THE COMPARATIVE PERFORMANCEOF THE SILICA FUMES BASED GEOPOLYMER CONCRETE AND GGBS BASED GEOPOLYMER CONCERTE

Abstract

The primary manufacture of Portland cement in the building sector results in the release of air pollutants, which causes environmental pollution. It is an eco-friendly and sustainable alternative to concrete made with Ordinary Portland Cement (OPC) and has the benefits of rapid strength gain, no water curing, good mechanical and durability properties, and good mechanical and durability properties. In this research used many tests like that compression test, split tensile test, workability, durability test, UPV (Ultrasonic pulse velocity) and Rehbar hammer test. This paper examines the compressive strength of geopolymer concrete made by substituting silica fume (SF) for ground-granulated blast-furnace slag (GGBS) at percentages of 0%, 20%, 40%, 60%, 80%, and 100%, as well as its studies at various molarities. At 7, 14, and 28 days under two types of curing, the compressive strength of the geopolymer concrete specimens was tested (water curing and room curing). Various mechanical properties of GPCs, including workability, have been the subject of experimental investigations. When exposed to 200 C, the UPV values decreased by 57%, 42%, and 44% for M1, M2, and M3, respectively. Likewise, UPV values also decreased for the other temperatures, resulting in a decreased of 81%, 64%, and 68% for M1, M2, and M3 after exposure to 400 C. By using just self-curing mechanisms and a ratio of 40% SF to 60% GGBS, geopolymer concretes made with various combinations of SF and GGBS may create structural concretes of high grades (far higher than 45MPa). The GPC mixes were simply made utilising tools that were already utilised to make ordinary cement concretes. The effects of SF on the strength of concrete mixtures including geopolymer were investigated.

Keywords: Geopolymer, Sodium Silicate, GGBS, Concrete, SF, Sodium hydroxide.

Table of Contents

CHAPTER 1

INTRODUCTION

1.1 Background of study

Concrete is a crucial component of modern construction projects such as highways, dams, and skyscrapers. It is created using cement and a mixture of aggregates or additives. These additives can be either artificial or natural, but because natural additives are used so frequently, this vital supply has been depleted. Thus, using alternative aggregate to address some of the depletion of natural aggregate is a logical step, and using alternative aggregate made from waste materials would seem to be an uniform better option [1].

More than fifty years ago, the hunt for an alternate substance for manufacturing concrete began. Reusing materials primarily serves the purpose of reducing the negative effects of human activity on the earth and its ecosystem. Sustainable concrete design will result from the use of inorganic industrial waste items in the production of concrete. Industrial and other wastes were added to concrete to enhance its qualities and lower its cost, such as oil palm shells, copper slag, fly ash, wood waste ash, cement kiln dust, granite sludge, silica fume, steel chips, and rice husk ash [2].

Portland cement production is rising by 9% yearly throughout the world. Due to the significant quantity of carbon dioxide gas discharged into the atmosphere and the fact that Portland cement is one of the most energy-intensive building materials, PC production is currently under investigation [3]. Currently, Portland cement manufacture contributes around 1.5 billion tonnes of greenhouse gas emissions yearly, or roughly 7% of all greenhouse gas emissions to the earth's atmosphere. The globe is currently dealing with environmental contamination as a big issue. However, because it emits CO2 during manufacture, cement production results in pollution. On the other hand, demand for concrete is rising steadily due to how simple it is to prepare and can be fabricated into a variety of useful shapes. Therefore, environmentally friendly concrete should be used to solve this issue [4].

In order to manufacture concrete that is environmentally friendly, industrial waste products like fly ash, GGBS, etc. must be used in place of cement. Only 15% of FA is now employed for high value adding applications corresponding concrete and building blocks; the remainder is disposed of in landfills, which is an increasing challenge for FA disposal. In the case of cemented concrete, SF increases strength. In recent years, Geopolymer concrete has emerged as another potential application for SF in the building sector [5].

Because geopolymer technology can be used to treat various types and grades of SF, there is a huge potential for lowering waste SF material stocks. Since SF may hold a sizable amount of the produced ash, it is taken into consideration in this study when producing geopolymer concrete [6]. By substituting for or enhancing traditional concretes, geopolymer concretes (GPCs) are a type of inorganic polymer composite that make up a significant portion of the construction and building materials market. The three-dimensional Alumino-silicates substance, which is a binder made from the interaction of a feedstock or source material rich in silicon (Si) and aluminium (Al) with a concentrated alkaline solution, was first described as a geopolymer by Davidovits in the 1970s [1].

For the synthesis of geopolymers, the raw materials may include industrial waste products including fly ash, red mud, rice-husk ash, slag, and silica fume. The concentrated aqueous alkali hydroxide or silicate solution contains soluble alkali metals, often based on sodium (Na) or potassium (K). The raw materials' silicon and aluminium atoms are made to dissolve and produce the geopolymeric binder using very alkaline solutions.

Cement, sand, coarse aggregate, and water are the main ingredients of the most widely used building material, concrete. It is employed in the construction of dams, roads, tanks, offshore projects, and canal lining in addition to multi-story buildings. Concrete mix design is the process of selecting the right concrete materials and figuring out their relative quantities through the goal of generating concrete with the required strength, workability, and durability as quickly as feasible [7]. The compressive strength of hardened concrete, which is generally seen as a gauge of its extra properties, depends on the quantity and quality of cement, water, and aggregates, as well as the batching, mixing, placing, compaction, and curing procedures. The cost of labour, the cost of cement, which is substantially more expensive than aggregates, and the price of raw materials all go towards the expense of manufacturing concrete. Due to the possibility of excessive shrinkage and cracking in structural concrete as well as the formation of high hydration temperatures in mass concrete, both of which can result in cracking, it is crucial to create a mix that is as viable from a practical aspect as possible. The price of the ingredients needed to produce a minimum mean strength, or characteristic strength, that is stipulated by the structures' designers determines the actual cost of concrete. Quality control increases the cost of concrete without a doubt, however it depends on the quality control processes. Engineers and scientists are currently working to make concrete stronger by adding a number of economical and alternative materials as an additive or as a partial replacement for cement. Some examples of these materials include fly ash, silica fume, steel slag, etc. [8]. For example, fly ash from power plants as well as silica fume from of the reduction of highly pure quartz by coke, coal, and wood chips in an electric arc furnace during the production of silicon metal or ferrosilicon alloys are examples of waste materials from other industries that are commonly used in these products. However, because silica fume enhances the characteristics of concrete, it is being utilised more frequently. The use of micro silica as a pozzolanic material has grown recently since it improves the durability, permeability, strength, flexural strength, compressive strength, flexural strength, and tensile strength of both fresh and hard concrete when mixed in particular quantities.

Concrete is a crucial component of modern construction projects such as highways, dams, and skyscrapers. It is created using cement and a mixture of aggregates or additives. These additives can be either natural or artificial, but because natural additives are used so frequently, this vital supply has been depleted. Thus, using alternative aggregate to address some of the depletion of natural aggregate is a logical step, and using alternative aggregate made from waste materials would seem to be an even better option [9]. More than fifty years ago, the hunt for an alternate substance for manufacturing concrete began. Reusing materials primarily serves the purpose of reducing the negative effects of human activity on the earth and its ecosystem. Sustainable concrete design will result from the use of inorganic industrial waste items in the production of concrete [10].

Portland cement production is rising by 9% yearly throughout the world. Due to the significant amount of carbon dioxide gas discharged into the atmosphere and the fact that Portland cement is one of the maximum energy-intensive building materials, PC production is currently under investigation [11]. Currently, Portland cement manufacture contributes around 1.5 billion tonnes of greenhouse gas emissions yearly, or roughly 7% of all greenhouse gas emissions to the earth's atmosphere. The globe is currently dealing with ecological contamination as a big issue. However, because CO2 is released during the manufacture of cement, pollution is also produced during this process.

On the other hand, concrete is becoming more and more popular due to how simple it is to prepare and create in a variety of useful shapes. Therefore, environmentally friendly concrete should be used to solve this issue [12]. In order to manufacture concrete that is environmentally friendly, industrial waste products corresponding fly ash, GGBS, etc. must be used in place of cement. Only 15% of FA is now employed for high value adding applications similar building blocks and concrete; the remainder is disposed of in landfills, which is an increasing challenge for FA disposal. In the case of cemented concrete, SF increases strength. In recent years, Geopolymer concrete has emerged as another potential application for SF in the building sector [13]. Because geopolymer technology can be used to treat various types and grades of SF, there is a huge potential for lowering waste SF material stocks. Since SF may hold a sizable amount of the produced ash, it is taken into consideration in this study when producing geopolymer concrete [14].

By substituting for or enhancing traditional concretes, geopolymer concretes (GPCs) are a type of inorganic polymer composite that make up a significant portion of the construction and building materials market. A concentrated alkaline solution and a source material as well as feedstock rich in silicon (Si) and aluminium (Al) interact to form the three-dimensional alumino-silicates substance, was initially referred to as a geopolymer by Davidovits in the 1970s [14]. For the synthesis of geopolymers, the raw materials may include industrial waste products including slag, fly ash, rice-husk ash, red mud, and silica fume. The concentrated aqueous alkali hydroxide or silicate solution contains soluble alkali metals, often based on potassium (K) or sodium (Na). The raw materials' silicon and aluminium atoms are made to liquefy and produce the geopolymeric binder using very alkaline solutions.

To combat global warming, numerous initiatives have been made to replace regular Portland cement with concrete. Among them is the utilisation of substitute cementitious materials such fly ash, silica fume, GGBS, etc. Davidovits Joseph hypothesised that binders can be created by using an alkali activator to react with the alumina silicate components in a source material of geological origin or in by-product materials like silica fume, fly ash, and GGBS. [15]

Experimental research is being done to control the qualities of geopolymer concrete that was generated under sunlight curing conditions in both its fresh state and its hardened form. For the resolve of determining the workability, mechanical, and durability properties of polymer concrete, GGBS was combined with class-F fly-ash and silica fume. [16, 17, 18] It is well knowledge that concrete members are weak in tension and prone to failure because of their low tensile strength. This concrete flaw can be fixed by adding fibres. The inclusion of fibres in the concrete mix functions as crack arresters to stop cracks, therefore this weakness is also caused by microcracks at the aggregate-mortar interface. [19]

Hybrid fibres are defined as the addition of two or more distinct fibres to the concrete mix. These hybrid fibres can be utilised to make glass and polypropylene fibres as well as steel polypropylene fibres. [20] [21] To observe the behaviour of Geopolymer Concrete (GPC) and its strength properties, tests must be conducted. [22] Activator solution, Fly ash, and a scheme of aggregates are required ingredients in geopolymer concrete. Better, more exceptional durability and thermal strength properties can be found in geopolymer moulds. [23]

A novel inorganic compound binding substance called geo-polymer was primarily created by the reaction of base and alkali materials. This combines alumino-silicates, such as fly ash, with strong alkalis, for example sodium silicate and sodium hydroxide, and the result is an amorphous, highly three-dimensional alumina-silicate mixture with novel adhesive capabilities. A side byproduct of the manufacturing of silicon amalgams, silica-fume is a highly reactive pozzolana that was frequently added to early concrete to improve its various strength assets. [24]

The secondary C-S-H formation is emphasised as the primary description for the extraction of oxide minerals from ancient concrete. Davidovits identified geo polymers as a related amorphous three-dimensional alumina-silicate binder material. To produce released silico-aluminate tetrahedral elements, aggressive materials similar ash made of corundum and oxide are promptly disbanded into the strong base-forming solution. However, there are just a few studies on fume oxide in geopolymer (GP) in the works that is currently available. [25] Restricted works have mostly focused on understanding the presentation of oxide fume-intermingled ash using GPC.

1.2 The research problem

The primary manufacture of Portland cement in the construction industry results in the release of air pollutants, which leads to pollution. In contrast to concrete's hydrated calcium silicate binder system, geopolymer concrete (GPCs) is one kind of class of concrete that is founded on an inorganic alumino-silicate binder system.

1.3 The purpose of the study

Researchers looked into how SF affected the strength of geopolymer concrete mixtures. It has been found that the compressive strength for geopolymer increases as the amount of SF decreases.

In addition to requiring less energy, GPCs use industrial waste to create the binding system in concrete. Utilizing SF and GGBS is advantageous from an economic and environmental standpoint.

The influences of SF and GGBS on the workability and mechanical properties of concrete.

It reduces the CO_2 emission and shows that it is more eco friendly.

1.4 The objectives of the study

- To investigate the comparative performance of GGBS and silica fume.
- To find the max compressive strength among GGBS and silica fume.
- Comparision among the workability of geopolymer concrete, GGBS, silica fume.
- To study the samples for different percentages of GGBS and SF for 7, 14 and 28 days of curing.
- To investigate the strength of two types of curing (Room curing and water curing).

1.5 CONTRIBUTION TO KNOWLEDGE & STATEMENT OF SIGNIFICANCE

(Maximum one page)

- After doing this project we will come to know the effect on the environment, as GGBS and SF reduces the emission of CO_2 and also the economical benefits.
- Also we will find out that which one (OPC, GGBS or SF) gives more strength and durability under the same condition.
- Also we will study the difference in room curing and water curing and its effect on the strength of concrete.

1.6 Statement of Significance (Practical Contribution)

Yes this study will have a very good contribution in the practical field, following are the few points in the support of the statement,

- By using GGBS and SF the cement cost will be lower down which will help a rapid growth in the construction industry.
- As we all know in the today's world the greatest problem is of CO_2 emission and cement is one of the biggest contributor to it and by using GGBS and SF in cement it will lower it's emission to a great extent.
- Also geopolymer based concrete give a better strength and durability.

CHAPTER 2

LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

More thorough study is needed on this subject since there is a growing need for a binding substance for concrete other than cement that is more environmentally friendly. Researchers and engineers from all around the world are looking at geopolymer as a potential new green and environmentally friendly material. The characteristics, durability, and microstructure of geopolymer concretes in both the soft and hardened stages are currently of major importance.

Following a review of the literature, this part presents the results of numerous experiments that had a geopolymer concrete as their primary subject.

Fly ash from various sources was examined by Allouche [12] for its influence on the mechanical qualities of geopolymer concrete (GPC). They based their research on the idea that, given fixed mix design and curing circumstances, fly ash with the greatest characteristics will produce geopolymer concrete with the best mechanical performance. Knowing the properties of the fly ash utilised, they were able to construct an empirical model that determines the mechanical behaviour of the GPC. Sodium silicate and a 14 M NaOH solution were utilised as the activating solution. The researchers combined the two solutions in a weight-to-volume ratio of 1:1. Well-graded sand was utilised as the fine aggregate and pea gravel as the coarse aggregate in the mixture. To achieve a slump of 10-15 cm, high range superplasticizer was added to the mixture in the final 60 seconds of mixing. The steps of the mixing process were as follows: 1. Stirring fly ash into the NaOH solution for 30 seconds. 2. Sodium Silicate addition and 30 second mixing. 3) Add coarse aggregate and stir for 120 seconds (in the last 60 seconds, the superplasticizer was added). For the compressive strength test in accordance with ASTM C39, cylindrical moulds were employed, and additional cylindrical specimens were utilised for the elastic modulus test in accordance with ASTM C469. Additionally, flexural strength was evaluated utilising an ASTM C78-compliant third point load. According to the experimental findings, the first three to five days were when 95 percent of the compressive strength and flexural strength were attained. The research also tested the density of geopolymer concrete, which ranged from 1890 to 2371 kg/m3. Flexural strength measurements ranged from 2.24 to 6.41 MPa. The values of the modulus of elasticity were

6,812 MPa to 42,878 MPa [12]. The values fluctuated greatly and were greatly influenced by the fly ash source. Results indicated that the aggregate and geopolymer paste moduli both have an impact on the elasticity of geopolymer concrete. Additionally, it was discovered that a larger porosity and a decrease in strength and elasticity come from increasing the activating solution to fly ash ratio. Additionally, it was discovered that the geopolymer concrete's mechanical characteristics are comparable to those of regular concrete. Additionally, it was discovered that the resistance of geopolymer concrete to corrosion brought on by sulfuric acids was significantly higher than that of OPC concrete. Accordingly, the study comes to the conclusion that geopolymer concrete is preferred in constructions that are subject to assaults from sulfuric salt [12]. To determine the ideal fly ash geopolymer concrete mix, Abdul Aleem and Arumairaj [13] carried out a new investigation. According to the mix percentage estimates, 103 kg/m3 of Na2SiO3 solution and 41 kg/m3 of NaOH solution were used. Na2SiO3 and NaOH were combined in the investigation in a ratio of 2.5:1. Because earlier study suggested that water curing is ineffective, the researchers employed steam curing for the concrete examples. This is because geopolymer concrete can only harden by steam curing or curing by hot air for at least 24 hours. But according to Nath and Sarker [15], the addition of GGBS to fly ash-based geopolymer concrete results in compressive strength and workability that is comparable to OPC concrete at low ambient temperature curing and without the requirement for heat curing. According to the findings of their [13] investigation, Abdul Aleem and Arumairaj, geopolymer concrete performs admirably in terms of strength and workability. Additionally, the researchers discovered that adding more coarse and fine particles strengthens the link between them and the alkaline solution, raising the concrete's compressive strength as a result. Temuujin and colleagues [21] also came at the same result. They came to the conclusion that the strength of the binder and the bond between the binder and the aggregate had an impact on the compressive strength of geopolymer concrete. They came to the conclusion [21] that a geopolymer binder may form a strong connection with the fine material. At the conclusion of Aleem and Arumairaj's [13] investigation, it was discovered that the ideal fly ash-based geopolymer concrete mixture provided a compressive strength of 52.44 MPa after 28 days. Fly ash to activating solution ratio was 0.35 [13]. The strength of concrete made entirely of fly ash-based geopolymer was evaluated by Ryu et al. [22] to see how the alkaline solutions affected it. They avoided using coarse material in their mixtures to avoid having an impact on the strength. There were three different NaOH molarities used: 6, 9, and 12 M. Additionally, the researchers looked at the effects of using NaOH alone as an activator vs combining it with another activator like sodium silicate (Na2SiO3). As a result of a quick geopolymerization process, the results demonstrated that a larger molarity of NaOH enhances compressive strength as well as early compressive strength. The maximum compressive strength was 46 MPa for 12 M NaOH after 56 days. The cause of this was attributed to the greater breakdown of the glassy fly ash chain caused by the addition of additional alkalinity as molarity increased. Additionally, it was discovered that utilising both NaOH and Na2SiO3 as the activating solution resulted in a compressive strength of 47 MPa, which was superior than using only one activating solution. SEM analysis was also employed by Ryu et al. [22] to examine the microstructure of the concrete made with fly ash. Alumina and silica are released from the fly ash particles' surface when the soluble phases of the fly ash are dissolved by the alkali solution. These phases create the shell of alumino-silicate gel by reacting with the alkalis coming from the activating agent and then condensing on the fly ash surface [6]. Figure 7 displays the SEM picture of the geopolymer specimen created by Ryu et al. [22] after 28 days, along with some fly ash particles that did not undergo the geopolymerization reaction.

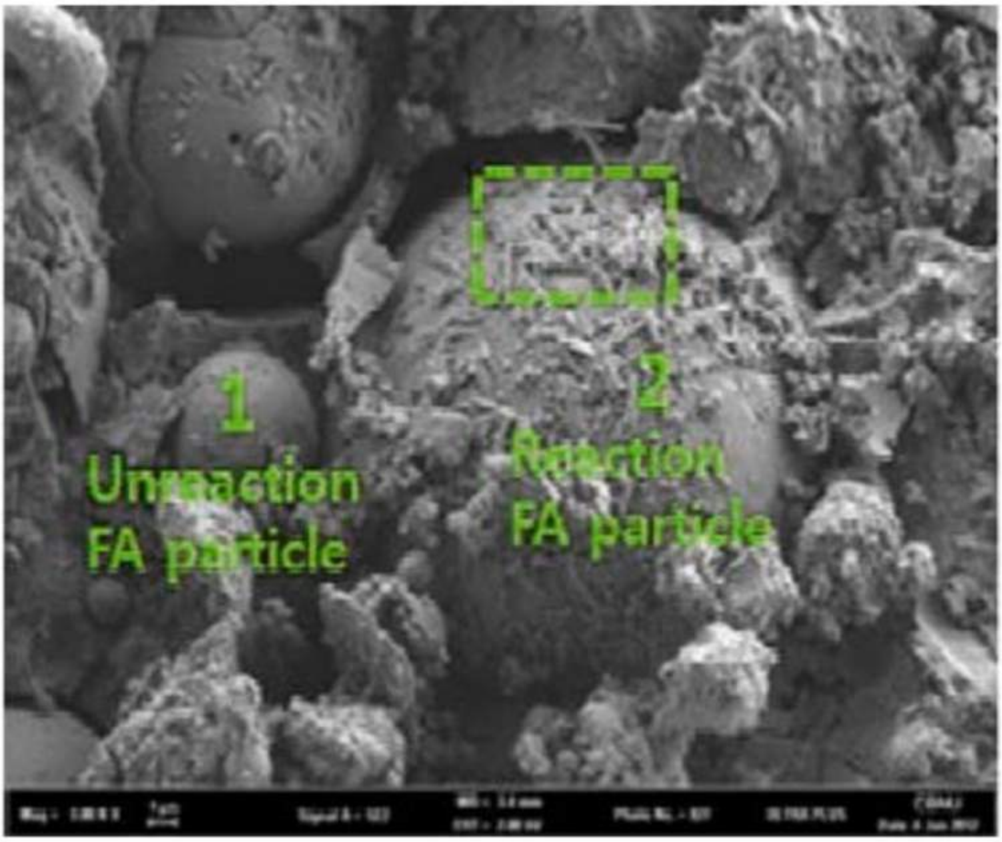


Figure 7: SEM image of fly ash based geopolymer concrete [22].

These particles don't operate as fillers, but they do contribute to long-term strength improvement since their surface effectively bonds particles together [22].

The influences on the compressive strength of GGBS- and geopolymer fly ash-based concretes were researched by Ravikumar et al. [26]. For geopolymer concrete mixtures based on fly ash and GGBS, they employed only 8 M NaOH as the activating solution. For two minutes, the fly ash/or GGBS was mixed with the fine and coarse aggregate before the activating solution was introduced. Following that, the entire mixture was stirred for a further 2 minutes for the GGBS mix and 4 minutes in the case of fly ash. That was caused by the GGBS-based geopolymer concrete's quicker setting time. After 24 hours, the specimens were demolded, and they were heated for 12, 24, and 48 hours at 60°C and 75°C to cure them. The ratio of activating to binder utilised was 0.4. When Ravikumar et al. [26] examined various amounts of fly ash and GGBS binder by volume, they discovered that 18 percent of fly ash binder and 25 percent of GGBS concrete, respectively, offered the maximum compressive strength. Additionally, they discovered that the compressive strength significantly enhanced when the curing temperature was raised from 60°C to 75°C. Additionally, greater compressive strength was attained when the curing time was extended from 12 to 48 hours. The study findings are summarised in Figure 8.

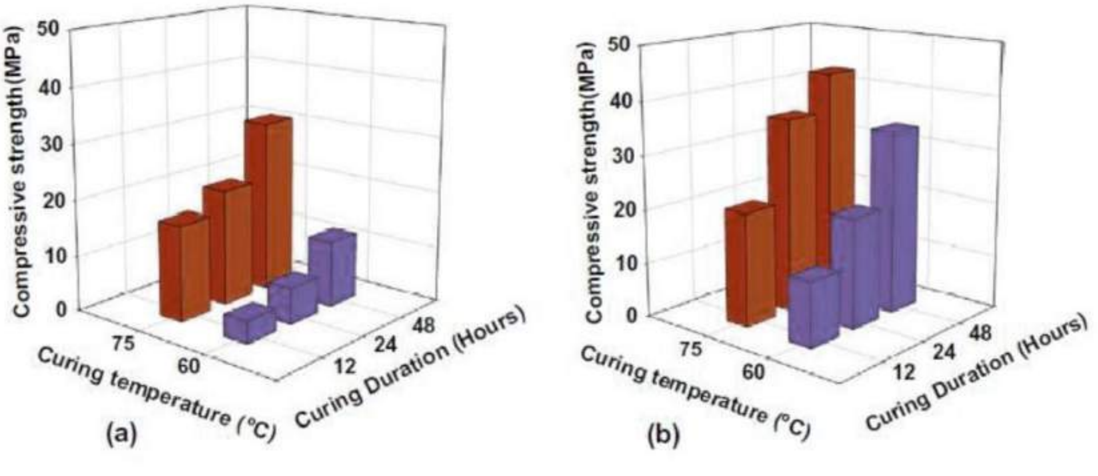


Figure 8: (a) Fly ash-based geopolymer concrete (b) GGBS-based geopolymer concrete [26].

According to Bondar [23], the kind and concentration of alkaline solutions, curing time and temperature, and the amount of silicate, aluminate, and potassium/sodium in the concrete matrix all affect the compressive strength of geopolymer concrete. As illustrated in Figure 9, Ravikumar et al. [26] also investigated the impact of the ratio of activating solution to binder and discovered that the ratio of 0.4 produced the maximum compressive strength for both fly ash and GGBS mixtures. Additionally, they discovered that the GGBS geopolymer mix outperformed fly ash-based geopolymer concrete in terms of compressive strength. They attributed this to the increased binder content per volume of the GGBS mix as well as to the material's self-cementing ability, which is brought about by the high CaO content. SEM microstructural examination revealed that the alkaline-aluminosilicate gel reaction product creates a shell around the particles. In the case of GGBS, this product was spread more uniformly. Fly ash also included more unreacted particles. However, with time, these particles will cause additional reactions, leading to larger compressive strengths [26].

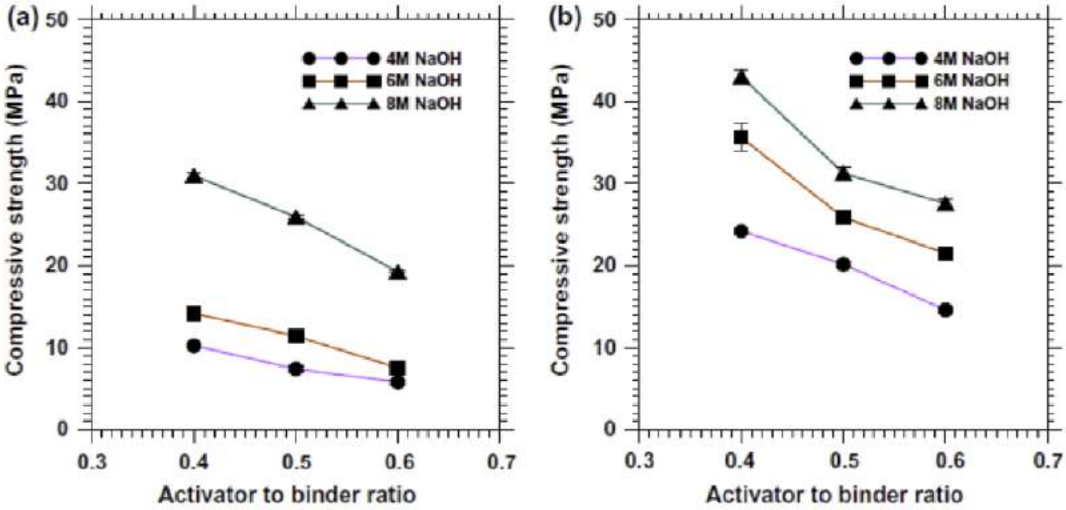


Figure 9: Effect of activating solution to binder ratio for (a) fly ash and (b) GGBS geopolymer mixes [26].

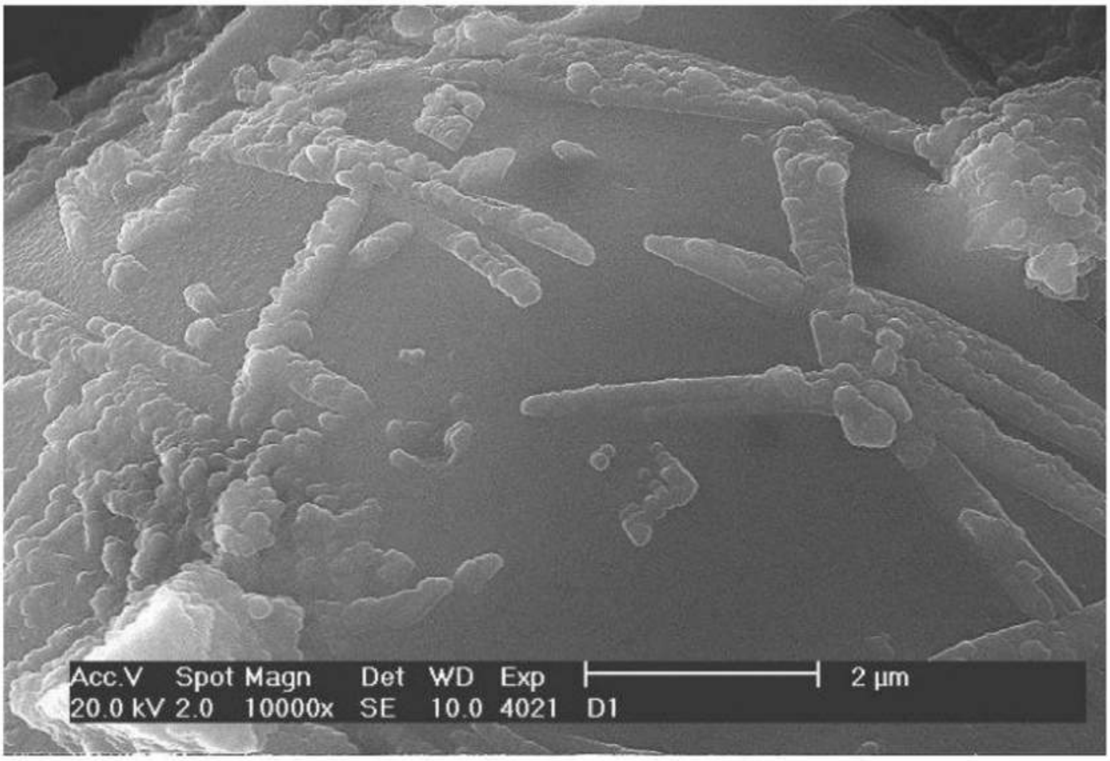


Figure 10: The initiation of geopolymer on the surface of an original fly ash particle [27].

Fly ash-based geopolymer concrete was tested with various molarities of NaOH by Motorwala et al. [27]. Three distinct alkaline solutions—NaOH, KOH, and Na2SiO4—were combined in various ways. A 24-hour oven curing period was employed. They discovered that raising the oven's temperature while curing specimens of geopolymer concrete boosted the concrete's compressive strength. The benefits of raising the temperature over 80 degrees Celsius, however, were minimal. The scientists discovered that newly-poured geopolymer concrete is rigid. This is consistent with Okoye et al[28] .'s observation that when mixing, geopolymer concrete formed pellets. In order to make the fresh concrete more workable, superplasticizer was added. Additionally, Motorwala et al. [27] discovered that a longer curing time and a greater sodium hydroxide molarity enhance compressive strength. They came to the conclusion that the choice of aggregate type and aggregate grading had a significant impact on the compressive strength of geopolymer concrete. Compressive strength increases with increased grading (more varied sizes of aggregate used in the mix). Additionally, the researchers discovered that sun curing may effectively increase compressive strength, which qualifies fly ash-based geopolymer concrete for usage in hot climates during the summer [27]. Initiation of geopolymer gel is depicted in Figure 10 on the surface of a fly ash particle discovered by Motorwala et al. [27]. The microstructure of the geopolymer concrete made from two separate mixes with various ratios of GGBS and fly ash was examined by Ravikumar et al. [26]. The first mixture had 10% GGBS mixed with fly ash, whereas the second mixture contained 50% GGBS. As activating solutions, sodium silicate was combined with naOH. SEM analysis of the mixture containing 50% GGBS showed more dense and less porous samples. But more GGBS particles remained unreacted. At 28 days, more fly ash unreacted particles were discovered in the 10% GGBS mixture. The researchers found that adding additional GGBS to the geopolymer mixture increased the calcium content and, as a result, the amount of calcium silicate hydrate (C-SH) generated, which in turn increased the bonding gel with the aggregate. In general, geopolymer concrete containing OPC is less workable than regular concrete. The use of more viscous ingredients in geopolymer concrete than in regular concrete was utilised to explain this [26], [28]. When additional GGBS was added, concrete was stiffer and less workable, according to Ravikumar et al. [26]. This is as a result of the GGBS's quicker reaction time and shorter sitting duration. Additionally, the workability is negatively impacted by the uneven form of GGBS particles. Workability is also influenced by how much activating solution is supplied; more activating solution results in greater workability [26]. More variables, such as the ambient temperature when mixing, the amount of time it takes to mix, and the moisture level of the aggregate, were reported by Ravikumar et al. [26] as impacting the workability of geopolymer concrete. Superplasticizers do not considerably increase the workability of geopolymer concrete, in contrast to OPC concrete, according to King and Sajayan [29]. According to them, adding more superplasticizer to the concrete matrix reduces overall strength and is ineffective in concrete exposed to high temperatures. Kong and Sanjayan [29] investigated how geopolymer concrete performed at high temperatures and contrasted it with OPC concrete specimens. Figure 11 illustrates how the compressive strength of geopolymers increased initially up to 300 oC before progressively declining to a maximum strength of 58 MPa at 800 oC. OPC samples, on the other hand, began to lose strength as soon as they were subjected to high temperatures, and the loss grew dramatically until the samples completely lost their strength at 400 oC. The breakdown of calcium hydroxide in the concrete paste was said to be the cause of this considerable loss of strength in the OPC samples.

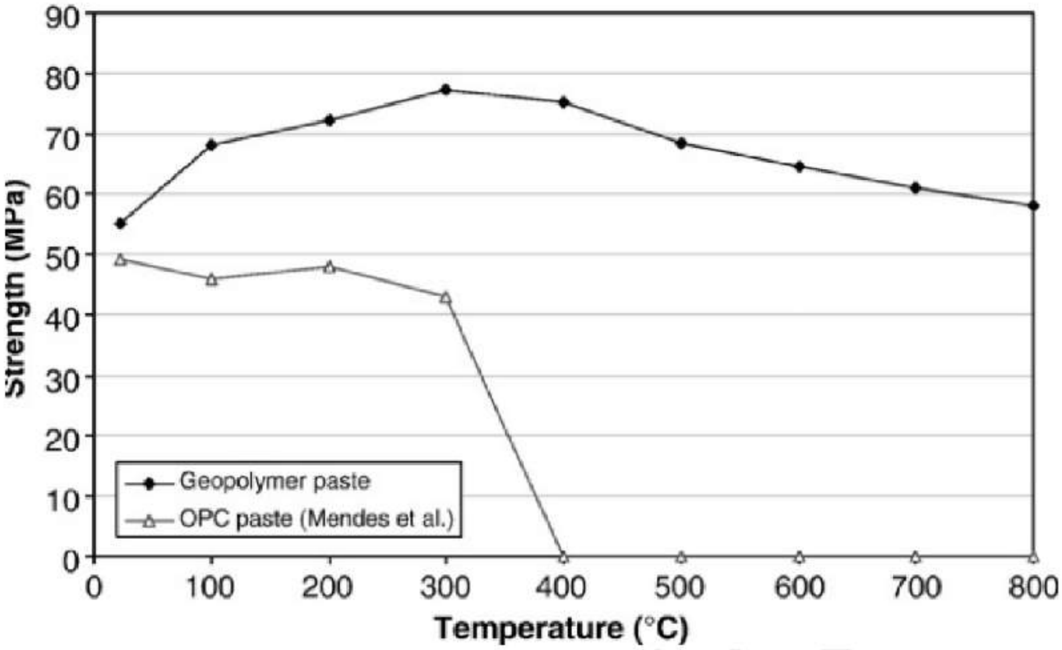


Figure 11: Comparison between strength of OPC concrete samples and geopolymer concrete samples at elevated temperatures [29].

Despite the fact that geopolymer concrete demonstrated greater fire resistance than regular concrete, this resistance is dependent on a number of variables. The size of the aggregate is one of these elements. Concrete samples with larger aggregate sizes (more than 10 mm) exhibited higher fire resistance, whereas those with lower aggregate sizes exhibited increased spalling and cracking [29]. The impact of silica fume on geopolymer concrete with fly ash was investigated by Okoye et al. [28]. When a larger amount of silica fume was injected, the specimens' compressive strength improved, according to the researchers. On the other hand, the fresh concrete's workability was shown to be negatively impacted. The identical result was discovered by [18]. Okoye et almethod .'s [28] of adding 40% silica fume to fly ash resulted in a 28-day compressive strength of 51 MPa. They attributed the enhanced strength to the silica fume's high SiO2 concentration, which promoted the development of the alumino-silicate gel [28], [20]. As the silica fume level in the matrix rose, they also noticed an improvement in the flexural and tensile strengths of the concrete samples. Geopolymer concrete has been found to be more resistant to chemical assaults than OPC concrete because it comprises finer components, a denser structure, and a variety of binding gels such Na-S-H and C-S-H. When silica fume was introduced as a percentage replacement to fly ash and slag, Lee et al. [18]

investigated how those materials responded to the alkali solution. They experimented with various silica gases derived from various sources. The researchers came to the general conclusion that silica fume can dramatically alter the chemical make-up and silicate structure of the various gels included in the geopolymer paste. They also claimed that silica fume reduces the fly ash's reactivity with the alkali activator and enhances it in the case of slag when it is added to the mixture. They explained this by stating that the silica fume has a more amorphous shape than fly ash. Fly ash particles are more crystalline than silica fume, which is more reactive to alkali solution. Additionally, they discovered that fly ash and silica fume react differently with Al from the slag [28].

Table 1: CO2 emission factors for different concrete production activities Adapted from Flower and Sanjayan [5]

Activity	Emission factor	Unit
Coarse aggregate-Granite/Hornfels	0.0459	t CO_2-e/tonne
Coarse aggregate – Basalt	0.0357	t CO_2-e/tonne
Fine aggregate	0.0139	t CO_2-e/tonne
Cement	0.8200	t CO_2-e/tonne
Fly ash (F-type)	0.027	t CO_2-e/tonne
GGBS	0.1430	t CO_2-e/tonne
Concrete batching	0.0033	t CO_2-e/m^3
Concrete transport	0.0094	t CO_2-e/m^3
On site placement activities	0.0090	t CO_2-e/m^3

The inorganic polymer "Geopolymer," created by French professor J. Davidovits in 1978, may offer a safe method for getting rid of industrial pollutants like fly ash and others. This geopolymer can serve as a concrete binder, hence lowering the need for Portland cement. An inorganic alumino-silicate polymer is called geopolymer. It is created by the extremely alkaline polycondensation process of aluminosilicate minerals, which results in a three-dimensional polymeric chain.

Because of the similarities in qualities between Portland cement concrete and geopolymer, it is easily accepted in the market. Geopolymer concrete's rate and quantity of strength growth are influenced by the alkaline activator concentration, curing circumstances, and chemical makeup. It was claimed that addition lime and silica fume to geopolymer concrete to replace some of the fly ash, up to 7.5 and 2 percent, correspondingly, increased the compressive strength of the material. Additionally, silica fume increased while lime decreased attributes including setting time and workability (30). The compressive strength of a geopolymer concrete was found to be at its highest at 28 days when the proportion of alkaline activator to binder was 0.4 and 0.35 for 14M and 12M NaOH concentration, respectively, in the alkaline activator solution (31).

It was found that adding 10% alcofine by weight to fly ash increased the compressive strength of geopolymer concrete to 43 MPa (32). Higher compressive strength was achieved by using just one actuating solution (10M NaOH) in ambient-cured geopolymer concrete that included 100% GGBS (33). For all ages up to 180 days, it was found that the compressive strength of fly ash-based geopolymer concrete, mixed with various ratios of GGBS, rose with the rise of the slag content. But the compressive strength was reduced once the activator liquid was reduced and water was added to make the material more workable (34). The 28-day compressive strength rose by around 10 MPa for every 10% increase in slag content. By growing the Si/Al ratio in the mixture's component materials, compressive strength was also boosted. On the other hand, when the quantity of alkaline liquid grew, the strength decreased while the setting time and workability rose (35).

Geopolymer made from Ground Glass Fiber (GGF), fly ash, and glass-powder were associated, and it was found that whereas the compressive strength of the fly ash-based and glass-powder geopolymers had increased with the addition of soluble Si (i.e., increase in SiO2/Na2O), the compressive strength of the GGF geopolymer samples had decreased. Larger Si content samples exhibited strong early-age strengths and no appreciable development in later ages. Comparing GGF samples to glass-powder-based geopolymer and fly ash samples, it was shown that GGF samples had the maximum compressive strength for all dose levels of activator (36). When making fly ash-based geopolymer concrete, it was discovered that 12M of NaOH solution was the ideal molarity to incorporate 10% alccofine (low calcium silicate slag), making the GPC more cost-effective (37).

Under ambient curing conditions, it was found that the geopolymer concrete with ground granulated blast furnace slag (GGBFS) as the aluminosilicate source had the highest 7-day compressive strength (60.4 MPa), a binder content of 450 kg/m3, an SS/SH ratio of 2.5, a SH composition of 14 M, and an alkaline to binder ratio of 0.35. But it was discovered that the setup time was brief (38). From as early as one day, fly ash-based geopolymer concrete that was mixed with additives like GGBFS (10 percent) and OPC (8 percent) demonstrated improved compressive strength. Additionally, by increasing the quantity of the binder from 450 kg/m3 to 730 kg/m3, the compressive strength was improved (39).

Similar outcomes were also observed when fly ash-based geopolymer concrete was made with 60:40 fly ash to slag ratio and 10% ground blast furnace slag (40,41). The ratio of Na2SiO3/NaOH of 1.5 produced improved compressive strength when associated to the other ratios of Na2SiO3/NaOH of 2 and 2.5, laterally with the proportion of Liquid/Binder kept at 0.5. It was also stated that the mixture comprising binder of GGBS and Fly Ash in a 40:60 ratio produced higher strength (42). For the production of geopolymer concrete, it was advised to use a maximum of 70% GGBS and 30% fly ash coupled with a 14M ratio of NaOH solution to achieve better compressive strength (43).

According to a study, replacing 25% of the fly ash with slag produced sustainable fly ash-slag blended geopolymer mortar (GPM) with the maximum compressive strength, regardless of the curing temperature (44). Additionally, it was shown that the activator solution, when combined 24 hours in advance, increased the compressive strength over 7 and 28 days even though the pH barely changed (45).

The literature that is now accessible makes it clear that an experimental database has to be created in order to fully comprehend the behaviour of geopolymer concrete from the standpoint of civil engineering. The vast mainstream of concrete instructions are based on a body of experimental evidence. This study would provide a contribution in this area and, in the process, help to clarify the factors that affect the characteristics of geopolymer concrete while it is new and when it has hardened.

Ganesan N. [46] looked at how fibres affected the durability of geo-polymer concrete and compared it to regular concrete. This study takes into account the durability characteristics of chemical resistance, water absorption, the impact of alternating drying, and wetting and resistance to chloride ion penetration. They came to the conclusion that geopolymer concrete (GPC) had larger durability qualities than ordinary concrete, and that the fibre addition increased GPC's durability capabilities.

The impact of silica fume substitution on the permeability and strength of AAS concrete was discussed by Qomaruddin. In comparison to AAS concrete, ordinary concrete with a proper mix demonstrated superior mechanical & durability qualities. This study replaces three different variants of silica fume with 5 percent, 10 percent, and 15 percent of the weight of slag in order to compare the effects on strength and permeability of AAS concrete. [47] In order to understand their impacts, two curing techniques—water curing and under plastic cover curing—were also investigated. The different tests were carried out to establish the percentage of water absorption, and the RCPT was used to assess the permeability and resistance to chloride-ion penetration. The water curing process was determined to be the most suitable kind. The experimental findings showed that the additional of silica-fume may lower the absorptivity of AAS concrete through an rise in compressive strength.

By employing GGBS instead of fly ash to produce tough, high-strength concrete without the use of OPC, Vignesh et al. [48] seek to identify various strength features of GPC. One day before to casting, the NaOH solution is combined with the Na2SO3 solution, and ambient curing has been used for the specimens. These studies led to the conclusion that GGBS at greater concentrations produced materials with high compressive strength. A GGBS instant setup replacement rate of greater than 30% was noted. By substituting GGBS for 9% of the fly ash in the feature of ambient and combustion curing, maximum strength is achieved. As GGBS rises, compressive strength rises as well. When exposed to a temperature of 5000 0 C for two hours, a maximum loss in strength of 25% was seen. Within 14 days, a compressive strength of around 90% was attained.

According to Khalid [49], larger molarity NaOH produced the highest compressive strength, while the highest mass ratio of NaOH to Na2SO3 solution produced the highest GPC strength. Additionally, it was discovered that the compressive strength of GPC rose with temperature, from 300 to 90 °C, and that a longer curing time also contributed to this rise.

Yao [50] performed research on the mechanical characteristics of concrete using various fibres in a hybrid procedure at the similar volume fraction (0.5 percent). Utilizing fibre mixtures of carbon plus steel, steel plus polypropylene, polypropylene plus carbon, three different types of fibres were combined to create hybrid materials. According to experimental research, the hybrid fibres produced better qualities than their fiber-reinforced concrete. The carbon-steel hybrid fibre demonstrated the uppermost compressive in addition flexural strengths between the three types of hybrid fibres. [50]

Naik [51] looked at how sodium -hydroxide concentration affected the growth of strength in fly-ash-based GPC. Without taking into account the molarity of the NaOH solution, it is also stated that the strength of ambient curing temperature concrete samples is, continuously less than roughly 95% to 97 percent of the heat-cured concrete sample. The strength needed for GPC may be obtained under precise sodium -hydroxide concentrations by ambient curing, and under laboratory circumstances heat curing is not necessary. For the manufacturing of precast units, heat curing may be used.

Geopolymer's durability characteristics were tested, and Albitar M et al. [52] compared it to conventional ordinary concrete. It is determined that geopolymer concrete experiences less degradation than conventional ordinary concrete. In comparison to fly ash-based GPC, which will experience a reduction of 13.4% when showing to the sodium-sulfate answer, it will experience a reduction of 15.4%. When evaluating the durability of geo-polymer concrete, Daniel A. Salas et al. came to the conclusion that manufacturing geo-polymer concrete has a possible environmental benefit over regular concrete if NaOH is combined with solar salt while taking a higher proportion of hydropower into consideration. Under these limitations, the global warming possible of geo-polymer concrete is 64% inferior than that of cement concrete. Though, due to fluorocarbon emissions during the chlorine alkali procedure, GPC performs badly in the gas depletion class. These emissions, which do not occur during cement manufacture, occur as a result of the usage of carbon tetrachloride [52].

In his experiments, Bharu [53] used geopolymer concrete. In order to create geo-polymer concrete, fly ash is added to an alkali reactor. The geopolymer concrete may be made without cement. Alternative materials can be used in place of aggregates in geopolymer concrete, increasing the strength of the finished product. Concrete made of geo-polymer will lessen environmental problems caused by carbon dioxide emissions. Fly ash and crushed blast furnace slag are used to lessen environmental and disposal issues.

The behaviour of geo-polymer concrete through fly-ash in a hardened and fresh states was studied by Albitar et al. [52]. Flyash is a superior workability feature when used in geopolymer concrete, which was examined with water/binder proportion and superplasticizer and binder proportion. Their research found that the tensile and flexural strengths of polymer concrete were more equivalent to those of traditional concrete. Results for Young's modulus and poisons-to-ratio were comparable to those of traditional concrete.

Daniel [54] conducted research on geo-polymer concrete made of aluminium silicate minerals as well as on the quantity and kind of alkaline-activators employed. There have been investigations on mechanical and durability qualities. The findings shown that geo-polymer concrete has strong resistance to corrosion, chemical assault, the effects of freezing and thawing, fire resistance, and the interaction between alkali and aggregate. The findings demonstrated the excellent strength and reduced shrinkage of geo-polymer concrete. The results demonstrate that the curing temperature and duration produce better results than average.

A study on GPC using cement, steel, and glass fibres in place of ground, granulated blast furnace slag was conducted by Khalid et al. [49]. About 60%, 70%, 80%, and 90% of the steel and 10%, 20%, 30%, and 40% of the glass fibres are further to GPC. The mechanical characteristics of the mixture were tested, and the results were assessed. Results indicated that adding fibres improved GPC's characteristics.

36 billion tonnes of CO2 were emitted in 2013 as a result of cement manufacturing in Australia [50, 51]. Ordinary Portland Cement (OPC) manufacturing is thought to emit around one tonne of CO2 into the environment [52, 53]. 3.7 billion metric tonnes of cement were consumed worldwide in 2014 [54]. Cement consumption will reach 4.7 billion metric tonnes by 2020, assuming an annual growth rate of 4%. As a result, it has become crucial to produce green concrete without OPC. Geopolymer concrete [55, 56] and alkali activated concrete [57–60] have lately acquired appeal as construction materials after years of research into them as OPC concrete substitutes. The sole subject of this essay is geopolymer concrete.

Due to the absence of OPC, geopolymer concrete is regarded as green concrete. It has been demonstrated that geopolymer concrete has high mechanical characteristics and lower greenhouse gas emissions [55]. In addition to having a smaller carbon footprint than OPC, it also employs a lot of industrial waste products such fly ash, slag, and silica fume [55].

The supply of aluminosilicate minerals and an alkaline activator are the two primary components of geopolymer concrete. A solution of sodium hydroxide and sodium silicate is the maximum typical alkaline activator. But you may also use potassium silicate and potassium hydroxide. In the polymerization process, the alkaline activator is crucial 5 [62]. The aluminosilicate source determines the origin of the ingredients used as the binder in geopolymer concrete. The silicate and aluminate (Al) content of these aluminosilicate materials must be high (Si). Slag [63], fly ash [64–66], and silica fume [67] are examples of by-product products that can include these aluminosilicates. Additionally, natural materials like as clay and metakaolin can be used to produce aluminosilicate [68]. The cost, availability, and application are only a few of the variables that influence the source material selection for geopolymer concrete manufacturing [69].

Geopolymer concrete can only be used for precast concrete members because the majority of earlier experiments used heat to cure the material. There will be more uses for geopolymer concrete in precast and in situ construction when it is ambiently curing. The energy and expense required for the heat curing process will be reduced by ambient curing conditions. The literature that is now accessible was researched with regard to the workability, compressive strength, and setting time, of geopolymer concrete and paste.

The compressive strength and final setting time of geopolymer mortar were studied by Rao and Rao [70]. A portion of the primary aluminosilicate source material (Class F) fly ash was substituted with ground-granulated blast furnace slag, and sodium silicate and sodium hydroxide solution were combined to make the alkaline activator. It was discovered that switching from fly ash to GGBFS considerably shortened the final setup time.

In a different investigation, Lee and Lee [71] examined the mechanical characteristics and setting time of alkali-activated fly ash/slag concrete made at ambient temperature. The test findings demonstrated that as slag and SH solution concentration grew, so did the alkali-activated fly ash/slag paste's setting times.

The compressive strength and workability geopolymer concrete of fly ash-based were studied by Nath and Sarker [72]. When GGBFS was employed as a minor fraction of the binder, it was discovered that workability was greatly decreased and compressive strength of fly ash-based geopolymer concrete was improved. Numerous research on geopolymer concrete have been done, however there is still no agreement on how different factors affect the material's qualities, such as its compressive strength and workability. Aluminosilicate supply, curing circumstances, alkaline activator type, activator combination and concentration, and the alkaline activator to binder ratio are the primary issues that affect the characteristics of geopolymer concrete [73]. It may be challenging to look at the impact of all the criteria in one study. However, a well-designed experimental programme may be used to thoroughly study the factors that affect the amount of geopolymer concrete [73].

For this, the well-known Taguchi technique [74] can be applied. In order to study a high number of variables with a small number of tests, a fractional factorial design approach, the Taguchi method, employs a specific set of arrays called orthogonal arrays (OA). When compared to conventional experiment design techniques, the design of trials utilising OA is relatively efficient [75]. The OA minimise uncontrolled factors and cut down on the number of experiments [75]. For instance, the classic factorial design takes 34 or 81 test runs when employing four limitations at three proportions, but the Taguchi technique only needs nine. The signal-to-noise (S/N) proportion is used by the Taguchi technique to optimise. The S/N ratio aids in data analysis and optimal outcome prediction. In essence, OA offers a collection of tests that are fairly balanced, and S/N ratio acts as an impartial function for optimization.

The efficacy, cost-effectiveness, resilience, and simplicity of output interpretation are the key benefits of Taguchi techniques. Although the Taguchi approach has been extensively utilised in other technical applications, it has only recently been applied to geopolymer concrete [76–80].

The compressive strength geopolymer concrete of fly ash-based created using the Taguchi technique was studied by Riahi et al. [81] for 2 and 7 days. Using the Taguchi approach, they looked at how SH concentration and curing conditions affected compressive strength.

By taking into account the impacts of aggregate amount, sodium silicate to sodium hydroxide ratio, alkaline activator to fly ash ratio, and curing process, Olivia et al. [81] created nine geopolymer concrete mixes. The mechanisms of the geopolymer concrete mix might reportedly be optimised using the Taguchi technique. According to Khalaj et al. [82], the Taguchi technique may be effectively used to develop geopolymers based on Portland cement to have split tensile strengths that are suitable.

One of the components of mineral alumino-silicate polymers, geopolymers are produced by the alkaline activation of a diversity of aluminosilicate-rich basis materials, counting natural basis materials like metakaolin, by-products of industry like fly ash (FA), and by-products of agricultural source materials like rice husk ash (RHA) [83]. Geopolymer materials have an amorphous microstructure and have many chemical properties with zeolitic minerals in nature. The end result of the polymerization process is influenced by the mineral makeup of the ash-based geopolymer and alkaline activators. Additionally, the polymerization process is often enhanced by the high temperature [84, 85].

Therefore, it may be said that geopolymer, following cement and lime, is the third generation of cementing materials [86]. Aluminosilicate binder, fine and coarse aggregates, alkaline solutions, and water make up the combined proportions of geopolymer concrete; the polymerization of these components results in a solid concrete that resembles regular concrete in many ways [87]. The alumino-silicate-rich binder source materials for geopolymer concrete include FA, RHA, POFA, GGBS, metakaolin, and any mixture of these ashes with or without Portland cement. Fly ash is the most widely utilised of them as a raw material for creating geopolymer concrete because of its low cost, wide availability, and increased potential for producing geopolymers [88]. Researchers have also substituted fly ash for Portland cement in a variety of concrete or cementitious composites [89]. To activate and expedite the polymerization procedure and set and harden the concrete specimens, high temperatures and oven or steam curing are required, which is a drawback of employing FA as the only source of binder material for the production of geopolymer concrete. The reactivity of FA-based geopolymer concrete that has been cured under ambient circumstances, on the other hand, has been shown to be minimal [90]. Under addition, because the majority of engineering applications are carried out in ambient climatic conditions, pure FA use for the training of geopolymer concrete results in restricted adoption of this technology in precast construction [91]. In order to address these issues, research has been done, including the use of GGBS [92-95] as a partial auxiliary of FA in the manufacture of geopolymer concrete because GGBS has a higher content of calcium oxide (CaO) than FA, which is what gives geopolymer concrete its increased strength under ambient curing conditions. Additionally, GGBS and FA-based geopolymer concrete was reported to have improved strength in the literature [96, 97].

The process of polymerization may be succinctly stated as follows: in the first step, silicon and aluminium oxide ions are produced when the silicate and aluminium components of the binder dissolve within the highly alkaline aqueous solution. In the second step, a combination of silicate, aluminosilicate, and aluminate species eventually generates an amorphous gel by the modern process of poly-condensation-gelation additional condensation [98]. The kind of binder, the amount of alkaline solution present, the molarity of sodium hydroxide, the ratio of sodium silicate to sodium hydroxide, mix proportion, additional water, and curing technique are only a few variables that may affect the performance of GC [99].

One of the greatest impressive mechanical qualities of completely concrete composites, counting GC, is their compressive strength. Typically, it provides an overall performance regarding the concrete composites' quality [100]. The compressive strength test is achieved in accordance with ASTM C39 [101] or BS EN 12390-3 [102] standard test procedures. Studies have been done in the past to find out how different mixture percentage factors and The mechanical properties of GGBS/FA-GPC are influenced by curing conditions. For instance, Nath and Sarker [104] observed that the GGBS replacement amount, content, and kind of alkaline solution have an impact on the fresh and hardened characteristics of GGBS/FA-GPC. The Si4+ and Al3+ release from of the base binders is controlled by the kind and quantity of alkaline liquids, which plays a part in the polymerization process. Alkaline solutions at higher concentrations are often useful for increasing compressive strength to a desirable degree [105]. In addition, different (Na2SiO3/NaOH) ratios were applied for making geopolymer concrete. For instance, Topark-Ngarm et al. [106] performed study utilising various Na2SiO3/NaOH ratios and found that compressive strength increased as Na2SiO3/NaOH was increased.

The samples' curing state is a significant factor that influences the performance of GGBS/FA-GPC. There are numerous diverse kinds of curing regimes, counting ambient curing [107], heat curing [108, 109], and steam curing [110, 111]. When specimens are preserved inside an oven at 65°C for 24 hours, the polymerization process quickly increases, causing the GC to gain up to 70% of its ultimate strength, after which there is a marginal rise in the compressive strength after 28 days of maturation [113]. Additionally, for the same GC combination, heat curing regimes provide better compressive strength than ambient curing conditions [114-118].

In order to save time, energy, and money, it is crucial to grow a reliable model for estimating the compressive strength of GC. This model also provides advice on how to schedule the building process and the removal of framework components [119]. Regarding the potential for altering or verifying the GC mix proportions, the compressive strength characteristic of the GGBS/FA-GPC must be modelled [119]. It is possible to create designs that are affordable and effective by choosing the right mixing ratios. As a result, several studies have attempted to speed up the process of selecting an appropriate proportional mix to provide the desired qualities; one such study is modelling with the creation of empirical equations. Modeling the properties of construction materials can be done in a variety of ways, including statistical methods, computer modelling, and recently developed methods like regression analysis [120, 121]. The compressive strength of the GGBS/FA-GPC is influenced by a number of parameters, which produces a range of compressive strength findings. As a result, forecasting compressive strength is a difficult problem for scientists and engineers. As a result, numerical and mathematical models are required [122]. The many engineering professions have made extensive use of machine learning's strong prioritising, optimization, forecasting, and planning capabilities [123]. Green concrete's compressive strength [124], recycled aggregate concrete's splitting tensile and flexural strength [125], recycled concrete aggregate's modulus of elasticity [126], high volume fly ash concrete's compressive strength [127], and eco-friendly GC including natural zeolite and silica fume's compressive strength [127] were all simulated using machine learning techniques in the literature..

The literature lacks measurements of the impact of numerous mixture percentage factors and curing regimens on the compressive strength of GGBS/FA-GPC at 28 days. Furthermore, a reliable and created model that employed a diversity of characteristics to forecast the compressive strength of GGBS/FA-GPC is extremely uncommon to be used by the construction industry, according to the thorough and systematic research on the material. Most efforts have focused on a single-scale model without taking into account extensive laboratory work data or other factors. Additionally, a number of factors influence the compressive strength of GGBS/FA-GPC. As a result, the effects of eleven parameters, including alkaline solution/binder (l/b), fly ash (FA), ground granulated blast furnace slag (GGBS), SiO2/CaO of GGBS, fine aggregate (F), coarse aggregate (C), sodium hydroxide (SH), sodium silicate (SS), (SS/SH) ratio, and molarity (M), were examined and quantified on the compressive strength of the concrete (M5P). Using 220 samples from the literature research, they were applied as predictive models to forecast the compressive strength of green GGBS/FA-GPC at 28 days.

CHAPTER 3

METHODOLOGY

3.1 MATERIALS USED

3.1.1 CEMENT:

It uses Ordinary Portland Cement (OPC) of 53 grades that complies with IS: 8112-1939. It was discovered that cement had a specific gravity of 3.0.

3.1.2 FINE AGGREGATES:

The primary component, sand, has a specific gravity of 2.62 and a water absorption rate of 1.8 percent after 24 hours when using grading zone II of IS: 383-1978.

3.1.3 COARSE AGGREGATES:

Stone that was mechanically crushed and met IS: 383-1978 specifications had a maximum size of 20 mm. At 24 hours, 20mm aggregates were found to have specific gravities of 2.62 and 2.64, and water absorption levels of 0.16 and 0.18 percent, respectively.

1.4 SILICA FUME:

In the production of silicon and ferrosilicon alloys, high-purity quartz is reduced with coke as a byproduct in electric arc furnaces. When precisely measured using nitrogen adsorption methods, micro silica consists of small particles with a surface area on the order of 215,280 ft2/lb (20,000 m2/kg), with particles that are around one hundredth the size of the typical cement. Micro silica is a particularly effective pozzolanic material particle due to its extreme fineness and high silica concentration. To improve the qualities of Portland cement concrete, particularly its compressive strength, bond strength, and abrasion resistance, micro silica is added.

These advantages are the consequence of pozzolanic interactions between the micro silica and the freed calcium hydroxide in the paste, as well as mechanical improvements brought on by the addition of a very small particle to the cement paste mix. When silica fume is added, the permeability of the concrete to chloride ions is decreased as well, protecting the concrete's reinforcing steel against corrosion, especially in chloride-rich environments like coastal regions. Early in the day, when silica fume is being integrated, OH ions and alkalis are released into the pore fluid, speeding up cement hydration. According to reports, silica fume has a considerable pozzolanic reaction and when added, the no evaporable water content drops between 90 and 550 days at low water/binder ratios.

Table 1 - Physical Properties Of Silica Fume

Properties	Observed Values
Colour	Dark grey
Fineness modulus	20000m2/kg
Specific gravity	2.2
Bulk Modulus	240kg/m3

Table 2- Chemical Properties Of Silica Fume

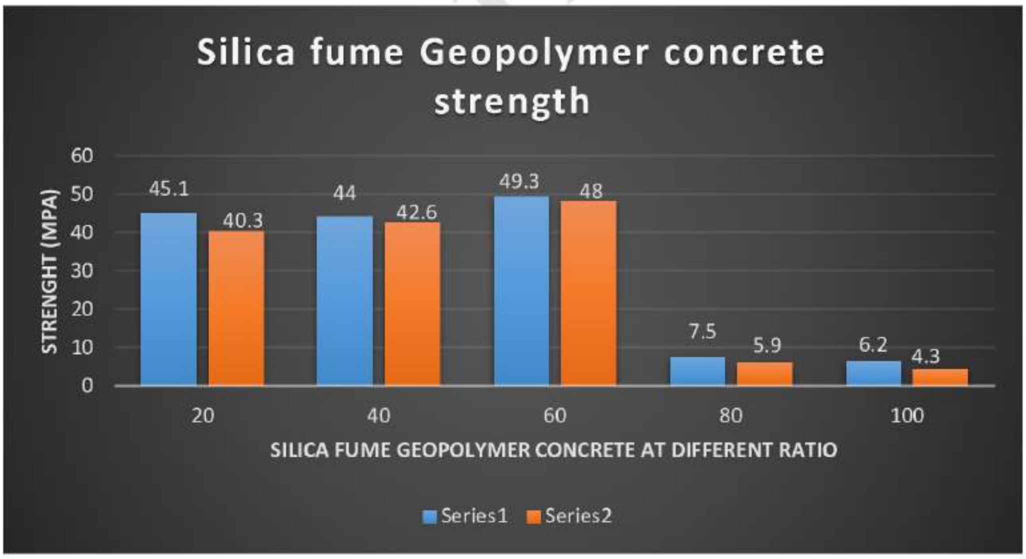
Properties	Observed value
Sio2	90-96%
Al2o3	0.6 -3.0%
Mgo	0.4-1.5%

Fe2o3	0.3-0.8%
Na2o	0.3-0.7%
Cao	0.1-0.6%
S	0.1-2.5%
K2o	0.04-1.0%
C	0.5-1.4%
Loss of ignition	(C+S) 0.7-2.5%

Silica fume Geopolymer concrete strength

Silica Fume (Water Curing)	
Silica Fume % Replacement	Strength (MPa)
20	45.1
40	44
60	49.3
80	7.5
100	6.2

Silica Fume (Room Curing)	
Silica Fume % Replacement	Strength (MPa)
20	40.3
40	42.6
60	48
80	5.9
100	4.3



Series1 = water curing

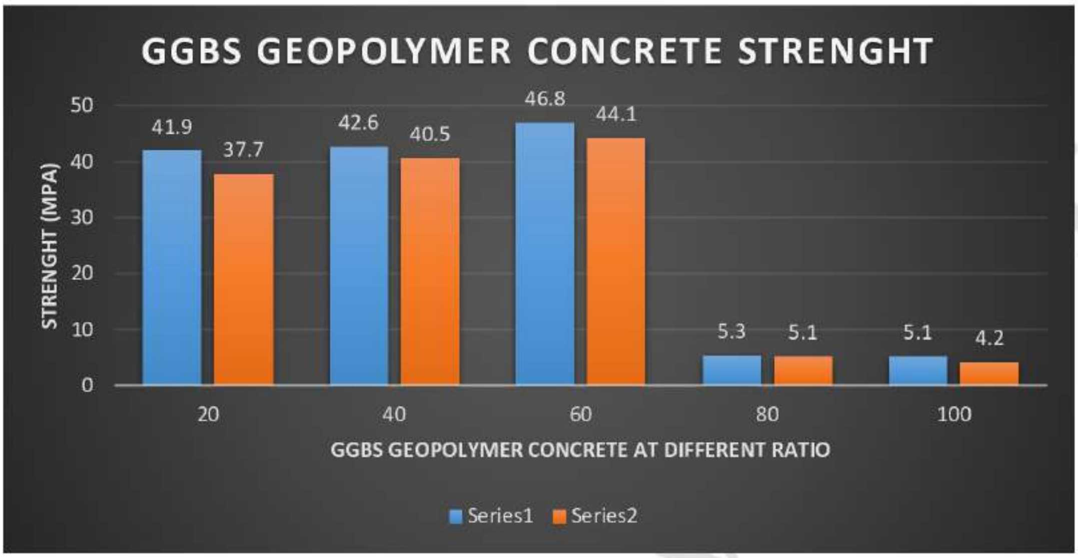
Series 2 = room curing

3.2 GGBS GEOPOLYMER CONCRETE STRENGHT

GGBS (Water Curing)	
GGBS % Replacement	**Strength (MPa)**
20	**41.9**
40	**42.6**
60	**46.8**
80	**5.3**
100	**5.1**

GGBS (Room Curing)	
GGBS % Replacement	**Strenght (MPa)**
20	**37.7**
40	**40.5**
60	**44.1**
80	**5.1**

100	**4.2**



Series1 = water curing

Series 2 = room curing

CHAPTER 4

RESULTS AND ANALYSIS

4.1 GRADATION

- Sieve Analysis for Fine aggregate (Sand) ASTM136-05

- Total sample Taken = 500 gm

Seive #	Retain wt (gm)	% Retain	% Commulative	% Passing
4	5	1	1	99
8	7	1.4	2.4	97.6
16	19	3.8	6.2	93.8
30	180	36	42.2	57.8
50	155	31	73.2	26.8
100	96	19.2	92.4	7.6
pan	38	7.6	100	0
		TOTAL = 317.4		

F.M = % Cumulative Retain / 100

F.M = 317.4 / 100 = 3.174

Range = (Fine sand = 2.3-2.6 , Medium Sand = 2.6-2.9 , Coarse Sand = 2.9-3.2)

Result= our Sample is Coarse Sand Type

- Sieve Analysis for Course aggregate (Crush) ASTM C136-05

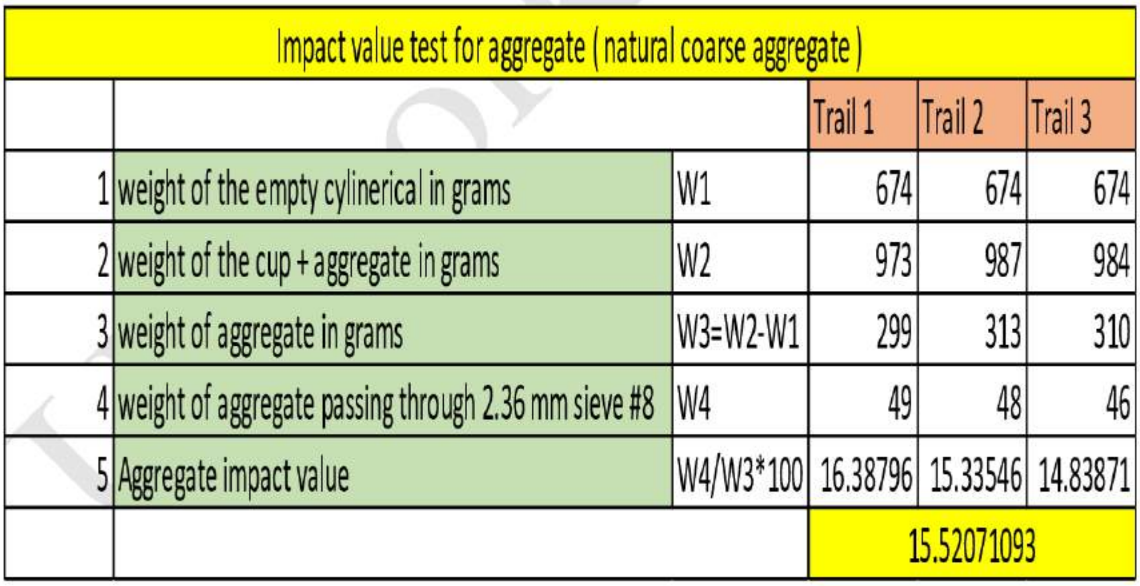
- Total sample Taken = 3000 gm

Seive #	Retain wt (gm)	% wt Retain	% Commulative	% Passing	% comm passing
1(1/2)"	0	0	0	100	100
1"	0	0	0	100	200
3/4"	656	21.87	21.87	78.13	278.1333333
1/2"	1543	51.43	73.30	26.70	304.8333333
3/8"	532	17.73	91.03	8.97	313.8
4"	269	8.97	100.00	0.00	313.8
pan	0	0	0	0	313.8
		TOTAL = 286.2			

F.M = % Cumulative Retain / 100

F.M = 286.2 / 100 = 2.862

4.2 IMPACT VALUE TEST FOR COARSE AGGREGATE (CRUSH)



Impact value test for aggregate (natural coarse aggregate)					
			Trail 1	Trail 2	Trail 3
1	weight of the empty cylinerical in grams	W1	674	674	674
2	weight of the cup + aggregate in grams	W2	973	987	984
3	weight of aggregate in grams	W3=W2-W1	299	313	310
4	weight of aggregate passing through 2.36 mm sieve #8	W4	49	48	46
5	Aggregate impact value	W4/W3*100	16.38796	15.33546	14.83871
			15.52071093		

4.3 SPECIFIC GRAVITY AND WATER ABSORPTION FOR COARSE AGGREGATE (CRUSH)

Determination of specific gravity and water absorption of Coarse aggregate (CRUSH)

S. No	Description		Trail 1	Trail 2
1	Weight of aggregate sample (grams)	W	2000	2000
2	Weight of saturated aggregate suspended in water with basket	W1	1880	1882
3	Weight of basket suspended in water (grams)	W2	632	633
4	Weight of saturated surface dry aggregate in air (grams)	W3	1994	1991
5	Weight of oven dry aggregate after 24 hr (grams)	W4	1976	1978
6	Specific Gravity	W3/(W3-(W1-W2))	2.673	2.683
	Specific Gravity (Average)		2.68	
7	Water absorption %	(W3-W4)/W4*100	0.911	0.657
	Water absorption (Average)		0.784	
Average values	Specific Gravity		2.68	
	Water absorption %		0.784	

4.4 COSTING, ESTIMATION AND TEST REPORT

Material calculation for different percentage replacement on the mix ratio which is (1 : 1.5 : 3)

Mix Ratio			**Sum of Ratio**
1	**1.5**	**3**	**5.5**
Amount material required for each cylinder			
13.39 kg			
Cement	**2.4345 kg**		
Sand	**3.6518 kg**		
Crush	**7.3036 kg**		

COSTING, ESTIMATION AND TEST REPORT

GGBFS REPLACEMENT AT DIFFERENET RATIO (1:1.5:3)				
%age replacement	**GGBFS (kg)**	**Cement (kg)**	**Sand (kg)**	**Crush (kg)**
20%	**0.486909091**	**1.947636364**	**3.6518**	**7.303**
40%	**0.973818182**	**1.460727273**	**3.6518**	**7.303**
60%	**1.460727273**	**0.973818182**	**3.6518**	**7.303**
80%	**1.947636364**	**0.486909091**	**3.6518**	**7.303**
100%	**2.434545455**	**0**	**3.6518**	**7.303**

SILICA FUME REPLACEMENT AT DIFFERENET RATIO (1:1.5:3)				
%age replacement	**SILICA FUME**	**Cement**	**Sand (kg)**	**Crush (kg)**
20%	**0.486909091**	**1.947636364**	**3.6518**	**7.303**
40%	**0.973818182**	**1.460727273**	**3.6518**	**7.303**
60%	**1.460727273**	**0.973818182**	**3.6518**	**7.303**
80%	**1.947636364**	**0.486909091**	**3.6518**	**7.303**
100%	**2.434545455**	**0**	**3.6518**	**7.303**

GGBS+CEMENT+SAND+CRUSH+NAOH(solid)

Material for preparing cylindrical sample at different ratios.

4.5 Slump Test

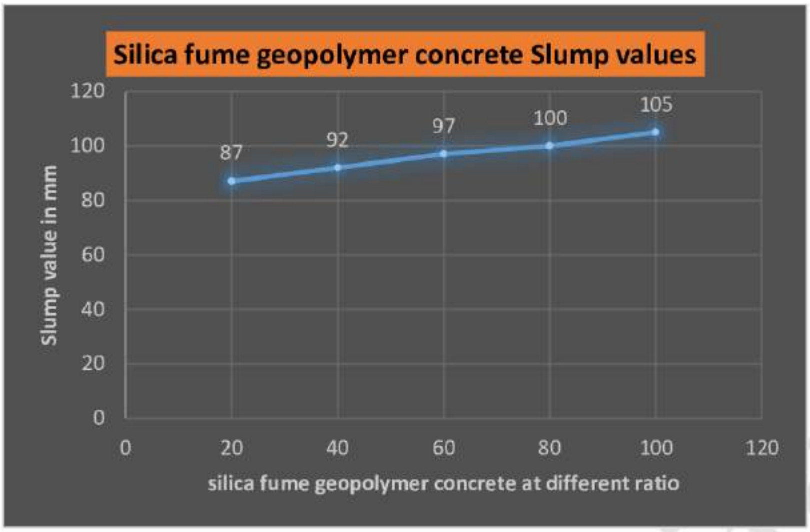
Around the world, this test is frequently used on building sites. Although ACI 116R-90 refers to the slump test as a consistency test, it does not assess the workability of concrete. The test is highly helpful in identifying variations in a mixture of specified nominal proportions' homogeneity. The slump test is required by BS 1881: Part 102: 1984 and ASTM C 143.

Slump Test

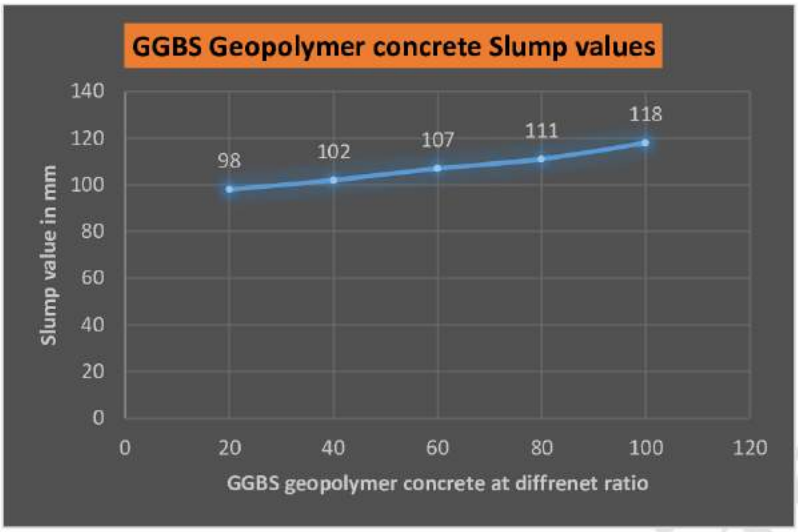
Materials %		Slump
GGBS	SF	
100	0	87mm

80	20	92mm
60	40	97mm
40	60	100mm
20	80	105mm
0	100	111mm

Material (Silica Fume)	**Slump (mm)**
20	**87**
40	**92**
60	**97**
80	**100**
100	**105**



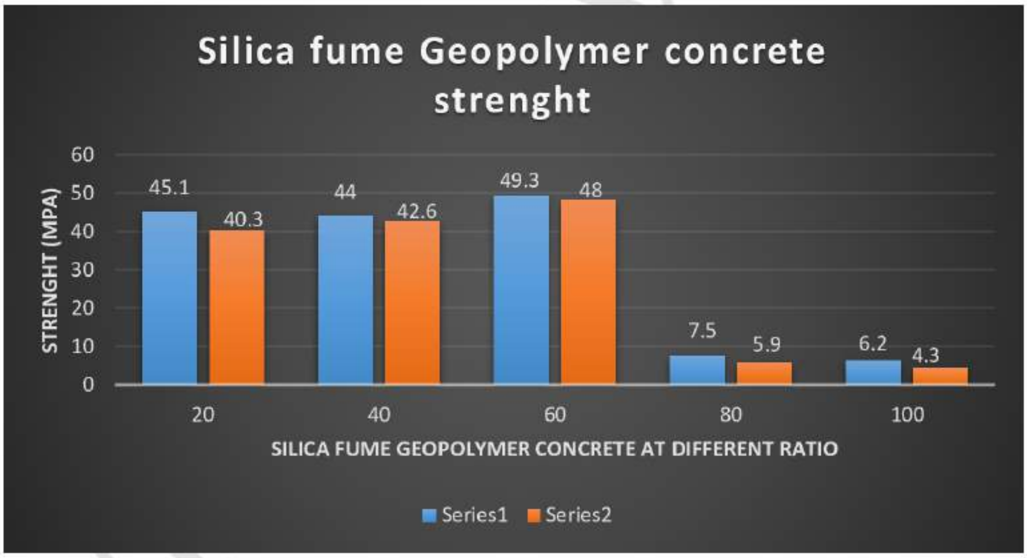
Material (GGBS)	**Slump (mm)**
20	**98**
40	**102**
60	**107**
80	**111**
100	**118**



Silica Fume (Water Curing)	
Silica Fume % Replacement	Strength (MPa)
20	45.1
40	44
60	49.3
80	7.5
100	6.2

Silica Fume (Room Curing)

Silica Fume % Replacement	Strenght (MPa)
20	40.3
40	42.6
60	48
80	5.9
100	4.3



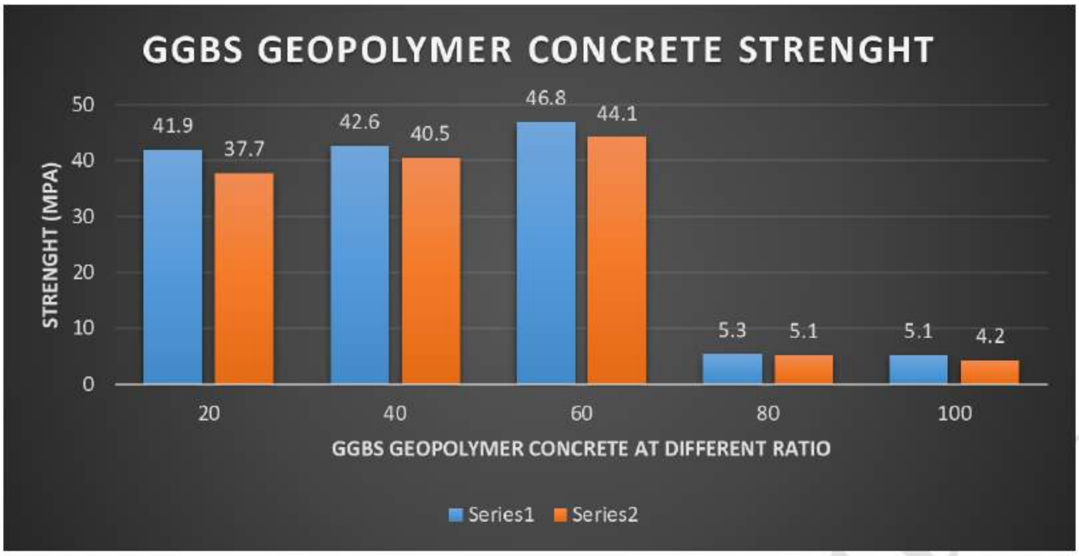
Series1 = water curing

Series 2 = room curing

Compressive Strength

GGBS (Water Curing)	
GGBS % Replacement	Strength (MPa)
20	41.9
40	42.6
60	46.8
80	5.3
100	5.1

GGBS (Room Curing)	
GGBS % Replacement	Strength (MPa)
20	37.7
40	40.5
60	44.1
80	5.1
100	4.2



Series1 = water curing

Series 2 = room curing

The mixture of geopolymer concrete has a variety of outcomes and varied replacements for SF to GGBS under room curing, as can be seen from the results graphs above. The concrete predicted by 100% of GGBS performed best in the compressive test at ages 7, 14, and 28 days. Additionally, when geopolymer concrete ages and GGBS is replaced with SF, its strength rises. The Geopolymer concrete is developing strength early, as can be observed by comparing the outcomes of curing under two different types of processors. Additionally, there is no discernible difference between water curing and temperature room curing. Additionally, Geopolymer Concrete attained the Mix Design Strength at above 40% of GGBS with 60% of SF.

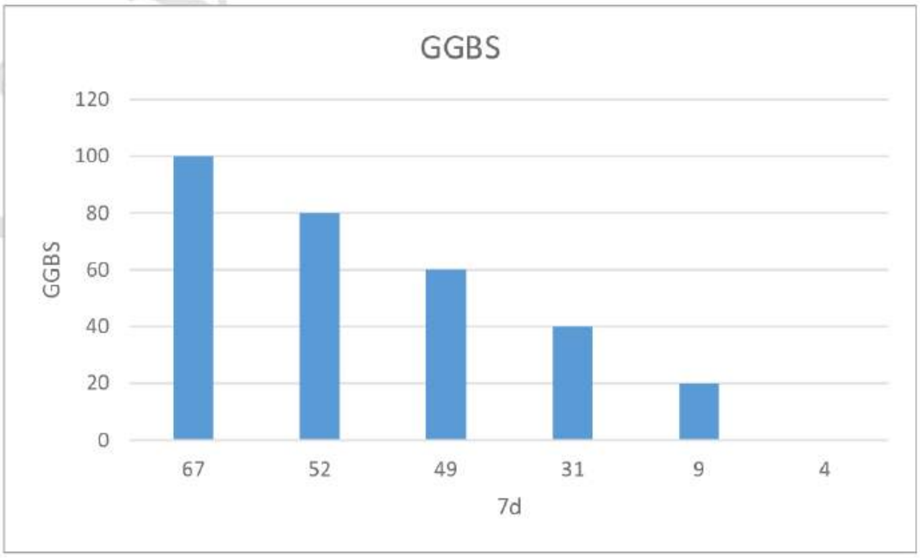
4.6 Compressive Strength

The study employed a single standard for each combination at 7, 14, and 28 days, in accordance with the British standard BS1881 Part 116: 1983. To measure the resilience of concrete during various cures, cubes were tested for compressive at 7, 14, and 28 days. Below is a graph showing how Geopolymer Concrete behaved when SF was substituted with GGBS in various degrees.

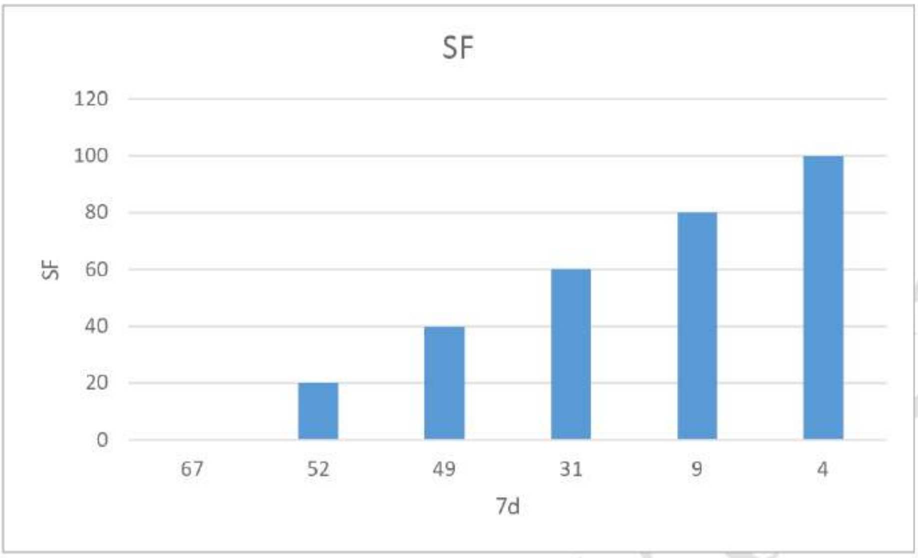
(A).-Water Curing

Table GGBS and SF compression test in 7 days

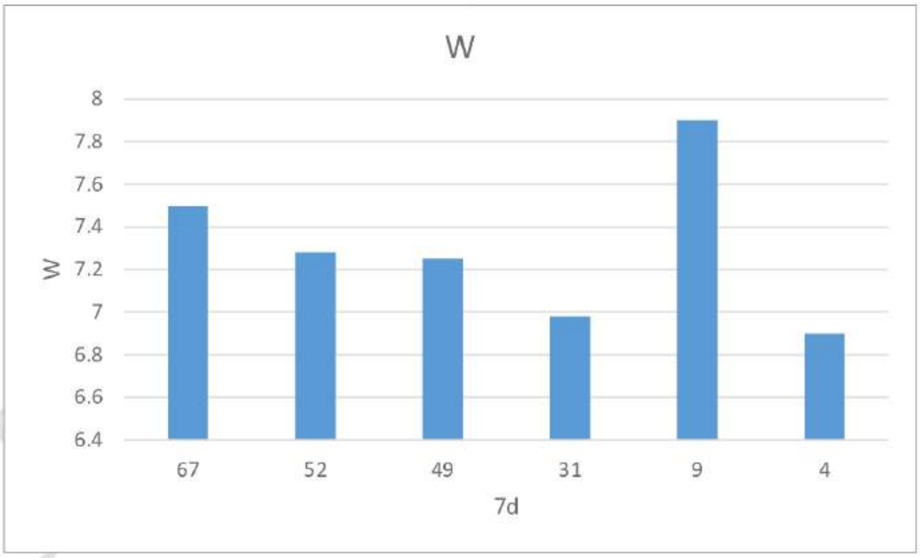
Materials			days	Date of product
GGBS	SF	W	7 d	19/05/22
100	0	7.50	67	15/05/22
80	20	7.28	52	17/06/22
60	40	7.25	49	17/06/22
40	60	6.98	31	17/06/22
20	80	7.90	9	19/06/22
0	100	6.90	4	20/06/22



(a)



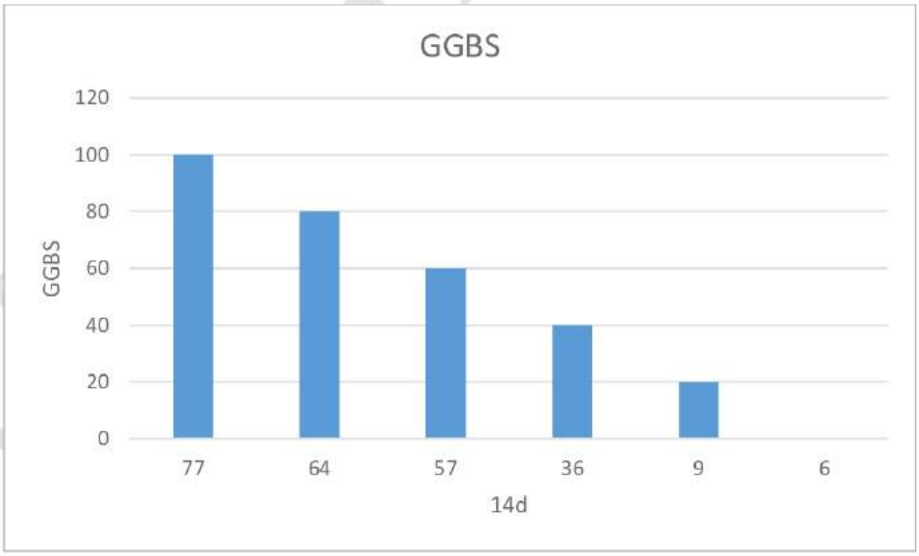
(b)



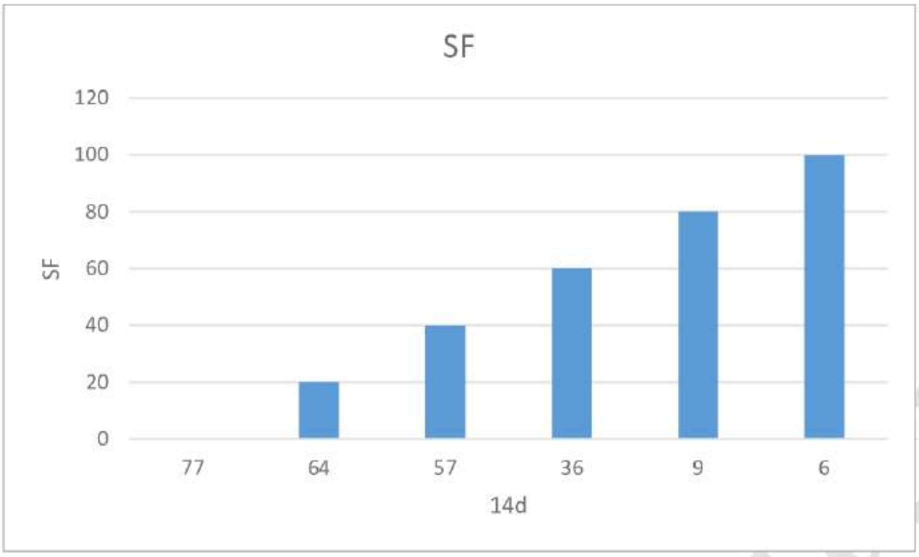
(c)

Table GGBS and SF compression test in 14 days

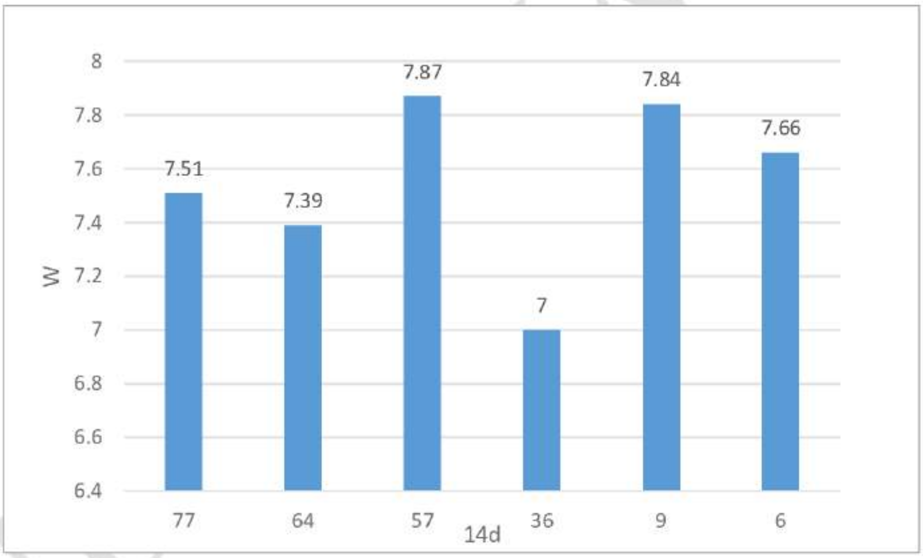
Materials			days	Date of product
GGBS	SF	W	14 d	19/05/22
100	0	7.51	77	15/05/22
80	20	7.39	64	17/06/22
60	40	7.87	57	17/06/22
40	60	7.00	36	17/06/22
20	80	7.84	9	19/06/22
0	100	7.66	6	20/06/22



(a)


SF
120
100
80
60
40
20
0
SF
77
64
57
36
9
6
14d

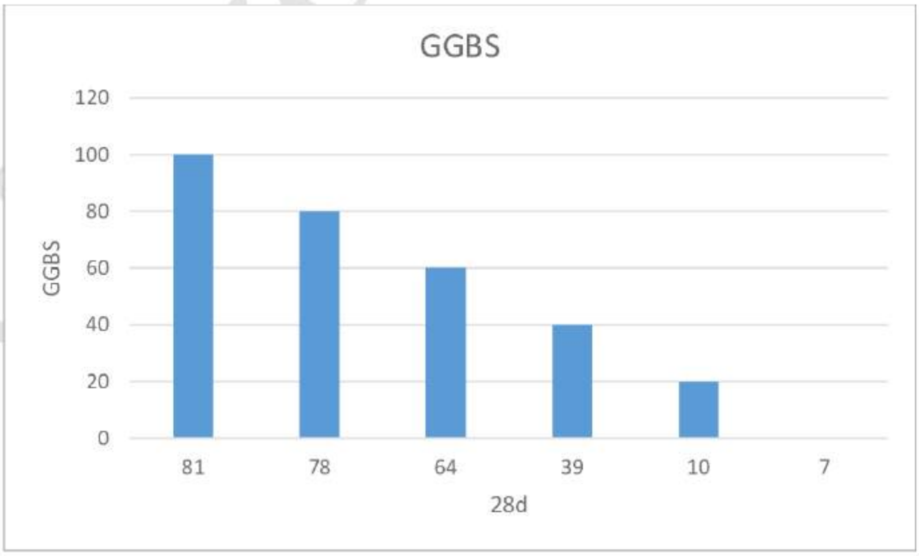
(b)


8
7.8
7.6
7.4
7.2
7
6.8
6.6
6.4
W
7.51
7.39
7.87
7
7.84
7.66
77
64
57
36
9
6
14d

(c)

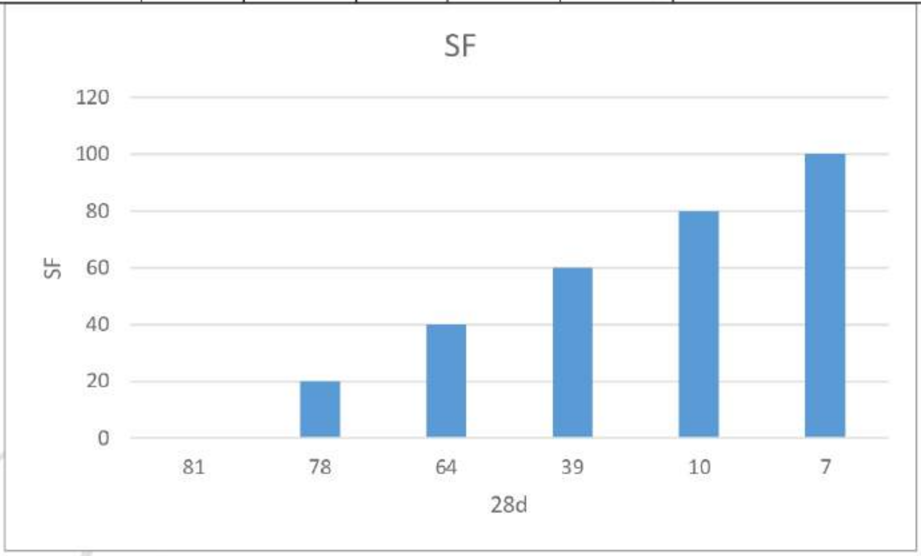
Table GGBS and SF compression test in 28 days

Materials			days	Date of product
GGBS	SF	W	28 d	19/05/22
100	0	7.60	81	15/05/22
80	20	7.45	78	17/06/22
60	40	7.20	64	17/06/22
40	60	7.07	39	17/06/22
20	80	6.99	10	19/06/22
0	100	6.82	7	20/06/22

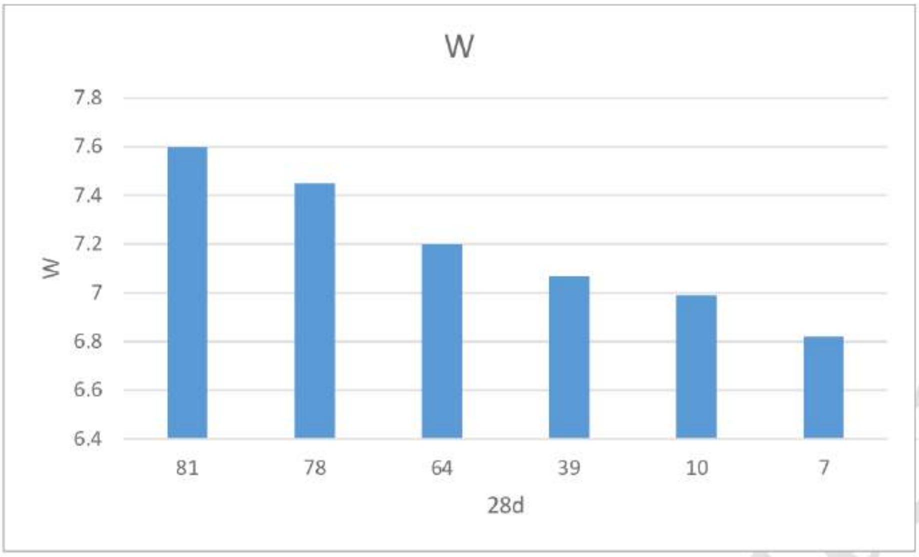


(a)

Materials			days			Date of product
GGBS	SF	W	7 d	14 d	28 d	19/05/22
100	0	7.60	67	77	81	15/05/22
80	20	7.45	52	64	78	17/06/22
60	40	7.20	49	57	64	17/06/22
40	60	7.07	31	36	39	17/06/22
20	80	6.99	9	9	10	19/06/22
0	100	6.82	4	6	7	20/06/22



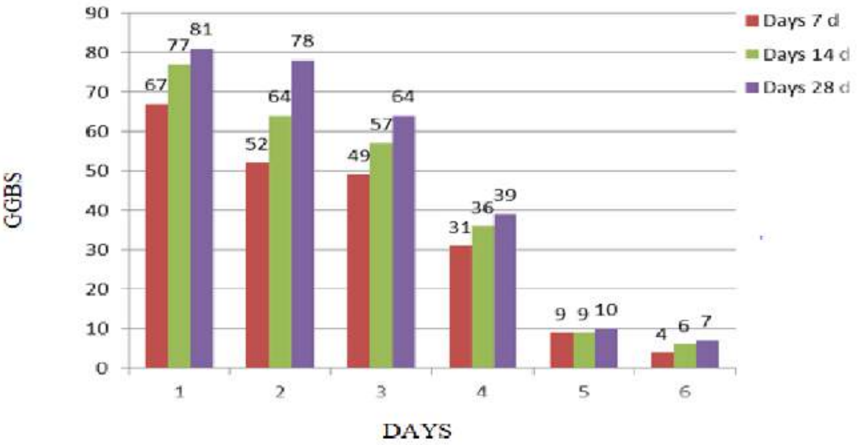
(b)



(c)

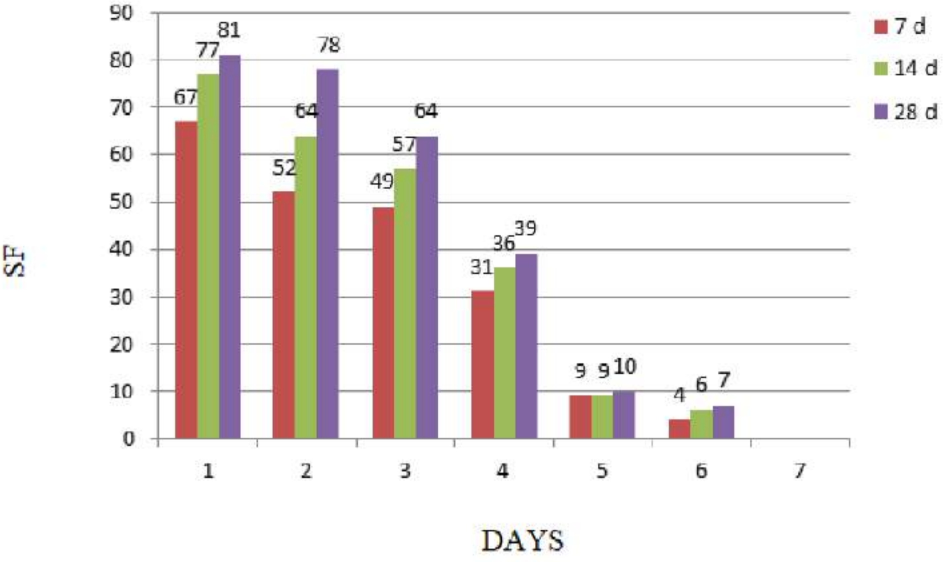
Mix results of GGBS and SF

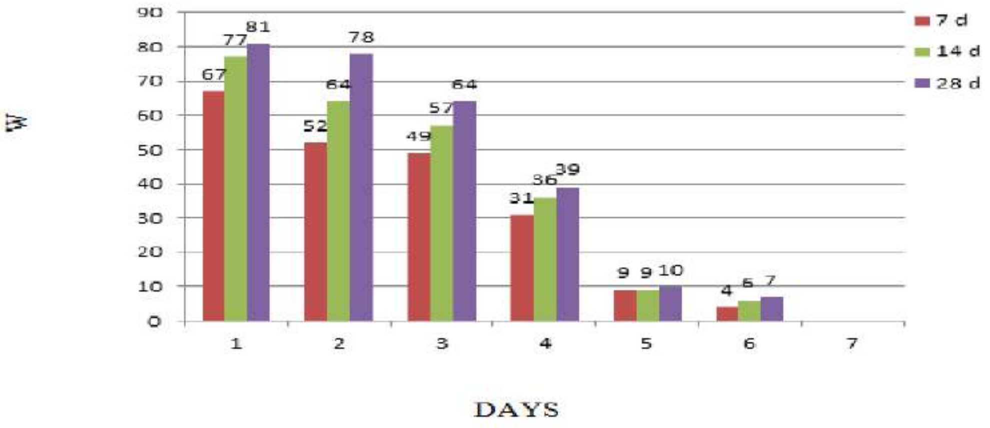
Materials	days			Date of product
GGBS	7 d	14 d	28 d	19/05/22
100	67	77	81	15/05/22
80	52	64	78	17/06/22
60	49	57	64	17/06/22
40	31	36	39	17/06/22
20	9	9	10	19/06/22
0	4	6	7	20/06/22



Materials	days			Date of product
SF	**7 d**	**14 d**	**28 d**	19/05/22
0	67	77	81	15/05/22
20	52	64	78	17/06/22
40	49	57	64	17/06/22
60	31	36	39	17/06/22
80	9	9	10	19/06/22
100	4	6	7	20/06/22

Materials	**days**			**Date of product**
SF	**7 d**	**14 d**	**28 d**	19/05/22
0	67	77	81	15/05/22
20	52	64	78	17/06/22
40	49	57	64	17/06/22
60	31	36	39	17/06/22
80	9	9	10	19/06/22
100	4	6	7	20/06/22


SF
DAYS
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
7 d
14 d
28 d
67
77
81
52
64
78
49
57
64
31
36
39
9
9
10
4
6
7


W
DAYS
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
7 d
14 d
28 d
67
77
81
52
64
78
49
57
64
31
36
39
9
9
10
4
6
7

4.7 Split Tensile Strength Test

When compared to normal concrete, the exhibits an increase in strength of 22.10 percent due to a 20 percent silica fume substitution. Again, strength decreases as silica fume percentage rises. As shown above, compared to a standard concrete mix, a 20 percent increase in compressive strength is gained by replacing silica fume with roughly 25 percent more cement.

Table: Split Tensile Strength Test

Mix	% Replacement	Compressive Strenght(N/mm^2)		
		7 Days	14 Days	28 Days
M-1	0	4.01	3.99	5.00
M-2	5.1	4.66	4.87	4.99
M-3	6.9	4.22	5.00	5.33
M-4	11.99	6.00	5.99	4.99
M-5	16	6.21	7.00	6.99
M-6	21	4.99	6.00	6.00
M-7	26	4.50	6.33	6.20

Table: Split tensile strength at 7 days

Mix	% Replacement	7 Days
M-1	0	4.01
M-2	5.1	4.66
M-3	6.9	4.22
M-4	11.99	6.00
M-5	16	6.21
M-6	21	4.99

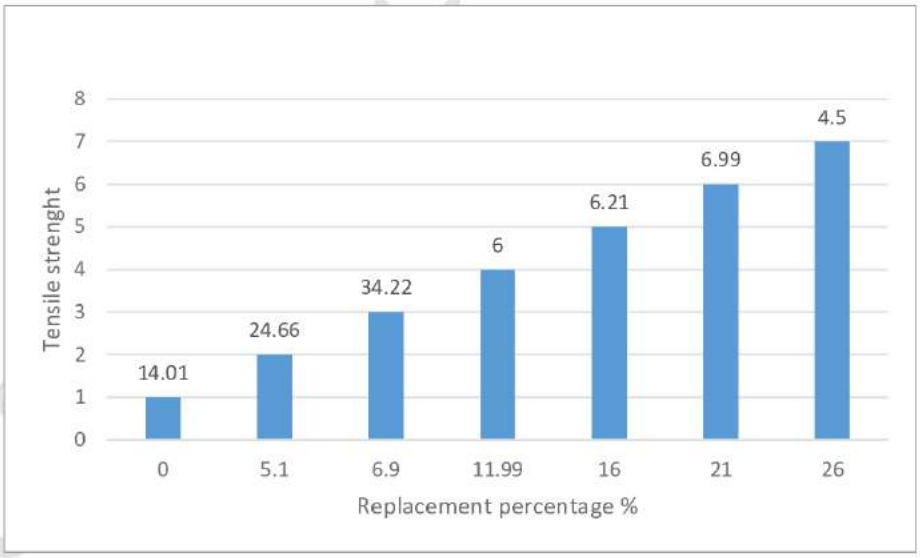


Table : Split tensile strength at 14 days

Mix	% Replacement	14 Days

M-1	0	3.99
M-2	5.1	4.87
M-3	6.9	5.00
M-4	11.99	5.99
M-5	16	7.00
M-6	21	6.00

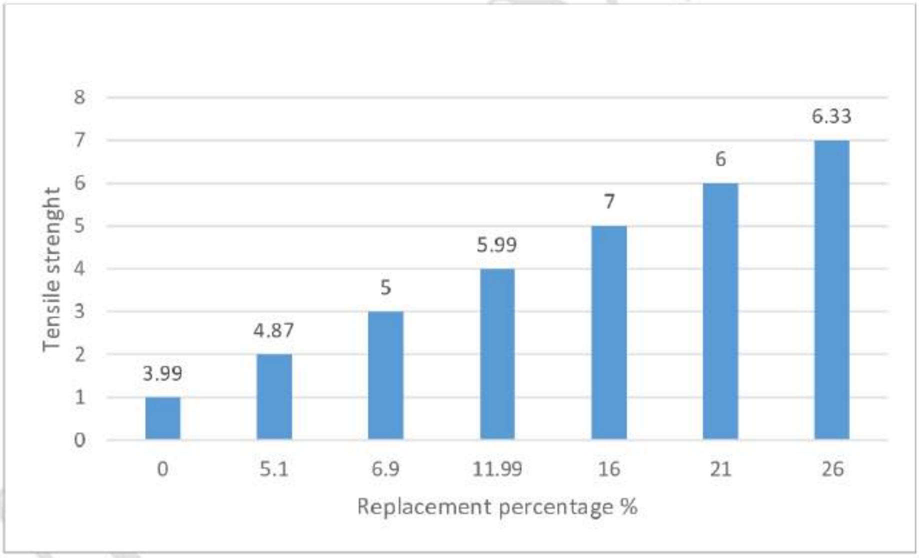
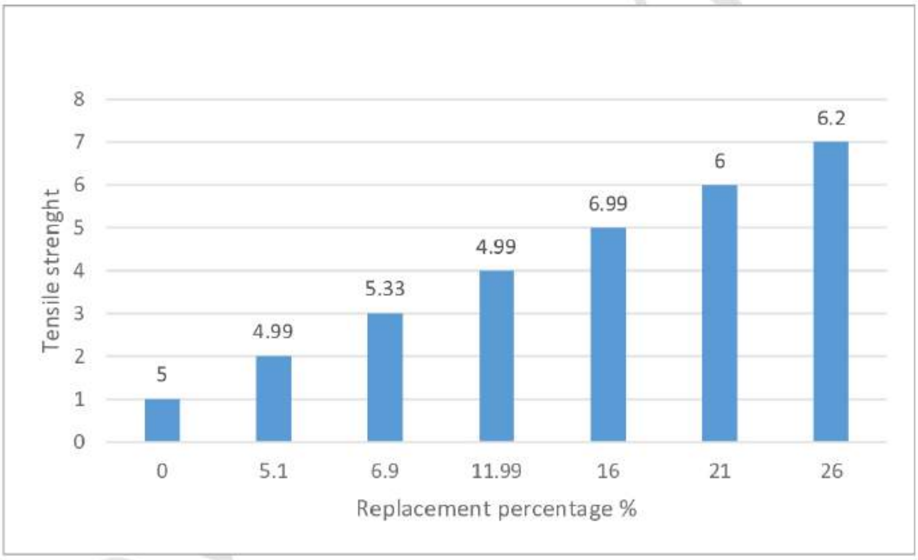


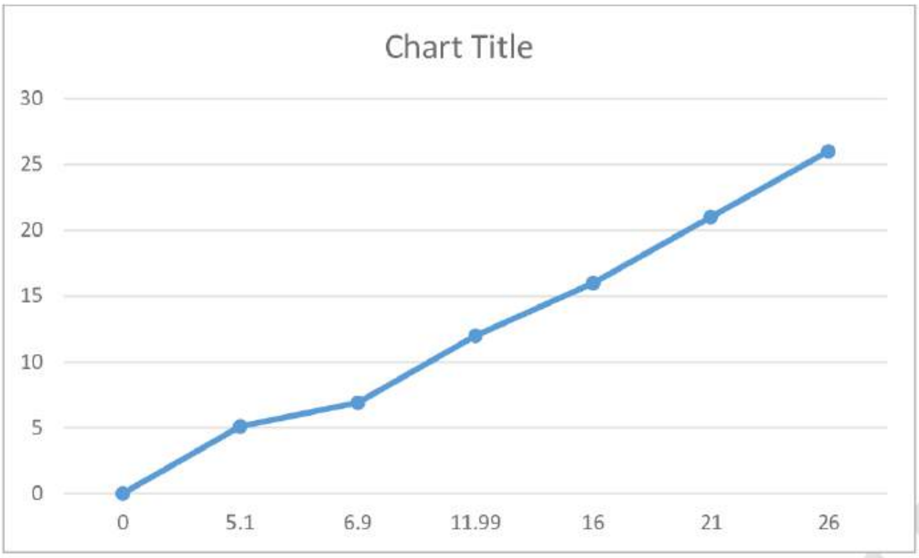
Table : Split tensile strength at 14 days

Mix	% Replacement	28 Days
M-1	0	5.00

M-2	5.1	4.99
M-3	6.9	5.33
M-4	11.99	4.99
M-5	16	6.99
M-6	21	6.00



Split Tensile Strength in N/mm2 at various age (Days)



The split tensile strength increases by 38 percent when cement is partially substituted with SF, as indicated in the graph at point 9 (7-day strength). After then, as the percentage of SF increases, strength begins to decline. When silica is replaced by 15% in graph 10 (14-day strength), the Split Tensile strength is increased by 42.39% in comparison to regular concrete. Strength also starts to decline in this case as the percent of SF increases.

In comparison to ordinary concrete, the graph of 28 days' strength in figure 11 indicates an increase of 45.58 percent in strength and a 15% replacement of silica fume. Again, strength decreases as silica fume percentage rises. As was said above, a 15 percent increase in compressive strength may be accomplished by replacing silica fume with roughly 45 percent more cement than in a standard concrete mix.

4.8 Workability

The workability of concretes of equal slump is typically improved by fly ash, slag, calcined clay, and shale. A concrete mixture may become sticky due to silica fume; modifications, such as the use of high-range water reducers, may be necessary to retain workability and enable correct compaction and finishing.

The ranges of material proportions for geopolymer concrete mixes are shown in Table 4 according to Davidovits [12]. The ratio of sodium silicate to sodium hydroxide solution was indicated to be 2.0-2.5, while the ratio of alkaline liquid to binder was 0.3-0.45. Aggregate makes between 65 to 85 percent of the mass of geopolymer concrete, with fine aggregate making up 30 percent of the overall volume of aggregate. Super plasticizer concentration is estimated to be between 1.5 and 4 percent by mass of binder. If more water is required, it can be added in the range of 0.02 to 0.06 percent of the cementitious material's mass.

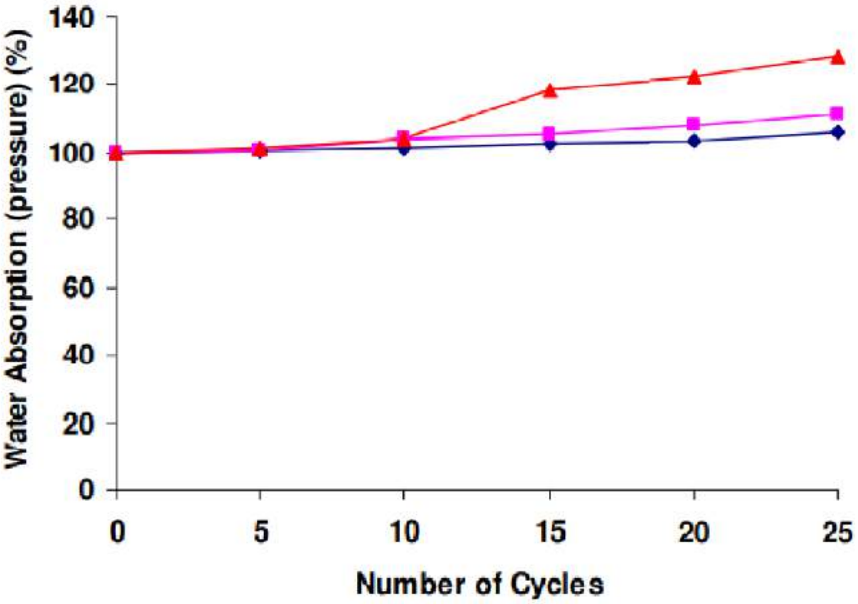
Standards of materials used in geopolymer concrete mixes.

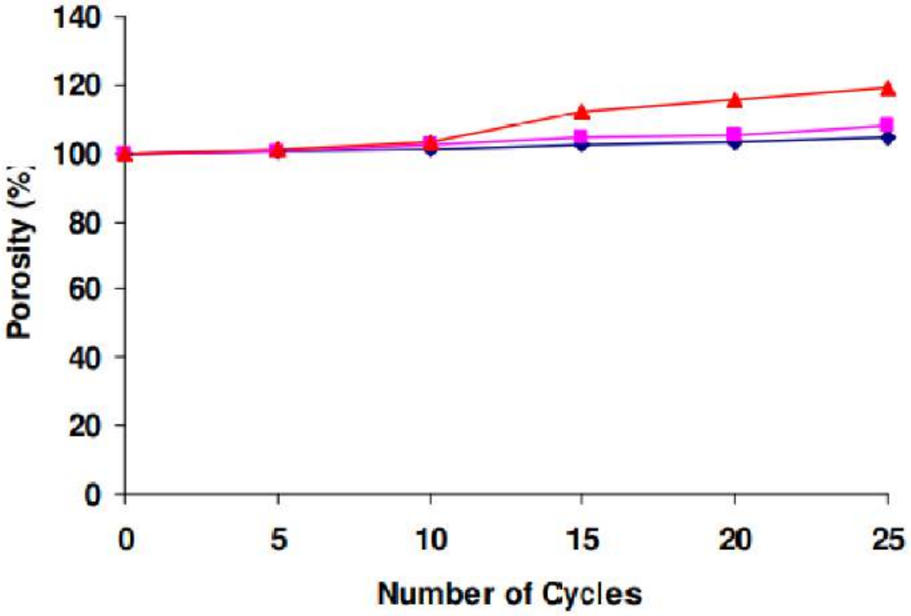
Materials	**Range**
Alkaline liquids/Binder	0.2–0.41
Sodium silicate/sodium hydroxide	2.1–2.7
Water/Binder	0.15–0.31
Total aggregate in mass of concrete	64%–83%
Fine aggregate content in total aggregate	29%
Added water content	0.03%–0.07% of mass of cementations material
Super Plasticizers	1.3%–5% of mass of cementations material

Fly ash, GGBFS, sodium hydroxide, sodium silicate, fine aggregates, coarse aggregates, water, and super plasticizer are the many components utilised in the geopolymer concrete mix design. The unit weight of plain concrete (2400 kg/m3) serves as the foundation for the mix proportions of all these elements. The percentages of coarse and fine aggregates utilised were, respectively, 70% and 30%. Alkaline liquid to cementitious materials was assumed to be in a ratio of 0.35, while sodium hydroxide and sodium silicate were in a ratio of 2.5.

If the weight (percent) vs the number of cycles test for the limestone at the lower levels of Tirtar is drawn, it may be inferred that the salt crystallisation offers a somewhat larger rise than the freeze-thaw test. The same conclusions may be made for porosity. Densities that are dry or saturated are not considerably impacted by the durability tests. 113 However, the durability tests have a considerable impact on the UCS. When compared to the freezing-thawing and wetting-drying tests, salt crystallisation results in the greatest drop in strength during the final cycles. Similar reduction order is plainly seen at sonic velocity. The salt crystallisation test, however, is once more the most successful test for reducing the sonic velocity. The strongest and fastest harm to the stone's strength and sonic velocity is caused by salt crystallisation. The limestone deteriorates dramatically during the salt crystallisation test, but not at all during the wet-dry test.

As a result, all other characteristics outside dry unit weight and saturated unit weight are impacted by the durability tests. It is evident that throughout the course of the durability testing, values for weight, porosity, water absorption, sonic velocity, and uniaxial compressive strength vary. After five test cycles, they are mainly increased. As a result, during the cycles, both weight losses and damages rise in a comparable manner. We may draw the conclusion that salt crystallisation, freeze-thaw, and wet-dry testing cause limestone to deteriorate in order from most effective to least effective. The salt crystallisation procedure is the most damaging test, according to the figures for uniaxial compressive strength and sonic velocities.


Water Absorption (pressure) (%)
140
120
100
80
60
40
20
0
0
5
10
15
20
25
Number of Cycles


Porosity (%)
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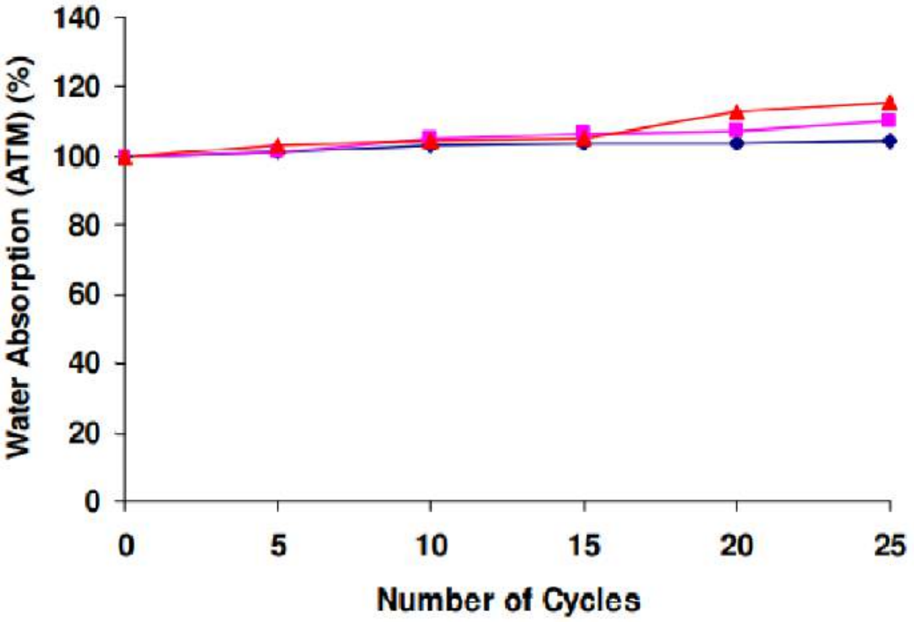
120
100
80
60
40
20
0
0
5
10
15
20
25
Number of Cycles


Water Absorption (ATM) (%)
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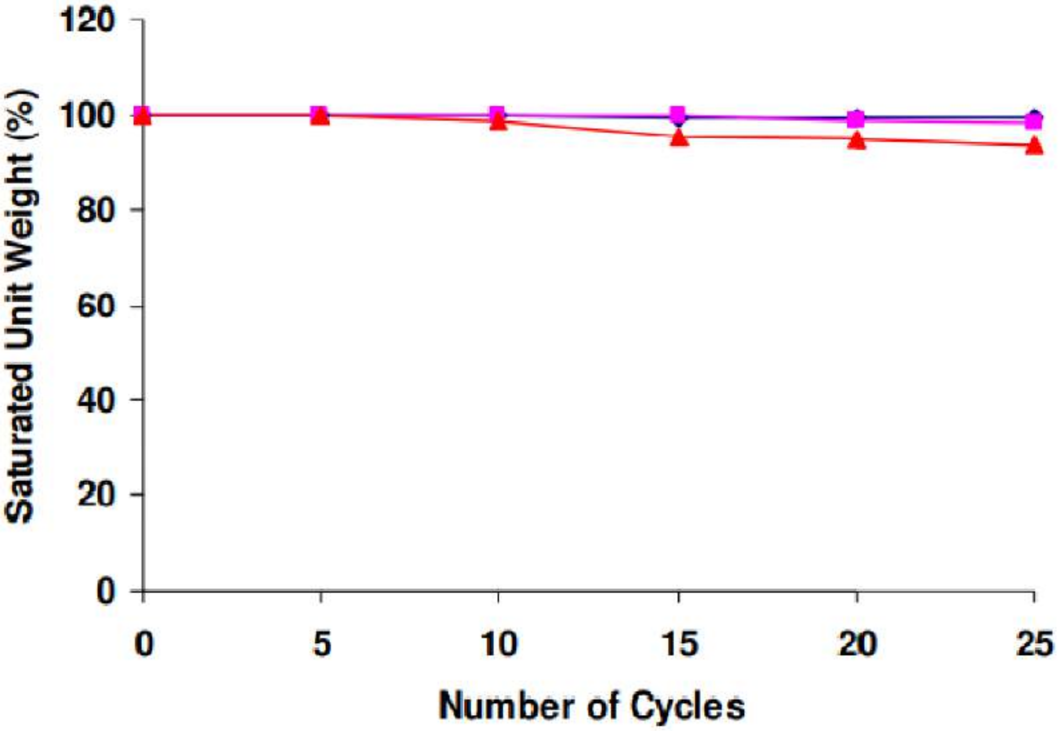
120
100
80
60
40
20
0
0
5
10
15
20
25
Number of Cycles


Saturated Unit Weight (%)
120
100
80
60
40
20
0
0
5
10
15
20
25
Number of Cycles

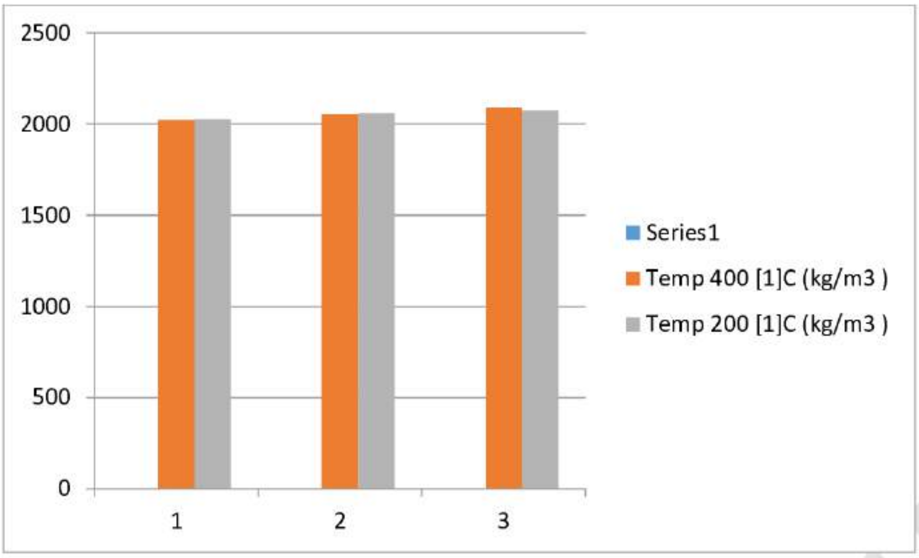
4.9 UPV TEST

Samples were heated to 200 C, 400 C, 600 C, and 800 C. Measured and compared were densities, compressive strengths, and UPV values.

Tables 3 and 4 show the densities of the mortar specimens both before and after being exposed to fire. Following exposure, the density fell everywhere. The average density decrease of the specimens is shown in Fig. 2. It can be noticed that the density reduction for every specimen was within 10% of one another (Table 5). For a temperature exposure of 200 C, the decrease for all blends was around 7%. The temperature exposure that caused the biggest density change, at 9%, was 800 C. Similar results were seen by Zhu Pan et al. [7], who discovered that the mass drop following temperature exposure was just 8 percent. The evaporation of water from the specimens as the temperature rises is the likely cause of the geopolymer mortars' density loss [7,23]. In addition to these results, the ratio of sodium hydroxide to sodium silicate had no discernible impact on the density of the mortars either before or after exposure.

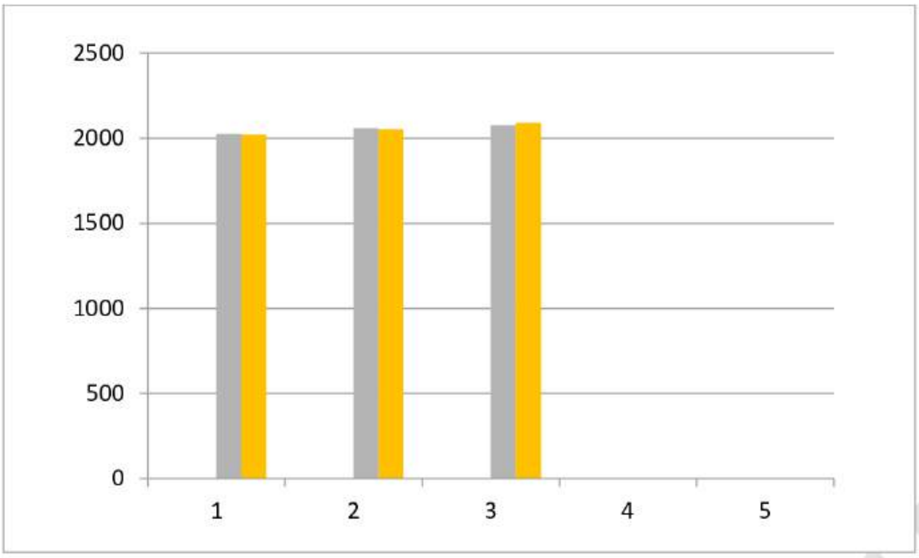
Prior to treatment to high temperatures, Na2SiO3 to NaOH ratios correlate to UPV and compressive strength.

Mix type	UPV (m/s)	Compressive strength, MPa 24 h	Compressive strength, MPa 7 days	Difference
M1	4086	19.5	18.8	4.9
M2	4245	38.2	32.6	4.8
M3	4353	39.2	37.3	4.3

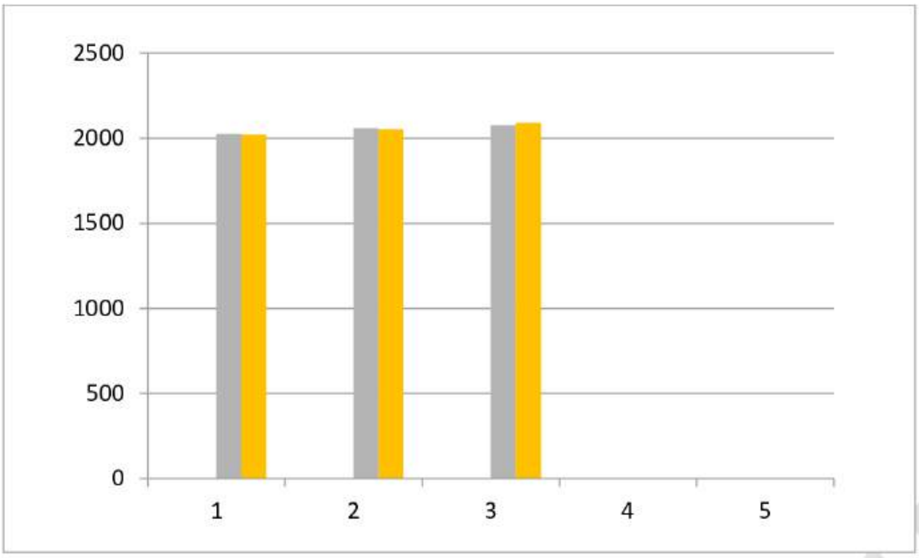


Density before exposure to elevated temperatures.

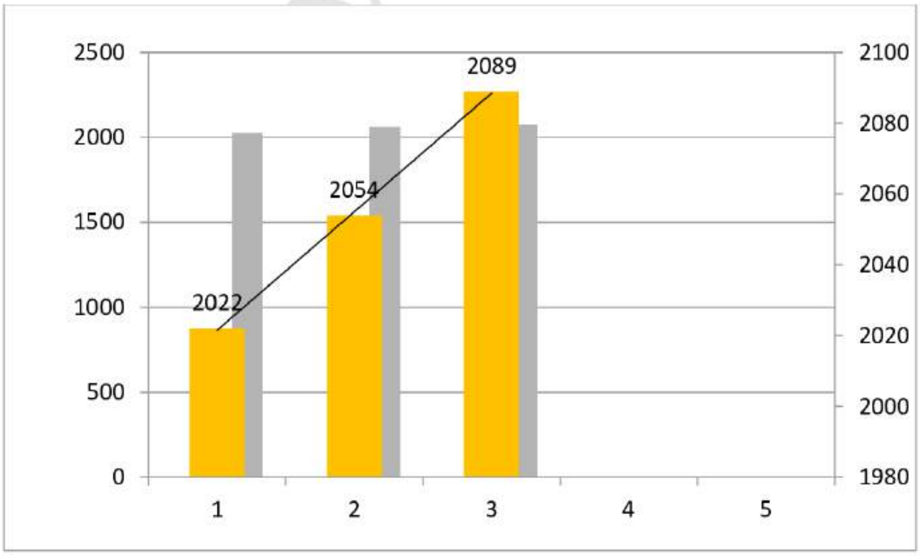
Mix type	Temp 200 C (kg/m3)	Temp 400 C (kg/m3)
M1	2181	2258
M1	2221	2123
M3	2248	2226



Mix type	Temp 200 C (kg/m3)	Temp 400 C (kg/m3)
M1	1667	800
M1	2383	1610
M3	2338	1538



Mix type	Temp 200 C (kg/m3)	Temp 400 C (kg/m3)
M1	2025	2022
M1	2061	2054
M3	2075	2089



Strength in compression following exposure to high temperatures. The findings regarding the cohesive strength of mortars following exposure to high temperature are shown in Fig. 3. It was discovered that the compressive strengths weakened with rising exposure temperature. The compressive strength for M1 fell by 26 percent, 47 percent, 69 percent, and 76 percent for exposure temperatures of 200 C, 400 C, 600 C, and 800 C, respectively.

The compres-sive strength did, however, rise by 5% and 1% for M2 and M3, respectively, following a temperature exposure of 200 C. (Table 6). Contrarily, for temperatures of 400 C, 600 C, and 800 C, respectively, the compresive strength fell by 19%, 44%, and 100% for M2 and by 31, 52%, and 100% for M3. The findings of Guerrieri and Sanjayan [18] that specimens with beginning strengths of 7.5 MPa or above exhibited a significant decline in compres-sive strengths up to 90% and those greater initial strengths led to larger strength reductions are strongly supported by the results attained. The two opposing processes that manifest in the specimens as the temperature rises can be linked to this phenomenon.

The UPV values for M1, M2, and M3 reduced by 57%, 42%, and 44% when exposed to 200 C, respectively. Similar to how they did for the other temperatures, the UPV values for M1, M2, and M3 after exposure to 400 C fell by 81 percent, 64 percent, and 68 percent. It was shown that higher temperatures caused a greater drop in UPV, but that larger sodium silicate to sodium hydroxide ratios had less of an impact on the effect of rising temperatures. These UPV results support the findings from the comparative strength measurements performed at the above-mentioned elevated temperatures, which showed that the comparative strength increased for higher sodium silicate to sodium hydroxide proportions at every temperature level and decreased even as temperature increased. The compres-sive strength and UPV values are displayed against the Na2SiO3 to NaOH ratio in Figs. 3 and 5. Despite the differences in size, there are similarities in trends, suggesting that UPV values may be accurate predictors of compressive strength for geopolymer mortar specimens subjected to high temperatures.

CHAPTER 5

CONCLUSION

The following conclusions may be drawn from experimental research on geopolymer concretes: 1) the addition of SF to geopolymer concrete mixes caused the pore structure to become finer, which produced concrete with low permeability. 2) By using just self-curing mechanisms and a ratio of 40% SF to 60% GGBS, geopolymer concretes made with various combinations of SF and GGBS may create structural concretes of high grades (far higher than 45MPa). 3) The GPC mixes were simply made utilising tools that were already utilised to make ordinary cement concretes. 4) The effects of SF on the strength of concrete mixtures including geopolymer were investigated. It has been shown that the compressive strength of geopolymer increases when the amount of SF is reduced. 5) In addition to requiring less energy, the GPCs use industrial wastes to create the binding system in concrete. Utilizing SF, fly ash, and GGBS has both economic and environmental advantages.

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