperature, period of curing, ratio of sodium silicate to sodium hydroxide, ratio of alkali to fly ash and molarity of sodium hydroxide are the main parameters those influences the properties of goepolymer concrete (GPC). The general ranges selected by different investigators for the alkali-fly ash ratio and the ratio of Na_2SiO_3 to NaOH were 0.25 to 0.75 and from 0.17 to 3, respectively.

2.18 MIX DESIGN

For any concrete, suitable mix design is essential for achieving the required strength and workability. Most of the researchers have adopted the normal concrete mix design procedure for geoploymer concrete. But, a few researchers have suggested their own mix design procedures for low calcium FA based geoplolymer concretes. Based on Indian Standard Code (IS: 10262), Ananda Kumar and Sankara designed different GPC mixes, in which for a constant percentage of fine aggregate, the amount of FA and ratio of activator solution to FA were fixed based on the compressive strength requirement. Anuradha et al. proposed a similar method of mix design of GPC. Based on the fine aggregate zone, a correction was applied for fine aggregate percentage at the end. Lloyd and Rangan, in their mix design procedure, the total mass of FA and alkali solution were obtained by deducting the fixed aggregate content (80%) from the density of GPC (2,400 kg/m^3). For different activator solutions to FA ratio, the amount of FA was arrived. Also, based on the adopted ratio of NaOH to Na_2SiO_3, the individual quantities of sodium hydroxide and sodium silicate were evaluated and then for different water/geopolymer solids ratio, the designed workability and compressive strength were evaluated. By taking the variability in concrete density, specific gravity of the materials, air content, workability and strength requirement, Ferdous et al. have proposed low calcium FA based geopolymer concrete mix design. The major issue arises was the determination of ratio of activator solution to FA and exact amount of activator solution based on FA quantity. Pavithra et al. proposed a mix design for low calcium FA based geopolymer concrete with flexibility in selecting the alkali activator solution (AAS) to FA ratio for required strength. Further, the specific gravity of the materials and volume were also taken into account. It was concluded that with the proposed mix design method, one can get 23–53 MPa strength range for different AAS to FA ratio. Phoo-ngernkham et al. established a mix design based on ACI standards for alkali activated high calcium FA based concrete (AAHFAC) cured under ambient temperature.

2.19 PREPARATION OF ALKALINE SOLUTION

Normally the mixture of sodium hydroxide and sodium silicate or potassium hydroxide and potassium silicate solutions are used as activator in the geopolymer concrete. - Many researchers reported that the combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) was the mostly used as an alkali activator for making geopolymer due to its availability and good mechanical properties. Phoo-ngernkham et al. reported that sodium silicate solution contains soluble silicates species, which was used for the condensation of alkaili activated binders, whereas, Panias et al. reported that the sodium hydroxide was normally used to dissolve Si^{4+} and Al^{3+} ions from FA to form aluminosilicate materials. Duxson et al. reported that the NaOH had enhanced capability to liberate silicate and aluminate monomers and sodium cataions play a better role in forming the geopolymer system due to its superior ability in zeolitization. Normally the commercial sodium hydroxide available in flakes form and it is to be dissolved in distilled water to avoid the effect of unknown contaminants. Similarly, the sodium silicates are available either in pellets or in liquid form. If the sodium silicate available in pellets form, it is to be dissolved in distilled water before making the alkaline solution. During the preparation of alkaline solution that is, mixing of NaOH and Sodium Silicate solutions high temperature generated and therefore, different researchers have proposed different ways of mixing of alkali solutions. Some researchers suggested to premix the alkali solution and wait till it reaches the ambient temperature (24 hr) for adding into the dry mix, -whereas some other investigators recommend to add the alkali solutions during dry mixing itself.

2.20 GEOPOLYMER PASTE

The type of alkaline solution and its concentration, curing temperature and method of curing, period of temperature curing, nature of source material, water content and rest period affect the end results of geopolymers. Geopolymers made with Class C-FA had faster setting (<10 min) than those prepared with Class F-FA (>1 day) due to the presence of high quantity of calcium glassy phases in Class C-FA. Fernandez-Jimenez et al. found that, the initial stage of alkaline activation of FA particles produces an Al-rich alumina-silicate gel which yields an increase in the mechanical strength of geopolymer derived from FA and it may further rise due to the improvement of silicates in the materials. Further, it was reported that even though the metakaolin has important role in the applications of adhesives, coatings and hydroceramics, due to increased porosity, the metakaoline may needs higher water and hence it becomes too soft for the applications in construction. As the nature of the initial source materials play a significant role in the microstructure and properties of geopolymers, one has to understand thoroughly the reactions and chemistry of raw materials so as to optimize the cost and technical performance of certain applications. Palomo et al., Swanepoel and Strydom, and Van Jaarsveld et al. found that the compressive strength was influenced by the curing temperature and curing duration and it was reported that at 85°C for 5 hr curing, 60 MPa compressive strength could be developed. Palomo et al. reported that the highest compressive strength yielded when the sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) was used as alkaline solution. The compressive strength of paste was optimum at curing temperature of 60°C and curing duration of 48 hours. Gorhan and studied the FA based geopolymer paste with 3, 6, and 9 M of NaOH concentrations and it was found the highest compressive strength at 6 M of NaOH when cured at 85°C for 24 hr. High compressive strength can be achieved when the samples cured at room temperature for a longer period before they cured under heat reduces the period of heat treatment. It was found that the samples precured at room temperature with 6 hr heat treatment had developed more strength than the samples cured at 24 hr heat treatment. The distribution of Si/Al ratio in alumina-silicate gel gets increased with the increase in curing temperature, whereas; this range of Si/Al ratio distribution can be decreased when the samples cured for a longer time at room temperature. The presence of calcium content in FA plays a vital role in the setting and hardening of the geopolymer paste. It was suggested that the workability, setting time, and compressive strength development were significantly affected by the calcium containing compounds which form during the geopolymerization of fly ash. Further, it was reported that the compressive strength was affected by the amount of CaO present in FA and the water to FA ratio.

Lee and van reported that by increasing the dosage of soluble silicates in the initial stage of activating solution can develop thicker binder and hence improve the aggregate/binder interface. By increasing the silicate ratio and increase in curing temperature, a mesoporous structure (3.6–50 nm) can be observed in a well reacted FA based geopolymer mortar. Garcia-Lodeiro et al. found that the expansion due to alkali silicate reaction in FA based geopolymer mortar was less than that of made with OPC binder. It was reported that the presence of calcium in the material shows a vital role in the expansive nature of gel.

With alkali activation of mixer of sodium hydroxide and sodium silicate solution and with optimum modulus of 1.5 (Molar ratio of SiO_2/Na_2O), a high compressive strength of geopolymer cement mortar with Class C-FA was obtained. Corresponding to this, the mass proportion of Na_2O to Class C-FA evaluated was 10%and it was reported that when these samples were cured at 75°C for 8 hr and then allowed to cure for 28 days at 23°C, the compressive strength was 63.4 MPa.

2.21 GEOPOLYMER CONCRETE

2.21.1 Workability

Hardjito et al. concluded that that the workability of geopolymer concrete could be enhanced without any segregation and reduction in compressive strength with the addition of 2% (by mass of FA) of naphthalene-based superplasticizer. By adding naphthalene sulphonate-based super-plasticizer, up to ~4% of fly ash by mass, improved the workability of fresh FA based geopolymer concrete. The workable flow depends on the ratio of NaOH and Na_2SiO_3 solution by mass and the maximum flow obtained in the range of 95–145 mm. Shankar and Khadiranaikar reported that with the increase in strength of concrete and molarity of NaOH, the workability of geoplymer concrete mixes reduces due to the reduction in the ratio of water to geopolymer solids and as well as decrease in the amount of water. Laskar and Bhattacharjee concluded that the molarity of NaOH significantly affect the workability of geopolymer concrete. It was reported that up to 4 M of NaOH, the workability increases and beyond this value of molarity of NaOH, the amount of plasticizer and superplasticizer had negative impact on the workability of geopolymer concrete. At higher concentrations of NaOH molarity still lignin based first generation superplasticizer had shown superior performance in relation to workability compared to third generation superplasticizer. Yasir and Iftekar reported that the workability of the geopolymer concrete increases with the increase in alkaline solution to flyash ratio and it was noticed that mixture with alkaline solution to fly ash ratio less than 0.3 was very stiff. The workability of FA based geopolymer concrete could be enhanced by adding up to 4% (by mass of FA) naphthalene-based super plasticizer, however, after 2% addition of superplasticizer, a slight reduction in compressive strength was reported. The workability of geopolymer concrete was poor when compared to Portland cement concrete as the GPC mixes were stiffer due to the use of sodium silicate which is a cohesive and lack of water content. Nevertheless, the higher slumps (230–270 mm) could be possible by the addition of naphthalene sulphonate polymer-based superplasticisers.

2.22 COMPRESSIVE STRENGTH

2.22.1 Under heat curing

Compressive strength of geopolymer concrete does not change with the age but longer curing time, water content and curing temperature especially up to 75°C improves the Geopolymerization process and compressive strength. Leung and Pheerapha reported that compressive strength was increased when the samples cured at higher temperatures due to the elimination of water from the fresh geopolymer, which yields the formation of dense microstructure by crumpling capillary pores. Joseph and concluded that the compressive strength of GPC increased with the increase in temperature upto 100°C and thereafter it decreases. This was due to the loss of moisture from the concrete. Further it was concluded that by choosing the curing temperature and curing period suitably, it could be possible to achieve the high early strength in case of GPC. It was reported that 96.4% of 28 days could be achieved in 7 days with 24 hr curing at 100°C. Palomo et al. reported that the extended curing at higher temperature gives a negative effect on the compressive strength due to collapse of the granular structure resulting in the desiccation and excessive shrinkage. The compressive strength of GPC increases with increase in alkali to FA ratio upto 0.55 and Na_2SiO_3/NaOH upto 2.5 and beyond these values the compressive strength decreases. The raise in compressive strength was mainly due to the effect of sodium silicate content on the change of geopolymer microstructure. The reduction in compressive strength was due to the incompletion of dissolution process during the geopolymerization due to insufficient amount of NaOH at larger ratios of Na_2SiO_3/NaOH. At 28 days, 52 MPa cube compressive strength was reported when the GPC made with 70% by volume of total aggregate content, fine aggregate to total aggregate ratio of 0.35, 10 M of NaOH, ratio of Na_2SiO_3/NaOH of 2.5 and alkali to FA ratio of 0.55 at 100°C. The compressive strength of Geopolymer concrete increases with NaOH concentration (molarity) and also loss in strength occurs when there was an increase in the alkaline liquid to flyash ratio. Weng and Sagoe-Crentsil, Duxson et al. and Sagoe-Crentsil and concluded that the NaOH concentration has progressive impact on hydrolysis, dissolution and condensation reactions during the geopolymer synthesis but at the same time the condensation process of silicate species deters due to the extra concentration of alkalis. Strength gain in geopolymer concrete was very fast; achieved 50% in 3 days. Optimum ratio between Na_2SiO_3 and NaOH was suggested as 2.5 because below or above which strength gets decreased.

Sofi and concluded in their investigation that the compressive strength of FA based geopolymer concrete was increased with the increase in NaOH concentration and temperature but decreased with the increase in alkaline to FA ratio. Further, it was concluded that the ratio of sodium silicate to sodium hydroxide up to 2.5, the compressive strength increases but thereafter the strength decreases with further increase in the ratio of sodium silicate to sodium hydroxide. Geopolymers made with Class C-FA had faster setting than that made with Class F-flyash due to larger proportion of calcium in glassy phases. Curing time and temperature, ratio of Na_2SiO_3 to NaOH and water content in the mix were the main parameters that influence the compressive strength of geopolymer concrete and it was found that the target strength could be achieved at 60°C for 24 hr. Larger compressive strength can be achieved by increasing the curing temperature and longer curing periods, which improves the polymerization. It was also reported that the compressive strength improved by increasing the rest period up to 5 days prior to the heat curing, increasing the concentration of NaOH molarity and larger ratio of sodium silicate to sodium hydroxide by mass. Further, it was reported that like in conventional concrete the compressive strength decreases with increase in w/c ratio, the compressive strength of geopolymer concrete also reduces with the increase in water to geopolymer solids ratio by mass. Geopolymer concrete made with FA had shown better resistance against drying shrinkage, creep and sulfate and acid attacks., et al. reported that the increase in the modulus of sodium silicate solution up to 1.4, the compressive strength increases and thereafter it decreases and it was drastic decrease when the modulus was more than 2. It was further reported that the compressive strength was maximum when the sodium silicate solution concentration was 32% and with further increase in the concentration, the compressive strength was decreased. It was also concluded that the samples curing at room temperature for 1 day prior to heat curing was advantage for the development of compressive strength. Hardjito and Rangan reported that in case of FA based geopolymer concrete also, as the compressive strength increases the modulus of elasticity increases and the poisons ratio was in the order of 0.12–0.16. Further, it was reported that under compression the behavior and failure mode of FA based geopolymer concrete was similar to that of concrete with OPC and the maximum failure strain in FA based geopolymer concrete was in the range of 0.0024–0.0026.

Lloyd and Rangan reported that the rest period of 24 hr prior to steam curing at 80°C yields an increase of 20% in compressive strength of geopolymer concrete with

Class F FA when compared to steam curing without rest period. Like the concrete with Portland cement, in GPC also the workability reduces and compressive strength increases when added water increases. Further, it was reported that the aggregate grading and shape had similar effect on the properties of GPC as they had on OPC concrete. The compressive strength of geopolymer concrete decreased with the increased aggregate/solids ratio and water to solids ratio. It was found that the effect of water to solid ratio on strength development of GPC same as the effect on strength development of concrete with OPC. Panias et al. reported that as the water content reduced in the geopolymer mixes, the concentration of alkaline activator increased in the GPC system, thus, the existing high alkalinity hasten the geopolymerization process and hence increase in the strength. It was reported that when the aggregate to solids ratio increased from 3.5 to 4.7, the compressive strength at 28 days dropped from 48.06 to 25.44 MPa. Fernandez-Jimenez and reported that more aluminosilicate bonds could be produced due to the increase of solids or dried alkaline activators which results an increase in the compressive strength of geopolymer concrete. It was further reported that the quantity of FA and aggregate, reduction in water content were the most significant factors to improve the compressive strength of GPC. Jaydeep and Chakravarthy concluded that the GPC specimens cured in hot oven yields higher strength than those cured in sun light. Joseph and Mathew reported that by suitably selecting the total aggregate content and fine aggregate to total aggregate ratio, the modulus of elasticity and poisson's ratio of GPC could be fetched similar to or even more than the corresponding normal concrete with OPC.

The effect of alkaline concentration and curing temperature on the compressive strength of FA based geopolymer concrete reported by different researchers are presented in Figures **3** and **4**, respectively. It shows that the compressive strength increases with increase in concentration of alkaline solution except the results reported by Joseph and Mathew and Singh et al.

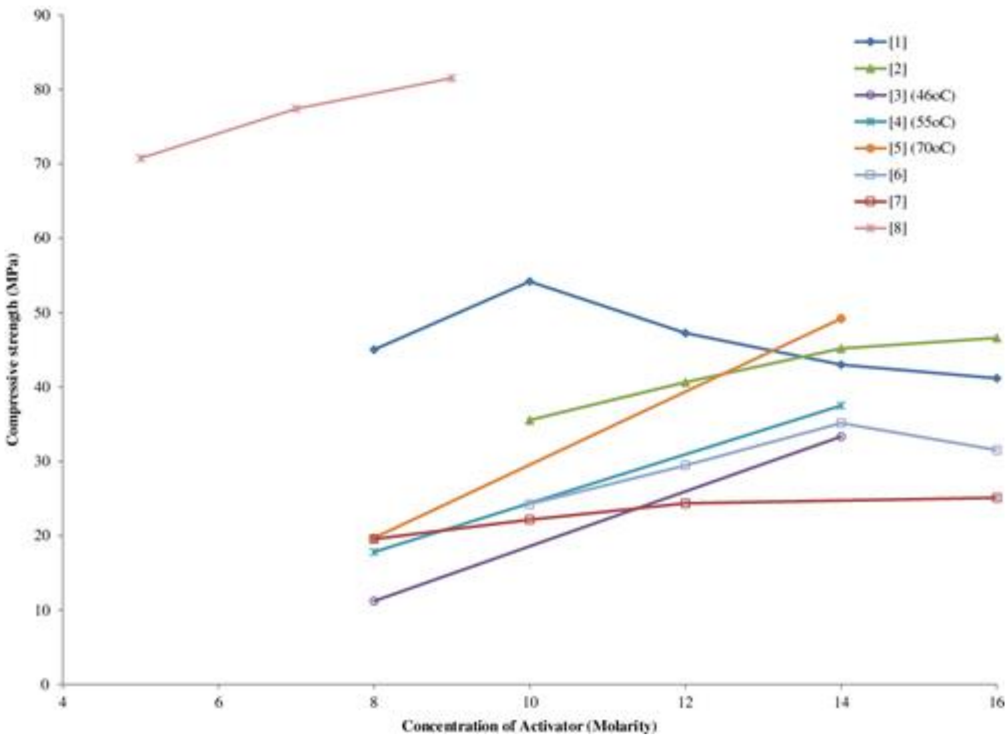


Figure 2.1 compressive strenght

Compressive strength of fly-ash based geopolymer concrete with alkaline activator concentration

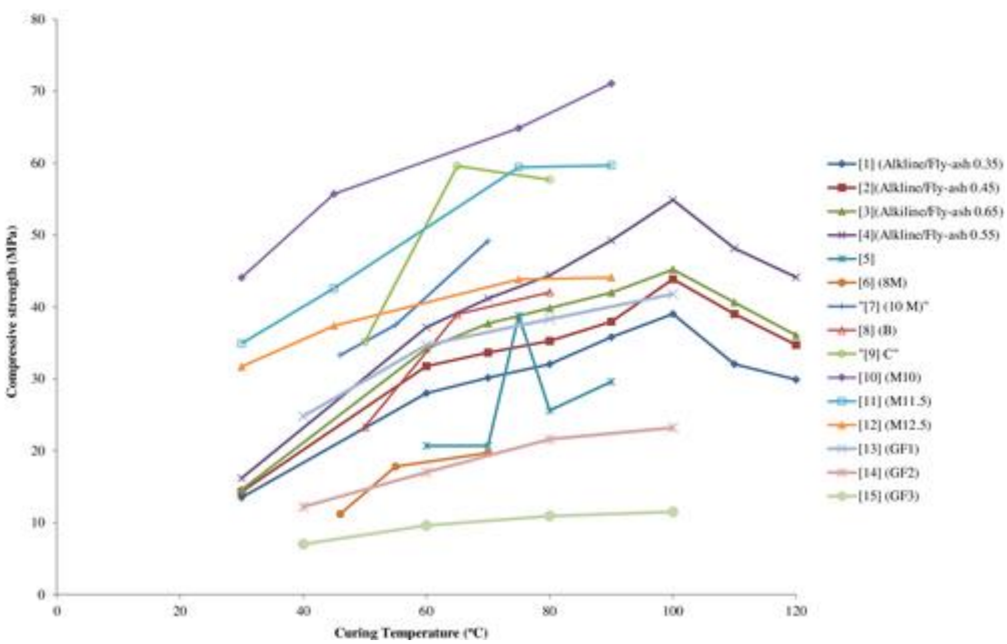


Figure 2.2 compressive strenght

2.23 Under ambient temperature

Due to the reaction of calcium presence, the geopolymer made with high calcium FA can be cured at ambient temperature. However, under ambient temperature, without additives the geoplymerization of high calium FA was slow, which yields low strength. Addition of Portland cement in geopolymer made with high calcium FA was more effective in strength development.

Chindaprasirta et al. studied the setting time and compressive strength of alkali activated high calcium FA based geopolymer concrete under ambient temperature with three calcium ironic materials such as Portland cement (PC), calcium hydroxide (CH) and calcium oxide (CaO). It was reported that the setting time was reduced with the incorporation of PC, CH and CaO in the geopolymer concrete, which is very much crucial prerequisite for repair material. The mixes made with PC and CH significantly improved the compressive strength, whereas, the compressive strength was reduced due to the incorporation of CaO in alkali activated high calcium FA based geopolymer concrete. It was further reported that 15% PC and 5–15% CH incorporation in alkali activated FA based geopolemer pastes were suitable as a substitute for repair material.

Nath and Sarker investigated the properties of low calcium FA based geopolymer concrete with some additives namely: ground GGBFS, OPC and hydrated lime under ambient temperature curing. It was found that the compressive strength of GPC mixes due to incorporation of additives has significantly improved when compared to control concrete. The flexural strength of GPC cured under ambient temperature was more than the normal concrete with OPC for same compressive strength, whereas, the modulus of elasticity of the same was lower than the control concrete.

Phoo-ngernkham et al. studied the compressive strength and shear bond strength of geopolymer mortar made with high calcium FA with Portland cement (PC) as additive and sodium hydroxide (SH), sodium silicate (SS) and combination of SH and SS (SHSS) as activators. In all mixes, alkali activator liquid to solid binder ratio of 0.6, SH of 10 M and ambient temperature of 25°C was adopted. It was reported that the addition of PC develops the formation of additional C-S-H which results the higher compressive strength and shear bond strength of geopolymer mortars. Further, it was reported that the alkali activators and PC affects the compressive strength and shear bond strength of geopolymer mortars. The use of SH and SHSS results the formation of additional C-S-H gel and sodium alumina silicate hydrate (NASH) gel hence the improvement in strength of geoplymer mortars. Singh et al. reported the influence of concentration of activator on the strength, ITZ and shrinkage of FA/slag based geopolymer concrete under ambient temperature curing.

It was found that beyond 14 M concentration of activator, due to the rigid microstructure and variation in phase composition at the interface of bulk matrix and aggregate, the compressive strength was reduced. It was further found that after 6 months the drying shrinkage of GPC was very small compared to OPC due to its prevailing zeolitic characteristics. It was also found that at room temperature the GPC had attained necessary setting and hardening at optimum concentration of activator. Nagalia et al. explored the influence of FA type, type and concentration of alkali hydroxide and curing environment on the strength and microstructure of geopolymer concrete. It was established that among NaOH, KOH, $Ba(OH)_2$, and LiOH alkali solutions, NaOH solution only gives the comparable results of compressive strength of GPC to Portland cement concrete. It was also established that the high calcium content (CaO) in FA yields higher compressive strength in GPC. Further, it was reported that longer curing period, higher temperatures results considerable improvement in compressive strength of GPC. Wang et al. investigated the properties of geopolymer concrete with different proportions of FA and slag (0, 20, 40, and 60% by weight) and different amount of NaOH solutions (0.5, 1, and 1.5%) at different curing periods 1, 3, 7, and 28 days. It was found that the compressive strength increased with the increased proportion of slag and 93.06 MPa was obtained as the maximum compressive strength. Deb et al. reported the maximum compressive strength of 51 MPa, when the geopolymer concrete made with 80% FA and 20% ground blast furnace slag (GBFS) with 0.4 alkiline to binder ratio cured at 20°C.

2.23.1 Density

Olivia and Nikraz reported that the density of geopolymer concrete mixes were in the range of 2,248–2,294 kg/m^3, are close to the density of Portland cement concrete, which is generally in the range of 2,200–2,600 kg/m^3. Hardjito and Rangan found that the unit weight of geopolymer concrete made with granite coarse aggregate was found to be 2,330–2,430 kg/m^3.

2.23.2 Shrinkage

It was reported that the geo-polymer concrete made with FA had exhibited good long term properties and durability. Wallah reported a low drying shrinkage was produced when FA based geopolymer concrete cured under heat and it was ~100 micro strains after 1 year period against the range of 500–800 micro strains generally experienced in concrete with OPC. Further, it was reported that the mixes with different compressive strengths and curing type does not show any significant difference in the shrinkage strain values. Davidovits and Hardjito and Rangan reported that during heat curing the water remain in the micro-pores of the hardened concrete was very little, as most of the quantity of water released during the chemical reaction may be evaporated during the heat curing and hence the geopolymer concrete under heat curing produces low drying shrinkage.

2.23.3 Durability

Shankar and Khadiranaikar studied the effect of sulfuric acid on the weight and strength of GPC. The GPC samples were immersed in 10% sulfuric acid solution over a period of 45 days after 7 days of casting and monitored continuously the changes in terms of weight and strength. It was reported that no changes were noticed in shape without any visible cracks. However, in the initial period of exposure, white powder deposition was observed, later it becomes hard with the time progress. Further, it was noticed that there was a reduction in compressive strength of 7–23% and split tensile strength of 8–45% with little weight loss. Sofi and Gull found that more reduction in compressive strength when the GPC samples with low alkaline liquid to FA ratio soaked in 10% sulfuric acid. Compared to Portland cement based materials, the geopolymer based materials had better resistance against acid attack due to very low amount of calcium. Bakharev investigated the durability performance of FA based geopolymers under 5% acetic and sulfuric acids. It was found that in case of low performance geopolymers, the deterioration was mainly through the crystallization of zeolites and in case of high performance geoploymers the deterioration with the fissures formation in the amorphous polymer matrix. Further, it was found that when samples prepared with sodium hydroxide solution and at elevated temperature curing and immersed in sulfate solution, the compressive strength was improved by 4–12%. Nguyen et al. studied the influence of curing temperature, curing time, rest period on compressive strength and acid resistance of geopolymer concrete with different molarities (1, 2, 4 M) of HCl at 80°C for 10 hr. It was found that the geopolymer concrete had shown better acid resistance under heat curing when compared to concrete with OPC due to the slow endosmosis in geopolymer concrete. Wallah and Rangan investigated the performance of low calcium FA based geopolymer concrete samples with respect to weight loss and residual compressive strength exposed to different concentrations (0.5, 1, 2%) of sulfuric acid over a period of 1 year after casting of 24 hr at 60°C curing. Based on the visual observation, It was reported that the surface of the specimens were marginally damaged. Also, it was reported that there was a relatively less loss of mass (3%) in GPC when compared to concrete with OPC. The dilapidation in compressive strength was also noticed when exposed to acid attack and the intensity of dilapidation depends on the acid concentration and exposure period.

Low calcium FA based geopolymer concrete samples after 24 hr of casting at 60°C curing; exposed to 5% sodium sulfate solution for about 1 year shows no damage to the surface of the concrete specimens and exhibited a very good resistance against sulfate attack (Wallah and Rangan. Further, it was noticed that no significant changes were observed in the compressive strength and weight after exposed to different periods over the period of 1 year. Shankar and Khadiranaikar observed that a nominal loss occurred in weight, 3–12% loss in compressive strength and 7–30% loss in split tensile strength of geopolymer concrete when they were soaked in 10% magnesium sulfate solution over a period of 45 days. Further, it was noticed that a very little white deposit on the surface and its deterioration. Sukmak et al. studied the sulfate resistance of geopolymer made with silty clay and FA in 5% Na_2SO_4 and 5% $MgSO_4$ solutions by weight. It was observed that the compressive strength decreased by 10.8 and 21.6% in Na_2SO_4 and $MgSO_4$, respectively, when they were exposed for 240 days. After exposure to the sulfate environment, ettringite, gypsum, and brucite were noticed and the C─S─H phase disappeared and ettringite phase formed.

The average water absorption and apparent volume of permeable voids (AVPV) of FA based geopolymer concrete were less than 5 and 12%, respectively, and these comes under the classes of low and good., By increasing the alkaline to FA ratio, aggregates to solids ratio and by reducing the water to solids ratio, these values could be further improved. The aggregate grading does not show significant effect on the water absorption and AVPV. Olivia and reported that the water permeability of GPC was in the range of 2.46×10^{-11} to 4.67×10^{-11} m/s and the void content was 8.2–13%. According to Rendell et al. the concrete quality as average when it permeability was in the range of 10^{-11}–10^{-12} m/s. Bhutta et al. reported that the geopolymer concrete made with blended FA had shown only 4% loss in mass when compared the 20% loss in concrete made with OPC samples when they were exposed to 5% sodium sulfate solution over a period of 1.5 year. Further, it was reported that the GPC was less susceptible to sulfate attack due to low calcium content and water absorption when compared to concrete with OPC.

2.23.4 Structural applications

Sumajouw et al. investigated the behavior of slender columns made with low calcium FA based geopolymer concrete with sodium hydroxide and sodium silicate as the alkaline solution. The columns were of size 175 mm^2 and 1.5 m long with two longitudinal reinforcement ratios (1.47 and 2.95%) and simply supported end conditions. All the samples were cured at 60°C for 24 hr. It was found that the load carrying capacity of the columns was increased with the decreased eccentricity and increased longitudinal reinforcement ratio. Further, it also increased with the increase in compressive strength. Fernandez-Jimenez et al. studied the bond strength of FA based geopolymer concrete by conducting the pull out test on

200 × 200 × 200 mm concrete cubes along with other engineering properties of GPC. It was reported that the FA based geopolymer concrete exhibits superior bond strength, very low drying shrinkage and hasty development in initial compressive strength. The fast development in initial compressive strength attributes the dense microstructure, which results in smaller pore sizes in the alkaline system compared to the sizes of pores in OPC system. Sumajouw and reported that the flexural behavior and mode of failure of FA based geopolymer concrete beams have shown to be similar to those of concrete beams made with OPC. Further, it was reported that the flexural capacity and deflection of FA based beams were in good agreement with the provisions stipulated by the current standards established for OPC concrete members. Sofi et al. performed the pull-out test on FA based geopolymer concrete beam and cube samples with different rebar sizes. It was found that irrespective of the size of the rebar, the failure occurred by splitting of the concrete surrounding the rebar and with the decrease in rebar size the bond strength increased and these results were conservative when they were compared with the predictions from various standards namely: Eurocode 2, ACI 318-02 and AS3600. Sarker et al. also studied the bond strength of geopolymer concrete and normal concrete with OPC. It was observed that the variation in bond stress and slip was similar in both geopolymer concrete and OPC concrete. Sarker investigated the bond strength of geopolymer concrete and concrete with OPC with different diameters (20–24 mm) of 500 MPa deformed steel bars. It was found that the cracking pattern of GPC and OPC were similar under pull-out load and the failure observed was brittle. Further, it was found that the bond strength of geopolymer concrete relatively more than that of OPC concrete due to the larger splitting strength of GPC than OPC of the same compressive strength. Songpiriyakij et al. reported that at 18 M, the geopolymer paste made with 60% FA and 40% silica fume yields the maximum compressive strength and bond strength. It was further reported that the bond strength of this geopolymer concrete was ~1.05–1.12 and 1.03–1.60 times higher for plain and deformed bars, respectively, when compared to control concrete. Chang et al. investigated the shear performance of nine rectangular reinforced geopolymer concrete beams. The combination of sodium hydroxide and sodium silicate as alkaline liquid and the concentration of NaOH of 14 M were used in the investigation. All the beams were of same size with different percentage longitudinal reinforcement (1.74%, 2.32%, 3.14%) and various percentages of shear reinforcements (0.1, 0.13, 0.17%) and were designed to fail under shear. It was found that the shear failure of GPC beams were similar those made with OPC. Rahman and Sarker studied the behavior of reinforced columns made with low calcium FA based geopolymer concrete under combined axial load and biaxial bending. Twelve slender columns with different reinforcement ratios tested with various combinations of biaxial load eccentricities. It was reported that under biaxial

loading, the failure behavior of reinforced GPC columns and OPC columns were similar. Further, it was reported that the experimental results of GPC columns had shown good agreement with results predicted by Bresler's formula, which is normally used for the design concrete columns made with OPC.

2.23.4 ECONOMIC BENEFITS

Utilization of the FA in geopolymer concrete is a resource and energy saving process and also, indirectly it reduces the release of greenhouse gas CO_2 during the production of cement. This is beneficial for resource conservation and environmental protection. Lloyd and Rangan reported that Class-F FA based GPC under heat curing have lot of benefits in terms of economy when compared to concrete based on OPC. The cost of FA (1 tonne) is a little fraction of the cost of OPC (1 tonne). It was reported that even after considering the cost of alkaline solution (NaOH and Na_2SiO_3), the cost of GPC (FA based) per cubic meter was ~10–30% economical than that of made with OPC. Further, it was reported that with proper use of 1 tonne of FA gets nearly one carbon-credit which has a substantial redemption value. Furthermore, GPC which is FA based receives economic benefits through carbon-credit trade, as three cubic meters of good quality of GPC can be produced with 1 tonne of FA. In addition, when it is used in the construction applications, it may result further economic benefits due to better long term and durability performance such as very low shrinkage and creep, superior resistance to acid and sulfate attack, low permeability, and so on. Vilamova and Piecha performed the standard cost analysis of materials for production of 1 m^3 geopolymer concrete with FA, concrete with Portland cement, concrete with cement and FA (more than 18%) and concrete with FA and superpalsticizer. The cost of FA was neglected in the analysis as it was a waste material and NaOH and Na_2SiO_3 are used as alkaline solution. The cost of materials for production of strength class C55/67 for different types reported by Vilamova and Piecha are presented in Figure **.**It was found that the cost of materials for production of 1 m^3 of FA geoplymer concrete a few-times more than that of concrete with Portland cement. Further it was observed that the cost of concrete with partial mixing of cement and FA was lower than that of geopolymer concrete with 100% FA. Furthermore, it was found that the cost of GPC could be minimized by partial replacement of FA with plasticizer. Mathew et al. conducted cost analysis of OPC concrete and GPC with FA and ground GGBFS. In the analysis, the transportation cost of FA and GGBS were considered same as cement. Further, the cost of alkaline solution and aggregates were as per the local market. It was reported that the cost of GPC was 7% higher than that of concrete with OPC. Also, it was reported that without normalizing the transporting cost of FA and GGBS, the cost of GPC would be more than two times that of OPC concrete. The cost contributions of each ingredient in GPC and OPC reported by Mathew et al. are presented in Figures and , respectively.

Chapter 3: Experimental Program

3.1 Materials:

Following materials are required to produce this concrete:

- Fly ash - A byproduct of thermal power plant.
- Sodium silicate is an inorganic sodium salt which has silicate as the counterion.
- Soduim hydroxide is sometimes called caustic soda or lye.
- Fine aggregates and coarse aggregates as required for normal concrete.
- sikament 163 m is Superiorly increases workability with concrete and is highly workable and fluid.

3.1.1 Fly ash

In the present study, low-calcium fly ash (FA) class F according to ASTM C618 (2008) produced in a coal-fired power plant was used as a source of a pozzolanic material with specific gravity of 2.31. The chemical composition of the used fly ash as determined by X-Ray Fluorescence (XRF) analysis is shown in Table (3.1).

Table 3.1 chemical comporrions

CHEMICAL COMPOSITIONS OF FLY ASH AS DETERMINED BY XRF

Oxide	(%) by mass
Silicon dioxide (SiO2)	60.25
Aluminum oxide (Al2O3)	28.57
Ferric oxide (Fe2O3)	4.99
Total SiO2 + Al2O3 + Fe2O3	93.81
Calcium oxide (CaO)	1.19
Phosphorus pent oxide (P2O5)	0.52
Sulphur trioxide (SO3)	0.04
Potassium oxide (K2O)	1.08
Titanium dioxide (TiO2)	2.31
Sodium oxide (Na2O)	0.01
Magnesium oxide (MgO)	0.24
Loss on Ignition (LOI)	0.55
Specific gravity	2.31
Specific Surface Area (cm2/g)	5000

3.1.1.1 What is fly ash?

Fly ash is the finely divided residue that results from the combustion of pulverized coal and is transported from the combustion chamber by exhaust gases. Over 61 million metric tons (68 million tons) of fly ash were produced in 2001.

3.1.1.2 Where does fly ash come from?

Fly ash is produced by coal-fired electric and steam generating plants. Typically, coal is pulverized and blown with air into the boiler's combustion chamber where it immediately ignites, generating heat and producing a molten mineral residue. Boiler tubes extract heat from the boiler, cooling the flue gas and causing the molten mineral residue to harden and form ash. Coarse ash particles, referred to as bottom ash or slag, fall to the bottom of the combustion chamber, while the lighter fine ash particles, termed fly ash, remain suspended in the flue gas. Prior to exhausting the flue gas, fly ash is removed by particulate emission control devices, such as electrostatic precipitators or filter fabric baghouses.

3.1.1.3 Where is fly ash used?

Currently, over 20 million metric tons (22 million tons) of fly ash are used annually in a variety of engineering applications. Typical highway engineering applications include: portland cement concrete (PCC), soil and road base stabilization, flowable fills, grouts, structural fill and asphalt filler.

Table 3.2 sample oxide analyses of ash and Portland cement.

Compounds	Fly Ash Class F	Fly Ash Class C	Portland Cement
SiO_2	55	40	23
Al_2O_3	26	17	4
Fe_2O_3	7	6	2
CaO (Lime)	9	24	64
MgO	2	5	2
SO_3	1	3	2

3.1.1.4 What makes fly ash useful?

Fly ash is most commonly used as a pozzolan in PCC applications. Pozzolans are siliceous or siliceous and aluminous materials, which in a finely divided form and in the presence of water, react with calcium hydroxide at ordinary temperatures to produce cementitious compounds.

3.1.1.5 Environmental benefits.

Fly ash utilization, especially in concrete, has significant environmental benefits including: (1) increasing the life of concrete roads and structures by improving concrete durability, (2) net reduction in energy use and greenhouse gas and other adverse air emissions when fly ash is used to replace or displace manufactured cement, (3) reduction in amount of coal combustion products that must be disposed in landfills, and (4) conservation of other natural resources and materials.

The dry collected ash is normally stored and handled using equipment and procedures similar to those used for handling portland cement:

- Fly ash is stored in silos, domes and other bulk storage facilities.
- Fly ash can be transferred using air slides, bucket conveyors and screw conveyors, or it can be pneumatically conveyed through pipelines under positive or negative pressure conditions.
- Fly ash is transported to markets in bulk tanker trucks, rail cars and barges/ships.
- Fly ash can be packaged in super sacks or smaller bags for specialty applications.

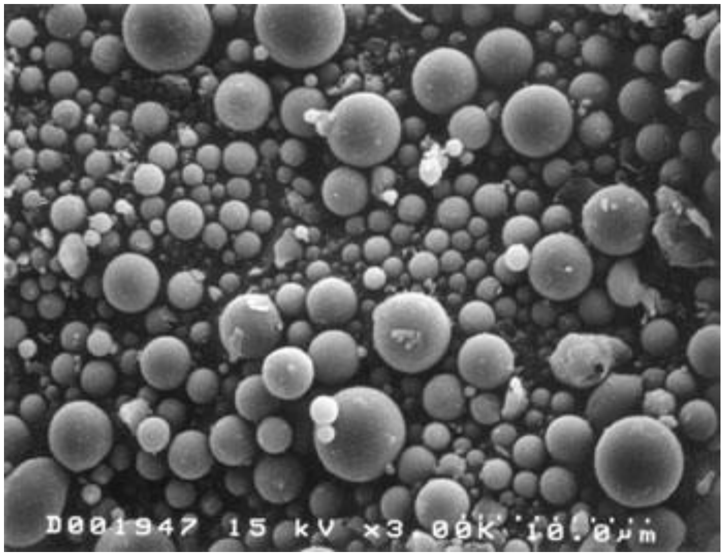


Figure 3.1 fly ash molecules

3.1.2 Sodium silicate:

sodium silicate employed in the treatment of concrete:

In most masonry products, concrete treated with a solution of sodium silicate helps to minimise porosity such as concrete, stucco, and plasters. This effect helps minimise water penetration, but has no known effect on minimising the absorption and emission of water vapour.

3.1.2.1 What is Sodium silicate?

Sodium silicate is an inorganic sodium salt which has silicate as the counterion. It is also called Sodium metasilicate or Waterglass. The chemical formula of Sodium silicate is (Na2O)x·SiO2.

Sodium metasilicate is a flaked solid or powdered substance. It dissolves in water to produce alkaline solutions. It has a polymeric anion. In alkaline and neutral solutions it is stable whereas, in acidic solutions, the silicate ions will react with hydrogen ions and form silicic acids, which are likely to decompose into hydrated silicon on the dioxide gel. When further heated, it drives off the water and a hard translucent substance called silica gel is obtained.

3.1.2.2 Properties of Sodium silicate – $(Na_2O)_x \cdot SiO_2$

colorless glassy or crystalline solids, or white powders. Except for the most silicon-rich ones, they are readily soluble in water, producing alkaline solutions.

Table 3.3 content of sodium silicate

Sodium silicate	$(Na_2O)_x \cdot SiO_2$
Molecular weight of Sodium silicate	122.062 g/mol
Number of hydrogen bond acceptor	3
Complexity	18.8
Number of covalent bonds	3

3.1.2.3 Uses of Sodium silicate ($(Na_2O)_x \cdot SiO_2$)

- Sodium silicate is used in wastewater treatment plants as an iron flocculant and an alum coagulant.
- It is used as hand-dyeing as a fixative.
- It is used in Pottery.
- It is widely used in food preservation, homebrewing, and aquaculture.

3.1.2.4 Production of Sodium silicate

Sodium silicate solution can be prepared in a reactor by treating a mixture of silica, water, and caustic soda with hot steam. The reaction is as follows:

$2x\ NaOH + SiO_2 \rightarrow (Na_2O)_x \cdot SiO_2 + x\ H_2O$

Sodium metasilicate can also be produced by dissolving silica SiO_2 in molten sodium carbonate (Na_2CO_3) at a temperature of 851 °C $Na_2CO_3 + SiO_2 \rightarrow (Na_2O)_x \cdot SiO_2 + CO_2$.

3.1.2.5 What are the uses of sodium silicate?

Sodium silicates are used primarily in detergents, paper, water treatment, and construction materials. One of the greatest uses of sodium silicate solutions is as a cement for the manufacture of cardboard. If used as a paper glue, there is a tendency for the sodium silicate joint to break gradually after a few years, at which point the paper surfaces are no longer holding together.

3.1.3 Soduim hydroxide:

The use of caustic soda in the treatment is a type of chemical treatment characterized by its effectiveness and low costs applied to sewage sludge in trenches. The former quality image, image is also known as alkaline lye (NaOH).

3.1.3.1 What is sodium hydroxide (NaOH)?

Sodium hydroxide is sometimes called caustic soda or lye. It is a common ingrediet in cleaners and soaps.

At room temperature, sodium hydroxide is a white, odorless solid. Liquid sodium hydroxide is colorless and has no odor. It can react violently with strong acids and with water. Sodium hydroxide is corrosive. NaOH can react with moisture from the air and may generate heat as it dissolves. This heat can be enough to cause a fire if it is near flammable materials.

Sodium hydroxide is useful for its ability to alter fats. It is used to make soap and as a main ingredient in household products such as liquid drain cleaners. Sodium hydroxide is usually sold in pure form as white pellets or as a solution in water.

3.1.3.2 What are some uses of sodium hydroxide?

Sodium hydroxide is used in bar soaps and detergents. Sodium Hydroxide is also used as a drain cleaner to unclog pipes.

Around 56% of sodium hydroxide produced is used by industry, with 25% of NaOH used in the paper industry. Some other uses include fuel cell production, to cure food, to remove skin from vegetables for canning, bleach, drain cleaner, oven cleaner, soaps, detergent, paper making, paper recycling, aluminum ore processing, oxide coating, processing cotton fabric, pickling, pain relievers, anticoagulants to prevent blood clots, cholesterol reducing medications, and water treatment.

Figer 3.2 sodium hydroxide

3.1.3.3 How might you be exposed to sodium hydroxide?

In the home, some household items like soaps or cleaners contain sodium hydroxide. Accidental ingestion or skin contact with these cleaners could cause harmful exposure.

Some industrial workplaces use sodium hydroxide. Here are some workplace exposure limits to NaOH in the air.

- Workplace air exposure limits.
- OSHA: The legal airborne permissible exposure limit (PEL) is 2 mg/m^3 averaged over an 8-hour work shift.
- NIOSH: The recommended airborne exposure limit (REL) is 2 mg/m^3 which should not be exceeded at any time.
- ACGIH: The threshold limit value (TLV) is 2 mg/m^3 which should not be exceeded at any time.

3.1.4 Fine aggregates and coarse aggregates

The fine aggregate used in this study was river siliceous sand complied to ECC-Appendix 3 (2007) with specific gravity of 2.55, a fineness modulus of 2.36 and water absorption of 0.90%. The physical and mechanical properties of the used sand are shown in Table (3.4). Moreover, the grain size distribution curve of the used sand is presented in Fig (3.3)

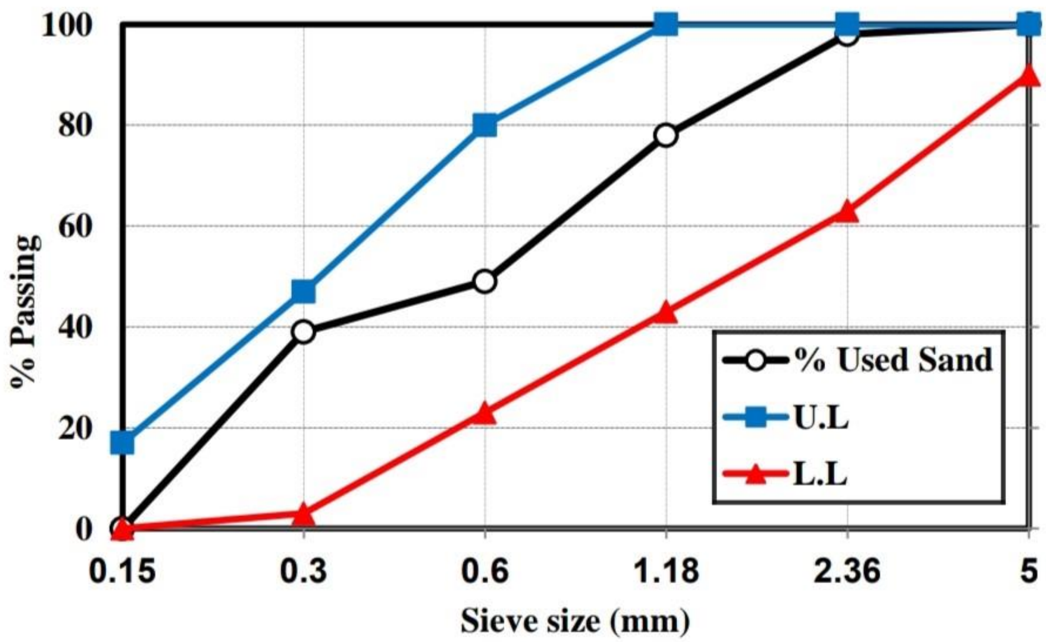


Figure 3.3 grading of the used sand

Table 3.4 physical and chemical properties of the used sand

Property	Value
Specific gravity	2.55
Unit weight,(t/m^3)	1.72
Void ratio, (%)	32.55
Fineness modulus	2.36
clay and fine matter % (by weight)	2
Water absorption, (%)	0.90

3.1.5 sikament 163 m:

Sikament® -163M is used as a highly effective waterreducing agent and super-plasticizer for the production of high quality concrete in hot climates. The dual action of Sikament® -163M promotes accelerated hardening with high early and ultimate strengths.

3.1.5.1 Uses:

As a substantial water-reducing agent, Sikament®163M is used where high early and ultimate strength is required, such as:

- Pre-stressed concrete surfaces.
- Concrete elements manufactured in Pre-cast factories, where rapid demoulding and early load application is required.
- Bridges and cantilever structures.

As a super plasticizer, Sikament®163M is used for flow concrete in:

- Slabs and foundations.

- Walls and columns.
- Slender components with densely packed reinforcements.
- Beams and ceilings.

Sekament will act as a strong plasticizer that increases high-quality workability with the construction of high-functional and streamlined materials such as:

- Slabs, foundations, walls, columns, beams and ceilings.
- Heavy-duty structural elements.
- Sicam is used as an agent
- Previous and bridge facilities.
- Concrete elements are pre-fabricated, as quick finishes require detachment and formwork or exposure to loads early.

3.1.5.2 Characteristics / Advatages.

-Sikament®163M provides the following properties:

- Substantial improvement in workability without increased water.
- Normal set without retardation.
- Accelerated hardening after setting.
- Significant increase of early and ultimate strengths.
- Especially suitable for concreting at elevated temperatures.
- Increased water tightness.
- Improved surface finish.
- Reduced shrinkage and creep.
- Chloride-free-does not attack reinforcement.

3.2 content of mixture concrete.

Table 3.5 : concrete mixture

Mix no.	Fly ash	F.A	C.A	Sodium silicate	Sodium hydroxide	No. of molarity	water	sikament
1	400	1000	700	90	90	8	81	4
2	400	1000	700	90	90	10	81	4
3	400	1000	700	90	90	12	81	4

Note :

- This mixture per cubic meter of geopolymer concrete.
- Three concrete mixtures were made with the same amounts of all materials, but the difference was in molarity.
- Ratio of activator solution (Sodium silicate : Sodium hydroxide) is (1 : 1) .
- Ratio of activator solution to fly ash is 45% .
- By increase the molarity properties of the mixture is getting better.

3.3 Tests:

Compressive, Tensil , Flexural strength , rebound hammer and denisty of geopolymer concrete

A total of tree

cubes (100 x 100 x 100) mm, three concrete cylinders of (100 x 200) mm, were cast from each batch and cured with temperature for 28 days to measure the concrete compressive strength. In addition, three beams (100 x 100 x 500) mm were cast from each batch and cured with temperature for 28 days to measure the concrete flexure strength. The average 28-day compressive strength values of batch cubes and cylinders were 330 and 380 kg/cm, respectively. The compressive strength test was carried out according to ECP 203-2018 and E.S.S 1658-1988, see Figures below

3.3.1 compressive strength:

Compression testing is a very common testing method that is used to establish the compressive force or crush resistance of a material and the ability of the material to recover after a specified compressive force is applied and even held over a defined period of time. Compression tests are used to determine the material behavior under a load. The maximum stress a material can sustain over a period under a load (constant or progressive) is determined.

Figure 3.4 - Compressive strength

Figure 3.5 - Compressive strength

3.3.2 Tensile strength:

Tensile strength is a destructive test process that provides information about the tensile strength, yield strength, and ductility of the metallic material .

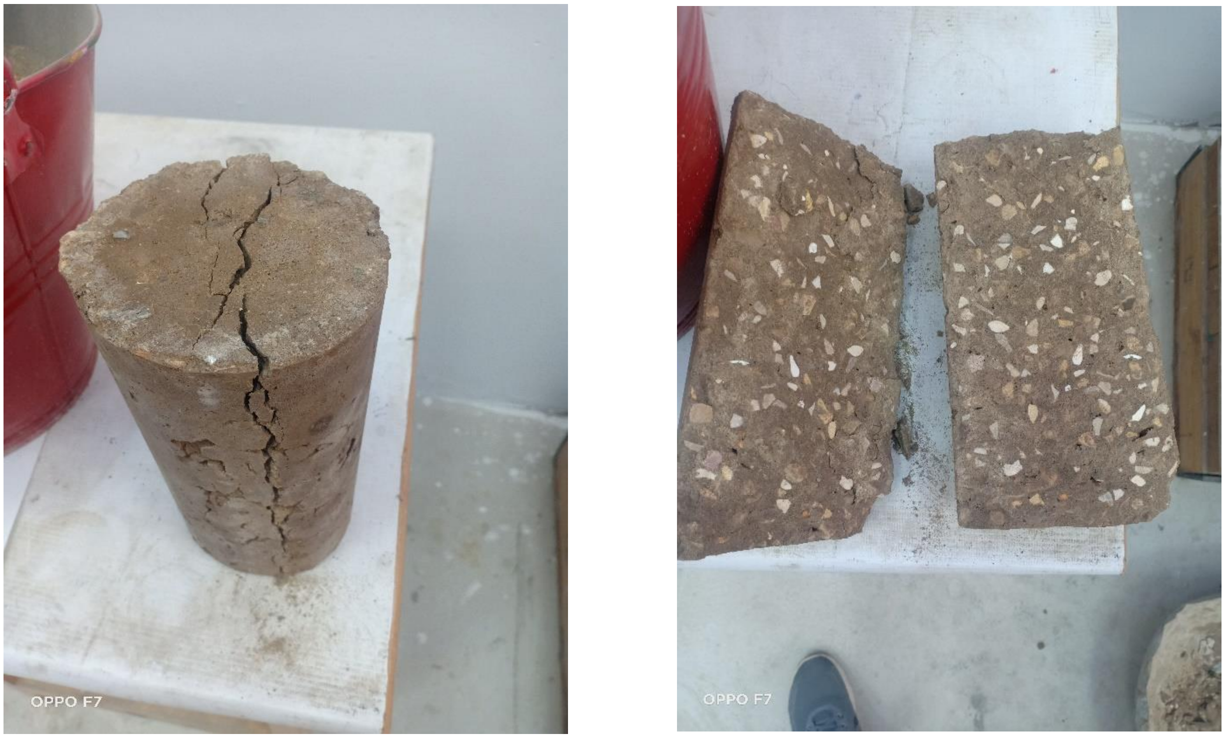


Figure 3.6 - Tensil strength

Figure 3.7 - Tensile strength

3.3.3 Flexural strength:

Flexural testing measures the force required to bend a beam of plastic material and determines the resistance to flexing or stiffness of a material.

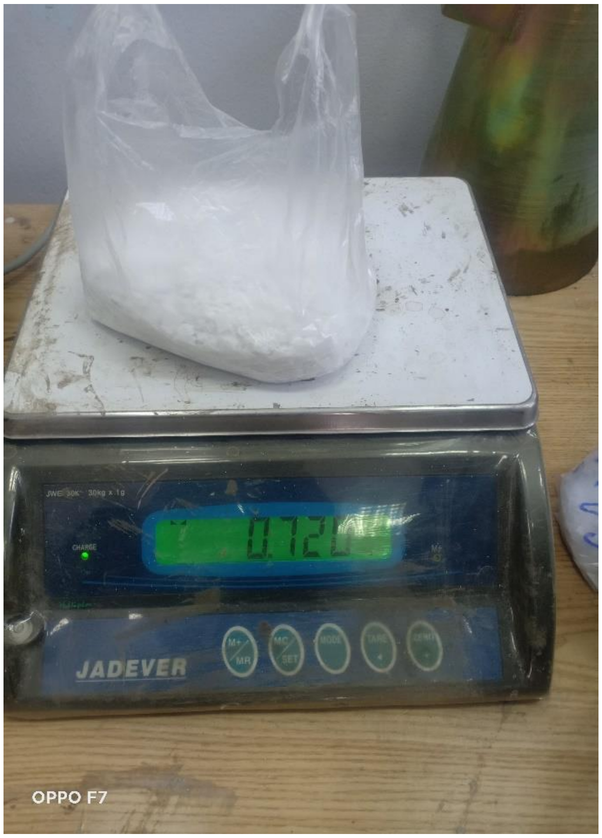

Figure 3.8 - Flexural strength

3.3.4 rebound hammer:

Rebound Hammer test is a Non-destructive testing method of concrete which provide a convenient and rapid indication of the compressive strength of the concrete. The rebound hammer is also called as Schmidt hammer that consist of a spring controlled mass that slides on a plunger within a tubular housing. The operation of rebound hammer is shown in the fig.1. When the plunger of rebound hammer is pressed against the surface of concrete, a spring controlled mass with a constant energy is made to hit concrete surface to rebound back. The extent of rebound, which is a measure of surface hardness, is measured on a graduated scale. This measured value is designated as Rebound Number (rebound index). A concrete with low strength and low stiffness will absorb more energy to yield in a lower rebound valu.

Figure 3.9 - rebound hammer

Figure 3.10 - rebound hammer


0.720
JADEVER
OPPO F7


JADEVER
OPPO F7


20.005
OPPO F7


14.005
OPPO F7

Figure 3.11 - quantity of concrete mix

Figure 3.12 - Tool processing and all material.

Chapter 4: Results and discussion.

4.1 Cube Compressive strength test:

4..1.1 After 7 days from casting concrete.

Table 4.1 - Cube Compressive strength test After 7 days from casting concrete.

Results After 7 day					
Mix Number	Cube number	Weight (Kg)	Fracture Load (KN)	Compressive Strength (N/mm^2)	
1	1	2.407	312.6	31.2	
	2	2.380	261.7	26.1	
2	1	2.270	227.1	22.7	
	2	2.345	285.7	28.5	
3	1	2.280	205.5	20.5	
	2	2.315	287.6	28.7	
	3	2.245	92.3	9.2	

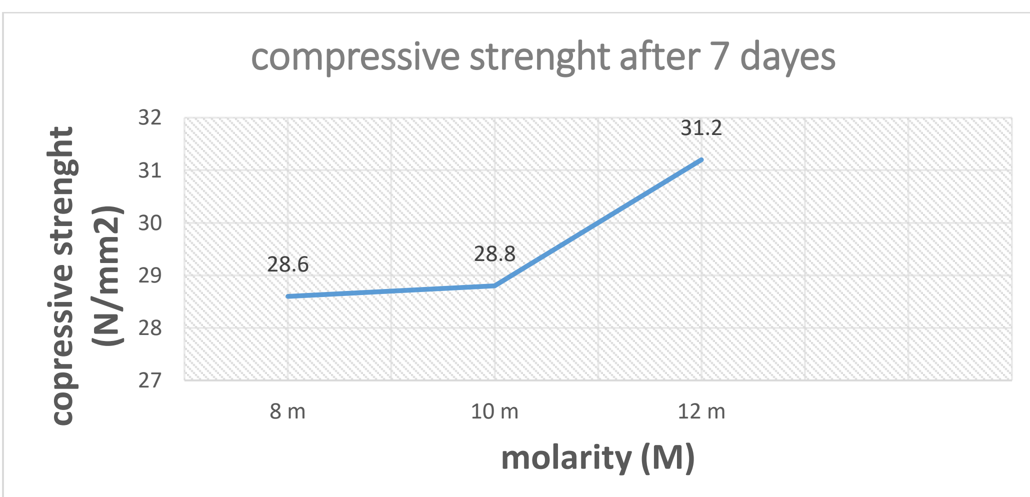


Figure 4.1 compressive strength after 7 days

Note:

- Cube No. 3 in mixture 3 was not heat treated like the other samples.
- Sodium hydroxide in the first mixture is .72 kg to 1.08 kg water.
- sodium hydroxide in the second mixture is .86 kg to .94 kg water.
- sodium hydroxide in the third mixture is 1.00 kg to .80 kg water.

4..1.2 After 28 days from casting concrete.

Table 4.2 - Cube Compressive strength test After 28 days from casting concrete.

Results After 28 day					
Mix Number	Cube number	Weight (Kg)	Fracture Load (KN)	Compressive Strength (N/mm^2)	
1	1	2.42	320.3	32	
	2	2.345	324	32.4	
	3	2.34	388.5	38.8	
2	1	2.375	408.8	40.8	
	2	2.375	325.6	32.5	
	3	2.365	326.1	32.6	
3	1	2.305	347	34.7	
	2	2.285	351	35.1	
	3	2.36	390.4	39.04	

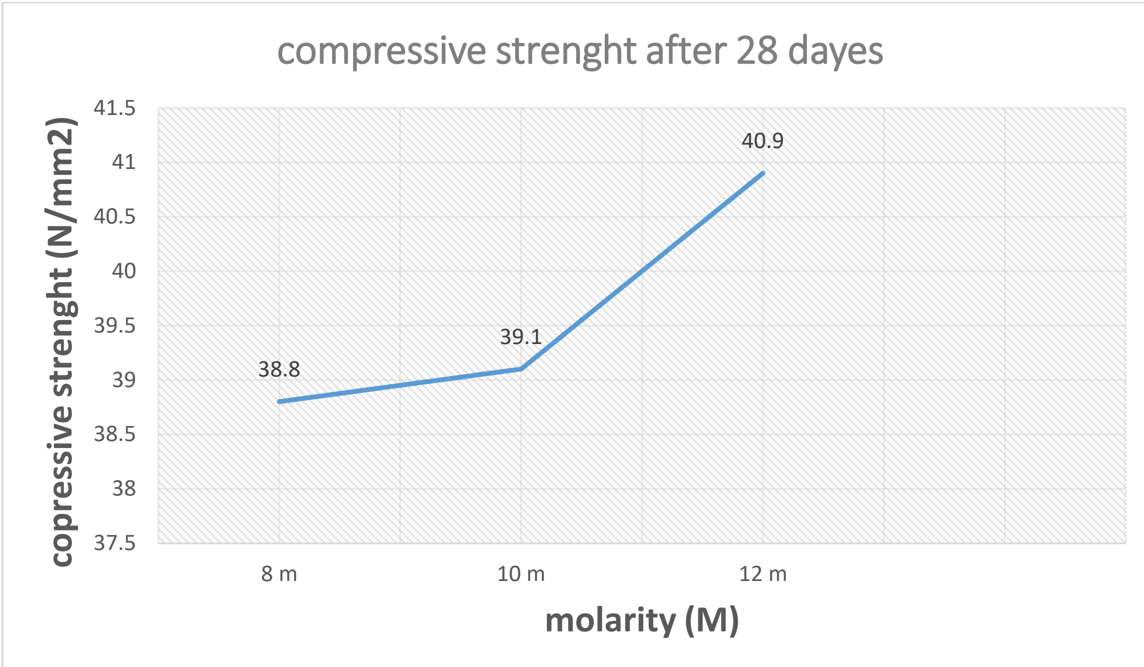


Figure 4.2 compressive strength after 28 days

4.2 cylinder tensile strength test:

Table 4.3 - Cylinder Tensile strength test After 28 days from casting concrete

Results After 28 day						
	Mix Number	Weight (Kg)	Fracture Load (KN)	Tensile Strength (N/mm^2)	
	1	3.560	102.8	2.59	
	2	4.175	106.6	3.3	
	3	4.05	107.5	3.39	

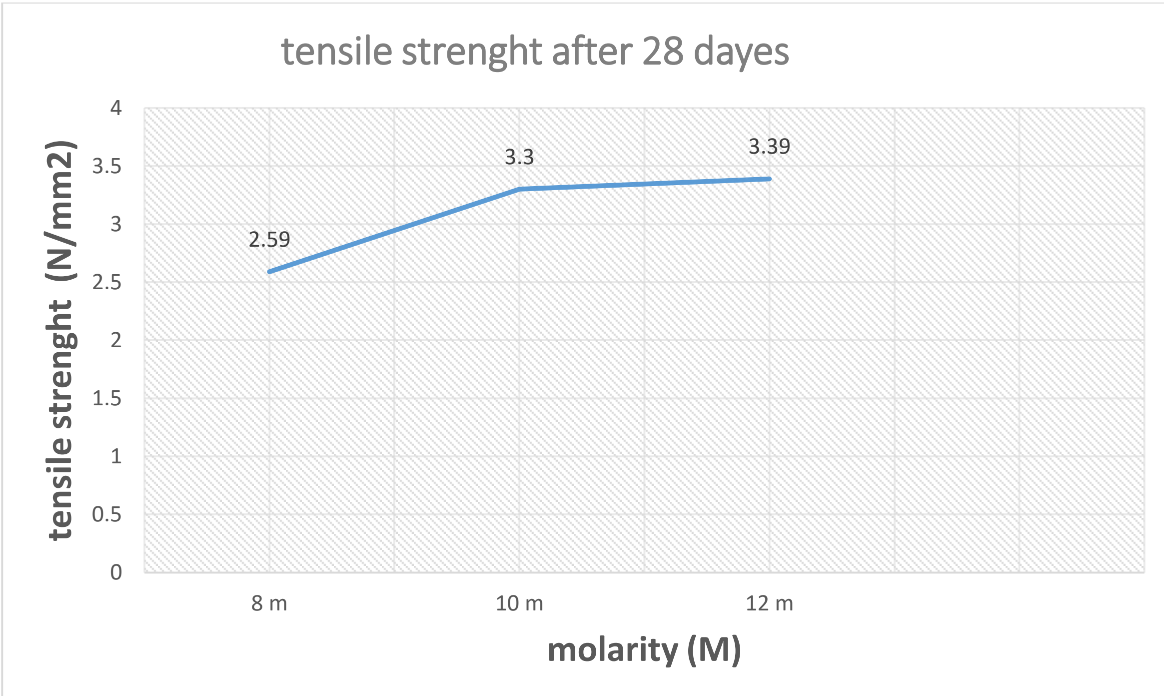


Figure 4.3 tensile strength after 28 days

4.3 Beam Flexural strength test:

Table 4.4 - Beam Flexural strength test After 28 days from casting concrete.

Results After 28 day					
	Mix Number	Weight (Kg)	Fracture Load (KN)	Tensile Strength (N/mm^2)	
	1	11.795	4.554	2.049	
	2	11.14	5.369	2.416	
	3	10.80	6.394	2.877	

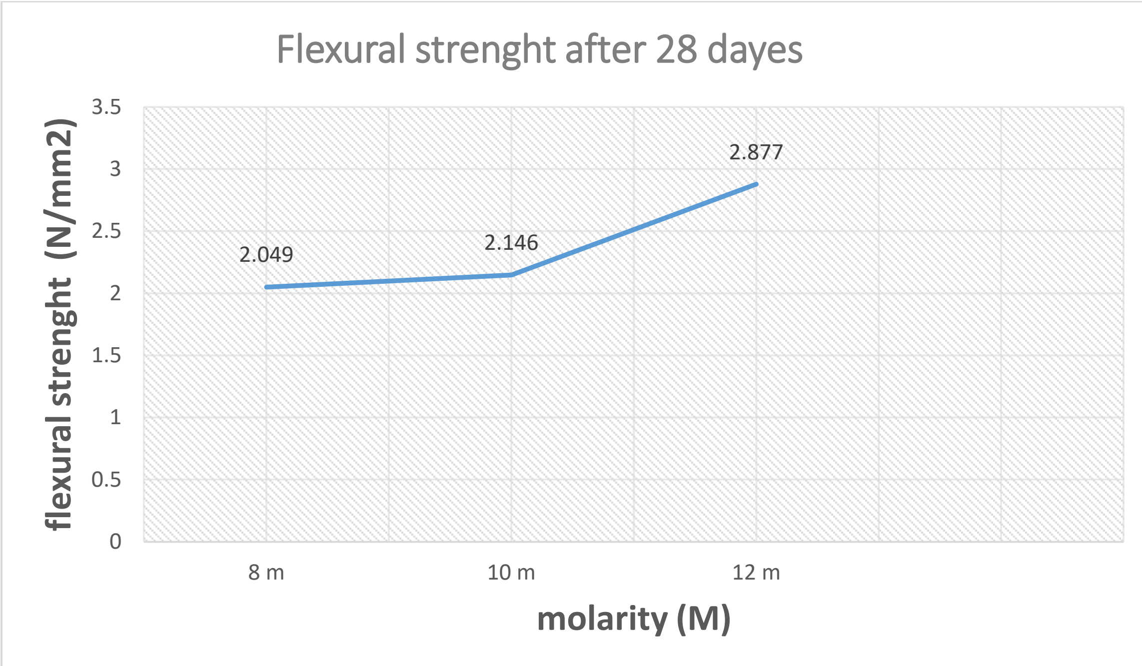


Figure 4.4 flexural strength after 28 days

4.4 rebound hammer test:

4.4.1 rebound hammer test after 7 days.

Table 4.5 - rebound hammer test after 7 days.

Mix Number	Cube number	Weight (Kg)	Rebound hammer
1	1	2.407	28-27-26-24-28-25-26-28
	2	2.380	25-28-27-29-30-28-26-24
2	1	2.270	28-29-30-32-25-23-28-27
	2	2.345	26-27-25-29-23-30-32-31
	1	2.280	27-25-26-29-24-28-30-25

3	2	2.315	29-26-24-28-26-24-29-27
	3	2.245	30-25-26-28-27-29-24-26

4.4.2 rebound hammer test after 28 days.

Table 4.6 - rebound hammer test after 28 days.

Mix Number	Cube number	Weight (Kg)	Rebound hammer
1	1	2.42	28-29-30-32-25-23-28-27
	2	2.345	26-27-25-29-23-30-32-31
	3	2.34	27-25-26-29-24-28-30-25
2	1	2.375	29-26-24-28-26-24-29-27
	2	2.375	30-25-26-28-27-29-24-26
	3	2.365	28-27-26-24-28-25-26-28
3	1	2.305	25-28-27-29-30-28-26-24
	2	2.285	30-29-28-32-34-28-29-27
	3	2.36	32-28-29-25-27-28-30-29

4.5 conclution:

From various studies conducted it can be concluded that fly ash-based Geopolymer is preferred over normal concrete as it excels in many aspects such as compressive strength, exposure to aggressive environment, workability and exposure to high temperature. The study shows that Geopolymer concrete is more resistant to corrosion and fire, and has high compressive and tensile strengths, it also gains its full strength quickly (cures fully faster). The shrinkage is also less compared to standard concrete. Thus, taking account these structural advantages it may be concluded that, in near future Geopolymer concrete may find an effective alternate to standard cement concrete. For the common conclusion of merits and demerits of geopolymer concrete detailed study and research is required by the researches.

Geopolymer concrete can be used easily under the same conditions which apply for ordinary Portland cement concrete. These constituents of geopolymer concrete are capable of being mixed with low alkali activating solution and are curable in short time, under natural conditions. The production of this geopolymer concrete can be effectively mixed and hardened like Portland cement. Geopolymer concrete can be used for repair and renovation works. Due to its property to attain high strength early, Geopolymer Concrete can be effectively used in the precast industries, so that in short duration huge production can be accomplished and the breakage during transportation shall also be minimized. The Geopolymer Concrete can be effectively used for the beam column junction of a reinforced concrete structure. Also, geopolymer Concrete shall be efficiently used in the Infrastructure works. In addition to that the Fly ash shall be effectively used and hence no landfills are required to dump the fly ash.

When steam cured than water submerged curing process geopolymer concrete gains better strength. The strength gained is increased by 10% when steam cured.

The necessary steps can be taken by government to extract sodium hydroxide and sodium silicate solution from the waste materials of chemical industries, so that the cost of alkaline solutions required for the geopolymer concrete shall be reduced.

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Appendix

1) Software Code

Tip Microsoft Word is a word processing program used for writing letters, memos, reports and paper presentations. Microsoft Excel is a spreadsheet program used for calculations, making charts and recording data about all sorts of business processes.

Uses for Microsoft Word

Microsoft Word is a word processing program designed to make it possible to create a variety of documents that will look the same between different computers and similar on the screen to how they appear on paper.

It's used by businesses and individuals to write personal and professional letters, reports for work and school and to take notes on conversations and in seminars and classes. Because it's so widely used, many businesses appreciate that it's possible to send documents created in Word to clients, employees and other business associates without worrying about whether or not they'll be able to open them.

The program allows for the use of a wide variety of fonts and styles in order to create a number of different types of documents, from informal lists of notes after a meeting to reports ready to ship out to a valued client or top executive.

Uses for Microsoft Excel

Microsoft Excel is a spreadsheet program. That means it's used to create grids of text, numbers and formulas specifying calculations. That's extremely valuable for many businesses, which use it to record expenditures and income, plan budgets, chart data and succinctly present fiscal results.

It can be programmed to pull in data from external sources such as stock market feeds, automatically running the data through formula such as financial models to update such information in real time. Like Microsoft Word, Excel has become a de facto standard in the business world, with Excel spreadsheets frequently emailed and otherwise shared to exchange data and perform various calculations.

Excel also contains fairly powerful programming capabilities for those who wish to use them that can be used to develop relatively sophisticated financial and scientific computation capabilities.

Alternatives to Word and Excel

Microsoft Word and Excel aren't the only word processing and spreadsheet programs available. Google's G Suite office software collection is increasingly popular with many businesses, and it offers free versions to many users. Apple's iWork suite, including Pages and Numbers, competes with Word and Excel, is also used by Mac users as an alternative to Microsoft Office.

The open source LibreOffice toolkit also includes free alternatives to Word and Excel, called Writer and Calc.

With PowerPoint on your PC, Mac, or mobile device, you can:

- Create presentations from scratch or a template.
- Add text, images, art, and videos.
- Select a professional design with PowerPoint Designer.
- Add transitions, animations, and cinematic motion.
- Save to OneDrive, to get to your presentations from your computer, tablet, or phone.
- Share your work and work with others, wherever they are.

2) Engineering Standards

Project Standards

1. Egyptian code ECP: 203 (2020): Egyptian code of practice for design and construction of reinforced concrete structures, Annual Book for testing of materials, part 3, Ministry of Housing and Urbanization, Housing and Building Research Center, Cairo, Egypt.
2. Egyptian standard specification ES requirements (4756-1/2005)

3) Relation With Environment.

Environmentally friendly geopolymer concrete.

An experimental analysis of the properties of geopolymer concrete, for both the fresh and hardened case of concrete, is presented in the paper. Concrete mixtures differed according to the type and quantity of mineral additives (fly ash). It is proved that the addition of fly ash significantly improves the mechanical properties and durability of geopolymer concrete, and it is environmentally friendly due to the reduction of carbon dioxide emissions. Based on the test results obtained, appropriate recommendations for practical application are given.