To Study the Mechanical Properties of Lightweight Geopolymer Concrete using Slag Aggregate at Elevated Temperature

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Declaration

I certify that this research work titled "*To Study the Mechanical Properties of Lightweight Geopolymer Concrete using Slag Aggregate at Elevated Temperature*" is my work. The work has not been presented elsewhere for assessment. The material that has been used from other sources has been properly acknowledged/ referred to.

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Abstract

Concrete is a major component of modern building practices. Researchers have been looking into viable alternatives to cement and natural aggregate because of the rapid depletion of natural resources, the enormous amounts of energy consumption, and the environmental degradation. Concrete's ability to resist fire is another major factor which requires attention. Slag based lightweight geopolymer concrete, which makes use of industrial wastes including Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBFS) and slag aggregate, has emerged as a possible alternative to address these challenges, thanks to their promising eco-friendliness and fire resistance. The fire resistance and mechanical properties at high temperatures of lightweight geopolymer concrete are compared with those of control samples in this investigation. FA and GGBFS are used to make an alkali-activated light weight geopolymer concrete matrix with various replacement ratios (F60G40, F50G50, and F40G60, respectively). The samples of geopolymer concrete were left to cure in the air for 28 days. At room temperature, 200, 500, and 800 °C, the material's mechanical properties were evaluated. While the control sample only managed 30 MPa and 4.4 MPa in compressive and flexural strength, respectively, at room temperature, the F60G40 mixture obtained 37 MPa and 5.5 MPa. All specimens lost strength with increasing temperature, although the F60G40 mixture lost less strength than the controls. The compressive strength of the F60G40 mixture remained at 13.1 MPa and the flexural strength at 2 MPa even after being heated to 800 °C, while those of the control sample were 11.8 MPa and 1 MPa, respectively. The stress-strain responses, elastic modulus retention, and energy absorption of geopolymer concrete were also significantly improved.

Keywords: Fly ash (FA), Ground Granulated Blast Furnace Slag (GGBFS), Fly ash (F), Slag (G), Modulus of Elasticity (MOE), Compressive Strength (CS), Flexural Strength (FS), Toughness Index (TI), Flexural Indices (FI).

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List Of Abbreviations

GGBFS	Ground Granulated Blast Furnace Slag
LWC	Light Weight Concrete
PCC	Portland Cement Concrete
LWA	Light Weight Aggregate
SF	Silica Fume
FA	Fly Ash
TC	Thermocouples
NSC	Normal Strength Concrete
UHPC	Ultra High-Performance Concrete
HSC	High Strength Concrete
TC	Thermocouples
F	Fly Ash
G	Ground Granulated Blast Furnace Slag
GPC	Geopolymer Concrete
OPC	Ordinary Portland Cement
C-S-H	Calcium silicate hydrate

CHAPTER 1

Introduction

1.1. General

Most buildings are made of concrete (Jahanzaib Khalil et al., 2021). It's famous because it's easy to get to, doesn't get damaged by water, and can be made into many different shapes and sizes. Over the course of history, people who make cement and concrete have had to deal with the natural effects of their work. Concrete is the second most used thing in the world, after water. On average, each person uses about one cubic meter of concrete per year (McCaffrey, 2002). The cement industry is at the heart of this growth, and its production is expected to reach a staggering 3.5 billion tons by 2015.

Modest estimates say that the cement industry is responsible for 5% of global CO_2 emissions in developed countries and up to 10% in developing countries (Amran et al., 2020; Davidovits, 1989) Despite attempts to use industrial byproducts as alternatives to cement because they work better and have less of an effect on the environment, their overall impact remains relatively small. Concrete is used to build infrastructure because it is cheap, flexible, and can keep steel support from rusting. It is also a good fire-resistant layer for reinforcing buildings, which helps to keep its high status in the construction world.

Calculations show that it takes about 94.76×10^6 Joules of energy to make one ton of cement (Kukreja et al., 2023; Luo et al., 2022). It’s interesting to find that making one ton of cement is about the same as putting out the same amount of CO_2 into the air. There has been a rise in cement production, especially in developing countries, (Belaïd, 2022) India was the second-largest cement maker in the world in 2013 (Aziz et al., 2022; Jahanzaib Khalil et al., 2021). Its cement production potential was close to 381 million tons. Environmental analysts are worried about the rise of greenhouse gas emissions into the environment. (Rehman et al., 2020) International meetings like the Earth meetings of 1992 and 1997 have expressed deep concern about the unchecked rise of greenhouse gas emissions.

A possible way to reduce CO_2 pollution is to use different materials for concrete, which would cut down on the amount of CO_2 released. In places like India, coal is the main source of energy, and coal's waste, fly ash, can harm the environment if it isn't handled properly. India made a huge amount of fly ash between 2012 and 2013 (Kukreja et al., 2023) 163.56 million tons. Unfortunately, only about 38% of this fly ash is used in building projects. The rest is dumped into ash ponds or lakes. Due to its size, chemical content, and ability to filter, poor dumping of fly ash could harm water and land. This adds to the worries about how to handle fly ash.

Ordinary Portland Cement (OPC) concrete has a lot of carbon emissions, so the building industry is looking for low-carbon options. Alkali-activated concrete (GPC) is being studied as a possible solution. GPC reacts with natural elements that are rich in silica and alumina to make binding agents (Davidovits, 1989; Huang & Wang, 2021). Notably, GPC concrete is different from OPC in that it doesn't depend on the calcination of calcium carbonate, which is a major source of CO_2 emissions in OPC concrete (McCaffrey, 2002). This could reduce emissions by 45% to 80% per cubic meter of replaced OPC concrete (Duxson et al., 2007; Hardjito et al., 2004). As Geopolymer becomes an option to regular concrete, it must have the same or better qualities as concrete. Fire protection is especially important. Several ways have been thought of to reduce the amount of cement used in concrete, such as partly swapping cement with other materials. Still, this method only reduces CO_2 pollution by a small amount. Completely replacing cement is a more comprehensive answer, and Geopolymer Concrete (GPC) stands out as a strong candidate. Alkaline reaction of alumino-silicate components makes GPC, and fly ash is a common and easy-to-get source of alumino-silicate. By not making cement, using geopolymer concrete with fly ash cuts down on CO_2 emissions. It also helps deal with a large amount of industrial wastage, which is fly ash. Since the 1990s, study on geopolymer concrete has been steadily going up. Most of the time is spent trying to figure out how different components, like aluminosilicates and alkalis, affect the complex physical and chemical processes of geopolymer concrete.

When concrete is exposed to high temperatures, such as in fires, heating processes, furnace conditions, or nuclear accidents, this can happen. In these situations, it's important to understand how concrete and other building materials react to high temperatures. Even though a lot of research has been done on how Ordinary Portland Cement (OPC) concrete acts at room temperature. Concrete is used in dams, buildings, bridges, infrastructure growth, and apartment structures. When lightweight materials became available in the late 1800s and early 1900s, it was a big step forward for lightweight concrete technology (Posi et al., 2013). Lightweight concrete has a lot of benefits over regular concrete, such as reducing structure loads, making buildings more soundproof, and lowering transportation costs (Posi et al., 2016; Rehman et al., 2020). It can be used for a wide range of things, from making walls and sidewalks to adding layers to metal structures, manufactured panels, and superstructures. From the point of view of ecology, lightweight concrete offers many structural and artistic options.

At 28 days after being poured, high-strength light concrete should have a compression strength of 40 MPa (Sanjayan et al., 2015). Coarse aggregate is used to make light concrete. However, according to the American code ACI 213R, the density of coarse aggregate should be no more than 880 kg/m3. Using 25%–35% less concrete mass than standard-weight concrete makes beams and supports 25%–35% smaller and requires 25%–35% less supporting bar (Mousavinejad & Sammak, 2021). This leads to a building option that is both affordable and long-lasting. Alkali-activated materials are seen as new ways to make binders, so study into them has grown a lot in recent years. These materials come from natural sources that are high in silicon and aluminum. They are made through an alkaline activation method that uses things like fly ash and blast furnace slag. Alkali-activated systems can be put into two groups: early CaO precursors with Al2O3 and materials rich in Si-Al precursors but not CaO, like ashes and metakaolin, which make up the majority.

When the two different systems (Ca/(Si-Al) and Si-Al) are put together, they set off different reactions that make gels with different properties. The Ca/(Si-Al) system goes through a complicated reaction process that makes the main binding phase an aluminum-modified C-A-S-H calcium silicate hydrate (International, 2002.; Zhang et al., 2009). This stage starts when CaO absorbs water in the presence of Al2O3, and it gets worse as the process goes on. On the other hand, to make a three-dimensional geopolymer gel in the form of (N-A-S-H) sodium alum inosilicate hydrate as the primary binding phase, the Al-Si system polymerization requires the initial dissolution of SiO2, then an exothermic condensation process, and finally crystallization processes. The alkaline action of a mixture of fly ash, slag, glass grinding waste, and palm oil fuel ash makes gels that stick together more strongly. These gels are made by the mixing system. These gels are made by this activation process, and the mixing process helps improve their mechanical performance. Compared to regular Portland cement concrete, this kind is more durable and can stand up to the damaging effects of salt and magnesium sulfate.

Geopolymers are artificial materials, usually ceramics, that form non-crystalline networks with long-range chemical bonds. They are a type of pottery that is made of alumino-silicate and nothing else. These materials are hard gels that are made in conditions of temperature and pressure that are not too extreme. Davidovits was the first person to use the word "geopolymer" in 1970. Most geopolymers are made by polymerizing different types of industrial waste, like fly ash, blast furnace slag, rice husk ash, and clay . One of the best things about geopolymers for building is how quickly they get stronger. Around 90% of their strength is reached within the first 4 hours of polymerization at high temperatures (Davidovits, 1989).

In a two-step process, geopolymers are made:

a) Activation: For this step, aluminates and silicates are dissolved in a highly alkaline solution to make Si-O-Al links.

b) Polycondensation: In this process, high temperatures cause polymerization, which leads to the formation of 3D molecular units that are joined together.

Geopolymer concrete is a new and environmentally friendly building material that can be used instead of Portland cement. It is made when solid molecules react with each other chemically. The most important part of making geopolymer concrete is the reaction between parts that are high in alumina and silica and an alkaline solution. This makes alumino silicate gel, which is used to hold geopolymer concrete together. Geopolymer concrete can be made from fly ash, ground granulated blast furnace slag (GGBS), and rice husk ash, among other things plants (Klima et al., 2022; Liu et al., 2014). One benefit of making geopolymer concrete is that it mostly uses waste from the coal, power, and iron businesses. This helps clean up the environment and deal with garbage. When compared to regular cement concrete, geopolymer concrete is more resistant to fire and rust. Compared to plain cement concrete, it also has stronger compression and tension strengths and shrinks less. Geopolymer concrete is known for how long it lasts and how it hardens with less heat than regular concrete. It has been used in many construction projects around the world, including the Global Change Institute (GCI) building at the University of Queensland, which was made completely of geopolymer concrete.

Pakistan gets 9% of its energy from coal-fired thermal power, and the country has the 7th biggest coal stockpiles in the world, so geopolymer concrete should be a top choice for building in a country like Pakistan. This method not only solves problems with getting rid of wastage, but it also lessens the effects of climate change by cutting greenhouse gas emissions by almost 90%.

1.2. Significance and Scope

This study looks at how Geopolymer Concrete (GPC) acts and what happens to it when it is exposed to high temperatures. For uniformity, the starting material is Class F fly ash, and the activators (silicates and hydroxides) are bought locally. The study looks at workability, residual compressive strength, residual indirect tensile strength, elastic modulus, strains at constant load, and stress-strain relationships. This study is one of a kind because it looks at how GPC concrete changes when the temperature goes up. Most of the research has been done on small pieces in the lab, so not much is known about its mechanical, heating, deformation, creep, and temperature changes. For performance-based design and to understand how GPC concrete acts, how its makeup changes, and how its physical and mechanical traits change, it is important to understand these qualities.

1.3. Problem Statement

The building industry keeps growing, and cement is a key part of that. On the other hand, making traditional Portland cement hurts the climate and atmosphere in a way that can't be fixed. It gives off a lot of carbon dioxide, which adds to the loss of the ozone layer and makes up 5-7% of all greenhouse gas pollution in the world (McCaffrey, 2002). A lot of energy is also used in the process.

Geopolymer concrete is a cleaner option to Portland cement. It uses waste from the coal and steel industries, like fly ash and slag, to cut carbon pollution by 85–95% (Farhan et al., 2019). The goal of this study is to find out how GPC concrete acts and what happens to it when it is exposed to high temperatures. In the study, the same amount of Class F fly ash source material and siliceous debris from the area are used. It also looks at how the shape of geopolymer concrete changes as the temperature goes up, which is something that hasn't been investigated much in the past. Understanding the mechanical, temperature, deformational, and creeping properties of GPC concrete is important for performance-based design and predicting how it will behave.

1.4. Objectives

Most of the work that has been published is about how Geopolymer pastes and binders act. Few studies have looked at how activators and source materials affect the chemical and mechanical properties of Geopolymers. Geopolymer concrete mixes can't be made in a way that everyone agrees on, and only small amounts of Lightweight Geopolymer concrete have been used in tests. In this study, our main goals are:

a) To find out what the best percentage of fly ash and ground granulated blast furnace slag (GGBS) is for making lightweight geopolymer concrete (LWGC) by replacing slag aggregate with NWA.

b) To study the effect of high temperature on the mechanical qualities of Light weight Geopolymer Concrete (LWGC), such as Compressive Strength, stress-strain behavior, Flexural Strength, etc.

1.5. Organization dissertation

Chapter 2: Literature Review: The second part is a thorough look at what is known about Geopolymer Concrete (GPC) and Portland Cement Concrete (PCC). The study looks at many different things about both materials, like how they affect the environment, how they work, and how they affect the economy.

Chapter 3: Methodology: In this chapter, we will explain in detail how the experiments were done to compare and analyze GPC and PCC. We will talk more about how alkaline solutions are used to make GPC, how concrete cylinders are poured and allowed to harden, and how compressive strength is tested.

Chapter 4: Results and Discussion: This part will talk about the results of the tests, with a focus on how the compression strengths of GPC and controlled samples are different. The chapter will also talk about the differences between them at elevated temperature.

References: The part on references will have a full list of all the academic sources that were used in the thesis.

CHAPTER 2

LITERATURE REVIEW

2.1. Overview

Before we started buying materials and trying things out, we did a thorough study of the different properties of geopolymer concrete to learn more about the subject. Information from places all over the world. Different details are talked about, such as how drying affects GC and how the qualities of GGBS slag-based and fly-ash-based geopolymer concrete with different mixes change. In this chapter, a thorough look at the large amount of academic material related to the focus of the ongoing research project is given.

2.2. Geopolymer technology

2.2.1. Geopolymer – An Inorganic polymer

The improvements that have been made in making geopolymer paste, mortar, and concrete have been carefully investigated. This investigation starts with a broad outline and then goes into a detailed discussion of key characteristics that have a big effect on how geopolymer concrete works. These factors include the source materials picked, the temperature and time of drying, the important Si/Al ratio in the mixture, the amount of alkali agents, and the ratio of water to solid components. This paper looks at both Ordinary Portland Cement (OPC) concrete and Geopolymer Concrete (GPC) in detail, including how they work after being exposed to very high or low temperatures. Also, this study has

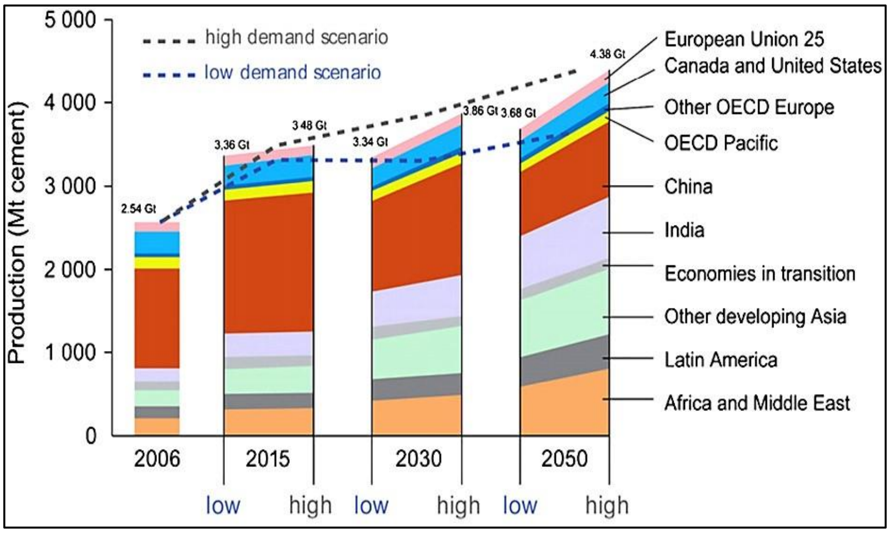


Figure 1 The yearly global cement production is estimated (Hasanbeigi et al., 2012)

a short look at how cylinders and beams behave when the temperature is normal and a look at how their behavior changes when the temperature goes up. Using the absorbed literature as a reference, the goals and limits of this study are set so that they fit with the main ideas of these results.

2.2.2. Brief history of geopolymer

The method for making cementitious materials has been around since the 8th century B.C. During that time, a common method was to dissolve rocks to make a paste that was like cement. This paste was then used to bind gravel and sand. But it's important to remember that not everyone agrees with this idea.

Table 1 History of Alkali-Activated Material Studied (DM Roy et. al, 1999)

Sl.No	Author	Year	Significance
1	Feret	1939	Slag used for cement
2	Purdon	1940	Alkali- slag combinations
3	Glukhovsky	1959	Theoretical basis and development of alkaline Cement
4	Glukhovsky	1965	First called "alkaline cement"
5	Davidovits	1979	"Geopolymer" term indroduced
6	Malinowsky	1979	Ancient aqueducts characterized.
7	Forss	1983	Clinger free cement (slag-alkalisuperplsticizer)
8	Langton and Roy	1984	Ancient building materials Characterized
9	Davidovits	1985	Patent of "Pyrament" cement
10	Krivenko	1986	DSc thesis, R_2O- Al_2O_3-SiO_2- H_2O
11	Malolepsy and Petri	1986	Activation of synthetic melilite slags
12	Malek. et al.	1986	Slag cement-low level radioactive wastes forms
13	Davidovits	1987	Ancient and modern concretes compared
14	Deja and Malolepsy	1989	Resistance to chlorides shown
15	Kaushal et al.	1989	Adiabatic cured nuclear wastes forms from alkaline mixtures
16	Roy and Langton	1989	Ancient concretes analogs
17	Majundar et al.	1989	Monocalcium Aluminate – slag activation
18	Talling and Brandstetr	1989	Alkali-activated slag
19	Wu et al.	1990	Activation of slag cement
20	Roy et al.	1991	Rapid setting alkali-activated cements
21	Roy and Silsbee	1992	Alkali-activated cements: an overview
22	Palomo and Glasser	1992	CBC (Chemically bonded cement) with Metakaolin
23	Roy and Malek	1993	Slag cement
24	Glukhovsky	1994	Ancient, modern and future concretes
25	Krivenko	1994	Alkaline cements
26	Wang and Scrivener	1995	Slag and alkali-activated microstructure

Ancient terra-cotta pots were made from earth using a low-temperature synthesis method (up to 200 °C) between the 7th and 9th centuries. In this process, clay sands and alkalis were mixed. The Coliseum is a good example of how durable Roman concrete buildings were constructed. They were like geopolymer concrete in that they lasted for a long time. This shows how long-lasting geopolymeric cements are by showing how long they have been around. In 1940, Prudon was the first person to make alkali-activated cement (Pacheco-Torgal et al., 2008), His work was all about combining GGBS, which was the aluminosilicate material, and sodium hydroxide, which was the alkali catalyst. After this turning point, alkali activation research spread across foreign lines, but it wasn't until the 1990s that big steps were made in this field. (DM Roy, 1999) has carefully put together a history picture of how alkali-activated cement has changed over time, and you can hear its effects in Table. The word "geopolymer," which was first suggested by Davidovits in 1982, has been used the most of all these terms. Davidovits chose the name "Geopolymer" because it sounds like the conditions that occur during the geothermal production of polymers. Geopolymer is made when alkali reacts with alumino-silicate rocks in a hot environment. The exact chemistry process behind how alkali-activated bonds harden and cement is still not clear, but it is thought to be based on both the basic material and the alkali activator. Several studies have come up with slightly different ideas about how geopolymers are made.

2.2.3. Chemistry of geopolymer

Davidovits proposed a model that shows how geopolymers are made exothermic, the chemical contact of geopolymeric, which is the first step, and the exothermic polycondensation, which is the second step. Davidovits says that alumino-silicates (geopolymers) have different three-dimensional shapes that range from amorphous to semi-crystalline. These structures include, The poly (Si-O-Al-O-) classification, Poly (Si-O-Al-O-Si-O-Si-O-) standard, Poly (Si-O-Al-O-Si-O-Si-O-Si-O-Si-O-Si-O-Si-O-Si-O-Si-O-).

Geopolymers are characterized by a chemical structure that is amorphous and three-dimensional. The expeditious setting and solidifying duration contribute to the formation of geopolymers with densely packed polycrystalline structures. Calcium silicate hydrate (C-S-H), calcium hydroxide, and ettringite are the main parts of hydrated cement paste. Out of these, C-S-H makes up about 60% of the makeup of wet cement. Figures 3 show a C-S-H model, in which the oxygen and hydrogen atoms in water molecules are shown by blue and white circles, respectively. In the same way, the green and gray spheres show calcium ions between and inside layers, while the yellow and red sticks show silicon and oxygen atoms inside silica tetrahedra.

To make a geopolymer, you need to use two different materials. First, you need a base material that has a lot of alumina and silica. This goes along with the use of an alkaline substance, which starts the process of polymerization.

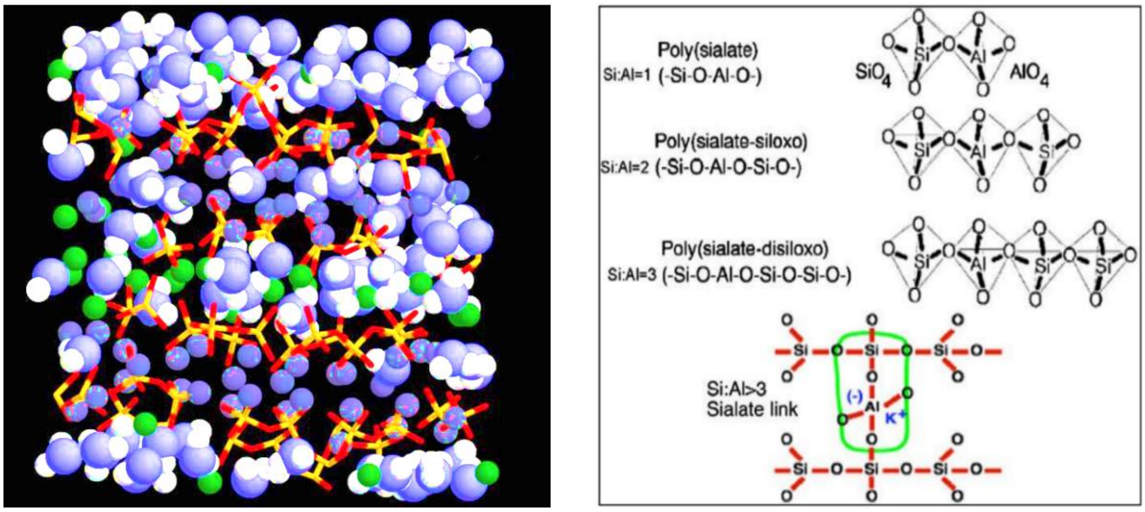


Figure 2 Figure 2 Oxygen reaction with Gel Si+ & Al+, CSH Model (Tayeh et. al, 2019)

In terms of industry wastage, fly ash comes from coal-powered thermal power plants, while slag comes from blast furnaces that make iron ore. Red mud comes from the waste made when bauxite is used to make aluminum.

An alkali component is added to the solution to speed up the polymerization process. These are generally elements from the first column of the periodic table's alkali metal group. Most geopolymers are made by mixing NaOH or KOH liquids with Na_2SiO_3.

(Tayeh et al., 2021) says that different clay rocks with alumina and silica oxides can also be used as raw materials for making geopolymers.

2.3. Geopolymer Concrete -Major Studies

In their research, (Xu & Van Deventer, 2003) investigated the geopolymerization of alumino-silicate minerals by studying 15 natural Al-Si crystals. Minerals like almandine, sillimanite, and kyanite were part of the collection. Using mixtures of sodium hydroxide and potassium hydroxide as alkalis, they heated the pieces for 3 days to fix them. The level of dissolution depended on the aluminosilicate material and the alkali used. When potassium hydroxide was present, stilbite had a high compression strength of 18 MPa. The result was that many different types of natural alumina-silicate materials could be used to make geopolymers. He also studied how the structure and surface of the source material affect the geopolymerization process. The study looked at several types of alumino-silicates, including kaolinite, albite, and fly ash.

The geopolymers that (Duxson et al., 2007) looked at were made from metakaolin and an alkaline liquid. The results showed what happened to compression strength and Young's modulus when the Si/Al mix changed. With a Si/Al ratio of 1.9, the strength and flexibility quickly went up, but with a ratio of 2.15, both went down. In their work, Duxson et al. looked at the link between the types of cations, the Si/Al ratios, and the compression strength of geopolymers made from metakaolin. They used alkaline liquid, mixed different kinds of alkali, and changed the ratio of Si to Al. The experimental material had solutions of sodium silicate with different amounts of SiO_2/M_2O. After 28 days, the compressive strength of mixed alkali specimens with ratios of 1.95 Si/Al was 30% higher than the compressive strength of single alkali specimens. The mechanical qualities depended on the type and number of cations. In terms of compressive strength and Young's modulus, mixed cations were better than single cations.

Study carried out to Investigate how particle size reduction and mechanical stimulation affect the properties of geopolymer. They looked at both raw fly ash and treated fly ash with different particle sizes and different high-molarity Alkali ratios. After 28 days, the compression strengths were 16 MPa and 45 MPa (Temuujin & van Riessen, 2009).

The behavior of geopolymer paste, especially in relation to different types of fly ash, such as "class F" and "class C" from different sources. As alkalis, NaOH and Na_2SiO_3 liquids were used in the trial procedure, and drying took place at 60 °C over the course of three days. The test included chemistry studies, XRD, and particle size distribution measurements. XRD and Raman spectroscopy were also used to look at the geopolymer paste. Also, samples of geopolymer concrete were tested for how long it took to set and how strong it was when compressed. Notably, liquids of NaOH and Na_2SiO_3 were mixed in a 1:1 ratio. The results showed that the chemical, crystalline, and physical properties of the fly ash were three of the most important factors that affected both the behavior of the fresh mixture and the mechanical properties of the hardened matrix. It was found that CaO content had a good effect on compression strength, even though setting time went down at the same time (Diaz-Loya et al., 2011).

A new way to deal with geohazards in these soils by using a pozzolanic soil-based geopolymer that can collapse. For the process, pozzolanic materials with different amounts and ratios of alkali were made active. At 25 °C, the curing times ranged from 7 days to 1 year. X-ray diffraction, SEM, FTIR spectroscopy, 27Al and 29Si NMR, and uniaxial compression tests were all used in a full study. After geopolymerization, the data showed that both amorphous and solid phases formed. The shear strength increased steadily with curing time, reaching a peak value of 42 MPa after one year of curing for the geopolymer that was made. How the concentration of sodium silicate, the modulus, and the curing method affect the properties of geopolymers (Verdolotti et al., 2008).

A Study carried out how and why geopolymer reactions happen during its casting. The study showed how the quantity of dissolved silicates dropped slowly as the process went on. Also, it was found that the ratio of SiO_2 to R_2O increased the setting time of the reaction mixture in a good way (Rahier et al., 2011).

How slag affects the compression strength of a Class F geopolymer (Liu et al., 2016). The results showed that adding slag made a big difference in how strong the composite was. There were a lot of different methods used to figure out how slag helps increase compression strength. It was found that adding slag helped make more flexible components, sped up the rate at which the raw materials reacted, and increased the compression strength of the material.

High strength geopolymer made from high calcium fly ash that was sorted into small groups (Chindaprasirt et al., 2007). The study looked at how different particle sizes affect geopolymer in different ways. The study found that when the bits of fly ash were smaller, they set faster and had a big effect on how well they could be worked with.

An in-depth study of geopolymer walls using the alkali-aggregate reaction as a guide. For the study, low-calcium fly ash was used as the base and an 8-molar solution of NaOH was used to make fly ash cement. There were three sets of specimens made: one with siliceous, one with opal, and one with a mix of aggregates. The cure was set for 24 hours at 85°C (Garcia-Lodeiro et al., 2011).

The flow of mortar drops in a straight line over time, and that geopolymer mortar loses flow at a faster rate than standard Portland cement mortar. When the amount of sodium SiO2/Na2O and the quality of the source material go up, the beginning flow goes down even more (Yang et al., 2009).

An experimental study was carried out to find out what happened when sulphuric acid attacked geopolymer mortar samples with different amounts of alkali. As part of the study, Class F fly ash was made active by mixing sodium hydroxide and sodium silicate in a solution with 5% to 8% Na2O. At 85 °C, curing took place for 48 hours. A big discovery was that the amount of alkali in the activator solution had a big effect on the acid resistance of geopolymer blocks. When the amount of alkali was higher, the longevity was better (Thokchom et al., 2009).

Study was done to test shrinkage, creep behavior, and salt protection in geopolymer concrete materials. For the geopolymer, class F fly ash, Na_2SiO_3, and NaOH solution were used. There were also 8 molar and 14 molar NaOH solutions, with Na_2SiO_3/NaOH ratios of 0.4 and 2.5, respectively. Specimens were left to dry at temperatures between 30 and 90 degrees Celsius for 3 to 100 hours. The study showed how the ratio of Na_2SiO_3 to NaOH affects the molarity of NaOH. Also, it showed that when the water content went down, the compression strength went down. It was also studien in another study the compressive strength of fly ash-based geopolymer concrete vs Ordinary concrete. They found that the best compressive strength was at a curing temperature of 90°C, and in another study, the highest compressive strength was at a curing temperature of 120°C for all specimens (Hardjito et al., 2004).

The mechanical properties of alkali-activated fly ash concrete (geopolymer concrete) and ordinary Portland cement (OPC) were carried out in another study. Two different kinds of alkaline liquids were shown. The study looked at different materials, ratios, and drying conditions. In the end, it was found that geopolymer concrete made with a mixed alkali solution was stronger than geopolymer concrete made with a single alkali solution (Fernández-Jiménez et al., 2003).

To improve geopolymer formulas by using the Andreasen particle packing method, which is usually used to make pottery. The study showed how the Andreasen method can be used to change the rheology of geopolymer concrete for different uses, considering mechanical strength, porosity, and perceived density (Henrique et al., 2016).

A detailed study to find out how many different things affect the compressive strength of geopolymer concrete. Their study included cementitious materials and alkaline solutions, as well as different factors like hardening time, temperature, rest time, and additive dose. The study gave more information about how these factors affect each other. For example, it showed that drying time, temperature, sodium hydroxide content, and additive dose all had a good effect on compression strength. In an interesting twist, the study also stressed how important water content is to get the right amount of compression Strength (Vora et al., 2013).

Geopolymer concrete by mixing fly ash and rice husk ash together. The study showed how important ratios, especially the ratio of fly ash to rice husk ash, are in determining the properties of concrete. The study found that the ratios of Si/Al and p/Agg are very important and that they have a direct effect on the quality of concrete. This study was important because it showed how the interaction of these factors can lead to different mechanical and leakage results (Wongsa et al., 2016).

In a study of geopolymer concretes, the amount of source material had a big effect on the highest compression strength. The study found that a higher amount of alkali to binder led to more holes. A microstructural study showed that geopolymer made with 4 molar NaOH and 8 molar NaOH were different, with the former having more particles that hadn't interacted (Ravikumar et al., 2010).

Strengthened geopolymer concrete beams bent prepared to studied in this study, and they found that these beams often had better load-bearing abilities. Jeyasehar et al. talked about what they learned from a bending strength test with geopolymer concrete beams and an OPC concrete beam, which showed that the moment curve behavior of these beams was the same as that of RCC beams (Dattatreya, 2014).

Another study was carried out to look into the stress and bond properties of geopolymer concrete mixed with fly ash. He found that geopolymer concrete specimens and Portland cement concrete beams had similar failure processes and crack patterns (Chang, 2009).

The fracture toughness critical stress intensity factor and the critical crack mouth opening shift of geopolymeric concretes strengthened by volumetric parts of basalt fibers also studied and their results showed that geopolymeric concretes have better qualities when they break than basalt fiber concrete and OPC concrete. In the end, these studies tell us a lot about the dynamic features of geopolymer concrete, how it can be used in building situations, and what other uses these materials might have (Dias et al., 2005).

The time alkali-activated fly ash and standard Portland cement lasted in strengthened samples it was observed in this study and Geopolymer concrete samples were more resistant to erosion caused by salt as compare to ordinary portland concrete (Kupwade-Patil & Allouche, 2013).

The behavior of geopolymers against solid-particle erosion was tested experimentally and they found that mixes of fly ash and slag made geopolymers more resistant to erosion (Goretta et al., 2007).

The compressive strength of geopolymer mortar by combining high calcium cementitious material with a solution fusion as the alkali component. The study found that the best drying temperature for all cases was 70°C, which was linked to the highest compression strength. Three different ways to test concrete have been set up so that its behavior at high temperatures can be evaluated and understood. In the unstressed test, on the other hand, the object is slowly heated to the target temperature, held there until thermal stability is reached, and then a predetermined rate of load or strain is applied until the point of failure is reached (Chindaprasirt et al., 2012).

The test for unstressed residual strength is heating a specimen without an initial load until the point when thermal equilibrium is reached, after which the specimen is cooled to the standard temperature. Increasing the load or strain that is being applied on a step-by-step basis until the point of failure is reached, as shown in Figure.

High-temperature investigations use two primary heating techniques: a steady, controlled heating rate and a second method that mirrors fire exposure using standard temperature increase-time curves. The continuous heating rate is used to analyze material characteristics after exposure to high temperatures, while the second method uses standardized temperature increase-time curves to replicate the impact of fire on structural components. The specific heating rate is adjusted based on the test's objectives.

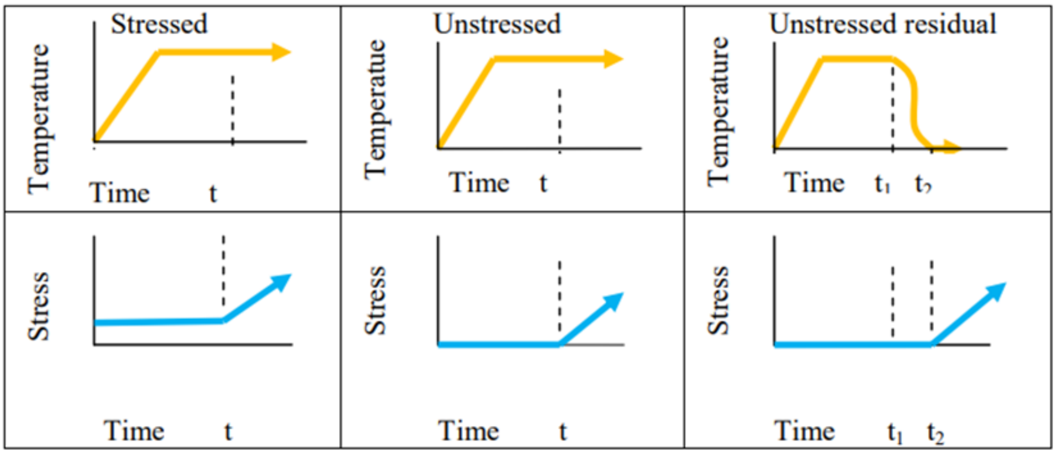


Figure 3 Temperature vs Time (Rate of heating) (Pan et al., 2010)

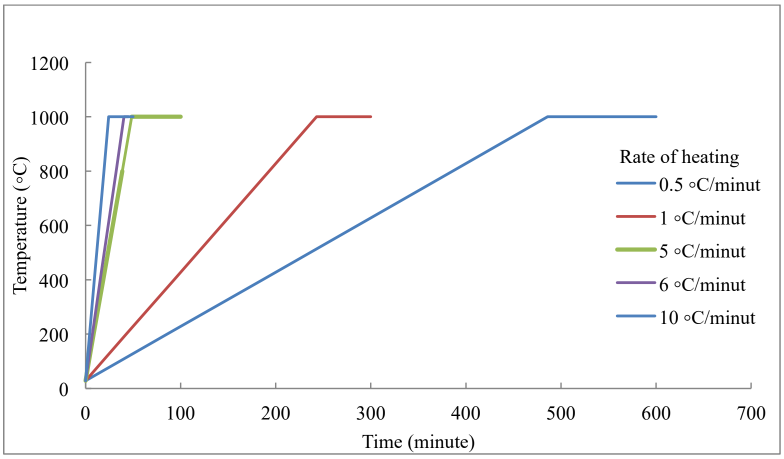


Figure 4 Stress vs Time (with Temperature) (Pan et al., 2010)

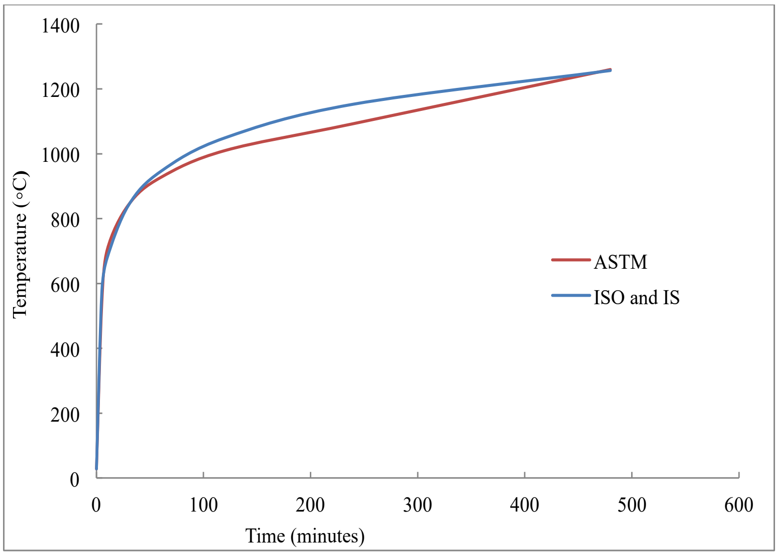


Figure 5 ASTM & ISO & IS Temperature & Time curve (Pan et al., 2009)

A thorough study of what causes concrete to break down when it is exposed to high temperatures. They found that things break down in four different ways. The first three processes lower the strength and hardness of the concrete. The fourth process reduces the cross-sectional area, which decreases the structural stability of the building (McLellan et al., 2011).

Pan studied what happened when ordinary Portland cement (OPC) concrete was heated at high temperatures. He found that the relationship between strength and temperature goes through three stages: the first decrease in strength (from room temperature to 200 degrees Celsius), the stability and recovery stages (from 100 degrees Celsius to 450 degrees Celsius), and the permanent decrease in strength (starting at 450 degrees Celsius). Line et al. used SEM and stereo imaging to look at fire-damaged concrete. They focused on changes in the microstructure of cement pastes and aggregates, the creation of microvoids and cracks, and the separation of cement paste from aggregates (Pan et al., 2009). They also studied on geopolymer cement, which was heated to high temperatures. They found that the changes in strength of geopolymer binders were proportional to how strong they were at room temperature to begin with. When animals were cooked to 800 degrees Celsius, those with higher initial strengths lost strength, while those with lower initial strengths gained strength. Researchers thought that the rise in strength was caused by the burning of unreacted material and the polymerization of the material.

The properties of concrete at temperatures as high as 800 degrees Celsius were investigated and it was found that the modulus of elasticity (MOE), strength, and many other factors did not change much up to 400 degrees Celsius. But at temperatures above 800 degrees Celsius, huge holes started to form and the concrete's structure started to fall apart (Joseph & Mathew, 2015).

The compressive strength of concrete made with limestone material at temperatures from 100 to 700 degrees Celsius. Because of accelerated cement drying, the remaining compression strength went up by 17% and the strength went down by 21% (Ahmed et al., 2023).

(Ganesan et al., 2015) theory compare the durability properties of plain and fiber reinforced geopolymer concrete to traditional Portland cement-based concrete. Water absorption, abrasion resistance, chemical resistance, the impact of alternating wetting and drying, and resistance to chloride ions are among the durability factors evaluated in this study. The results of the tests demonstrated that plain and fiber reinforced geopolymer concrete had better durability qualities than conventional concrete of the same grade in most of the durability metrics.

(Kong et al., 2010) et al. also looked at the geopolymer paste, which was made of metakaolin and fly ash. At 800 degrees Celsius, they saw a change in color and tiny cracks in the metakaolin-based geopolymer samples. Another study looked at what happened to the geopolymer paste and concrete made with fly ash when they were heated to as high as 800 degrees Celsius. During the process of getting the object ready, alkalis like sodium hydroxide and sodium silicate liquids were used. The amount of fly ash to alkali made a big difference in how strong geopolymer paste was and how well it resisted fire.

he stress-strain relationship of geopolymer paste when it was heated to very high temperatures to see how well it could fight fire. They found that when the temperature was between 200°C and 290°C, a small decrease in the size of the object made the geopolymer stronger. But when the temperature went from 380°C to 520°C, it grew bigger while getting stronger (Pan et al., 2010). When geopolymer concrete was heated to high temperatures, it could break in weak pieces. In another study, the effects of loading rate and measuring temperature on the dynamic properties of geopolymer strengthened with glass or carbon fiber were looked at. As the temperature went from room temperature to 300 degrees Celsius, they saw that the material's final strength and bending stiffness went down. But as the rate of forcing went up, both the final strength and the rigid stiffness of each example went up. They found that the behavior of geopolymer concrete at high temperatures was mostly based on the size of the sample and the size of the particles. When superplasticizer was added, the strength of the material went down, and the 26% and 41.5% leftover strengths show this. Provis et al. also found that at temperatures between 700 and 800 degrees Celsius, the volume of geopolymers with good strength increased by a small amount.

In an experiment, cement paste baked to different temperatures, from 100 to 800 degrees Celsius. They found that the rate of mass loss changed most quickly around 100°C and then stabilized around 250°C. Most of the free water in the geopolymer paste could be released at temperatures below 200°C (Hassan et al., 2020).

2.4. Concluding Remarks

Alkali activation, also called geopolymerization, is a way to make cementitious materials. It was first used in the 1930s. But experts didn't start using this method in a big way until the 1990s. In this process, different raw materials that are high in alumino-silicates are mixed with alkali. This mix makes three different types of structures made of alumino-silicates. These structures are called geopolymers. Depending on the ratio, the type of geopolymer that is made is different.

In past study, the properties of geopolymer paste, mortar, and concrete were looked at, with a focus on how alumino-silicate components affected the strength and stability of the materials. On the other hand, not nearly enough thought is given to how the makeup of the aggregates affects the traits of geopolymer concrete. Geopolymer concrete's dynamic properties depend on a number of factors, such as the shape of the alumino-silicate material, the ratio of silicon to aluminum, the size distribution of the particles, the type and amount of alkali, the amount of water, and more. When thinking about using geopolymer concrete as an option to traditional cement concrete, it is important to have a good idea of what happens to it when the temperature goes up. On the other hand, there haven't been enough studies done to fully understand how geopolymer concrete acts when it's exposed to higher temperatures. Also, parts made from geopolymer concrete might behave differently than parts made from standard materials. More research needs to be done to learn more about how different things affect the properties of geopolymer concrete, especially how it reacts to higher temperatures and what structural effects this has.

2.5. Objectives

Our main objectives of this research are:

- To investigate the best Percentage of fly ash and Ground Granulated blast furnace slag (GGBS) by replacing Slag Aggregate with NWA in making of Lightweight Geopolymer Concrete (LWGC).
- To study the elevated temperature effect on the mechanical properties of light weight geopolymer concrete (LWGC) like compressive strength, stress-strain behavior etc.

2.6. Scope

With the objectives firmly established, the current investigation's scope has been delimited as follows:

This investigation focuses on using fly ash as a source material and NaOH and Na_2SiO_3 as alkali components. Geopolymer specimens will be created using various parameters to evaluate their mechanical properties and determine the ideal mixture composition. The study will also examine the strength and breaking tendency of geopolymer concrete at elevated temperatures, and the microstructural behavior of the concrete.

CHAPTER 3

MATERIALS AND PROCEDURE

In this chapter, we will go through the many types of materials that were utilized, the procedure for casting and curing the specimens, as well as the tests that were carried out in connection to this research.

3.1. Materials

3.1.1. Fly Ash

The thermal power plant in Karachi is from where it was purchased and used. According to the information given by the provider, the various chemical components that make up fly ash. The chemical components of fly ash are listed in Table.

Table 2 Fly ash Composition

Sr.	Composition	Percentage
1	SiO2	50
2	Al2O3	34.34
3	Fe2O3	4.46
4	CaO	3.5
5	Na2O	0.72
6	MgO	3.1
7	Mn2O3	1.33
8	TiO2	0.21
9	SiO3	1.37
10	Loss of ignition	0.97

The fly ash in question has a relatively low calcium concentration and so satisfies the criteria for being classified as class F fly ash in accordance with the ASTM standard. Examining the table will allow you to make note of this information. Figures 3.1 and 3.2, respectively, illustrate the results of an X-ray Diffraction (XRD) analysis performed on fly ash, as well as the particle size distribution curve for this material. Fly ash, a secondary product produced from coal-fired power stations, was classified as class F fly ash in line with the specifications of ASTM C618 Class F. The results of an X-ray fluorescence

(XRF) examination were used to assess the physical characteristics and chemical composition of fly ash. The findings are summarized in Table 2, which may be seen below.

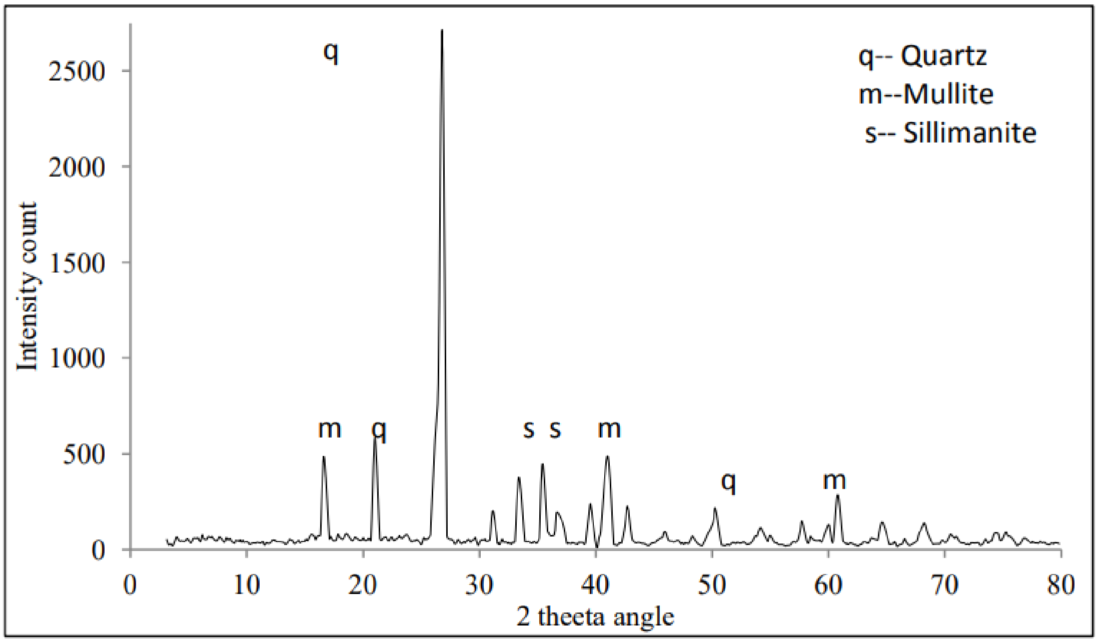


Figure 6 XRD Analysis of Fly ash

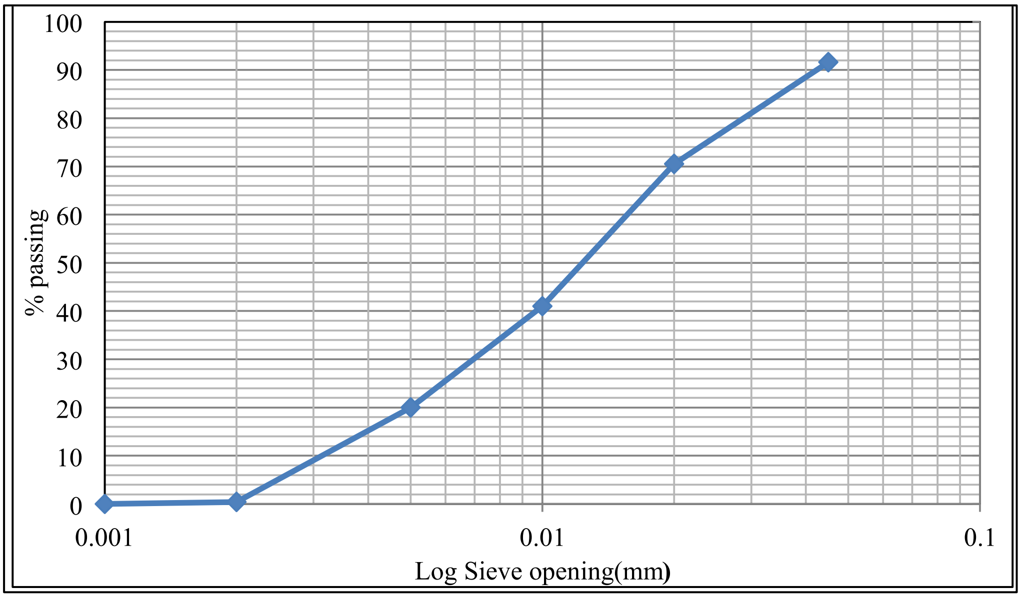


Figure 7 Gradation curve of Fly ash

Chemical Properties

Table 3 Chemical Properties of Cementitious materials used.

Sr.	Parameter	Cement	Fly ash	GGBFS
1	SiO_2	21.87	50	30.12
2	Al_2O_3	6.14	34.34	14.7
3	Fe_2O_3	3.85	4.46	10.3
4	CaO	60.1	3.5	37.5
5	Na_2O	0.94	0.72	0.28
6	MgO	2.38	3.1	5.01
7	K_2O	0.78	1.33	0.78
8	TiO_2	-	0.21	-
9	SO_3	2.39	1.37	0.48
10	LOI	1.51	0.97	0.83

3.2. Ground Granulated Blast Furnace Slag (GGBFS):

Ground granulated blast furnace slag (GGBFS), which was created by fast water cooling, was extracted from the waste products of the iron industry. The value of 2.61 was determined to be the specific gravity of GGBFS. In Table 4, we have compiled a summary of the GGBFS's extensive chemical makeup as well as its physical qualities.

Figure 8 Fly ash from Karachi factory, GGBFS and Slag Aggregate

Physical Properties

Table 4 Physical and chemical properties of cement, fly ash & ground granulated blast furnace slag (GGBFS)

Material	Cement	Fly ash	GGBFS
Specific gravity	2.66	2.60	2.61
Colour Grey	Light greenish	Cemented/Grey	Brown

3.3. Fine Aggregate

The fine aggregate consisted of natural siliceous sand, which was chosen because it was free of impurities, had particles that were smooth and rounded, and had a particle size that ranged from 0.15 to 5 millimetres. The specific gravity of the fine aggregate was found to be 2.65, and its fineness modulus was found to be 2.63.

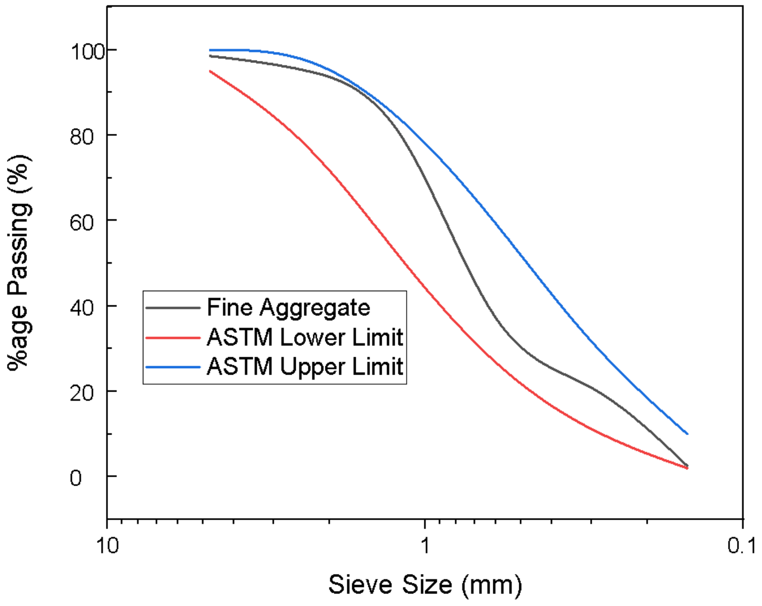


Figure 9 Gradation Curve of Fine Aggregate

3.4. Coarse Aggregates

The coarse aggregate component made use of local natural weight aggregates that were procured from the Mardan region in Pakistan. The specific gravity of these aggregates was 2.68, and their unit weight was 2600 kilograms per cubic metre. In addition to that, lightweight coarse materials such as slag were included into the mixture. The specific gravity of these lightweight coarse aggregates was 1.35, and their bulk unit weight was 1350 kilograms per cubic meter, respectively. The maximum nominal size for all kinds of coarse aggregate corresponded to the standards set out in ("ASTM C33/C33M − 13 Standard Specification for Concrete Aggregates), which specified a size of 12.5 millimeters across the board. Table 5 contains an abundance of information covering a wide range of topics.

Table 5 Properties of Fine & Coarse Aggregates

Properties	Fine aggregate	Natural Weight aggregate	Slag aggregate
Specific Gravity	2.65	2.68	1.35
Fineness Modulus	2.63	6.92	6.73
Impact Value	-	21.67%	6.38%
Crushing Value	-	30%	17%
Water Absorption	-	0.8%	3%

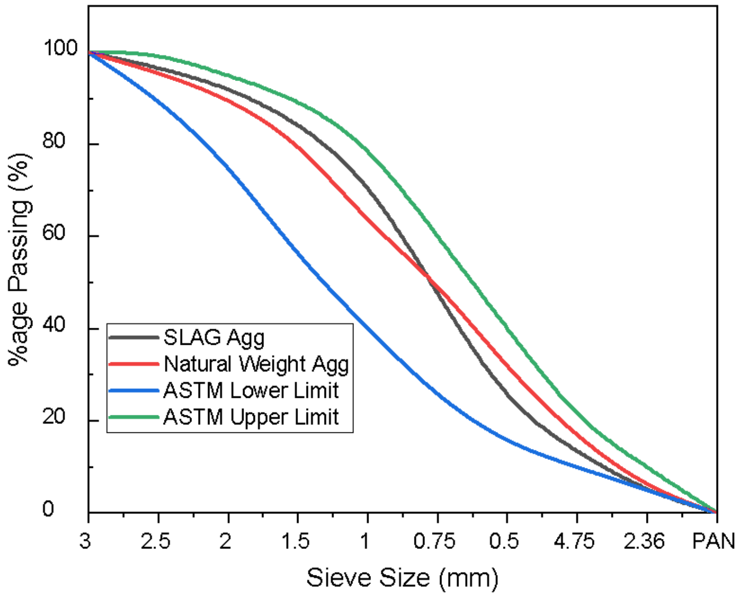


Figure 10 Gradation Curve of Coarse Aggregates Used

3.5. Lightweight Slag Aggregate

Normal weight aggregate (NWA) is a common building material, but slag aggregate is a flexible building material that could be used instead. Slag aggregate is known for being light and strong at the same time. It has several benefits that can make a big difference in many building uses.

One thing that makes slag aggregate unique is that it has a lower density, which is about 1200 kg/m3. Slag aggregate is a lightweight material because it has a very low density. This makes it a good choice for many projects where reducing weight is the most important thing. The lower weight of slag gravel helps reduce structural stress and make construction easier, whether it is used in poured concrete, lightweight concrete mixes, or building infrastructure.

When it comes to strength, slag aggregate is a strong competitor to NWA. Even though it is made of light materials, slag aggregate is very strong, which makes it different from other aggregates. This edge in strength is due to the way slag, a waste of the iron and steel business, is made. During the making of slag, a process called vitrification gives it better joining properties. This makes the aggregate stronger and last longer.

When slag aggregate is compared to NWA, it is different and has clear benefits. First, the difference in weight is a major issue. NWA is heavier, with a normal density of between 2500 and 2700 kg/m3, but slag aggregate is lighter, which is helpful in uses that need strong structures without extra weight. This is especially helpful for projects like lightweight concrete roof systems and areas prone to earthquakes, where less weight can help make things more stable. Slag aggregate's higher strength is also a big plus. When the strength of a structure is important, like when making a bridge or a high-rise building, adding slag material can make the structure stronger and last longer. The fact that it is both light and strong gives designers and builders a material that can be used in many ways and will hold up well.

3.6. Superplasticizer

Sika® ViscoCrete®-3110 is a third-generation polycarboxylate-based superplasticizer for concrete. It has been particularly developed for use in ready-mixed concrete to give extended slump retention and high strength development of normal grade concrete mixes. Here are some of its beneficial properties.

It helps in the production of self-compacting concrete. Due to extremely high water reduction, it provides high impermeability and strength. Improved shrinkage and creep characteristics: It helps in improving shrinkage and creep characteristics of the concrete. It results in minimal placing and compacting efforts due to excellent flowability. Slower rate of carbonation and chloride ingress: Especially when silica fume or pozzolanic products are used, it slows down the rate of carbonation and chloride ingress. It offers a very good cost/performance ratio. Does not contain chlorides or other steel corrosion promoting ingredients: Therefore, it may be used for reinforced and pre-stressed concrete construction. It’s suitable for use in hot and tropical climatic conditions, and in concrete mixes containing microsilica and other pozzolanic materials such as GGBS and fly ash1.

It acts by surface absorption on the cement particles producing steric hindrance as well as electrostatic repulsion between cement particles which results in higher dispersion, flow, and retention.

3.7. Concrete Mixture

This investigation focused on geopolymer concrete, which was based on fly ash as the primary aluminosilicate raw material. To increase calcium content, additives like sodium hydroxide and sodium silicate were used as partial substitutes. The mix design considerations included the quantity of additive, alkaline activator, and sodium silicate to sodium hydroxide ratio. The final unit weight of the concrete was determined to be 2330 kg/m3, with the overall binder content maintained at 400 kg/m3. The workability of the wet concrete is crucial for its mechanical and durability qualities.

3.8. Mix Designations:

This meticulous design and array of concrete mixes will enable us to comprehensively evaluate the performance of lightweight concrete under various conditions, including high-temperature exposure, and yield valuable insights into the properties and behavior of these materials.

Sr no	**Material**	**Ambient Temp**	**Elevated Temperature**			**Cylinders**	**Prism Beams**
			200	**500**	**800**		
1	NWOC	3	3	3	3	12	12
2	LWOC	3	3	3	3	12	12
3	F40G60	3	3	3	3	12	12
4	F50G50	3	3	3	3	12	12
5	F60G40	3	3	3	3	12	12
Total sample						60	60

3.8.1. Mixing, Casting, and Curing Procedure

In Lightweight Ordinary Concrete (LWOC) and Lightweight Geopolymer Concrete (LWGC), a complicated chemical process involving the interaction of an alkaline solution, a superplasticizer, and water played a big role in getting the ideal initial condition and then the ideal compressive strength.

Different names were given to the concrete pieces being looked at to make it easier to tell them apart and put them into groups. Normal Weight Ordinary Concrete (NWOC) and Lightweight Ordinary Concrete (LWOC) were used to describe the control sample. The combos that were labeled F60G40, F50G50, and F40G60 were made up of different amounts of fly ash (F) and cement (G), which showed how much of each was used in the concrete mix.

In the case of LWGC, the solid components, like fly ash or granulated blast furnace slag, as well as the fine and coarse pebbles, especially slag aggregate, were mixed dry in a pan mixer for about three minutes. On the other hand, ordinary lightweight concrete (LWOC) was made by mixing cement with both fine and slag material. The mixture was then mixed for 2 minutes. During the mixing time, which lasted about 2 minutes, the water and superplasticizer were added gradually and at the same time.

During the casting process, the sodium hydroxide solution, which had been made the day before to make lightweight geopolymer concrete (LWGC), mixed with the sodium silicate solution and the superplasticizer.

After carefully following a step-by-step process for pre-mixing, After the mixing was done, the freshly made concrete was put in a methodical and exact way into steel molds. The LWOC and LWGC animals behaved differently in response to the next steps in the treatment process. As part of the study, the LWOC samples were put in water for a while. Samples of LWGC were cooked in an oven for 24 hours at a hardening temperature of 60 degrees Celsius. "Heat curing" was the name for this process. It's important to remember that the results of the tests about the mechanical and physical properties are based on the average measures of three different samples. After the hardening process was done, the test samples were given acclimatization time. During this time, they were exposed to an average outdoor temperature, which was in line with the conditions set for the length of the testing.

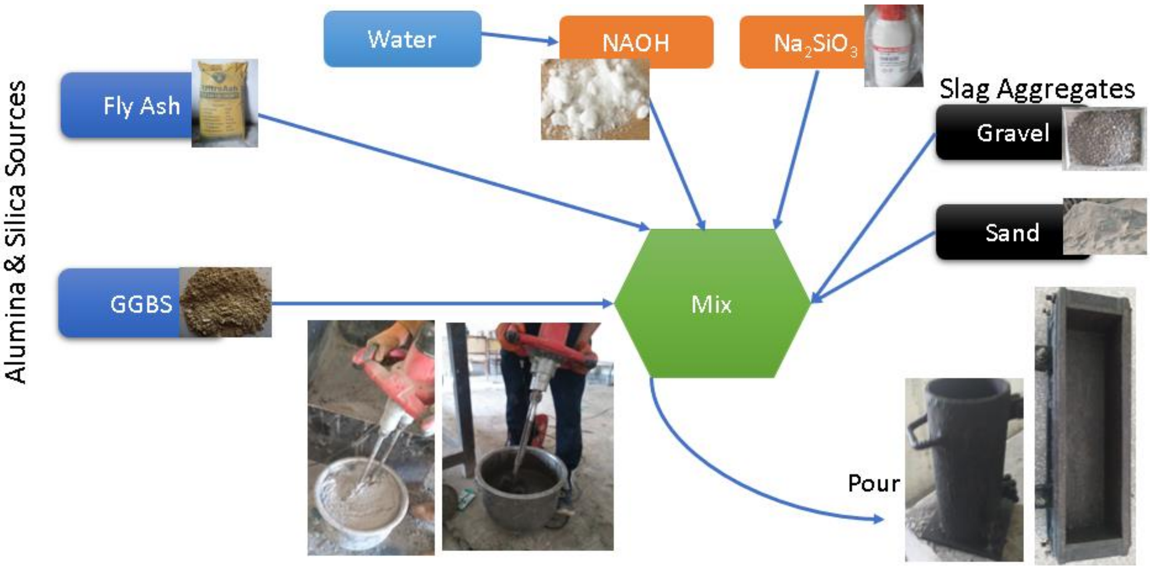


Figure 11 Ingredients of geopolymer concrete mixture ready for final mixing.

In the case of LWGC, the solid components, which included cementitious materials, fine and coarse sediments, and especially slag aggregate, were mixed dry in a pan mixer for about three minutes. Lightweight Ordinary Concrete (CS), on the other hand, was made by mixing cement with both fine and waste material. The mixture was then mixed for 2 minutes. During the mixing time, which lasted about 2 minutes, the water and superplasticizer were added gradually and at the same time. During the casting process, the sodium hydroxide solution, which had been made the day before to make lightweight geopolymer concrete (LWGC), mixed with the sodium silicate solution and the superplasticizer. After a careful step-by-step process of pre-mixing, the liquid ingredients were added to the dry mixture, and the whole thing was mixed for three minutes to make sure it was all the same. After the mixing was done, the freshly made concrete was put in a methodical and exact way into steel molds. Both the CS specimens and the LWGC specimens responded differently to the next steps in the treatment process. As part of the study, the CS samples were put in water for a while. Samples of LWGC were cooked in an oven for 24 hours at a hardening temperature of 60 degrees Celsius.

It's important to remember that the results of the tests about the mechanical and physical properties are based on the average measures of three different samples. After the hardening process was done, the test samples were given acclimatization time. During this time, they were exposed to an average outdoor temperature, which was in line with the conditions set for the length of the testing.

Table 4: Mix design detail for lightweight ordinary concrete (CS) & geopolymer concrete samples at different ratios in kg/m3

Mix	Fly ash	GGBFS	Cement	Na2SiO3	NAOH	Sand	Aggregate	Solution	Superplasticizer
LWOC	0	0	520	0	0	673	629.1	182	4.7
F60G40	312	208	0	130	52	673	629.1	182	4.7
F50G50	260	260	0	130	52	673	629.1	182	4.7
F40G60	208	312	0	130	52	673	629.1	182	4.7

3.9. Testing procedure

The evaluation of slump values for newly mixed concrete was conducted in accordance with the ASTM C143 guidelines. To assess the compressive strength of the mixtures after 3, 7, and 28 days, cylindrical specimens with dimensions of 100x200 mm were utilized, following the guidelines outlined in standard C496/C496M. The flexural strength testing, adhering to the ASTM C78/C78M standards, was performed on prism specimens measuring 100x100x400 mm over a period of 28 days. The average value of the collected specimens at each age was reported. Furthermore, the modulus of elasticity for the cylindrical specimens with dimensions of 100x200 mm was measured on day 28, in accordance with the standards set by ASTM C469.

To conduct an inquiry on the impacts of increased temperatures, a total of three samples were chosen from each batch. The samples were subjected to testing in order to determine their average strength following a 28-day period of immersion in water, followed by an additional 28-day period of air curing. Following a duration of 28 days, the specimens underwent a heating procedure lasting approximately 2 hours in a furnace with temperatures varying from 200 ◦C to 800 ◦C. The evaluation of compressive strength was conducted under two conditions: ambient temperature and after subjecting the samples to different increased temperatures ranging from 200 ◦C to 800 ◦C, with a duration of 2 hours. Microstructural analyses were conducted on specimens comprising Lightweight Concrete (CS) and Lightweight Geopolymer Concrete (LWGC) as well. The hold time of the specimens to reach the target temperatures (200, 500 and 800˚C) @5˚C/min.

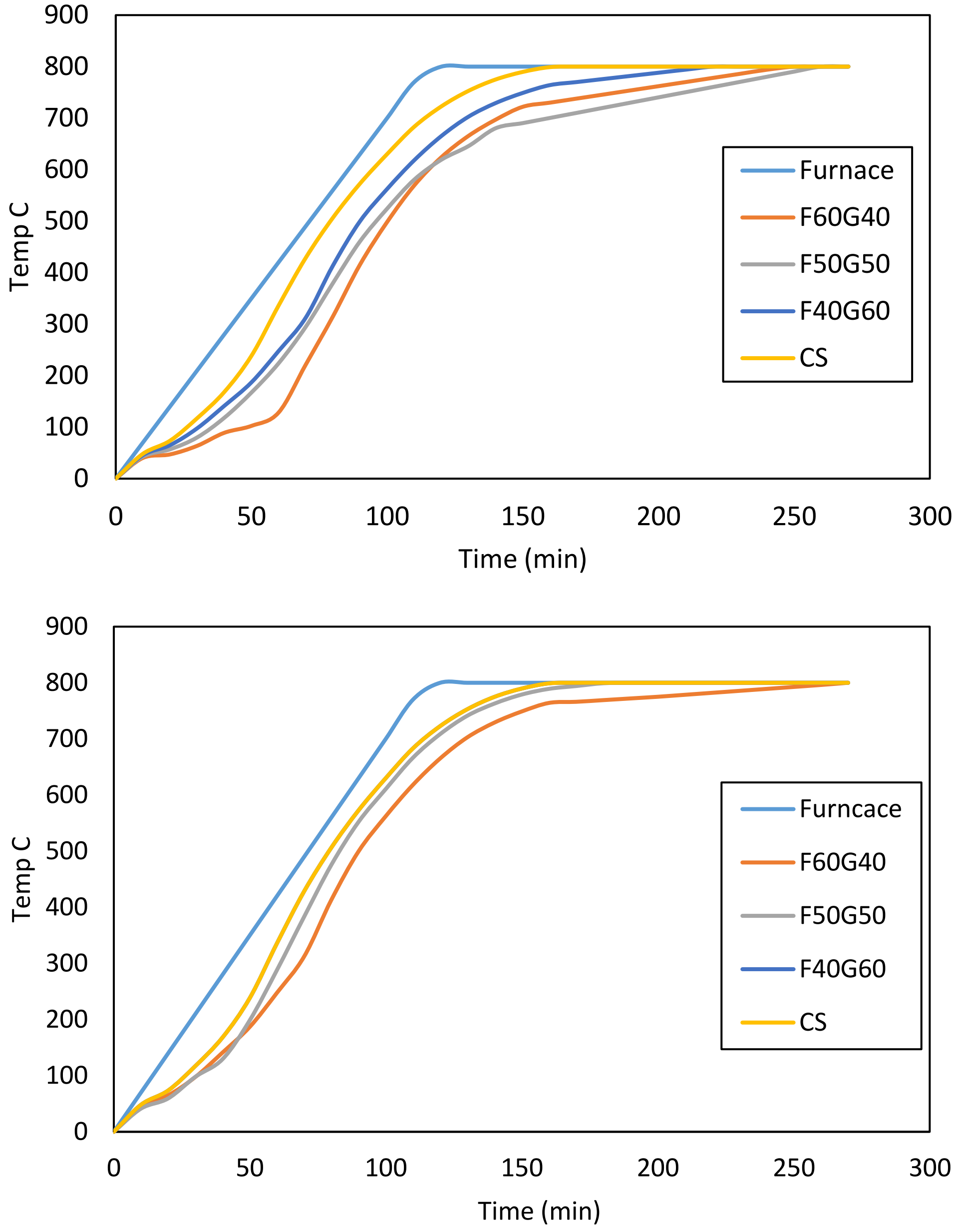


Figure 12 Time vs temperature of Furnace and internal sample core temperature for (a) cylinders (b) Prism beams.

3.10. Aggregates:

Saturated surface dry (SSD) conditions were applied to the coarse and fine aggregates. The coarse aggregates were soaked in water for 24 hours before being air dried till the SSD condition was achieved. The amount of water in the mixture is important, particularly during ambient curing since it impacts the final reaction result. Although fine material was not soaked, sand was sprayed with tap water to boost moisture levels. Thorough mixing ensured that moisture was distributed evenly. To prepare fine aggregate to SSD state, the ASTM C 128-07 guideline was applied.

3.11. Heating and Cooling of Specimens

To get the specimens up to the required temperature, an electric furnace used. The temperature of the furnace may reach up to 1200 degrees Celsius. A photograph of the furnace is shown in Fig. 17.

Geopolymer concrete is a sustainable alternative to standard Portland cement, as it does not require cement and produces no greenhouse gas emissions. Instead, it uses waste from coal and steel industries, such as fly ash and slag, which conserves nature and minimizes carbon emissions by 80-90%. This study investigates the behavior of GPC concrete and its effect of high temperature exposure on its characteristics. The same batch of Class F fly ash was used throughout to maintain consistency, and the activators (silicates and hydroxides) were purchased locally from the same supplier. Most mixes employed natural siliceous aggregate, while non-pelletized fly ash aggregates were investigated in a few instances.

Figure 13 Electric furnace and Thermocouple attached with Samples

The study also investigates how geopolymer concrete changes form as temperatures rise. Most studies on geopolymer concrete behavior at high temperatures have focused on the strength or spalling of small laboratory samples. Little is known about its mechanical properties, thermal properties, deformational behavior, creep, or the change of these material properties with temperature. Understanding how thermal and dynamic properties vary with temperature is crucial for performance-based design.

Specimens were heated to specified temperatures at a rate of 5 degrees Celsius per minute, ensuring consistent temperature maintenance. Air and water cooling were used to reduce the specimens' temperature to the surrounding environment. In the air-cooling procedure, specimens were removed from the furnace immediately after the soaking phase and allowed to undergo natural cooling.

CHAPTER 4

RESULT & DISCUSSIONS

4.1. Findings and Concluding Remarks

4.1.1. Hardened properties

The evaluation of the mechanical properties of materials such as Lightweight Ordinary concrete (CS) and Lightweight Geopolymer concrete (LWGC) is of utmost significance in establishing their appropriateness for use in construction-related purposes. Table 4 provides crucial data, such as compressive strength, cracking tensile strength, flexural strength, and modulus of elasticity. These features offer engineers valuable information to make well-informed judgments when selecting concrete for residential and infrastructure projects, considering factors like as load-bearing capacity, durability, and cost-effectiveness.

4.1.2. Unit weight

Fig. 3 shows the specific gravity measurements of hardened Lightweight Ordinary Concrete (CS) and Lightweight Geopolymer Concrete. The unit weights of control samples exhibited a range of values, spanning from 1680 kg/m³ to 2290 kg/m³. On the other hand, the unit weight of Lightweight Geopolymer Concrete (LWGC) samples showed a variation spanning from 1660 to 2260 kg/m³. The data shown in Table 2 illustrates that the principal factor influencing the weight of concrete units is the specific gravity of coarse particles. The density of geopolymer concrete, which includes fly ash (FA) and ground granulated blast furnace slag (GGBFS), has a similar magnitude as that of Portland cement concrete. The replacement of natural aggregates (NWA) with lightweight aggregates (LWA), such as slag aggregate, leads to a decrease in unit weight.

4.1.3. Mass loss

The analysis of mass loss at various temperatures (32°C, 200°C, 500°C, and 800°C) for different concrete variations, including Control (CS), F60G40, F50G50, and F40G40, is presented in Table 1. To quantify the mass loss in each sample, the ratio of mass at the target temperature to that at ambient conditions (MT/M) was calculated .Mass loss is a critical factor that signifies the removal of moisture from the concrete matrix in different forms, such as free, adsorbed, absorbed, interlayer water, and capillary water.

Figure 14 (a) Electric Furnace (range up to 1200°C) (b) thermocouples installed in samples for testing

Table 6 Mass Loss for Different Concrete Mix Cylinder

Temp (°C)	Control (CS)	F60G40	F50G50	F40G40
32	3.75	2.11	2.10	2.09
200	3.66	2.10	2.09	2.07
500	3.50	2.08	2.05	2.04
800	3.40	2.05	2.03	2.02

As illustrated in Table 6 and further elaborated in Fig. 16, it is evident that mass loss is influenced by temperature, with higher temperatures resulting in greater mass loss. The phase change of moisture from a liquid to a vapor state occurs up to 200°C, contributing to initial mass loss in all samples.

The data presented below illustrates the percentage reduction in mass for concrete samples as the temperature increases from ambient conditions to higher temperatures.

Control (CS), As the temperature progressively rises to 200°C, 500°C, and 800°C, the mass reduction percentages increase to 2.34%, 6.67%, and 9.33%, respectively. Geopolymer mixes, with varying compositions, showed varying mass losses. F60G40, with a higher proportion of fly ash, displayed superior thermal stability due to its geopolymerization process. As the temperature increases to 200°C, 500°C, and 800°C, the mass reduction percentages increase to 0.47%, 1.42%, and 3%, respectively. For F50G50, the mass reduction values increase to 0.48%, 2.38%, and 3.33%, respectively and For F40G60, the mass reduction percentages continue to increase, measuring 0.96%

at 200°C, 2.39% at 500°C, and 3.35% at 800°C.It showed slightly higher mass losses due to altered fly ash-slag ratios affecting geopolymerization reactions. The control mix (CS) experienced the highest mass loss at all elevated temperatures due to the absence of geopolymerization reactions. The findings highlight the enhanced thermal stability of geopolymer concrete compositions compared to light weight ordinary concrete at elevated temperatures. The primary reason for improved performance lies in the geopolymerization process, which forms a more resilient matrix capable of withstanding thermal stresses. These insights are crucial for selecting concrete mixes in applications requiring resistance to high-temperature environments.

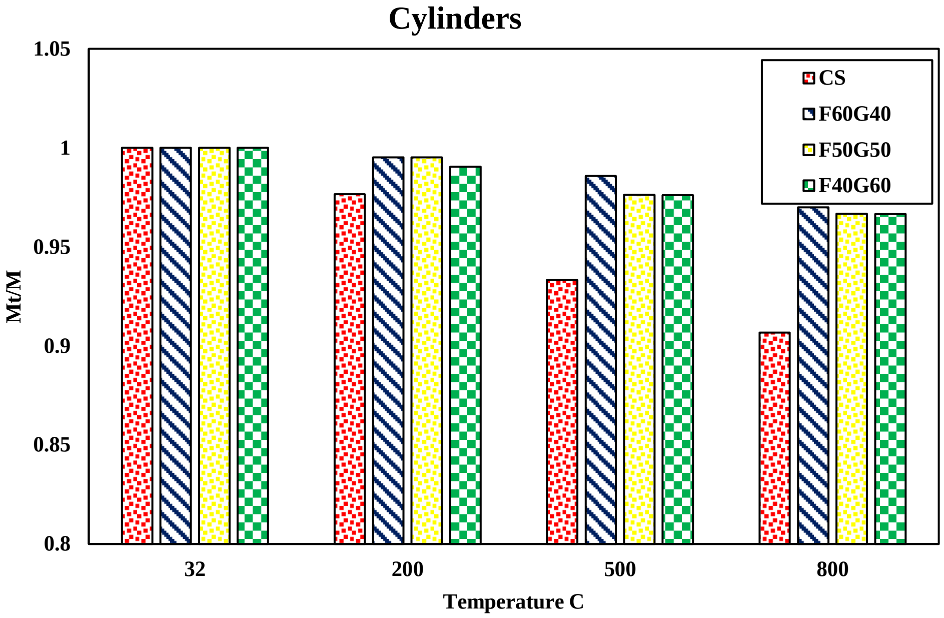


Figure 15 Mass loss of Cylinders (MT/M)

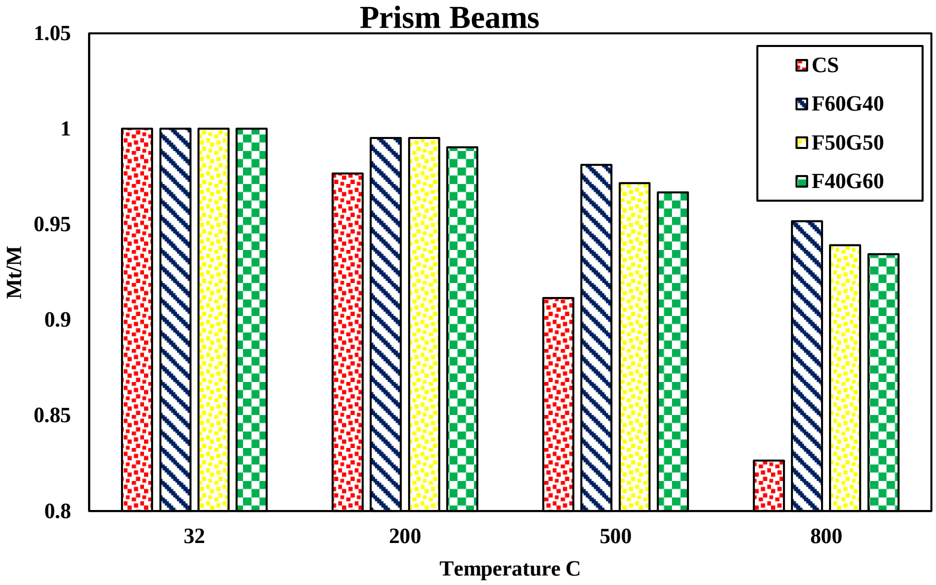


Figure 16 Mass loss of Prism Beam

4.2. Compressive strength.

The subsequent data displays the compressive strength values of lightweight conventional concrete, characterized by a density of 1680 kg/m³. Following a period of 3 days, the material demonstrated a compressive strength of 14.5 MPa. This value subsequently rose to 21.9 MPa after 7 days and further climbed to 32.7 MPa after 28 days. On the other hand, the compressive strengths of normal cement concrete, which has a density of 2290 kg/m³, and its compressive strength is 12 MPa, 20 MPa, 30.4 MPa on 3, 7, and 28 days, consequently.

The outcomes of the manufacturing of Lightweight Geopolymer Concrete (LWGC) and Lightweight Ordinary Concrete (CS) were found to be very comparable. However, when Normal Weight Aggregate (NWA) was replaced with slag aggregate, the compressive strength increased for Lightweight Concrete (LWGC and CS) in comparison to Normal Weight Ordinary Concrete (NWOC). The utilization of lightweight concrete, characterized by a density of 1680 kg/m³, led to a notable enhancement in compressive strength, exhibiting an increase of up to 20% in comparison to conventional weight concrete. The increased strength observed is due to the strong and compact matrix structure that is formed when slag is utilized as a coarse aggregate. Slag, when used as coarse aggregate in lightweight concrete, contributes to a strong matrix structure by interlocking better than typical coarse aggregates. This results in a denser and more robust network within the concrete mix, enhancing the overall strength. The lower density of lightweight concrete reduces voids and air pockets, resulting in a more solid and dense structure. Slag can also enhance chemical reactions in geopolymer concrete, which contribute to its strength. The smaller, more uniform size of slag particles allows them to fit together more closely, reducing space between them and resulting in a more efficient packing arrangement. Slag aggregate also reduces the porosity of the concrete, reducing the pathways for water or other damaging agents to penetrate, leading to greater durability and higher compressive strength over time. Scholars have constantly underscored the significance of aggregate selection in determining the strength of concrete.

In brief, the findings of the study revealed that the manufacture of lightweight concrete had an adverse effect on the compressive strength at various test durations (3, 7, and 28 days) in comparison to conventional weight concrete. The replacement of Normal

Weight Aggregate (NWA) with slag aggregate resulted in density reductions of 19.6%, 22.3%, and 15.7% at the 28-day testing period. In a similar vein, it was shown that the compressive strength experienced reductions of 37.8%, 38.9%, and 25.2% when evaluated at the 28-day mark. The observed higher compressive strength of slag aggregate, in comparison to other natural weight aggregates, can be attributed to its increased surface roughness. This roughness leads to a greater requirement for bonding material, resulting in a stronger bonding area within the interfacial transition zone.

4.2.1. Stress-strain response

The stress-strain response of the control sample is shown below in Fig. 9. The stiffness, peak value, yield point, and maximum compressive strength of this sample serve as a baseline for comparing the geopolymer samples. F60G40 sample shows the best results among the geopolymers. It has higher stiffness, indicating that it resists deformation under stress better than the other samples. Its peak value is also higher, meaning it can withstand more stress before deforming. The yield point, which is the stress at which a material begins to deform plastically, is also higher for this sample. Finally, its maximum compressive strength, which is the maximum stress that a material can withstand under compression, is also the highest among the geopolymers. F50G50 & F40G60 samples have lower stiffness, peak values, yield points, and maximum compressive strengths compared to both the control sample and F60G40. This analysis suggests that F60G40 has superior mechanical properties compared to the other geopolymer samples at 32°C. The maximum compressive strength is the highest stress value in the data, which is 32.21 MPa. This is the maximum stress that the material can withstand under compression before failure. The yield point is the stress at which a material begins to deform plastically. Without more information or a visual graph, it’s challenging to determine the exact yield point from this data. Typically, it’s where the stress-strain curve deviates from linearity. The stiffness of a material is represented by the slope of the initial, linear portion of a stress-strain curve. The peak value could refer to either the maximum stress or the strain at which this maximum stress occurs. From data, the strain at maximum stress is 0.0016 mm/mm.

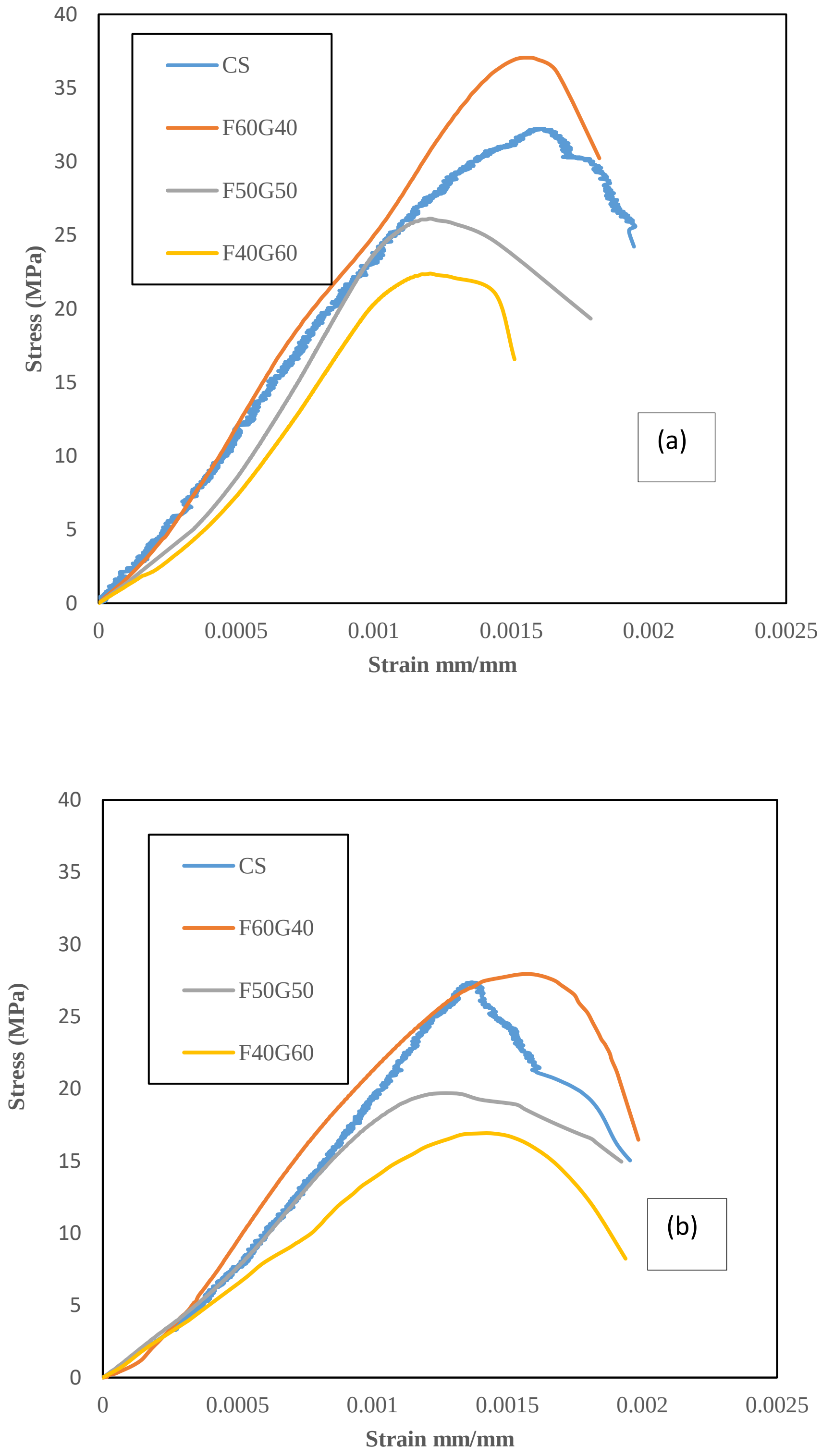
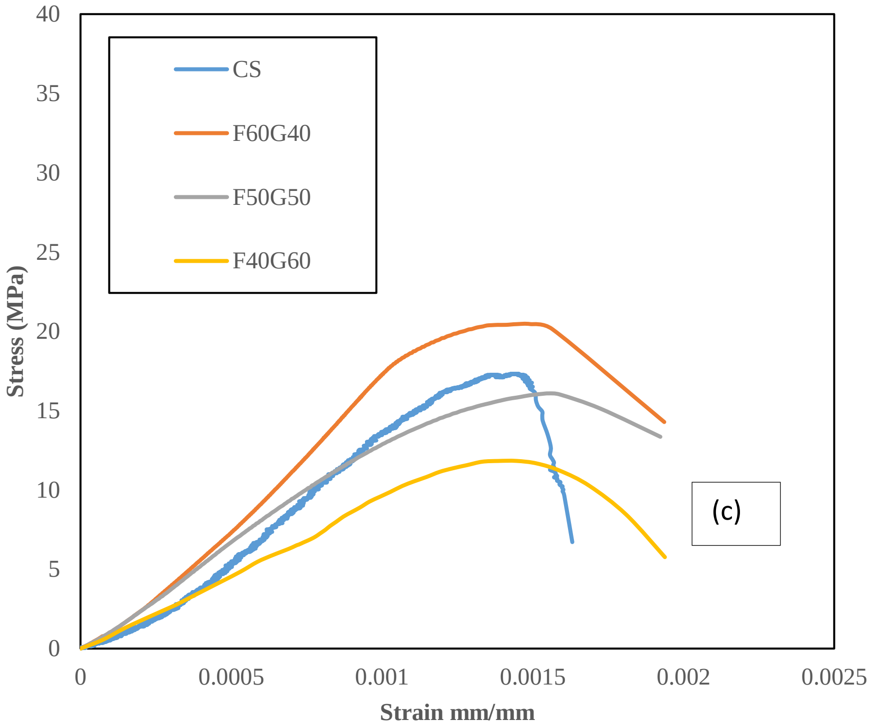


Figure 15 Stress Strain Response for different ratios at (a) 32°C (b) 200°C



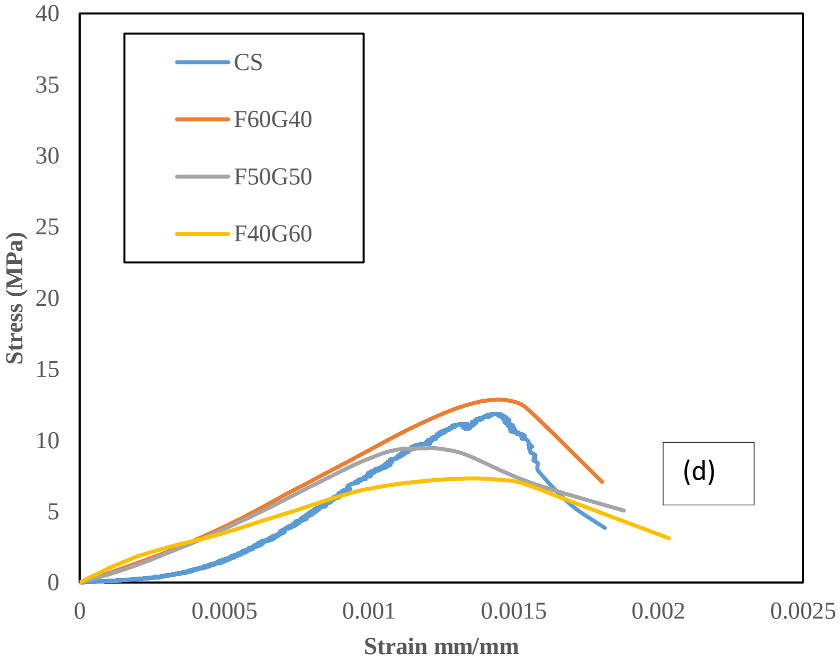


Figure 16 Stress Strain Response for different ratios at (c) 500°C (d) 800°C

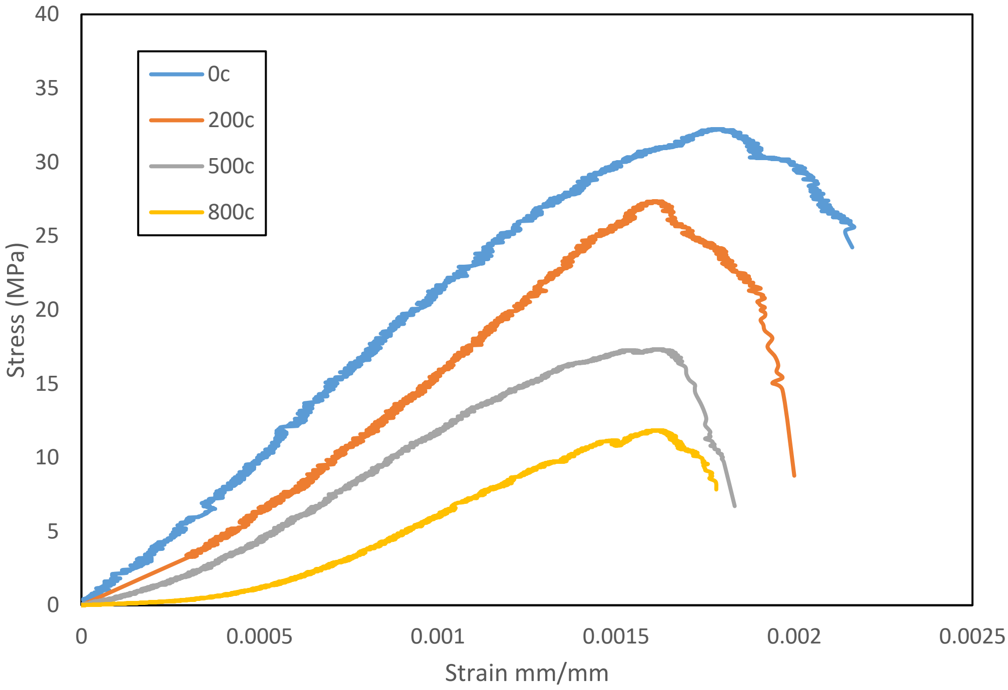


Figure 17 Controlled Sample stress strain Response at different temperatures.

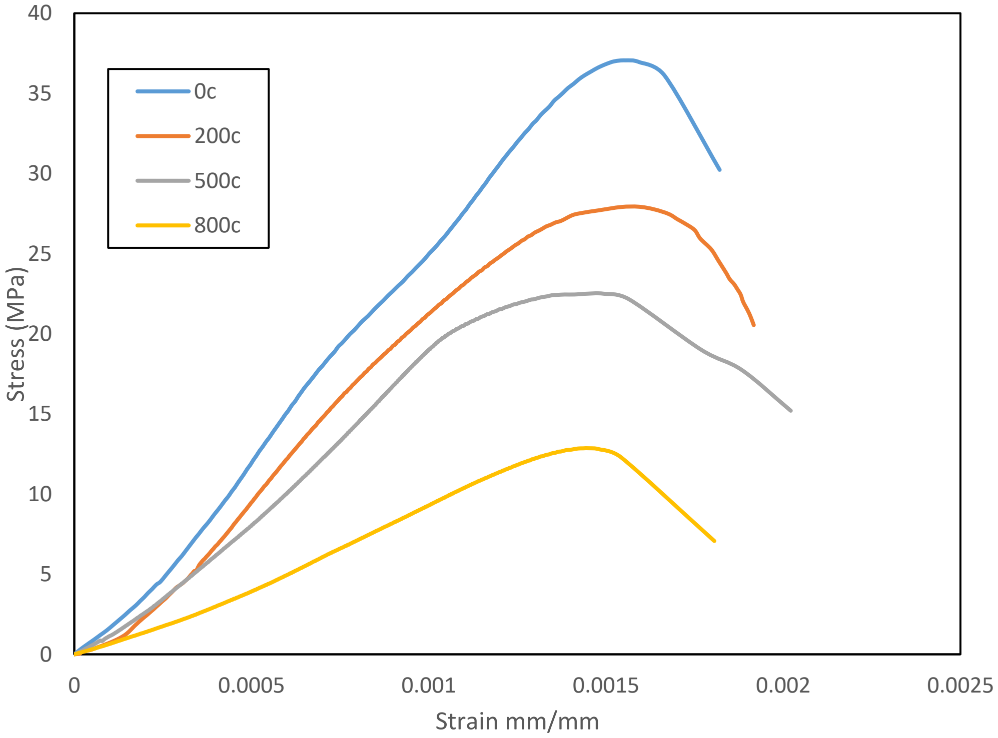


Figure 18 F60G40 Stress strain Response at different temperatures

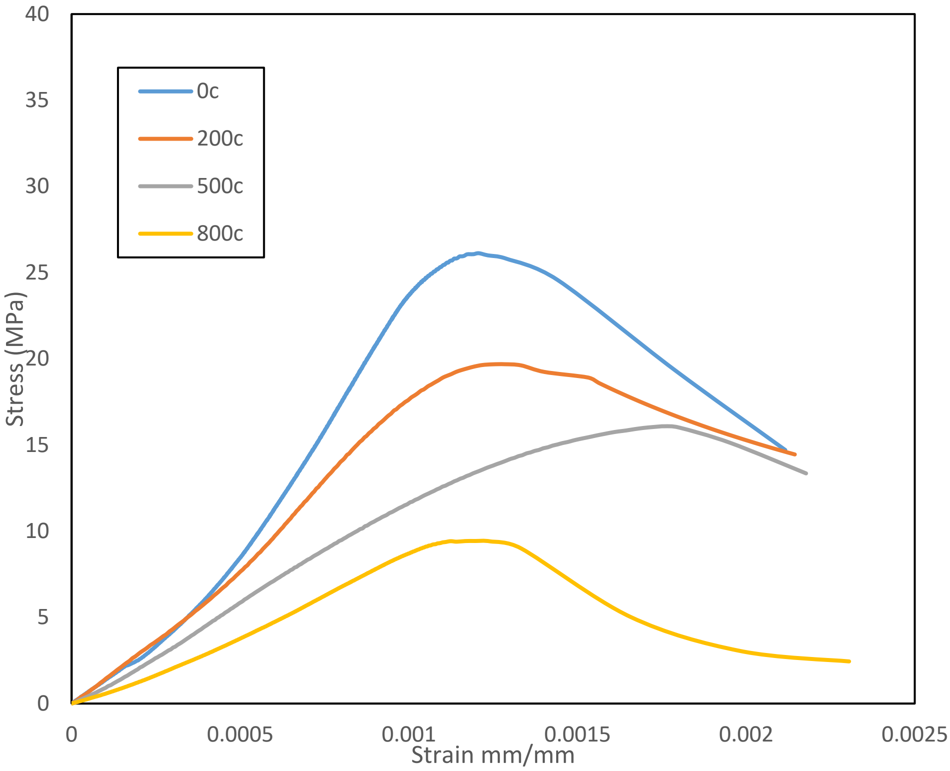


Figure 19 F50G50 Stress strain Response at different temperatures

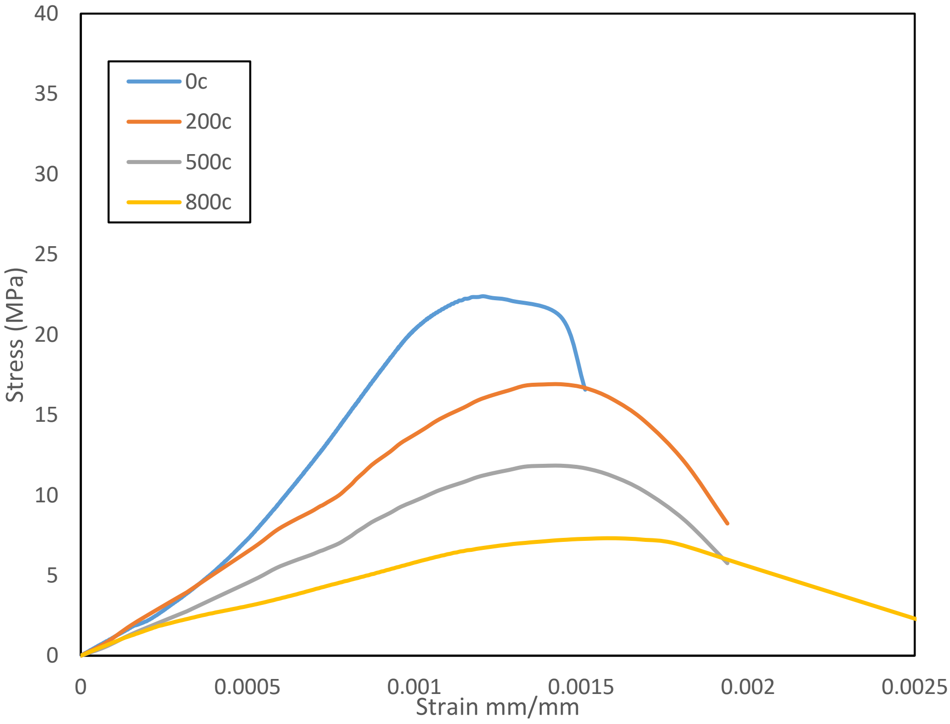


Figure 20 F40G60 Stress strain Response at different temperatures

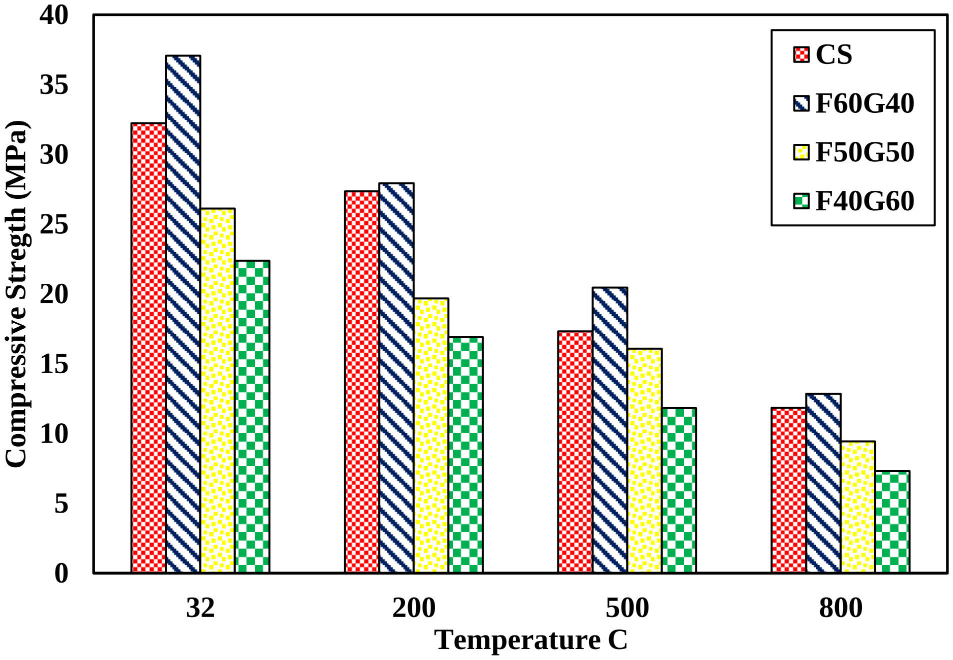
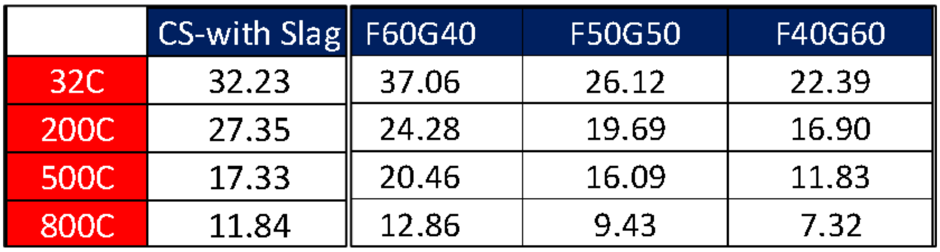


Figure 21 Compressive strength of CS and geopolymer samples at different temperature

Table 7 Compressive Strength (MPa) CS and Geopolymer sample at elevated temp.



	CS-with Slag	F60G40	F50G50	F40G60
32C	32.23	37.06	26.12	22.39
200C	27.35	24.28	19.69	16.90
500C	17.33	20.46	16.09	11.83
800C	11.84	12.86	9.43	7.32

In Portland cement concrete, the hydration process occurs when water is added to the cement. This triggers a series of exothermic chemical reactions, primarily the reaction of water with the cement to form calcium silicate hydrate and calcium hydroxide.

On the other hand, geopolymer concrete does not involve a hydration process. Instead, it undergoes a process known as geopolymerization4. This is an exothermic process where molecules known as oligomers integrate to form geopolymer networks with covalent bonding. The main constituents of geopolymers are a source of silicon and aluminium, which are provided by thermally activated natural materials (e.g., kaolinite) or industrial byproducts (e.g., fly ash or slag), and an alkaline activating solution which polymerizes these materials into molecular chains and networks to create a hardened binder.

Geopolymerization occurs at ambient or slightly elevated temperature, where the leaching of solid aluminosilicate raw materials in alkaline solutions leads to the transfer of leached species from the solid surfaces into a growing gel phase, followed by nucleation and condensation of the gel phase to form a solid binder.

So, while both processes are exothermic and result in a hardened product, they are fundamentally different in terms of the reactions involved and the products formed. This shows why Geopolymer samples have greater resistance against fire and with greater compressive strength.

4.3. Flexural strength.

The research demonstrates the increased resistance to temperature-induced stress displayed by geopolymer concrete compositions, especially F60G40. The geopolymerization process is responsible for the improved performance because it produces a more robust matrix that can tolerate thermal stresses. The flexural strength of F60G40 was 5.52 MPa at 32°C, while that of the control sample (CS) was 4.41 MPa, so both were reasonably strong due to the presence of slag aggregate. All compositions showed a reduction in flexural strength as the temperature was raised to 200 °C, with F60G40 maintaining the maximum strength at 4.20 MPa. Since geopolymerization promotes a sturdy structure, it is no surprise that geopolymer mixtures perform so well. F60G40 maintained the best strength at 500°C, 3.54 MPa, among all geopolymer blends. At 800 °C, however, flexural strength dropped significantly in all compositions due to substantial heat deterioration. These results have significant bearing on the choice of concrete for use in fireproof buildings and other high-temperature conditions, such as hot industrial settings. Because moisture and air were released during the thermal degradation processes at 200 degrees Celsius, the mass of the concrete decreased. Mass loss owing to thermal breakdown reactions became more severe at temperatures of 500 and 800 degrees Celsius. In terms of thermal stability, geopolymer blends with a higher fly ash content, like F60G40, performed better. Increased mass loss was observed in F50G50 and F40G40 because of the different fly ash-slag ratios. Due to the lack of geopolymerization reactions, the control mix lost the most mass. The exceptional thermal resistance of geopolymer concrete is particularly important in high-temperature settings.

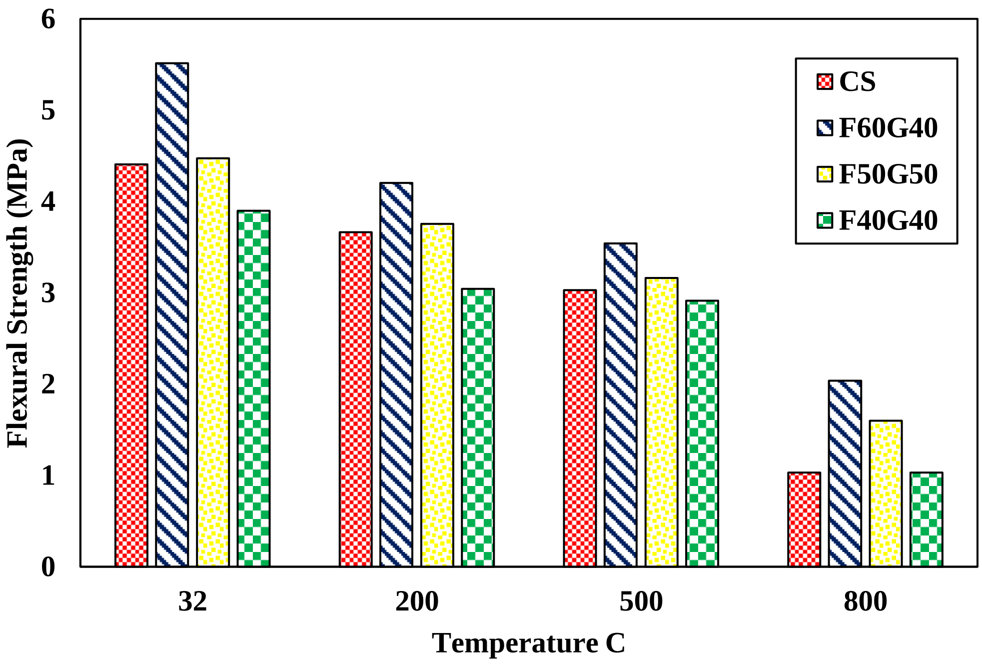


Figure 22 Flexural strength of CS and geopolymer samples at different temperature

4.3.1. Load Deformation Curve

Geopolymer Variation MIX (F60G40) consistently demonstrates higher flexural strength than CS. The strength of geopolymer concrete is attributed to the nature of the geopolymerization process and the resulting geopolymer structure. Here are a few reasons why geopolymer concrete tends to have higher strength, Covalent bonds are generally stronger than hydrogen bonds found in cement-based concrete, leading to a stronger material.

The microstructure of geopolymer concrete is dense and lacks the calcium hydroxide crystals that are present in cement-based concrete. This results in improved durability and strength. Geopolymer concrete uses alkali-activated materials such as fly ash or slag, which can contribute to its high strength. These materials undergo a polymerization process, forming a strong and durable geopolymer binder. Geopolymer concrete has been noted for its rapid strength gain. This means it reaches its final strength more quickly than traditional cement-based concrete, which can be beneficial in construction applications. Geopolymer concrete has been found to have low drying shrinkage and creep, which can contribute to its overall strength and durability. It's important to note that while geopolymer concrete can have higher strength than traditional cement-based concrete, the specific properties can vary depending on the mix design, the type of alkali-activated material used, and other factors.

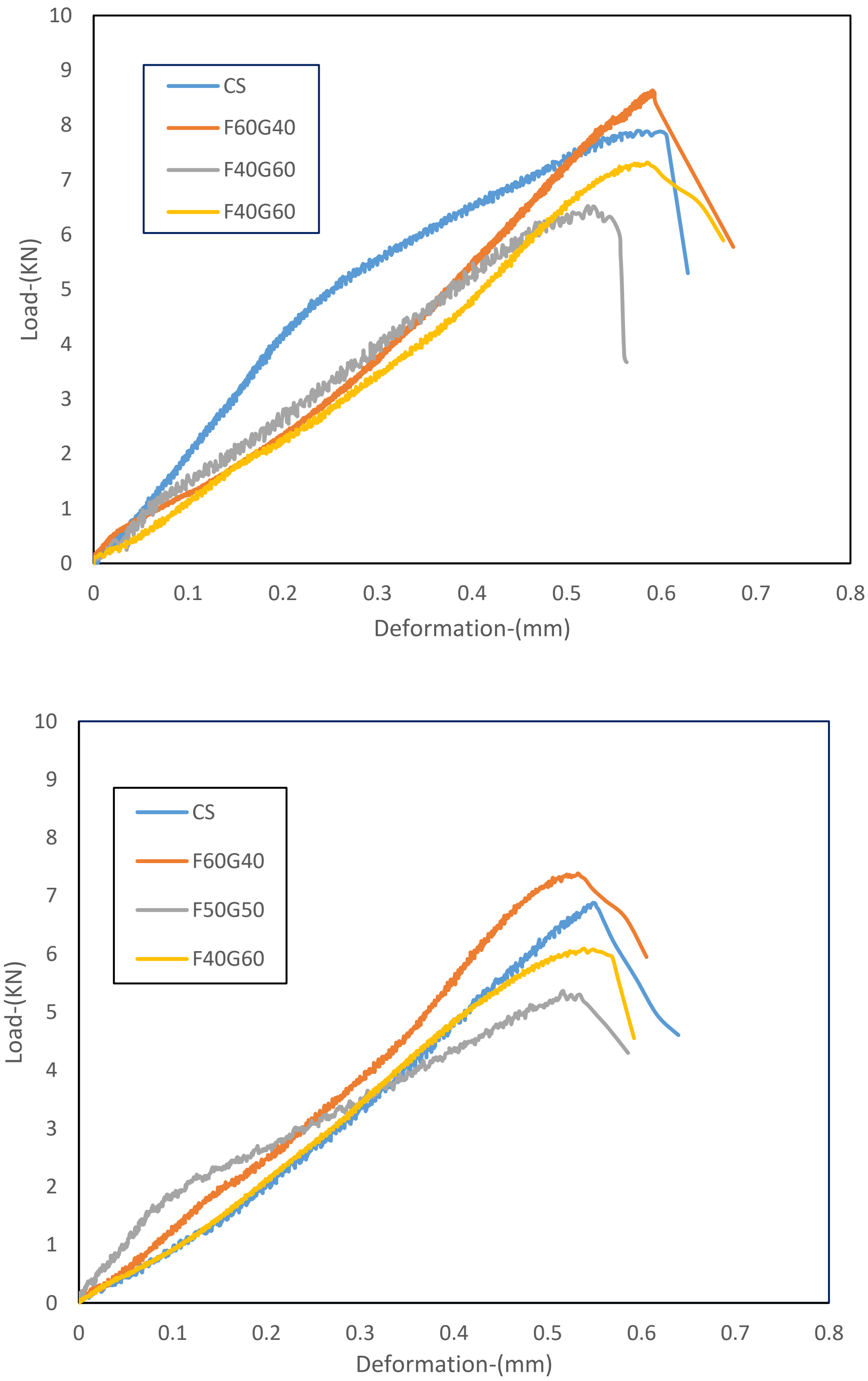


Figure 23 Load Deformation Curve at different Temp (a) Ambient (b) 200C

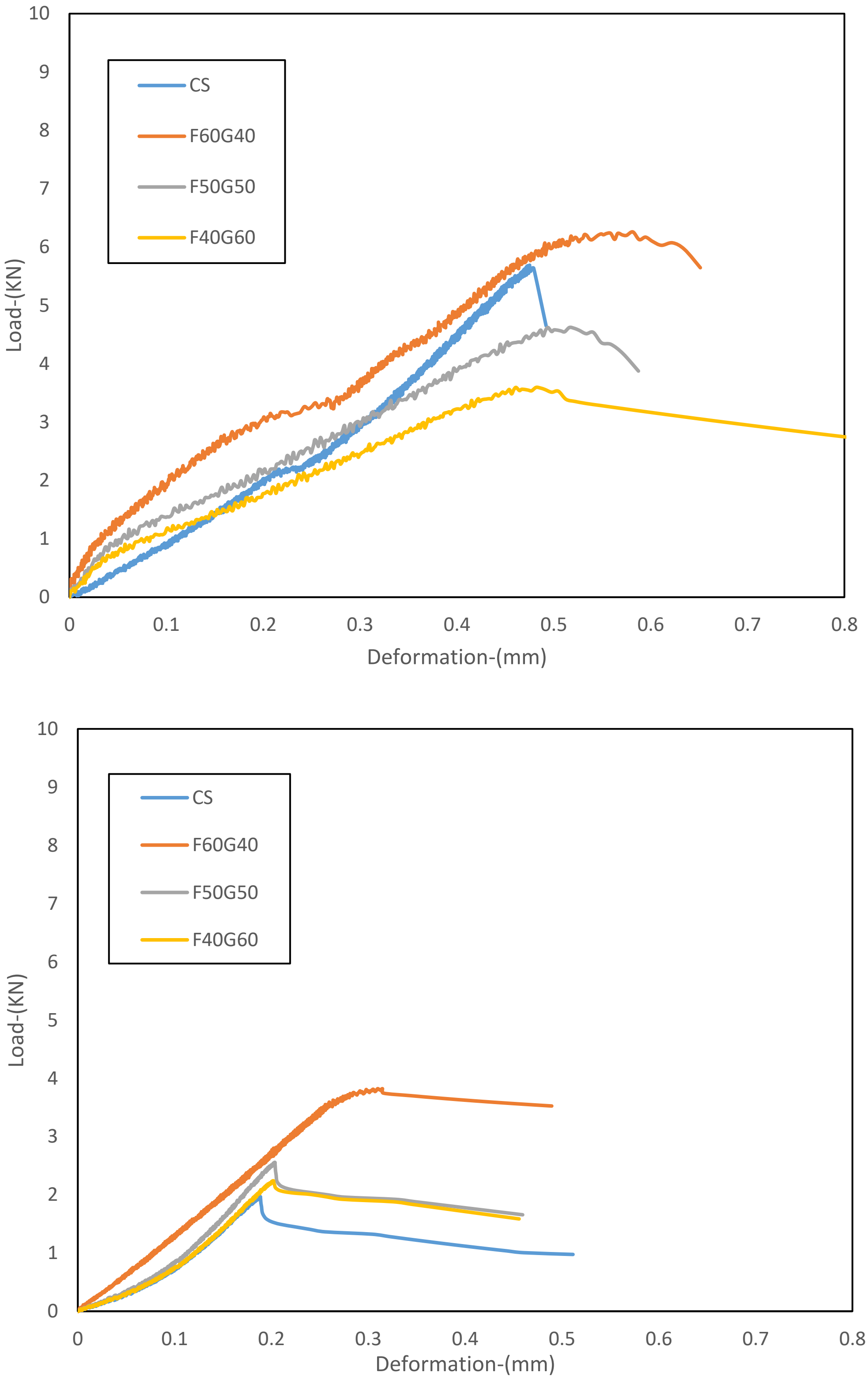


Figure 24 Load Deformation Curve at different Temp (a) 500C (b) 800C

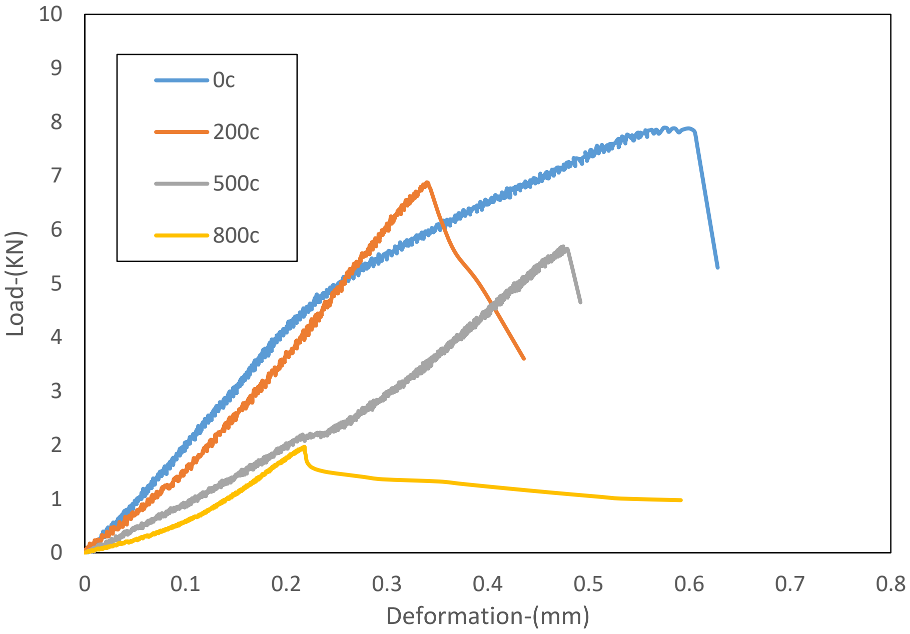


Figure 25 Control Sample at Elevated Temperature-Load Deformation Curve

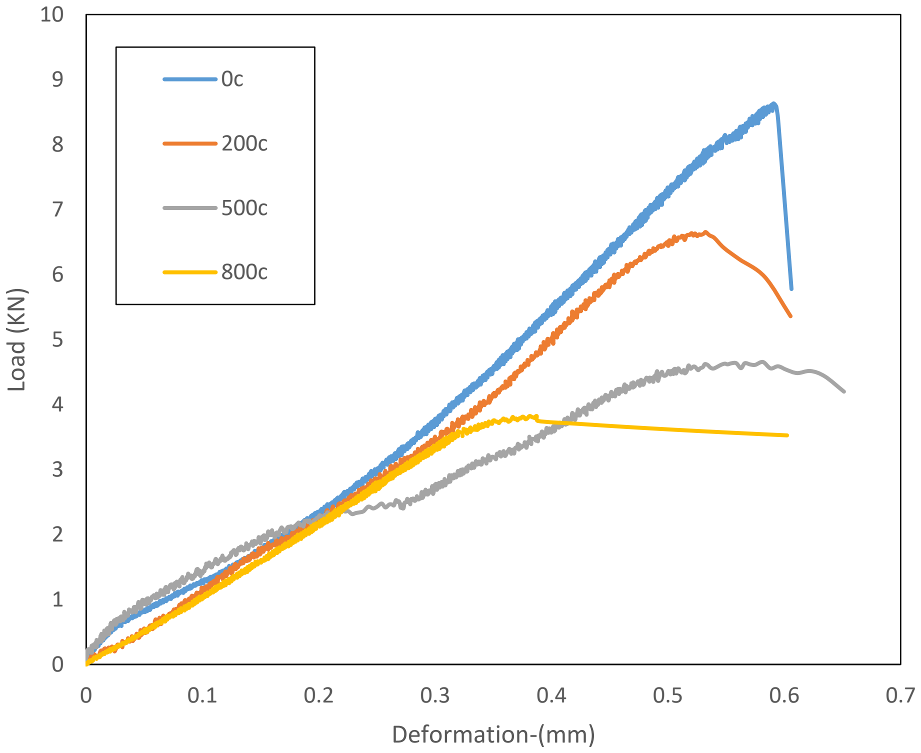


Figure 26 F60G40 Geopolymer at Elevated Temperature-Load Deformation Curve

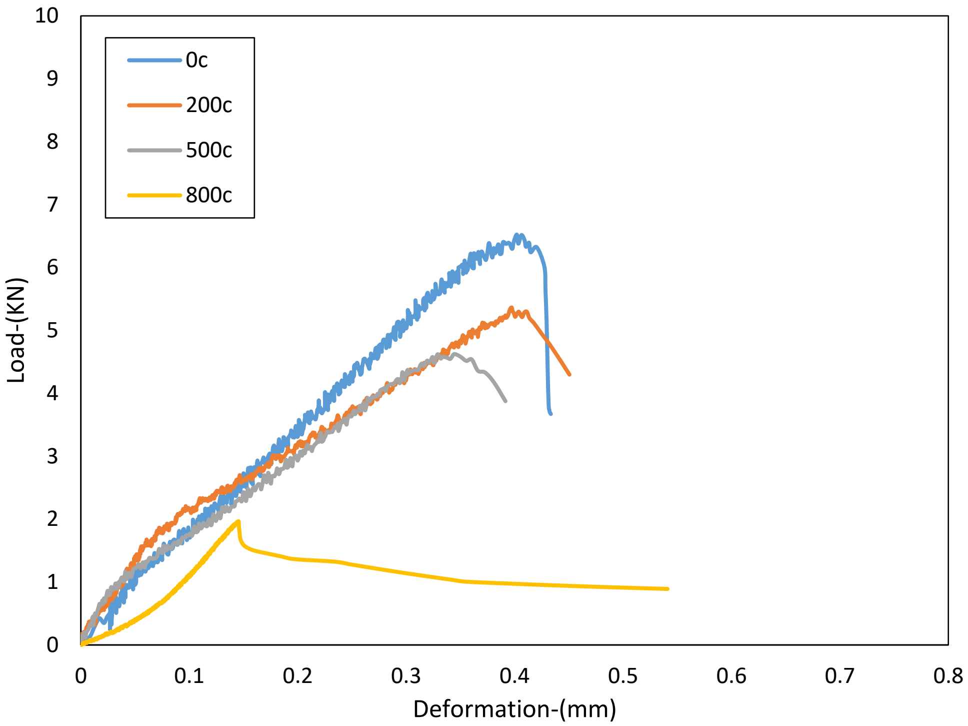


Figure 27 F50G50 Geopolymer at Elevated Temperature-Load Deformation Curve

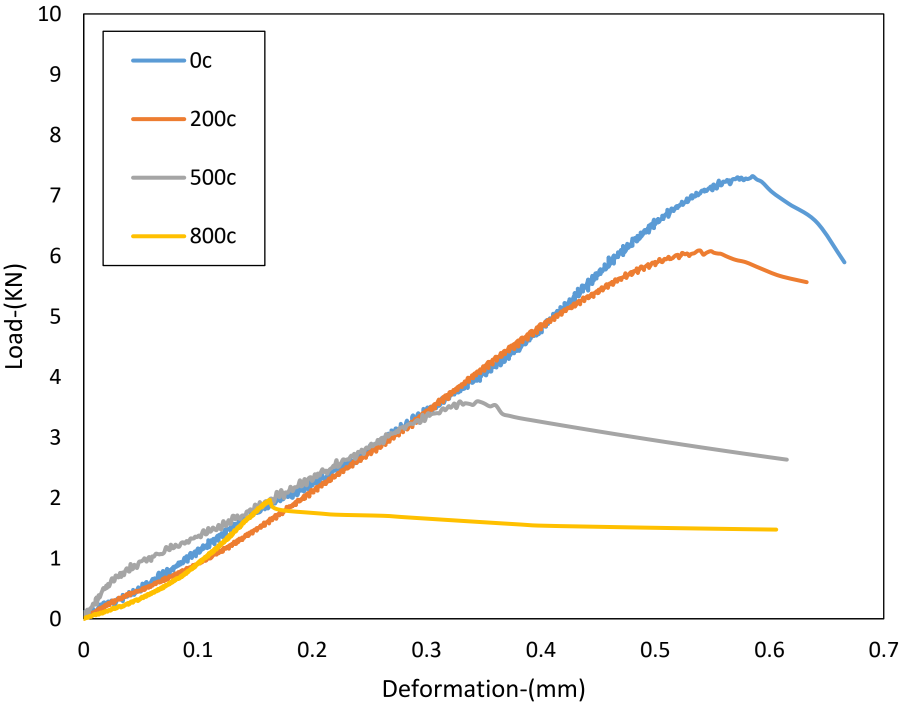


Figure 28 F40G60 Geopolymer at Elevated Temperature-Load Deformation Curve

4.4. Elastic modulus

The elastic modulus of all concrete formulations falls with increasing temperature. This is a common property of building materials and is caused by thermal expansion and microstructural changes. When we compare the different formulations, we see that F60G40 consistently has the greatest elastic modulus values across all temperature points, followed by F50G50, F40G60, and CS. Surprisingly, geopolymer concrete mixtures (F60G40, F50G50, F40G60) retain more elastic modulus at higher temperatures than lightweight standard concrete (CS). At 500°C, for example, F60G40 preserves an elastic modulus of 21.26 MPa, whereas CS only retains 18.82 MPa. At 800°C, an extreme temperature seldom encountered in typical construction scenarios, both the lightweight ordinary concrete (CS) and the F60G40 geopolymer concrete samples exhibit spalling, indicative of a substantial loss in mechanical strength and, consequently, a reduction in the elastic modulus. However, it is worth noting that even under these exceptionally challenging conditions, the F60G40 geopolymer concrete displays a remarkable level of resilience. This remarkable resilience of the F60G40 geopolymer concrete at 800°C reaffirms its position as the superior choice among the tested formulations. While all materials experience a reduction in mechanical properties at such extreme temperatures, the F60G40 formulation retains a higher degree of structural integrity compared to the lightweight ordinary concrete (CS), underscoring its exceptional suitability for applications demanding high-temperature resistance.

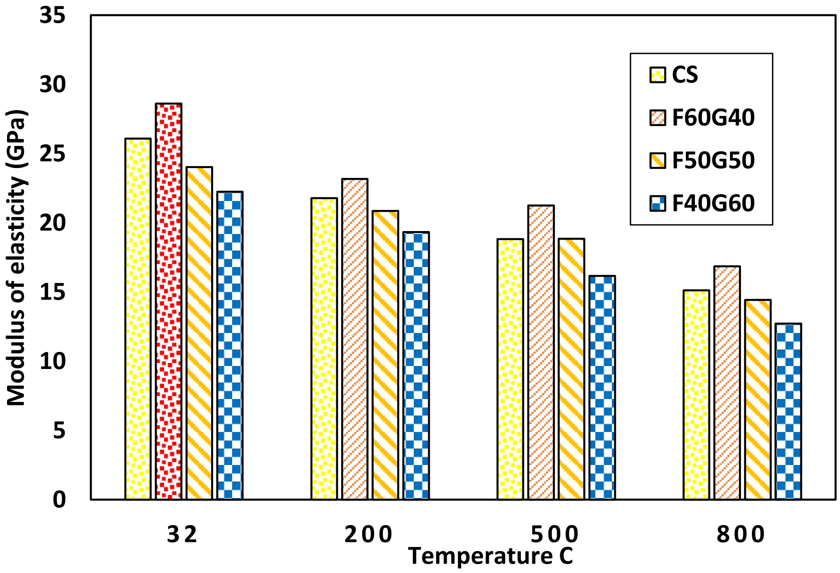


Figure 29 Elastic Modulus of CS and Geopolymer Samples

4.5. Compressive toughness

The F60G40 geopolymer concrete formulation outperforms other formulations (CS, F50G50, F40G60) at all tested temperatures. The toughness of a material is determined by calculating the area under the stress-strain curve in (KJ/m^3). At 32°C, F60G40 has the highest toughness value at 72, indicating its superior energy absorption capacity and resistance to deformation. At 200°C, F60G40 maintains a higher toughness value of 71.16, showcasing its ability to absorb energy and resist deformation under elevated temperatures. At 500°C, F60G40 continues to excel with a toughness value of 45.297, demonstrating its capacity to absorb substantial energy even in extreme heat. At 800°C, F60G40 maintains the highest toughness at 41.79, demonstrating its resilience and ability to absorb energy before failure. CS has the lowest toughness value at 10, indicating its reduced capacity to withstand deformation and absorb energy at such extreme temperatures. The F60G40 geopolymer concrete formulation outperforms other formulations (CS, F50G50, F40G60) at all tested temperatures. At 32°C, F60G40 has the highest toughness value at 72, indicating its superior energy absorption capacity and resistance to deformation. At 200°C, F60G40 maintains a higher toughness value of 71.16, showcasing its ability to absorb energy and resist deformation under elevated temperatures. At 500°C, F60G40 continues to excel with a toughness value of 45.297, demonstrating its capacity to absorb substantial energy even in extreme heat. At 800°C, F60G40 maintains the highest toughness at 41.79, demonstrating its resilience and ability to absorb energy before failure. CS has the lowest toughness value at 10, indicating its reduced capacity to withstand deformation and absorb energy at such extreme temperatures.

Prism Beams' Energy Dissipation values vary among formulations. At ambient temperature F60G40 has the highest toughness of 2.95, indicating its ability to absorb energy before failure. CS, F50G50, and F40G40 show slightly lower toughness values, with CS having the lowest 2.81. F60G40 maintains a higher toughness value at 200°C, 2.17, and 2.69 when exposed to 200°C. At 500°C, F60G40 maintains a higher toughness value of 2.10, demonstrating its ability to resist deformation and absorb energy. CS and F50G50 experience a decrease in toughness, while F40G40 shows the lowest at 0.71. At 800°C, F60G40 maintains a higher toughness value of 1.58, compared to Lightweight ordinary concrete samples.

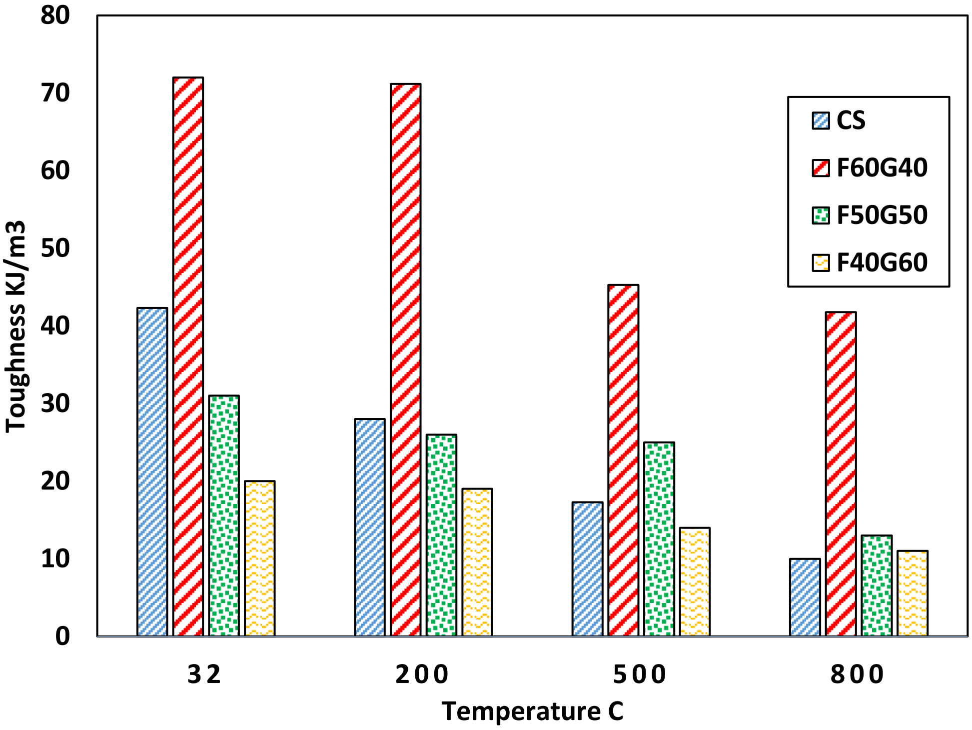


Figure 30 Compressive Toughness for Cylinders

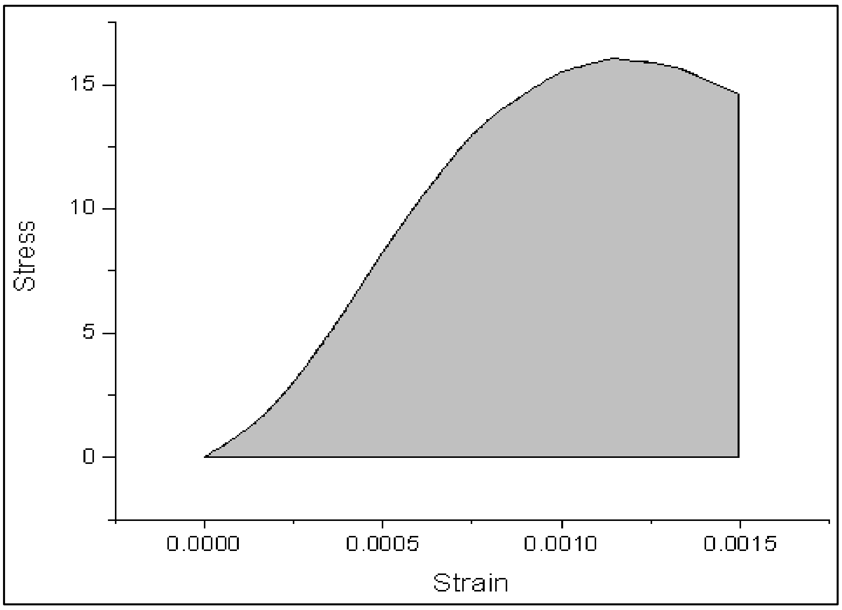


Figure 31 Origin Pro used to calculate Area under the curve

Calculating the area under the stress-strain curve up to the 20% drop in peak stress, which measures concrete energy absorption before failure and its ability to resist deformation under compression.

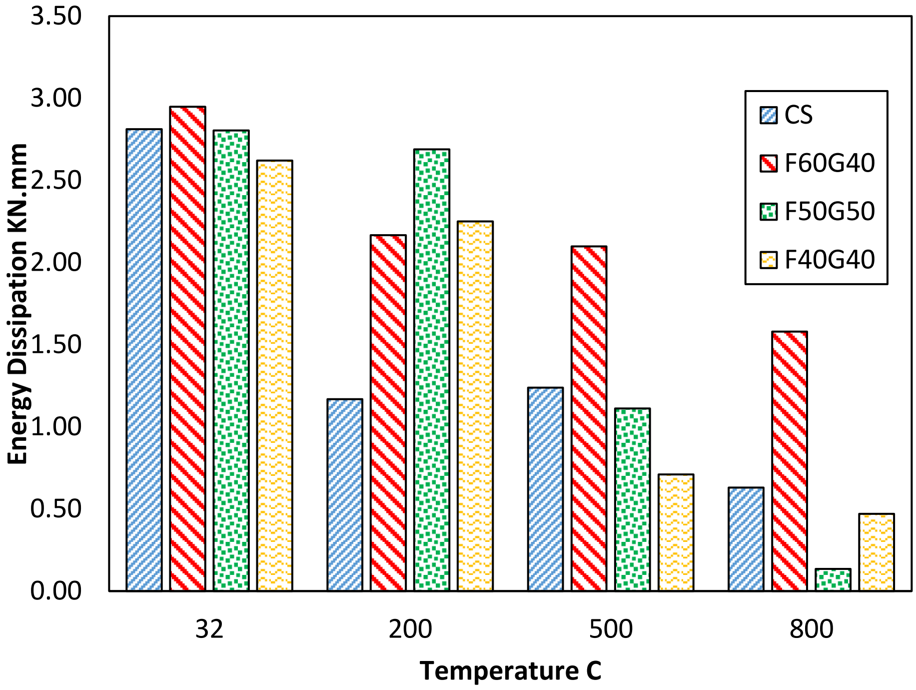


Figure 32 Energy Dissipation for Prism Beams

Energy Dissipation (E) is also calculated by calculating the area under the Load-Deformation curve up to the 20% drop in peak stress, which measures concrete energy absorption before failure and its ability to resist deformation under compression. The results show that Geopolymer concrete samples at all targeted temperatures there is an increase of energy Dissipation.

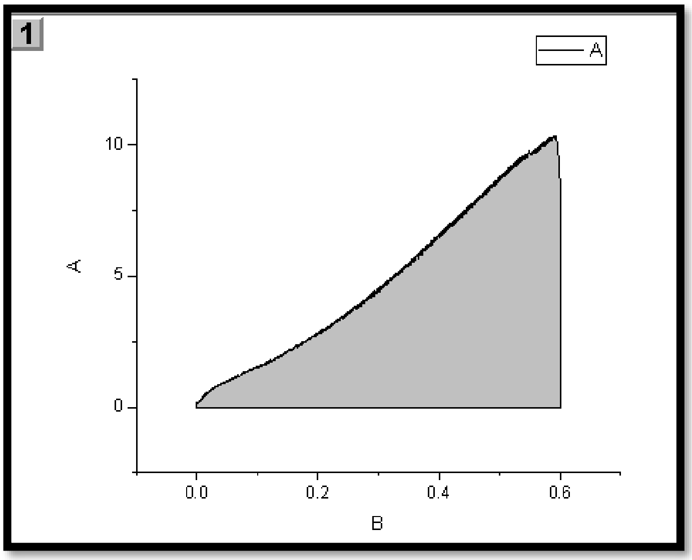


Figure 33 Energy Dissipation for Prism Beam calculated using Area Under the curve method (Origin Pro)

4.6. Toughness index (TI)

The Toughness Index (TI) is a measure that evaluates the resistance of concrete mixtures to fracture and deformation under different temperature conditions. It is calculated as the ratio of modified concrete mixtures to control samples at specific target temperatures. A higher TI indicates an improvement in deformability and fracture resilience of the material. For cylindrical concrete specimens, the TI is computed for these different mixtures: CS (Control Sample), F60G40, F50G50, and F40G60. Results show that at ambient temperature, the F60G40 mixtures exhibit higher toughness indices compared to the control sample. At 200°C, the modified mixtures display significantly higher toughness indices compared to the control sample, suggesting they maintain their resistance to deformation and fracture even at elevated temperatures. At 500°C, the F60G40 mixtures outperform the control sample in terms of toughness, with increments of approximately 161.83%, 144.51%, and 80.93%, respectively. Even at 800°C, the F60G40 mixtures continue to demonstrate a higher toughness index compared to the control sample, indicating their ability to withstand higher temperatures while maintaining their resistance to deformation and fracture.

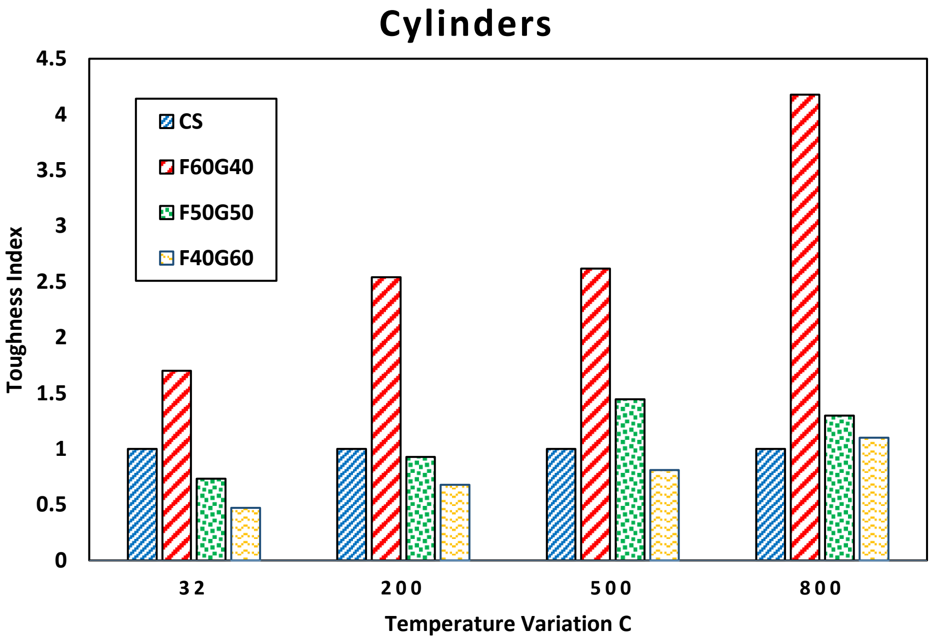


Figure 34 Compressive Index for Cylinders

4.7. Flexural Indices (FI)

Behavior of Flexural indices indicates that the Geopolymer in the matrix of sample have improvement in deformability. The Flexural Indices (FI) of prism beams concrete specimens results show that at ambient temperature, all modified concrete mixtures (F60G40, F50G50, F40G60) show toughness index values exceeding 1. The toughness indices increase by approximately 5.92%, 0.78%, and 6.40% for F60G40, compared to the control sample. At 200°C, F50G50 exhibits the best resistance to deformation and fracture among the modified mixtures. At 500°C, F60G40 maintains its deformability and fracture resistance at 70.58%, making it the most effective at this temperature compared to the control sample. At 800°C, F60G40 again demonstrates the best resistance to deformation and fracture compared to the control sample.

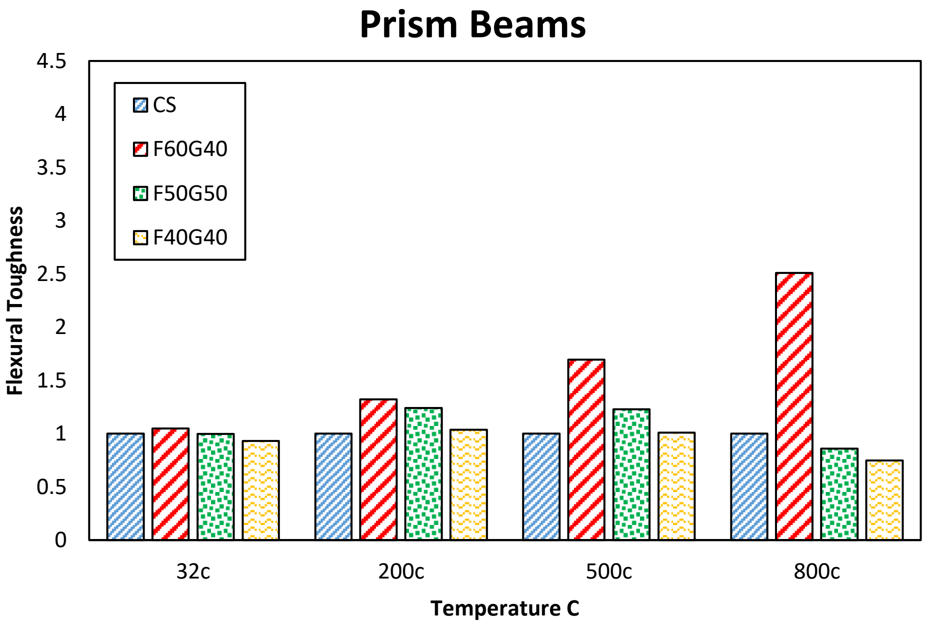


Figure 35 Flexural Indices (FI) for Prism Beams

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

5.1. Conclusion:

This study investigated the impact of lightweight concrete (CS) and lightweight geopolymer concrete (LWGC) formulations incorporating fly ash, GGBFS alkaline activator, and slag aggregate as complete replacements for traditional natural aggregates (NWA). The research focused on evaluating their influence on both fresh and mechanical properties, including the compressive strength of the specimens when subjected to high temperatures of up to 800°C for a duration of 2 hours. According to the findings of the research:

- geopolymer samples maintain a greater residual compressive strength at higher temperatures, sustaining a strength loss that is 44% lower in F60G40 and 38% lower in F50G50 when compared to the control specimen's strength loss of 54%.
- At increased temperatures, the geopolymer samples exhibit superior stress-strain responses in comparison to the control samples. The geopolymer samples had a stress value of 20.45 MPa and a strain value of 0.0014. At room temperature, each sample exhibits a failure mode consistent with brittleness.
- In comparison to the controlled samples, the elastic modulus of the geopolymer samples only degrades by 34% when heated to 500 degrees Celsius, whereas the controlled samples degrade by 41%. At 800 degrees Celsius.
- Toughness drop by a considerable amount; nonetheless, F60G40 continues to have the maximum toughness (41.79 KJ/m3). CS has the most substantial loss in toughness as the temperature rises, showing that it is more sensitive to changes in temperature than other materials. The toughness index hints to an increase in the sample's matrix's deformability, the toughness index of F60G40 shows a 260% rise at 500 degrees Celsius.

5.2. Recommendations

- Evaluate the practical application of LWGC with slag aggregate in real-world construction scenarios exposed to elevated temperatures. This could involve prototype testing and comparison with traditional concrete to ascertain its viability and advantages.

- Prolonged exposure tests to investigate LWGC's long-term durability and resilience at elevated temperatures. Monitoring changes in mechanical properties over extended periods will offer a clearer picture of its reliability in high-temperature environments.
- A comprehensive assessment of the environmental benefits of using LWGC with slag aggregate, including potential reductions in carbon emissions and energy consumption compared to conventional concrete. This information is crucial for promoting sustainable construction materials.
- Evaluate the economic feasibility of adopting LWGC with slag aggregate by comparing its material and production costs to those of traditional concrete.

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