BASALT FIBER REINFORCED GEO-POLYMER CONCRETE (BFRGC)

Thesis Submitted for the Award of the Degree of

DOCTOR OF PHILOSOPHY

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Civil Engineering

By

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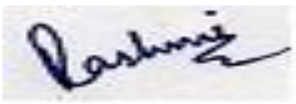
2025

DECLARATION

I, hereby declared that the presented work in the thesis entitled " **Basalt Fiber Reinforced Geo-Polymer Concrete** " in fulfillment of degree of **Doctor of Philosophy (Ph.D.)** is outcome of research work carried out by me under the supervision of **Dr. Pushpendra Kumar Sharma**, working as **Professor**, in the **School of Civil Engineering** of Lovely Professional University, Punjab, India. In keeping with general practice of reporting scientific observations, due acknowledgements have been made whenever work described here has been based on findings of other investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.



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<u>CERTIFICATE</u>

This is to certify that the work reported in the Ph.D. thesis entitled " **Basalt Fiber Reinforced Geo-polymer Concrete** " submitted in fulfillment of the requirement for the award of degree of **Doctor of Philosophy (Ph.D.)** in the **Civil Engineering**, is a research work carried out by **Rashmi Pantawane, 41800705**, is bonafide record of his/her original work carried out under my supervision and that no part of thesis has been submitted for any other degree, diploma or equivalent course.

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ABS-TRACT

Basalt fiber in the geo-polymer concrete made with meta-kaolin clay powder has been resulted in providing great strength to the geo-polymer concrete, it is promising modern concrete. It had been found out that incorporation of basalt fiber in geo-polymer increases the overall strength of the concrete.

Depending on the basic properties of cement, the basis was choosing the suitable material in place of cement in concrete . Hence , meta-kaolin clay was used to fully replace the cement. The Meta-kaolin clay have high percentage of alumina and silica, which were further confirmed by EDS results. The experimental program was set up to develop M30 geo-polymer concrete (GPC). The production of GPC requires the source material to be first activated with the help of alkali activated solution. The sodium based products were used as alkali activated solution. The molarity of the NaOH solution was maintained between 10M and 16M while using alkali activated solution (AAS). It was maintained that the alkali activated solution's mix ratio ranged from 1 to 2.5. The compressive strength and workability of the each concentration of alkali activated solution infused geo-polymer was found out. The maximum strength was provided by 14 molar sodium hydroxide solution and 2.5:1 mixing ratio of AAS. This combination was used in the further study. This study is based on the usage of basalt fibers in the geo-polymer concrete. Fibers acts as reinforcement material. The strength like compressive, flexural and split tensile of the meta-kaolin based geo-polymer were evaluated by casting cubes , beams and cylinder. The research work included the addition of basalt fibers 0.5% to 2.5% with replacement of meta-kaolin. The basalt fibers of different length as 3mm, 6mm,12mm,18mm and 24mm were used in the study. This research provides insight into the ideal proportion of basalt fiber for usage in geopolymer concrete based on meta-kaolin. The compressive strength of M14 concentration of alkali activated solution was found to have maximum strength. It was discovered that the meta-kaolin based geo-polymer concrete has higher flexural and split tensile strengths than regular cement concrete.

The XRD. SEM ,EDS and FTIR test were performed on the meta-kaolin concrete to verify the experimental results.

Keywords: basalt fiber, meta-kaolin, geo-polymer, alkali activated solution, XRD, SEM, FTIR.

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Rashmi Pantawane

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TERMINOLOGY

%	Percentage
Π	Pi
A	The separation between the fracture line and the closest support, mm.
A	Loaded area of cube, mm^2
AAS	Alkali activated solution
B	Width of sample beam, mm
B	Width of sample
BF	Basalt fibers
D	Depth of sample beam, mm
D	Diameter of specimen,mm
EDS	Energy dispersive X –Ray
Fcomp	Compressive strength of sample, N/mm^2
Fflex	Flexural strength of sample, N/mm^2
F_{split}	Split Tensile strength of sample, Mpa
FTIR	Fourier transform infrared spectroscopy
Gm	Gram
GPC	Geo-polymer concrete
Kg	Kilogram
Kg/m3	Kilogram per meter cube
L	Length of the specimen,mm
Mm	Milimeter
M	Molar
MK	Meta-kaolin Clay
Mpa	MegaPascal
N	Newton
NaOH	Sodium Hydroxide
Na2SiO3	Sodium silicate
N/mm2	Newton per millimetre square
Pcomp	Failure load in compression, N
Pflex	Load in centre at failure, N
Psplit	Load at failure, N
SEM	Scanning electron Microscopy

LIST OF TABLES

Table 3.1 : General information of Meta-kaolin clay

Table 3.2: Chemical composition of Meta-kaolin clay versus Cement in percent by weight

Table 3.3: Basalt fiber's physical characteristics

Table 3.4: Observation table for fine aggregate's modulus of fineness for sample 1

Table 3.5: Observation table for fine aggregate's modulus of fineness for sample 2

Table 3.6: Observation table for fine aggregate's modulus of fineness for sample 3

Table 3.7 : Table of observations regarding specific gravity of fine aggregate

Table 3.8 : Evaluation of Fine aggregate properties

Table 3.9 : Table of observation for determining specific gravity of coarse aggregate

Table 3.10: Table of observation for determination of coarse aggregate's crushing value

Table 3.11: Table of observation for determining the impact value of coarse aggregate

Table 3.12: Sieve analysis of Coarse aggregate

Table 3.13: Test results for coarse aggregates

Table 3.14: Quantity of required water per meter cube of concrete

Table 3.15: Required water correction per meter cube of concrete

Table 3.16: Quantity of materials for M30 meta-kaolin GPC

Table 3.17: Quantity of materials for different ratio of AAS for M30 meta-kaolin GPC

Table 4.1: Workability of meta-kaolin based geo-polymer concrete

Table 4.2: Table of observation of compressive strength of M30 Meta-kaolin Geo-polymer concrete

LIST OF GRAPHS

Graph 4.1: Comparison of 28 days strength of Metakaolin geopolymer concrete with Conventional concrete

Graph 4.2: Compressive strength of BFRGC using 3 mm Basalt fiber length

Graph 4.3: Compressive strength of BFRGC using 6 mm Basalt fiber length

Graph 4.4 :Compressive strength of BFRGC using 12 mm Basalt fiber length

Graph 4.5: Compressive strength of BFRGC using 18mm Basalt fiber length

Graph 4.6: Compressive strength of BFRGC using 24 mm Basalt fiber length

Graph 4.7: Split tensile strength of BFRGC using 3 mm Basalt fiber length

Graph 4.8: Split tensile strength of BFRGC using 6 mm Basalt fiber length

Graph 4.9: Split tensile strength of BFRGC using 12 mm Basalt fiber length

Graph 4.10: Split tensile strength of BFRGC using 18 mm Basalt fiber length

Graph 4.11: Split tensile strength of BFRGC using 24 mm Basalt fiber length

Graph 4.12: Flexural strength of BFRGC using 3 mm Basalt fiber length

Graph 4.13: Flexural strength of BFRGC using 6 mm Basalt fiber length

Graph 4.14: Flexural strength of BFRGC using 12 mm Basalt fiber length

Graph 4.15: Flexural strength of BFRGC using 18 mm Basalt fiber length

Graph 4.16: Flexural strength of BFRGC using 24 mm Basalt fiber length

LIST OF FIGURES

Figure 1.1: How temperature affects the failure stress of carbon fiber, E-glass, and single basalt

Figure 3. 1: Effect of quantity of Flyash on compressive strength for different fineness at solution to flyash ratio of 0.35

Figure 3. 2: Relationship between density of Geo-polymer and fineness

Figure 3. 3: Relationship between aggregate content and Modulus of fineness

Figure 3. 4: Compressive strength test on Geo-polymer Concrete

Figure 3. 5: Flexural Strength test

Figure 3. 6: Split Tensile test

Figure 3. 7: EDS analysis of Meta-kaolin GPC

Figure 3.8: Intensity versus degrees 2 theta graph of Meta-kaolin GPC

Figure 3.9: (A) Different techniques of FTIR

(B) FTIR spectra example

Figure 3.10: FTIR graph of Meta-kaolin Geo-polymer concrete

Figure 3.11: SEM Image of Meta-kaolin Geo-polymer Concrete

TABLE OF CONTENTS

DECLARATION ……………………………………………………………..2

CERTIFICATE……………………………………………………………….3

ABSTRACT…………………………………………………………………4

ACKNOWLEDGEMENT……………………………………………………6

TERMINOLOGY……………………………………………………………..7

LIST OF TABLES……………………………………………………………..8

LIST OF GRAPHS……………………………………………………………10

LIST OF FIGURES…………………………………………………………….11

CHAPTER 1 : INTRODUCTION…………………………………………..15

1.1 Thesis Background…………………………………………………15
1.2 Objective……………………………………………………………17
1.3 Significance of Basalt Fiber……………………………………...18
1.4 Advantage of Basalt Fiber………………………………………..18
1.5 Application of Basalt Fiber………………………………………19
1.6 Organisation of Thesis……………………………………………...19

CHAPTER 2: LITERATURE REVIEW……………………………………..20

2.1 General………………………………………………………………20

2.2 Literature on Meta-kaolin………………………………………….20

2.3 Literature review on Basalt Fiber……………………………………………………21

2.4 Literature review on Geo-polymer Concrete…………………………………..24

CHAPTER 3: EXPERIMENTAL PROGRAM……………………………………26

3.1 Material used in Research work……………………………………………….27

3.1.1 Meta-kaolin Clay…………………………………………………………...28

3.1.2 Alkaline solution……………………………………………………………29

3.1.3 Basalt fiber………………………………………………………………….30

3.1.4 Water………………………………………………………………………..30

3.1.5 Aggregate…………………………………………………………………...31

3.2 Test on Aggregate……………………………………………………………31

3.2.1 Fine Aggregate……………………………………………………………..31

3.2.1.1 Fineness test on Fine aggregate……………………………………..33

3.2.1.2 Specific Gravity of Fine aggregate……………………………………….34

3.2.2 Coarse aggregate…………………………………………………………....34

3.2.2.1 Pcynometer bottle technique for determining coarse aggregates specific gravity……………………………………………………………………………..35

3.2.2.2 Test for determining crushing value of coarse aggregate…………………36

3.2.2.3 Impact value test for coarse aggregate……………………………………37

3.2.2.4 Modulus of Fineness for coarse aggregate…………………………………37

3.2.2.5 Test for elongation index…………………………………………………..38

3.2.2.6 Coarse aggregate flakiness index in accordance with IS 2386-1963………38

3.3 Mix Design for M30 Geo-polymer concrete…………………………………38

3.3.1 Information needed for mix design……………………………………….…39

3.3.2 Design steps……………………………………………………………….42

3.4 M30 grade geo-polymer concrete design mix……………………………...43

3.4.1 Steps for design of M30 meta-kaolin based GPC…………………….…45

3.5.1 Preparation of alkali activated solution…………………………………45

3.5.2 Geo-polymer casting……………………………………………………46

3.5.3 Geo-polymer concrete curing…………………………………………..46

3.5.4 Preparation of specimens for testing purpose………………………….47

3.6 Test performed on Geo-polymer concrete……………………………….47

3.6.1 Compressive strength test………………………………………………47

3.6.2 Test for flexural strength………………………………………………..48

3.6.3 Split tensile strength test……………………………………………..…50

3.6.4 Energy dispersive X-ray spectroscopy (EDS)……………………………….52

3.6.5 X-ray diffraction analysis (XRD)……………………………….…..53

3.6.6 Fourier transform infrared spectroscopy (FTIR)…………………………….54

3.6.7 SEM analysis……………………………………………………………57

CHAPTER 4: RESULTS……………………………………………………….58

CHAPTER 5: CONCLUSION………………………………………………….64

REFERENCES…………………………………………………………………66

LIST OF PUBLICATION………………………………………………………75

CHAPTER 1: INTRODUCTION

This chapter addresses the necessity, significance, challenges faced during the work. This study revolves around the use of meta-kaolin in geo-polymer along with incorporation of basalt fiber into it.

1.1 Thesis background

In this century, population is increasing rapidly giving rise to infrastructure developments catering overall needs such as transportation, residential , hospitality etc. Requirements has also changed along with the modern world. To fulfill this need of the construction industry, the raw materials are getting used up vastly. One such material is cement, which is most widely used and an important ingredient in the manufacturing of concrete. Due to its overuse, the natural resources are getting destroyed speedily, and its replenishment is very essential to maintain the balance of environment. To prevent expeditious decomposition of limestone mines and the reduction of carbon emissions, a sustainable and more environment friendly product should be designed, and one such great alternative is the geo-polymer concrete, this concrete uses another material as an alternative for cement, generally those materials are waste products which can be replaced partially or fully with cement. Alkali activation and geo-polymerization are the two important steps involved in the manufacturing of geo-polymer concrete. This concrete requires an alkali activated solution which reacts with the pozzolanic substitute. These solutions are the backbone of geo-polymer concrete, includes potassium or sodium silicates and potassium or sodium hydroxides. Sodium based chemicals are generally preferred due to its low cost and availability. This research uses meta-kaolin clay or powder as a replacement in the place of cement. The alkali activated solution of the required concentration of both the chemicals is prepared first and then the dry constituents are included in the creation of the geo-polymer concrete.

To enhance the various properties of concrete, various researchers are using fibers such as natural fibers as well as fibers procured from other sources. These fibers provide different properties to the concrete. Cement like materials are also weak in tension and hence they cannot resist tensile forces [01] and thereby the addition of fibers in material comes into its action. These fibers play crucial role in transmitting tensile forces and try to arrest the crack. Fibers have gained lot of attention for its multiple uses into the concrete. Geo-polymer reinforced with fiber provides significant structural as well as engineering properties to the concrete, which helps in developing cleaner and sustainable environment.

This research focuses on the application of chopped basalt fibers into the meta-kaolin based geo-polymer concrete. The basalt fibers are procured from basalt rocks in a similar way such as the manufacturing of glass fibers. These basalt fibers perform better as compared to glass fibers in the tensile behavior [02]. As well as the basalt fibers have greater resistance when subjected to chemical environment. The basalt rocks are kind of waste materials ,which needs to be recycled instead of dumping into the landfills.

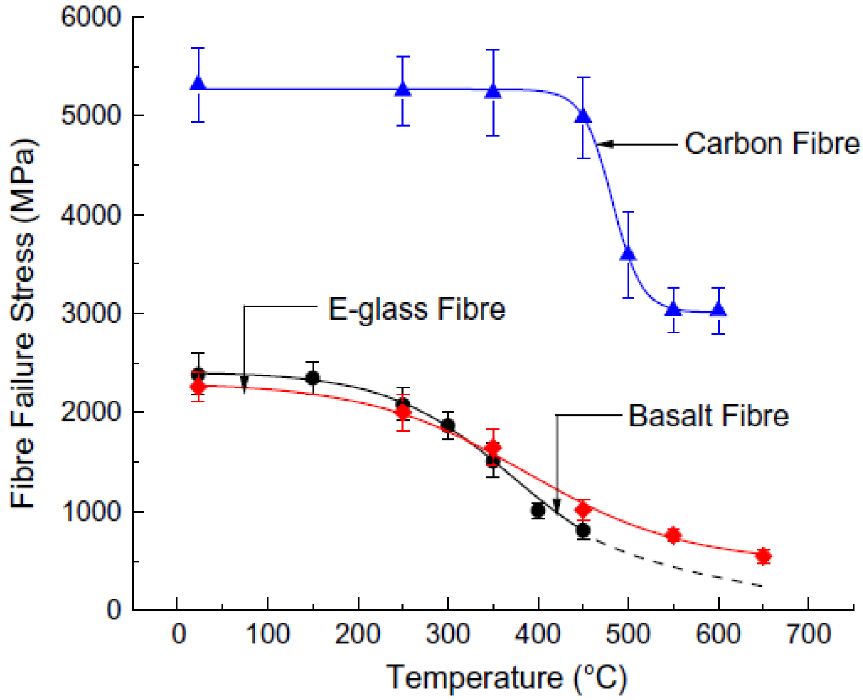


Figure 1. 1. How temperature affects the failure stress of carbon fiber, E-glass, and single basalt .Source [02].

The basalt fibers shows the reduction in failure stress when compared with E-glass and carbon fiber at the temperatures required for waste material incineration [02]. The addition of basalt fibers provides significant strength to the concrete and the studies also suggest that it may help assisting in strengthening the concrete's ability to rupture [03]. Incorporating the increasing content of basalt fibers increases the splitting strength of the concrete, but it reduces the workability of the concrete such as slump flow. The voids/ pores in the concrete also increases with increasing basalt fiber content [04]. As the basalt fibre is found to be hydrophilic in its property [05] So, this experiment also aims in finding out the optimum basalt fiber content which can be replaced with the source material. As the content of basalt fiber increases, the concrete becomes very stiff hence it loses its workability because the fibers reduces the ability of aggregates to settle down. Basalt fiber based geo-polymer concrete performance is greater than that of normal geo-polymer concrete [05].

Fly ash is most commonly used as replacement of cement in geo-polymer concrete, meta-kaolin (MK) is new material and it differs from other source materials in a way that it is not a waste product from industry [06] whereas the secondary binder materials are by-products such as ground granulated blast furnace slag (GGBS), fly ash (FA), rice husk ash (RHA), and silica fume (SF). MK is a pozzolanic substance that is very reactive. It has significant impact on performance of concrete. MK is an aluminosilicate material having 40% to 45% of alumina and 50% to 55% of silica. It is available in the form of white powder which is finer than the regular cement. Determination of mechanical properties of any type of concrete is very important as it gives an overall idea about the strength and durability of its constituent materials. Mechanical properties of any material include testing of strength such as compressive, tensile and flexure. Application of meta-kaolin in concrete has been found in achieving high mechanical strengths. Meta-kaolin incorporation provides high grade, strength, performance and light weight concrete [07].

There are various advantages of geo-polymer concrete such as minimal or negligence maintenance, low carbon emission, sustainable construction material, recycle of industrial by-product, cost saving, great life cycle, reduction in global warming, service life is long, reduction in the usage of virgin material. On comparing with the traditional concrete, the geo-polymer concrete has option for variable curing methods for achieving strengths, low air and water permeability, high chemical resistance, operator determined fast or slow set times, resistance to freeze and thaw cycles. There are also types in which geo-polymer concrete can be manufactured. Slag based, rock based and fly ash based are the major categories of geo-polymer concrete. The process of geo-polymerization involves various steps such as dissolution, special equilibrium, gelation, reorganization, polymerization and hardening.

1.2 Objective

Basalt fiber and meta-kaolin powdered clay are the emphasized composition of this research. Glass, aramid, carbon, nylon, polypropylene, steel are different types of fiber available which are used extensively. Insulating properties, resistance to heat, stability under radioactive ambiance, great resistance to corrosion, high resistance to alkalinity, low thermal conductivity are some of the exceptional qualities of the basalt fibers [05]. The behavior of basalt fiber has been studied, but the study of its combined effect with meta-research to study the behavior and strength of the combined matrix.

The objectives of the research work carried are defined as below:

01. To investigate the mechanical properties of the geo-polymer concrete
02. To get the ideal level of basalt fiber in the geo-polymer concrete
03. To investigate how the concentration of alkali-activated solution affects geopolymer concrete's compressive strength.

1.3 Significance of basalt fiber

Over the past ten years, basalt fibers have seen a notable increase in use in a variety of industrial applications. Basalt fibers are finding applications in many different sectors as the potential of using them with materials is becoming more and more apparent. The largest industry that uses basalt fiber materials in its products is, generally speaking, the construction sector. Chopped fibers, for instance, are primarily utilized in the building of wall panels and slab floors, foundations, and also in asphalt concrete road as reinforcement.

Buildings such as tunnels, marine constructions, houses, highways, and bridges can last longer when concrete contains basalt fiber. The rate at which the dosage is applied to the concrete mixture determines the amount of augmentation attained. The global market for continuous basalt fiber, estimated at US 51.4 million in 2012 and projected to increase at a rate of 10.9% between 2013 and 2019, is predicted to reach US 104.7 million.Therefore, the importance of this research is to offer suggestions to the construction sector on utilizing the optimal ratio of basalt fiber material to improve the mechanical characteristics of concrete.

1.4 Advantages of basalt fiber

Basalt rock fibers do not react with air or water, are non-flammable, and are resistant to explosions when exposed to other chemicals without creating any reaction. Basalt can substitute nearly all uses of asbestos and offers three times the heat insulation capability. Basalt fiber is not liable to galvanic corrosion. Mixing the fiber is a simple task. Reduces the width of cracks . Thickness of concrete cover decreases significantly in reservoirs and underground water channels, resulting in shorter construction time. Basalt fibers can be environment friendly and non-hazardous material.

1.5 Application of basalt fiber

Basalt has exceptional control over thermal, electrical, and sound-insulating qualities in addition to great chemical and thermal stability. It is therefore employed in fire safety . Chopped basalt fiber strands add a high level of durability, and tremendously obstructs abrasion ,shock ,frost, corrosion and water. Basalt resists chemicals well and is a superb electrical insulator, particularly against strong alkalis . Therefore, basalt composite pipes are suitable for conveying corrosive liquids and gases. Uses of basalt fiber concrete in the field include industrial concrete floors, airport runways, highways, shop floors with heavy equipment, slope stabilization, building repair and reconstruction, concrete water channels, and fire-proof construction.

1.6 Organisation of thesis

The thesis incorporates six chapters and the contents are explained in the sections below.

Chapter 1 gives an idea about the major constituents of the research work, such as the necessity and significance of basalt fibers in the concrete, need of the geo-polymer concrete, an alternative to the traditional concrete, aim and objective of the study.

Chapter 2 gives detailed review on the literatures done wherein the various research previously done on the major materials of the geo-polymer concrete are noted down.

Chapter 3 summarizes various steps involved into the processing of the basalt fiber meta-kaolin based geo-polymer concrete. The detailed steps for performing the experimental study under standard method has been done.

Chapter 4 includes the numerical results obtained under the experimental work and its discussion.

Chapter 5 includes the findings of the research and summarizing it into the conclusion

CHAPTER 2 : LITERATURE REVIEW

2.1 **General**

A detailed study has been made by studying various researchers which has been already done in the past. It has been found out that the application of fibers in the geo-polymer enhances the quality of concrete. Great results have been obtained by use of geo-polymer concrete.

2.2 **Literature on Meta-kaolin**

Cement products yields significant release of carbon dioxide in the environment. SO_3 and NO_X are also released along with CO_2 during the production of cement , which are major contributors in greenhouse effect and acid rain [8] . 5-8% of the world wide carbon dioxide emission is contributed alone from the manufacturing of cement[9]. Workability, durability and mechanical properties have been found to be improved by using Meta-kaolin in concrete. To reduce the environmental damage caused by the cement industries, meta-kaolin geo-polymers are used significantly. The major constituents of the meta-kaolin comprises of SiO_2 and Al_2O_3 [10]. High Strength and high performance concrete can be achieved by using meta-kaolin in concrete. In India, there are widespread reserves of kaolin mineral available [11]. In the country the price of meta-kaolin is 3-4 times that of cement and the meta-kaolin is proven economical over silica fume. Pozzolanic as well as micro filler properties are the main characteristics of the meta-kaolin [12]. High strength self compacting concrete can also be developed with meta-kaolin [13]. Meta-kaolin produces concrete which have low water permeability due to the decrease in pore size influencing from the meta-kaolin particle size, hence the performance of the concrete is increased and also the sorptivity is decreased .It is also mentioned that the reduction in sorptivity is demonstrated into high strength of concrete. The infiltration of aggressive substances into the concrete commonly referred as absorption of concrete. Water absorption of meta-kaolin mixes are lower than that of the cement mixes. The meta-kaolin's high alumina content aids in the binding of chloride ions leading to a decrease in free chloride ion which is responsible for corrosion of reinforcement [14]. Lower chloride permeability is observed by using meta-kaolin [15]. Workability of the meta-kaolin geo-polymer concrete is greater than cement concrete. And it has showed a good co-relationship between destructive and non destructive tests .so, the materials like meta-kaolin can be used as a supplementation with cement [19]. Increase in workability of meta-kaolin has been attributed to the fact that it has high surface area as well as high chemical activity, hence it has high water intake, which results in high workability. The thixotropic nature of the clay minerals is the factor which attributes to the increased flow of meta-kaolin concrete. And also there is improved dispersion of meta-kaolin particles resulting in reduction of void which attributes to the compaction factor [18]. Meta-kaolin is found to be favorable replacement material in marine regions where there are more chances of chloride attack [16, 17]. As the meta-kaolin production process has lack of CO_2 emission ,it provides serviceability and sustainability to the marine structures [20].

2.3 Literature review on basalt fiber

Jongsung Sim et.al conducted research on comparison between basalt fiber , carbon fiber and glass fiber properties. Specimens were casted and then strengthened with basalt fiber layers and tested for strengthening, mechanical properties and durability. Basalt fiber having 1000MPa tensile strength was used into the study whose strength was 30% stronger than carbon fiber and 60% stronger than glass fiber. Great resistance to accelerated weathering test was shown by basalt fiber. It also maintained 90% of its strength when exposed to high temperature and maintained volume integrity when compared with other fibers. The yielding and ultimate strength of the beam specimen was improved with basalt fiber strengthening. The basalt fiber was found as a promising alternative to modern strengthening techniques [21] .

When more than two hybrid materials are reinforced in a matrix, hybrid nano-composites are formed. A synergetic effect is developed which enhances new properties like light weight, elasticity, ductility and flame retarding ability [22]. There are a lot of inorganic and organic fibers on the market, but the majority of them are pricey and weak structurally. One such material that is inorganic in nature and also most choice material is basalt fiber. Basalt fiber has variety of structural properties such as excellent modulus, high strength, resistance to high temperatures, stability, resistance to chemicals, and enhanced resilience to failure. It has easy process of procuring, natural , non toxic , eco-friendly and inexpensive [23] ,[24] ,[25] ,[26] .Basalt fibers are made from basalt igneous volcanic rocks from molten lava. The extrusion of which is very efficient and also simple manufacturing process than its similar fibers. Properties like compressive and tensile strength of basalt fibers are excelled than their counterparts such as that of fiber E-glass and also it is cheaper than the carbon products. Hence, as a reinforcement material , basalt fibers have high attention [27],[28],[29],[30]. There is rise in use of natural fibers for the manufacturing of lightweight cement as well as polymer composites. Basalt fiber is extensively used and it provides low cost and exhibit great properties over glass fibers. And can be used as an alternative to glass fibers [31].Cory high et.al [32] used commercially available basalt fiber bars as flexural reinforcement and additionally used basalt fibers to produce mechanical strength to concrete members. The requirements for serviceability was satisfied and compression failure was ensured with the help of basalt fiber bars. The flexural strength of members was correctly predicted with the help of ACI 440.1R-06 code. An increase in compressive as well as flexural strength was found with inclusion of basalt fibers. The basalt fibers are added in concrete mixes to provide high performance [32]. The performance of concrete can be increased by the addition of fibers with mere percent addition. In studies it has shown that by addition of two percent of basalt fiber volume with the admixture resulted in compressive strength improvement. There was also improvement in strain and split tensile strength results. In elastic modulus property, there was little influence from the basalt fibers [33]. Greco et al. investigated the basalt fibers' mechanical characteristics. To ascertain the strength of various fiber types and surface treatments, single filament tensile tests were performed. It was noted that neither the surface treatment nor the place of origin had a substantial impact on the fibers' tensile strength [34]. A study on the impact of elevated temperatures on the characteristics of basalt fiber was conducted by Zhongyu Lu et al. Pultruded polymer plates and roving basalt fiber were utilized in the investigation. Tensile strength and elastic modulus were found to decrease for both polymer plates when temperatures were raised from room temperature to 200˚C. When the results were compared with other fibers such as E-glass fiber, basalt fiber and its polymer plates showed high tensile properties as well as high temperature resistance [35].

Basalt fibers can also be used in textile as cross weaved basalt fiber fabric (CBFF), for designing of surface hydrophobic material having high chemical stability and being non toxic , can be used for oil recovery where oil is separated from water [36]. Additionally, according to Xinzhong Wang et al., there was a noticeable increase in the modulus of rupture and compressive strength of concrete after basalt fibers were introduced. Additionally, it was shown that shrinkage fractures dropped initially and then gradually increased with an increase in fiber length. It was indicated that the ideal length of basalt fiber to employ in concrete was 18 mm [37]. Manibalan P et.al also evaluated the optimum content of basalt fiber in concrte. They concluded that the mechanical strength parameters were doubled by the accession of 0.9% fraction of volume in basalt fibers as the basalt fibers provided crack arrest mechanism to the concrete [38]. Francis L King et.al discovered that the proportion of fiber content is more crucial than its length for the advancement of tensile, flexure and impact strength of the concrete. Also by increasing the fiber content there was increase in water absorption [39]. Basalt fiber and its composites have shown good resistance to salt and water corrosion when compared with glass fibers. The basalt fibers can be used for fire protection and thermal insulation. In stressed conditions, the basalt fibers showed great endurance than that of E-glass fibers and high thermal stability was also observed. Basalt fibers have recyclable property and good interfacial adhesion. It can be used in RCC structures as rebars as it has high strength to weight ratio than that of steel, resistance to external environmental factors such as salty, acidic and alkali medium, heat proof and electricity proof. Such properties of basalt fiber makes it feasible alternative to polypropylene fibers [40].

Hao Zhou et.al noticed that the toughness and crack resistance and compressive strength of the concrete was improved by addition of basalt fibers, but the flexural strength does not increased much [41],[44]. The alkali resistance of the basalt fiber increased mechanical strength of concrete which were confirmed with mercury intrusion porosimeter (MIP) and scanning microscopy (SEM) which showed the great bonding among fibers of basalt which enhanced the concrete model [42]. On comparison of basalt fibers and glass fiber, the basalt fibers were concluded to have superior properties than glass fibers [43].

Basalt fiber reinforced polymers (BFRP) can be used to strengthen the reinforced concrete structural members, and provides a better alternative for repairing and strengthening techniques[45].When basalt fibers are added with E-glass fibers to form hybrid fiber reinforced concrete, it exhibits higher resistance to impact, good modulus of rupture and stiffness compared with traditional concrete[46]. There is a positive result in mechanical properties by using natural fibers[47],[48]. Magnesium phosphate cement also provides high temperature resistance and water resistance by including basalt fibers in it [49]. Initial setting time, final setting time and bulk density had also shown positive results by inclusion of basalt fibers [50]. Basalt fibers can replace asbestos as it has greater heat insulation characteristics. Basalt fiber and it composites have greater adhesion compared to its carbon counterparts. It has wide application in industries like nuclear power plants as eradicative material, abrasion resistant pipes for transporting liquid and gases, in concrete as reinforcement by forming basalt rebar, for sound insulation , can be used for soil stabilization, drainage pipes for agricultural use [51]. Basalt fiber can effectively replace glass and carbon fiber. It is a simple material that can be used to develop other industrial material [52]. The wide application of basalt fibers as composites are in electromagnetic function [53],[54],treatment of water [55],catalytic reduction[56], insulation from fire/heat [57], [58], detection of sense [59] and antibacterial [60].After surface modification of basalt fiber, various functional composites can also be prepared [61].

2.3 Literature review on geo-polymer concrete

Geo-polymers are the materials having chains or networks. Geo-polymer concrete is generally made by using waste products like ground granulated blast furnace slag(GGBS) and fly ash. Fly ash is produced by thermal power plants as trash , also steel plant generates ground granulated blast furnace slag as waste [68],[69]. The geo-polymer source material should contain high traces of silicon and aluminum , which can be derived by natural materials such as kaolinite as well as from by-products from blast furnaces, include fly ash and crushed granulated slag [65],[70].

The geopolymerization process starts in the concrete with the help of an alkali activated solution, which polymerizes the source materials into molecular chains and networks resulting into a hardened binder. Alkali-activated cement and inorganic polymer concrete are other names for geo-polymer concrete. The strength of the geo-polymer concrete increases with the concurrent rise in alkali-activated solution concentration, temperature, and cure time [62]. When there are occurences of sodium sulphate attack and sulphuric acid attack, geo-polymer concrete can be used[64]. By using geo-polymer concrete, there is almost ninety percent reduction in carbon dioxide emission in the atmosphere[63]. Geo-polymer concrete is promising alternative to conventional binding materials [65],[66]. Larger amount of recycled aggregates can be used in geo-polymer concrete [71]. Using geo-polymer concrete reduces the carbon dioxide emissions upto eighty percent which is caused during cement production. Hence the cost of procurement of raw material for cement production will be decreased [72]. Replace all of the ground granulated blast furnace slag and meta-kaolin without suffering a noticeable reduction in flexural strength [73]. Geo-polymer concrete shows comparable results to those of cement concrete in shear- friction characteristics [74]. High performance concrete (HPC) can be developed with the formation of geopolymer concrete. HPC was developed at ambient conditions where the alkaline solution to binder ratio of 0.25,0.35 and 0.45 was used in the preparation of metakaolin based geopolymer concrete. Fresh and hardened properties of concrete formed were studied. The geopolymer concrete with the ratio of activator to metakaolin ratio of 0.3-0.4 was found to have reduced water permeability [78].Alkaline solution to binder ratio (A/B) of 0.35 was found to have higher strength and water permeability[79]. Alkaleri maetakaolin (AMK) based geopolymer binder was made with A/B ratio of 0.35 and the fresh and hardened concrete properties were investigated. All the results were in accordance with the ranges provided by international standard codes such as ASTM and british standard. They concluded that metakaolin powder was qualified to be used as metalkaolin based geopolymer binder[80].

CHAPTER NO.3: EXPERIMENTAL PROGRAM

In this study design mix of M30 grade geo-polymer concrete has been used. The components including fine and coarse aggregates have been tested for their physical properties which are required to perform mix design. Meta-kaolin is used as the source material in replacement with cement in the geo-polymer concrete. Alkali activated solution comprising of sodium silicate solution and sodium hydroxide is utilized to begin the geo-polymerization process in the concrete. The sodium hydroxide solution is prepared and the solution's molarity is maintained within the range of 10 M, 12M, 14M and 16M. The ratio of alkali activated solution is taken as 1:1, 1.5:1 , 2:1 and 2.5:1 between sodium hydroxide and sodium silicate solutions.The geo-polymer concrete formed was tested for compressive strength , tensile strength and flexural strength. Basalt fibers are further added in the geo-polymer concrete and tested for compressive strength. In weight percentages of 0.5%, 1%, 1.5%, 2%, and 2.5% of the concrete, the fibers are added. The optimum percentage of basalt fiber was determined. Further, to study the microstructure and composition of the meta-kaolin based geo-polymer concrete, the XRD analysis, SEM, EDS and FTIR analysis has been carried out.

3.1 Material used in research work

While there are many different source materials that can be utilized to make geopolymer concrete, metakaolin clay was employed in this study, and just like with OPC, the aggregates made up 75–80% of the total mass of the concrete. The components used to make geo-polymer concrete are covered in the sections that follow. This section presents the constituent materials' physical and chemical properties. The materials listed below are utilized in the study to prepare geo-polymer concrete:-

1. Meta-kaolin clay (MK)
2. Fine aggregate and Coarse aggregate
3. Alkaline liquids (sodium silicate and sodium hydroxide)
4. Basalt fiber
5. Water

3.1.1 Meta-kaolin clay

Meta-kaolin clay is a form of clay mineral that is anhydrous in nature and is derived from kaolinite mineral. When kaolinite mineral is calcined at high temperatures (> 600°C) ,highly reactive meta-kaolin is formed , which is amorphous in nature.It is highly reactive aluminosilicate pozzolan. Meta-kaolin is utilized as the aluminosilicate raw material in the investigation in replacement with cement.

As meta-kaolin is formed at higher temperature levels, it have high thermal resistance. Meta-kaolin can be derived from various raw sources such as deposits of pure kaolin and kaolinite deposits. If paper sludge waste and oil sand tailings is containing kaolinite mineral in it, then meta-kaolin can be also derived from them. The smaller particle size of meta-kaolin lies between that of cement and silica fume. Meta-kaolin is sometimes also referred as thermally activated kaolin clays. Fine size of meta-kaolin particle is an important parameter which helps in developing strength of the geo-polymer concrete. Due to smaller particle size of meta-kaolin, the geo-polymer concrete has reduced shrinkage, which is a result of particle packing. Also the geo-polymer concrete has a superior surface polish and a denser consistency.

Table3.1 . General Information of Meta-kaolin clay

Presentation	Finely divided dry powder
Colour	Off white
Moisture (%)	0.1-0.5
Retention on 325 mesh (%)	5.0-7.0
Lime reactivity (Chapelle test)	750-1000
Meta-kaolin content	98%

Table 3.2 Chemical composition of Meta-Kaolin clay versus Cement in percent by weight [14]

Chemical Composition	Meta-kaolin%	Cement %
Calcium oxide (CaO)	0.39	63
Silicon oxide (SiO_2)	54.3	34
Aluminum oxide (Al_2O_3)	38.3	5.5
Ferrous oxide (Fe_2O_3)	4.28	4.4
Sulphur tri-oxide (SO_3)	0.22	1.92
Potassium-oxide (K_2O)	0.50	0.48
Magnesium oxide (MgO)	0.08	1.26
Sodium oxide (Na_2O)	0.12	0.1
Loss of Ignition (LOI)	0.68	1.3

3.1.2 Alkaline solution

The alkali activated solution consisted of mixture of sodium hydroxide and sodium silicate solutions. Sodium silicate solution and lab-grade sodium hydroxide pellets are used.

Preparation of Sodium hydroxide solution

Sodium hydroxide is available in the form of pellets, which are required to be added in water to produce the required molar solution. The relative molecular mass of sodium hydroxide is 40. For preparing 10 Molar solution of sodium hydroxide, One liter of solution is created by dissolving 400 g of sodium hydroxide flakes in distilled water after they have been weighed. To construct a one-liter solution, take a volumetric flask with a capacity of one liter, and slowly add sodium hydroxide flakes to water.

The alkaline liquid was determined to be a mixture of sodium hydroxide and sodium silicate solutions. Technical grade, 3 mm flakes of sodium hydroxide solids with a specific gravity of 2.130 and 97% purity were used. One of the two methods used to prepare solution, in water the pellets or flakes had to be dissolved using the sodium hydroxide (NaOH) solution. The mass of NaOH solids in a solution varied according to the concentration of the solution, which is expressed in molar units, M.

Take note that water makes up the majority of the NaOH solution and that the mass of the solid NaOH was only a small portion of the total mass. This study examines the compressive strength of geopolymer concrete for mixes containing 10, 12, 14, and 16 molarities of sodium hydroxide solution. The proportion of sodium hydroxide to sodium silicate was kept in the range of 1.0:1.0, 1.5:1.0 , 2.0:1.0, and 2.5:1.0 . The geopolymer concrete that offered the highest compressive strength for the aforementioned criterion was chosen for additional research that included the infusion of basalt fibers.

3.1.3 Basalt fiber

Basalt fiber originates from volcanic lava, which is the extremely hot, semi-fluid liquid beneath the Earth's crust that hardens in the open air, frequent word for a variety of volcanic rocks with a grayish-black color is basalt. After that, the melted rock is forced through tiny nozzles to create continuous basalt fiber filaments. Because basalt fibers are produced without the need for extra additives, they offer an additional cost benefit. The fibers found in basalt rock are non-flammable, explosion-proof, and do not react negatively with air or water. They don't interact chemically with other substances in a way that might be hazardous to the environment or public health.

The thermal and hardness characteristics of basalt fiber are good. For ground concrete slabs, basalt fibers are a successfully applied foundation material. Basalt fibers may be produced industrially for the same or even less money than glass fiber thanks to modern technologies. When comparing basalt fibers and materials to glass, carbon, and other forms of fibers, they have the most favorable quality-to-price ratio.

The ability of basalt fibers to chemically react with cement is what mostly affects its mechanical qualities. They have the power to slow the spread of cracks, improving the concrete's compressive and tensile strengths. Additionally, they have a great resistance to heat and alkali, which increases concrete's longevity. Consequently, the impact of utilizing basalt fibers at varying lengths and ratios on their mechanical characteristics.

Basalt fibers are regarded as non-hazardous and environmentally beneficial materials. Although this material is not new, its uses in a variety of industrial and commercial domains—from building and construction to energy efficiency, from automobiles to aircraft—are undoubtedly novel due to its efficient mechanical, chemical, and thermal properties. Some of the physical and chemical properties of Basalt Fiber are listed as follows

Table 3.3: **Basalt fiber's physical characteristics**

Sr. No.	Basalt fiber's physical characteristics	Range
1	Specific Gravity of fiber	2.71
2	Potential of Hydrogen	>12,<15
3	Friction Coefficient	0.41-0.51
4	Content of Moisture	0.09%

Its exceptional qualities include a high modulus, great strength, increased resistance to corrosion, and the ability to maintain its strength at a high level for composite mixes with varying volume fractions.

3.1.4 Water

Water was seen to emerge out in the mixture in the course of the polymerization process based on the reaction between chemicals. In the Geopolymer mix , water is used to procreate the concrete workable while it is still plastic; it shows zero effect on the strength of the concrete once it has hardened. In a similar vein, given the same level of workability, the requirement for water rises as source material fineness increases. Thus, the degree of workability, fineness, and grading of fine aggregate are taken into consideration when determining the minimal amount of water needed to produce the specified workability.

3.1.5 Aggregate

Inert mineral filler that makes up 70–85% of the volume of concrete is called aggregate. In order to minimize voids in the concrete mass, fine and coarse particles are combined when making geopolymer concrete. Fine aggregate was graded in order to achieve this, and an appropriate fine-to-total aggregate ratio was chosen. The grading of fine aggregate affects the workability of geopolymer concrete in a manner similar to cement concrete. Thus, for the suggested mix proportioning approach shown in Fig. 2, The fine aggregate's grading determines the fine aggregate to whole aggregate ratio.

3.2 TEST ON AGGREGATE

Practical experiments performed on fine aggregate

Fine aggregates were investigated for the below test procedure:

i. Modulus of fineness of aggregate
ii. Fine aggregate's specific gravity

Practical experiments performed on Coarse aggregate

Fine aggregates of size 10mm and 20mm were investigated for the below test procedure:

i Coarse aggregate's Specific gravity
ii Crushing value test
iii Aggregate impact test
iv Finesse modulus
v Elongation index test
vi Flakiness index test

3.2.1 Fine Aggregate (IS 303-1970)

Concrete is made up of separate aggregate bits joined together by cement; the cement paste constitution largely determines the characteristics of finished product. The connection between the aggregate and cement paste affects its strength as well. Whatever being the aggregate strength, strong plaster or a strong binding between the paste and aggregate are necessary for producing strong concrete, and without either, poor-quality concrete will be produced. which naturally occurring aggregates are robust enough to produce concrete with a standard strength Numerous tests have been performed on Fine aggregates to determine its quality and grading, including specific gravity, absorption of water, impact strength, crushing strength. Tests have been performed on sand, and the outcomes are listed below. In accordance with IS 383-1970, natural sand is utilized.

3.2.1.1 FINENESS TEST ON FINE AGGREGATE

Sample No. 1:-

Table No. 3.4 Observation table for fine aggregate's modulus of fineness

Size of Sieve	Retain mass in gms	Cumulative mass retain	Collective mass retain (%)	Mass passed (%)
4.75 mm	198	198	19.80	90.20
2.36 mm	160	258	25.80	74.20
1.18 mm	320	578	57.80	42.20
600 µ	231	809	80.90	19.10
300 µ	089	898	89.80	10.20
150 µ	090	988	98.80	01.20
Pan	012	1000	100	-

Fineness modulus = sum of cumulative % of mass retained on the sieve / 100

= 462.9 / 100

= 4.629

Sample No. 2

Table No.3.5 Observation table for fine aggregate's modulus of fineness.

Size of Sieve	Retain mass in gms	Cumulative mass retain	Collective mass retain (%)	Mass passed (%)
4.75 Mm	110	110	11.00	89.00
2.36mm	178	288	28.80	71.20
1.18mm	347	635	63.50	35.50
600 µ	210	845	84.50	15.50

300 µ	925	940	94.00	06.00
150 µ	038	978	97.80	02.22
Pan	022	1000	100.00	-

Fineness modulus =sum of cumulative % of mass retained on the sieve / 100

= 479.60 /100

=4.796

Sample No.3

Table No.3.6 Observation table for fine aggregate's modulus of fineness

Size of Sieve	**Retain mass in gms**	**Cumulative mass retain**	**Collective mass retain (%)**	**Mass passed (%)**
4.75 mm	079	079	07.90	92.10
2.36 mm	163	242	24.20	75.80
1.18 mm	380	622	62.20	37.80
600 µ	249	871	87.10	12.90
300 µ	107	978	97.80	02.20
150 µ	012	990	99.00	1.00
Pan	010	1000	100.00	-

Fineness modulus = sum of cumulative % of mass retained on the sieve / 100

=478.20 / 100
= 4.782

As fineness is above 3.50 the given sample is very coarse

Fine aggregate confirms to grading zone II

Average of fineness modulus of the fine aggregate = 4.735

3.2.1.2 Specific gravity of the fine aggregates

Table No.3.7 Table of observations regarding specific gravity of fine aggregate

S. No.	Observation	Sample wt. (gms)
1	Wt. Of the sample taken	500
2	Mass of pycnometer (m1)	460
3	Mass of pycnometer + sample (m2)	910
4	Mass of pycnometer + sample + water (m3)	1537
5	Wt. Of pycnometer + water (m4)	1253
6	Wt. Of the oven dry sample	450

Specific gravity (g) = 450/450−284
= 2.71

Table No. 3.8 Evaluation of Fine aggregate properties

S. No.	Performed test	Evaluation
01	Fineness modulus	4.735
02	Specific gravity	2.70

3.2.2 Coarse Aggregate:

If the concrete can be placed easily and completely surrounds all reinforcement, filling the form's corners, the maximum size of coarse aggregate should be permissible within the given consideration, but it can not be exceeded than one-fourth of the minimal member thickness. The aggregate with a 20 mm size will be utilized in accordance with IS 383-1970. Sand, gravel, and naturally occurring stones—either crushed or uncrushed—or a combination of these—must make up aggregate. They must be devoid of adhering coating, veins, and harmful magnitude of broken pieces, alkali, degradable matter, and other harmful materials. They must also be sufficiently hard , extremely strong, durable, and clear of any organic matter. Flaky, coriaceous, as well as elongated parts should be avoided at all costs. This investigation will employ 20 mm-sized crushed angular coarse material that is readily available locally and complies with IS 383:1970.

3.2.2.1 Pycnometer bottle technique for determining the coarse aggregate's specific gravity

Table No. 3.9 Table of observation for determining specific gravity of coarse aggregate

Table of observation	Weight of sample 1 in gm	Weight of sample 2 in gm
Wt. of sample	2000	2000
Initial wt. of Agg. under water W_1	2050	2050
Wt. of empty basket under water W_2	800	800
Wt .of saturated surface dry Agg. in air W_3	2019	2012
Wt. of oven dryAgg. in air W_4	1987	1986
Specific gravity (G) =	(3 - (1 – 2)	

Sp. Gravity of coarse agg. Sample = 2.59

3.2.2.2 Test for determining the crushing value of coarse aggregate

Table No. 3.10 Table of observation for determination of coarse aggregate's crushing value

S. No	Recorded observation	Weight of specimen 1	Weight of specimen 2	Weight of specimen 3
1	Sample weight	4000 gm	4000 gm	4000 gm
2	Wt. of the sample passing through the 2.36 is sieve	820 gm	812 gm	818 gm

Aggregate crushing value for the sample 1

= (820/ 4000) x 100

= 20.5 %

Aggregate crushing value for the sample 2

=(812 / 4000) x 100

= 20.3 %

Aggregate crushing value for the sample 3

= (818 / 4000) x 100

= 20.45%

Average aggregate crushing value = (20.5 + 20.3 + 20.45) / 3

= 20.41

3.2.2.3 Impact value test for coarse aggregate

Table No.3.11 Table of observation for determining the impact value of coarse aggregate

S. No.	Examination	Specimen 1	Specimen 2	Specimen 3
1	Sample weight	500 gm	500 gm	500 gm
2	Sample weight after impact on passing through 2.36 sieve	45 gm	52.5 gm	38.5 gm

Coarse Aggregate’s impact value for sample 1 = 45/500 x 100 = 9%

Coarse Aggregate’s impact value for sample 2 = 52.5/500 x 100 = 10.5%

Coarse Aggregate's impact value for sample 3 = 48.1/500 x 100 = 9.62%

Average value for impact of coarse aggregate = 9.70%

As the average value for impact of coarse aggregate is coming less than ten percent, the aggregates are strong enough for investigation purpose.

3.2.2.4 Modulus of fineness for coarse aggregate

Weight of aggregates taken for the experiment = 5000 gm

Table No. 3.12 Sieve analysis of coarse aggregate

Sieves in accordance with IS	Retain weight	Cumulative retain weight	Collective Retain weight in percent	Cumulative weight passing through it in percent
20 mm	2364	2364	47.28	52.72
10 mm	2347	4711	94.22	5.78
4.75 mm	169	4880	97.60	2.40
Pan	120	5000	100	-

Fineness modulus = 339.1 /100

= 3.3

3.2.2.5 Test for Elongation Index (IS: 2386 (Part I) – 1963)

The Elongation Index Test in accordance with IS: 2386 (Part I) – 1963 is used in this section.

1 The percentage of particles by weight whose largest size (length) is larger than one and a quarter times (1.8 times) their mean size dimension is known as the elongation index of an aggregate.

2. Sizes smaller than 6.3 mm are not suitable for the elongation test.

3 Flaky and elongated particles should be exempted.

4 If flaky and elongated aggregates are present in significant amounts, the strength will be negatively impacted because of the potential for failure under loads.

Test	Result
Elongation Index	9.70

3.2.2.6 Coarse aggregate's flakiness Index in accordance with IS: 2386 (Part I) – 1963)

1. The Coarse aggregate flakiness index is calculated as the weight percentage in which the smallest dimension in thickness is less than three-fifths of their average dimension.
2. Aggregates having size below than 6.3mm are not considered for the above test.

Test	Result
Flakiness Index	8.5

Table No. 3.13 Test results for coarse aggregates

S. No	Name of the experiment	Result
1	Specific gravity	2.59
2	Test for Crushing value	20.41
3	Test for Impact value	9.70
4	Modulus of fineness	3.39
5	Elongation Index	9.70
6	Flakiness Index	8.5

3.3 Mix Design for M30 Geo-polymer concrete

3.3.1 Information Needed for Mix Design

1. Meta-kaolin based geopolymer concrete's compressive strength (fck)
2. The fineness (in m2/kg) of the raw materials, such as meta-kaolin clay
3. The geopolymer concrete's workability in terms of flow (mm)
4. Curing technique, such as heating an oven to 60 °C for a full day.
5. Aggregate fineness modulus (coarse and fine)
6. The value of w/c ratio and absorption for coarse and fine aggregate

Design procedures that are utilized to determine the appropriate mix proportion of geopolymer concrete based on meta-kaolin clay are listed below. [Patankar]

3.3.2 Design Steps

1. **M30 Geo-polymer concrete's target mean strength (Fck)**

Fck is equal to fck + 1.65 x S.

In accordance with IS 456-2000, Table 1 is used as the value of S in clause 9. 2. 4. 2.

2. Quantity of meta-kaolin clay (MK)

The mean target strength and fineness of meta-kaolin at alkaline solution to meta-kaolin ratio of 0.35 from the following figure determines how much meta-kaolin clay powder is needed.

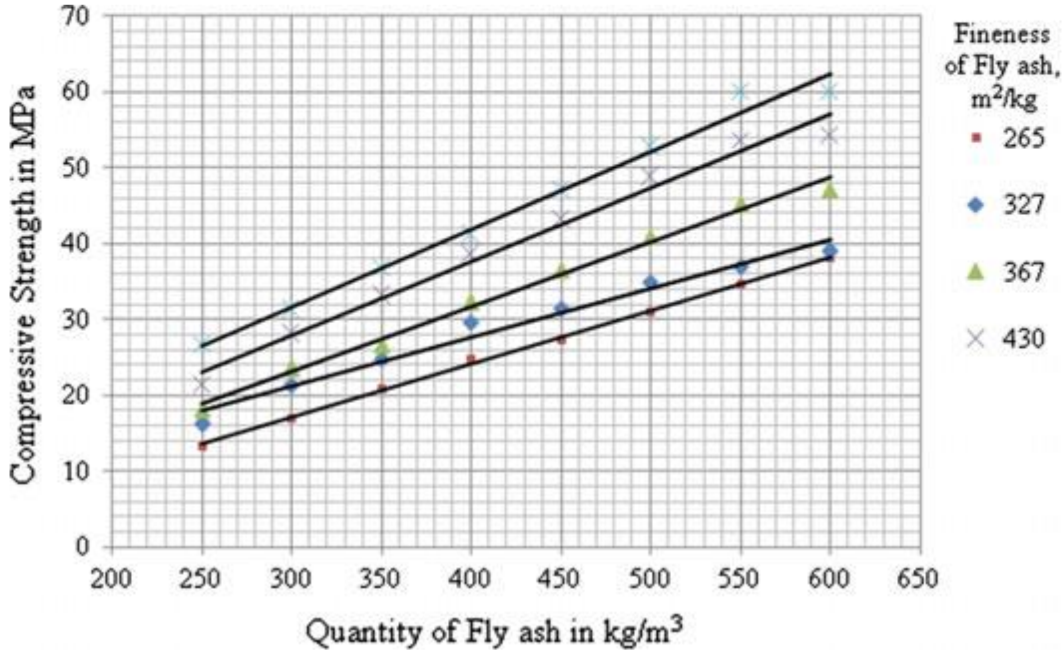


Figure 3.1 . Compressive strength for different fineness at solution-to-flyash ratio [12]

3. Calculation for alkaline activator solution quantity

The alkali activator solution quantity is determined by applying a mass-based alkaline solution to meta-kaolin ratio of 0.35[77]. The quantity of both the solution is computed by utilizing the needed mass ratio of sodium silicate and sodium hydroxide.

4. Total Solids present in Alkaline Solution

Using the percentage of solids in each solution, determine the solids present in sodium based solution.

5. Quantity of Water

The degree of workability and the total water required, which includes water found in both the constituents of alkali solution, determine how workable geopolymer concrete is. By using below table, determine the total water required to satisfy the workability depending on the meta-kaolin fineness.

Table 3.14: Quantity of required water per meter cube of concrete

Workability level	Percentage flow	Required water in Kg/m^3 depending on fineness in m^2/Kg >500
Low	>0, <25	110
Medium	25≥, <50	120
High	50≥, <100	135
Very high	100≥, < 150	160

6. Required correction for Water Content

The quantity of coarse aggregate and sand in concrete makes up roughly 70–85% of the total volume. Similar to coarser particles, finer particles require more water to create a workable mix since they have a larger surface area. A few adjustments to the water content were recommended by IS 10262 for the cement concrete mix proportioning based on the fine aggregate grading. Water's function in the geopolymer concrete is to increase the work condition of material. Therefore, it is advised that the same adjustment be made to the Geopolymer in the suggested mix design based on the fine aggregate grading zone. Below table displays the adjustment of the water content for concrete based on the fine aggregate grading zones.

Table 3.15: Required water correction per meter cube of concrete

Grading zone in accordance with IS 383(20)	Required water correction in w/c content in percent
I	-1.5
II	——
III	+1.5
IV	+3

7. Calculation of Additional Quantity of Water

Alkaline solution are employed in the geopolymer concrete which contain a specific amount of water based on its concentration. However, more water may be added externally to the mixture in order to meet workability criteria. This can be estimated as follows:

Additional water quantity, if needed

= (Total water quantity) - (water contained in alkaline solutions)

8. Densityof Geopolymer Concrete in wet condition

Based on the fineness of meta-kaolin, choose the geo-polymer concrete's wet density.

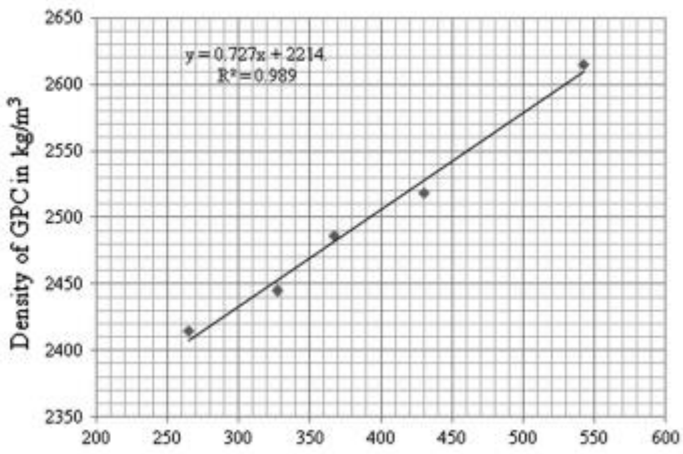


Figure 3.2: Relationship between density of geo-polymer and fineness

9. Calculation of Fine aggregate to Aggregate in total Content

Depending on the fineness modulus of the fine aggregate, the quantity of fine aggregate and total aggregate content is obtained from below figure.

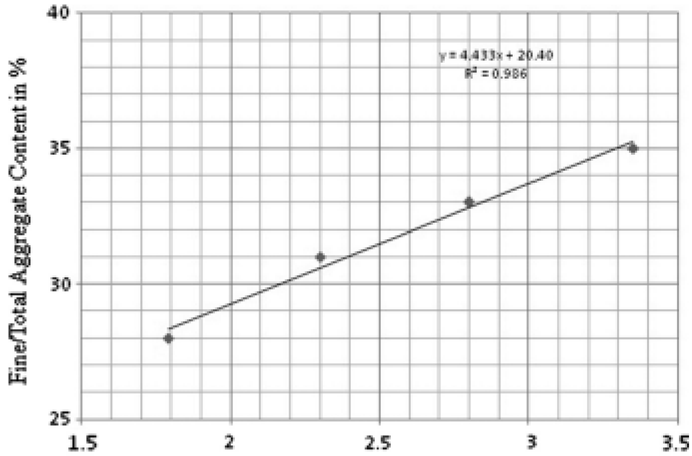


Figure 3.3: Relationship between aggregate content and modulus of fineness

10. Calculation of quantity of both the aggregates

The quantity of aggregates is computed by using the steps described below.

Aggregate quantity = (Geopolymer concrete wet density) - (Quantity of meta-kaolin + water added in addition)

Quantity of sand = (Fine aggregate to aggregate in total content in %) * (aggregate quantity)

Quantity of coarse agg. = (Aggregate quantity)- (quantity of sand)

11. Material quantity needed depending on Field Conditions

Aforementioned mix proportion was determined under the presumption that the aggregate is both surface dry and saturated. Divergence if any from this requirement, such as aggregates are wet, dried in air, or sunbaked, requires adjusting the amount of water mixed with the aggregates

3.4 . M30 Grade geo-polymer concrete design mix

Using Suggested Technique The suggested method is used to carry out a sample of mix proportion for M30 GPC , which is based on the procedures covered in the previous section.

Initial design data required to carry out design

1. Geopolymer concrete compressive strength (fck) : 30 MPa.
2. Curing method used : samples are cured in oven at 60 °C for one full day

3. Flow required : between 25 to 50 percent (Medium workability)

4. Metakaolin clay fineness : 710 m2/kg

5. Activators used : Sodium based

   (a) Sodium hydroxide concentration: 10M

   (b) Sodium silicate solution concentration : 50.31 %

6. Alkaline Solution to meta-kaolin ratio : 0.35 by mass

7. Mixing ratio of sodium silicate solution and sodium hydroxide: 2

8. Property of fine aggregate

   (a) Specification: zone-II sand , Modulus of fineness : 4.7

   (b) Absorption of water by aggregate: 3.6 %

   (c) Any amount of water content in aggregate : no

9. Property of coarse aggregate

   (a) Specification: angular crushed

   (b) Size used: 20 mm maximum

   (c) Absorption of water by aggregate: 0.9 %

   (d) Any amount of water content in aggregate : N0

3.4.1 Steps for design of M30 meta-kaolin based GPC

1. Mean strength targeted in study

Fck = 38.25 MPa

2. Metakaolin clay quantity

The meta-kaolin quantity is 300 kg/m3 for 38.25 MPa strength at 0.4 ratio of alkali solution to meta-kaolin

3. Alkaline activator quantity

The ratio of mass for alkaline solution to meta-kaolin = 0.35

Total weight of (Na_2SiO_3 + NaOH) / meta-kaolin = 0.35

Mass of(Na_2SiO_3 + NaOH) = 0.35 X 300

Mass of (Na_2SiO_3 +NaOH)=120 kg/m^3

If the ratio of sodium silicate and sodium hydroxide is 2, then

Quantity of NaOH = 40 kg/m^3

Quantity of Na2SiO3 = 80 kg/m^3

4. Total solid content in AAS

Sodium silicate content of solid = (50.31 /100) * 80

= 40.248 kg/m^3

Content of solid in NaOH = (38.5/100) * 40

= 15.4 kg/m^3

Final content of solid in AAS = 40.2480 + 15.4 = 55.648 kg/m^3

5. Water content

Medium workability requires 120 kg/m^3 of water content from table 3.2

6. Alkaline solution water content

Alkaline solution water quantity = 120 – 55.648 = 64.352 kg/m^3

7. Quantity of water added extra calculation

= [Water quantity total] − [Alkaline solution water content]

= 120 − 64.325 = 55.675 kg/m^3

8. Density of GPC

The density of GPC is 2730.17 from figure 3.3

9. Fine aggregate to whole aggregate content selelction

Figure 3.2, modulus of fineness of sand is 4.7 which gives the aggregate content as 41.23%

10. Aggregate content of sand and CA

Quantity of total aggregate = GPC density - Meta-kaolin qty + AAS qty + water additionally added

= 2730.17 - (300 + 120 + 55.675)

= 2254.5 kg/m^3

Quantity of sand = (sand to total aggregate content in %) * (quantity of total aggregate)

= (41.23 /100) * 2254.5

= 929.5 kg/m^3

Quantity of Coarse agg. = (Qty. of total agg.) - (Qty. of sand)

= 2254.5 – 929.5

= 1325 kg/m^3

Table 3.16 Quantity of materials for M30 meta-kaolin GPC

GPC	MK	NaOH	Na2 SiO3	FA	CA	Total water	Ex. water
Qty. in kg/m^3	300	40	80	929.5	1325	120	55.675
Ratio	1	0.4		3.09	4.41	0 .4	0.185

3.5 Preparaton

3.5.1 Preparation of alkali activated solution ,

Sodium hydroxide solution prepared with distilled water and Na2 SiO3 solution were combined in order to create the alkali activating solution (AAS) used in GPC mixes. In order to prepare solution of NaOH with a 13molarity (13M), for example, 520 grams of NaOH solids were mixed in distilled water to form one liter. The necessary solution concentration, which is stated in molarity, M, will determine the weight of solids to be added. The process of polymerization that occurs when sodium hydroxide and sodium silicate solution are combined releases a significant amount of heat, meaning that the alkaline liquid that is created needs to be used within 24 hours for more exploration.

The GPC used in this investigation was made with several concentration of Sodium hydroxide, ranging from 10 M, 12 M, 14 M, and 16 M. Additionally, the ratio of sodium hydroxide to sodium silicate was maintained within the range of 1 to 2.5. For additional research, the geopolymer concrete with the highest compressive strength was selected.

Table 3.17 Quantity of materials for different ratio of AAS for M30 meta-kaolin GPC

Solution to MK ratio	MK (Kg/ m^3)	Fine to Total agg. ratio	CA Kg/ m^3	FA Kg/ m^3	Na_2SiO_3 :NaOH	Sodium silicate Kg/ m^3	Sodium Hydroxide Kg/ m^3	Extra water Kg/ m^3
0.4	300	0.41	1355	930.3	1	60	60	50.22
0.4	300	0.41	1354	930.2	1.5	72	48	53.72
0.4	300	0.41	1325	929.5	2	80	40	55.675
0.4	300	0.41	1352	929.7	2.5	85.72	34.28	56.43

3.5.2 Geopolymer Concrete Casting

The meta-kaolin GPC binder and aggregates were firstly combined on a pan for roughly 2 to 3 min in lab until uniform color. After adding liquid component of the mixture, the ingredients are mixed for an additional four minutes on average. The purpose of adding sodium silicate is to speed up the geopolymerization process. In mixer, meta-kaolin and alkaline activator were combined until a homogenous paste was produced. To cast the specimens, mixture prepared is poured into moulds into three layers alongwith tamping with rod in between the layers.

3.5.3Geopolymer Concrete Curing

Curing plays significant role in assessing the strength of concrete, hence it is of utmost importance to select proper curing method.

It is commonly advised to heat cure GPC since the strength of GPC is found to be influenced by both the temperature and the duration of curing.The demoulded specimens were place in oven at 60°C for one day curing. Afterwards, they were left in open air.

3.5.4 Preparations of Specimens for testing purpose

Each test required different sizes of specimen.

i. Flexural strength was calculated by using (100 x 100 x 500) mm beam size

ii. Compressive strength was calculated by using 150mm size cubes.

iii. Split tensile strength was calculated by using150 mm Diameter x 300 mm Length cylinder.

3.6. Test Performed on Geopolymer concrete

On hardened metakaolin based GPC, below test were executed for strength determination:

i) Strength test for compression

ii) Strength test for flexure

iii) Strength for Split tensile

3.6.1 Compressive Strength Test:

Concrete characteristic that is vital for the longevity and structural integrity of concrete constructions is its strength in compression. It gauges the concrete's resistance to axial loads, or forces that would otherwise squeeze or crush the substance. In order to ensure that concrete can hold applied loads without failing, compressive strength is vital parameter taken into consideration during the design and evaluation of concrete constructions. The ability of concrete to bear applied load on its exposed surface without showing any deformation and cracking is referred its compressive strength. Materials typically shrink when compressed, yet they elongate when under tension stresses.

Compressive strength is computed when the area of cross section in specimen fails under the applied load. Test were performed at intervals of 7 days, 14 days and 28 days on standard cube size 150mm.

.

The following expression was utilized in assessing compressive strength:

$$F_{comp} = P_{comp} / A$$

Where P_{comp} = Compression at failure load, N

A = Surface area of cube on which load is applied, mm^2

F_{comp} = Calculated compressive strength, N/mm^2

Figure. 3.4 Compressive Strength Test on Geopolymer concrete

3.6.2 Test for Flexural Strength :

The concrete tensile strength is determined by flexural testing. It helps to evaluate beam resistance to failure in bending without the presence of reinforcement. The rupture modulus (MR) describes the results of strength of flexure performed on specimen. The load at centre or at one third length can be provided to specimen for testing the flexure on concrete.

It is determined that by providing center load yields a modulus of rupture result that is approximately 15% less than the load applied to the setup for one third length . Furthermore, bigger size concrete specimens resulted in low modulus of rupture. Also, the rupture modulus is 10 to 15 percent of strength of concrete in compression, which is dependent upon aggregate volume, its size and ratios at which the aggregate were utilized in the specimen preparation.

The expression employed for finding flexural strength is stated:

$$F_{flex} = P_{flex} * L / b * d^{3} \quad \text{or } 3\ P_{flex} / b * d^{2}$$

Where,

F_{flex}= Strength in flexure , N/mm ^{2}

P_{flex} = Laod in centre at failure , N

L = beam length, mm

b = beam width, mm

d = beam depth, mm

a = The separation between the fracture line and the closest support, mm

Figure No. 3.5 Flexural Strength Test:

3.6.3 Split Tensile Strength Test:

An important mechanical parameter to assess the split tensile strength of cylindrical concrete specimens is the test for Split Tensile strength. The splitting tensile test evaluates the material's resistance to tensile forces, in contrast to conventional compression tests, which determine the concrete's compressive strength. Engineers can evaluate the strength of a cylindrical specimen by placing diametrically opposing forces on it until it fractures. Tensile strength is vital criterion for analyzing the structural integrity and concrete’s durability in variety of construction applications. The test results add to our knowledge of concrete's mechanical behavior overall and offer insightful information about the material's capacity to bear tension.

The fundamental and significant concrete characteristics that provides a significant impact on degree and amount of crack present in structures is defined by its tensile strength. Furthermore, due to brittle character, the concrete performs weakly under tension. It is therefore not able to perform in tension. In other words, when tensile pressures are greater than tensile strength, concrete fractures. To ascertain the load when structural member shows fracture, it is imperative to find the tensile strength. Additionally, one way to ascertain the strength of concrete is to do test on tensile strength on a cylindrical specimen.

A popular procedure for figuring out the concrete strength is split tensile test. Many methods has been devised to assess the tensile strength due to the challenges associated with performing the direct tension test. In these tests, a concrete specimen is typically subjected to a compressive force in a way that the member fails as a result of tensile strains that are created within the specimen. 150 mm diameter and 300 mm height cylinder was subjected to a split strength test. Cylinder specimens' split tensile strength is ascertained by sandwiching them into the two plates of the machine for compression test. Thickness of 3 mm , 25 mm wide, and length of 300 mm plywood strips were positioned in between plates and surface of the concrete member.

The expression for analyzing split tensile strength is depicted below

$F_{split} = 2 * P_{split} / \pi * D * L$

Where,

F_{split} = Split Tensile strength in Mpa

P_{split} = Failure load, N

L = Cylindrical specimen length , mm

D = Cylindrical specimen diameter, mm

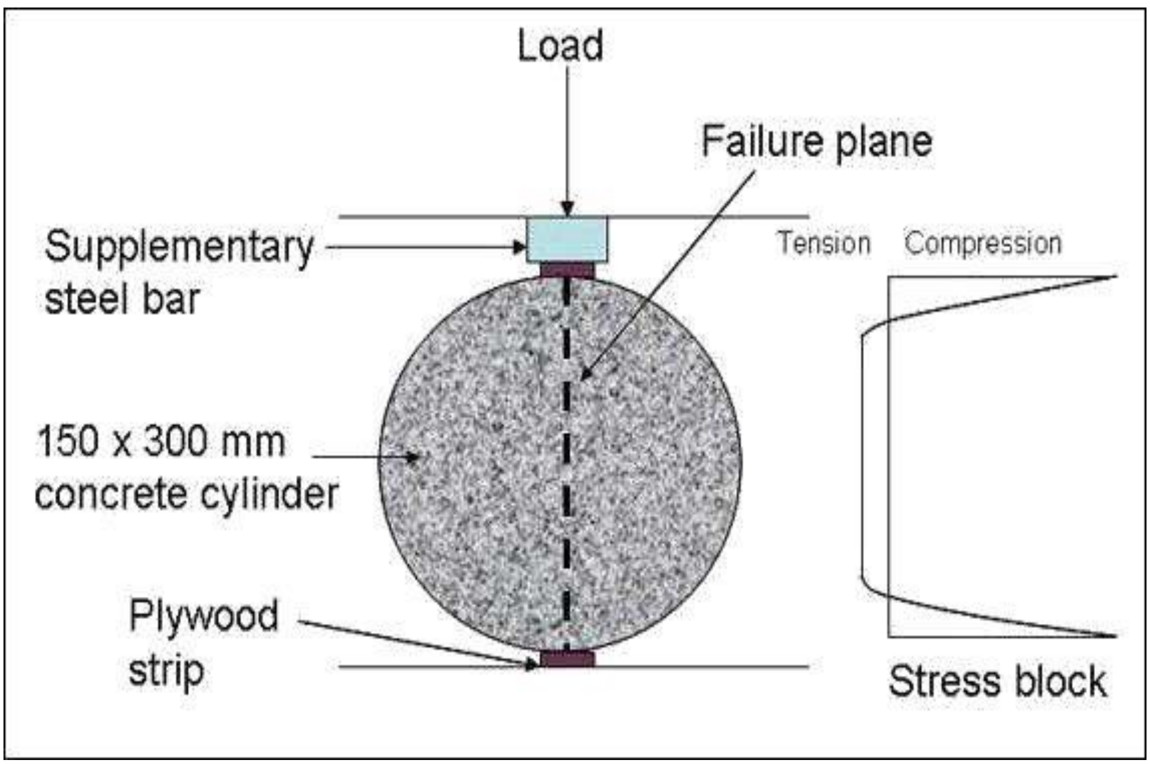


Figure 3.6 Split Tensile Test

3.6 .4 Energy Dispersive X-Ray Spectroscopy (EDS)

Energy-dispersive X-ray spectroscopy (EDS), sometimes shortened to EDX or XEDS) allows elemental and chemical examination of various substances. When any substance is activated by any source of energy, such an beam of microscope's electron, some absorbed energy is released as core-shell electron. Then, electron in outer-shell with a high energy moves into its stead, releasing the energy difference as an X-ray with distinct spectrum determined by the atom from which it originated. This makes it possible to analyze the composition of a sample and its volume that has been electrified by the source of energy. The elemental constitution may be identified by its position of spectrum, and concentration of which can be derived by the intensity of signal.

EDS analysis can be accurately used to discover the elements constituting a given sample. In determination of metallic coating layers and analysis of any alloy, the EDS can be employed. The original sample nature also affects the accuracy of the composition measured. EDS emits X-ray beams in all directions of sample. The beams are absorbed by the sample, measurement of the absorption helps in estimation of composition of material.

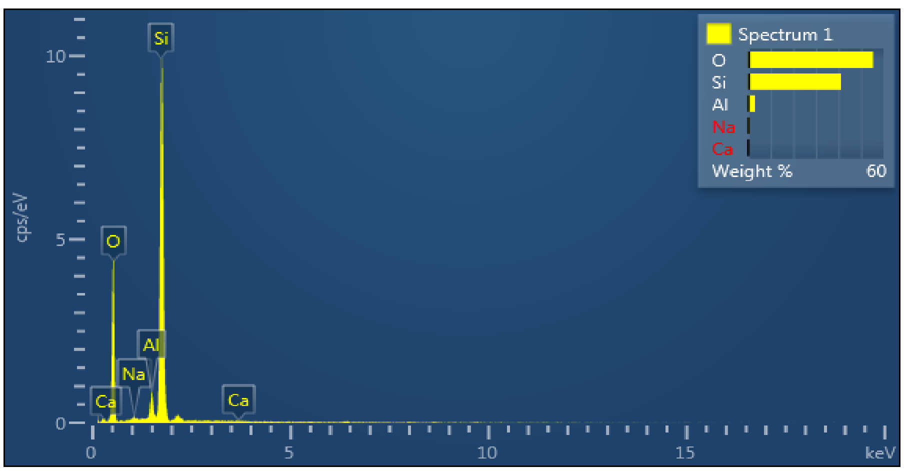


Figure 3.7: EDS analysis of metakaolin GPC

3.6.5 X-ray diffraction analysis (XRD)

X-ray diffraction is a method utilised to find out atomic and molecular structure of the crystalline materials. XRD is most commonly adopted for identification of constituents such as minerals and metals products found inside the solid material. It is widely used to find out the material composition and also for discovering any source of unwanted deposits. XRD can also provide insight into the other structural parameters such as the average grain size and distribution of strain.

Solid mineral or the powdered form of the samples are required for submission. The materials which are available in solid form are crushed into fine powder, to be transferred to the sample stage. XRD patterns are generated with the help of instrument called goniometer, which when rotated around the sample material at specific angles, bombarding of the X-ray takes place. As a result of which the distribution of atoms within the lattice takes place, the peak intensity of this diffraction pattern is noted down. The X-ray diffraction patterns are fixed for a specific material determined by the periodic arrangement of atoms. The XRD output data is in the form of counts (intensity) versus degrees 2-theta.

XRD analysis was carried out on sample of meta-kaolin geo-polymer concrete. The test has been conducted to study the cystallinity of the meta-kaolin based geo-polymer concrete . it provided the detailed data about the structural charactersitics , chemical constituents and physical properties of meta-kaolin geo-polymer concrete.

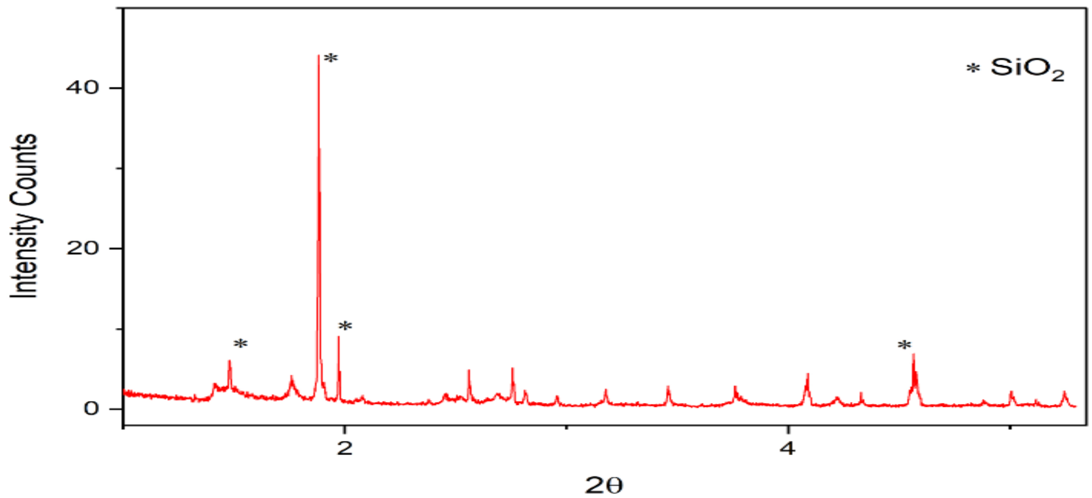


Figure 3.8. Intensity versus degrees 2 theta graph of Metakaolin GPC

3.6.6 Fourier transform infrared spectroscopy (FTIR)

Fourier transform infrared spectroscopy (FTIR) is rapid, efficient ,economical , easy and undestructive analysis. FT-IR spectroscopy is the most useful method not only for determining the composition and structure of clay minerals, but also for studying the interaction of clay minerals with inorganic or organic compounds. FTIR is a very useful technique for determining the identity of pure compounds, but its value is limited when used on mixtures of compounds. This method is based on the identification of functional groups in a molecule, such that these groups vibrate (stretch or bend in different ways) when irradiated with light of a specific wavelength. These oscillations and intensity in percent transmission are plotted against the frequency (cm^2) of light at which the sample was kept, producing the FTIR results .

A range of infrared region is produced in spectrometer. When the sample is exposed to this region, radiation of specific wavelength is absorbed by the materials. The molecules present in the material travels to excited state from ground state. This energy gap between the molecules determines the intensity of absorption. Most of the molecules absorb infrared radiation except O_2, N_2 and Cl_2. All the samples in the form of liquid, gas and solid can be analyzed for FTIR.

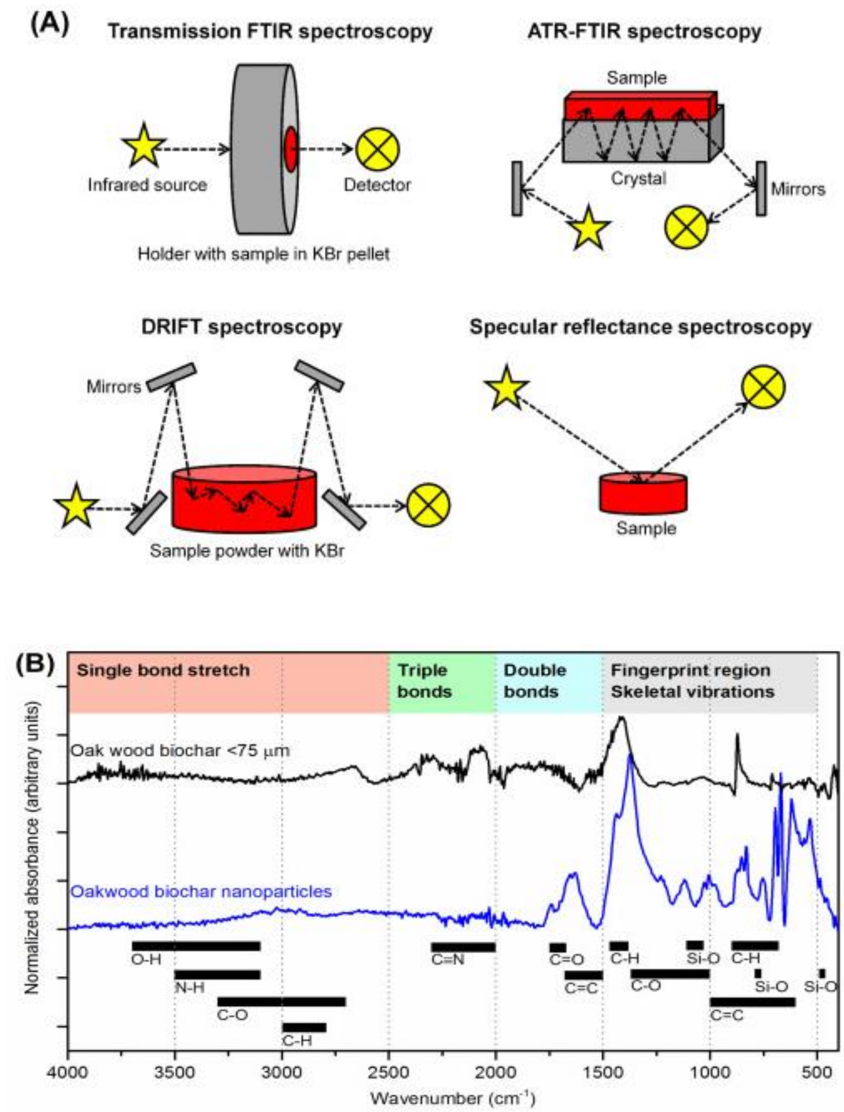


Figure 3.9: (A) different techniques of FTIR. (B) FTIR spectra example

In a typical FTIR, specimen is kept between the source of infrared beam and detector. Tablet form of the sample is prepared by mixing it with KBr. Quantative analysis of the materials like liquid and gas can be done with transmission type of FTIR. Surface properties can also be mapped if combined with micro FTIR.

In diffuse reflection technology, the KBr is added to specimen and diffusion of the infrared beam occurs as it makes contact with specimen. The mirror sends the scattered signal to a detector. Very less specimen quantity preparation is required, which can also be used to obtain various data such as qualitative and quantitative for powders.

Specular reflectance method takes into account the reflected light from the sample surface and allows investigation to be made about the sample's absorbance. Method is used to reveal variety of surfaces. This method can be used in combination with microprobes.

In Attenuated total reflection (ATR), infrared light is reflected back from highly refractive and optically dense crystals. A wave thus formed travels partially outside the crystal, while partial absorption is possible when sample is in contact with the crystal, attenuating that wave. Variety of powders and liquids can be studied by this way.

In particular, the latter two methods, specular reflection and ATR, gives excellent results for dry and wet powder samples which requires very minimal sample preparation.

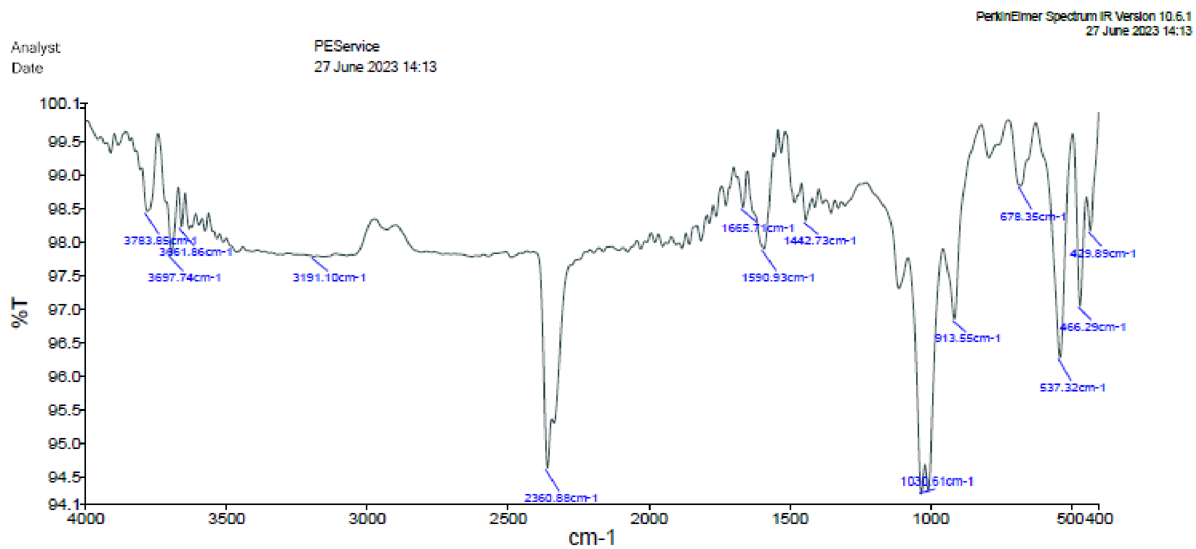


Figure 3.10. FTIR graph of metakaolin geo-polymer concrete

3.6.7 Scanning electron microscopy (SEM) Analysis

Scanning electron microscopy (SEM) generates image of specimen. It is non destructive method in a way that there is no loss in volume of sample. High resolution images are developed which helps in better understanding of material structure and organisation. Solid samples can be tested for SEM. The physical size of sample particles can be found.

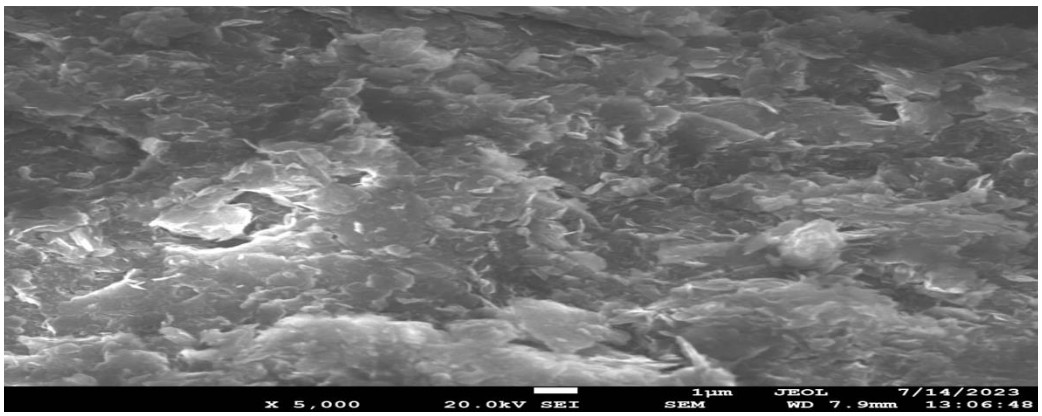


Figure 3.11: SEM Image Of Meta-Kaolin Geo-Polymer Concrete

CHAPTER 4: RESULTS

Table 4.1 : Workability of meta-kaolin based geo-polymer concrete

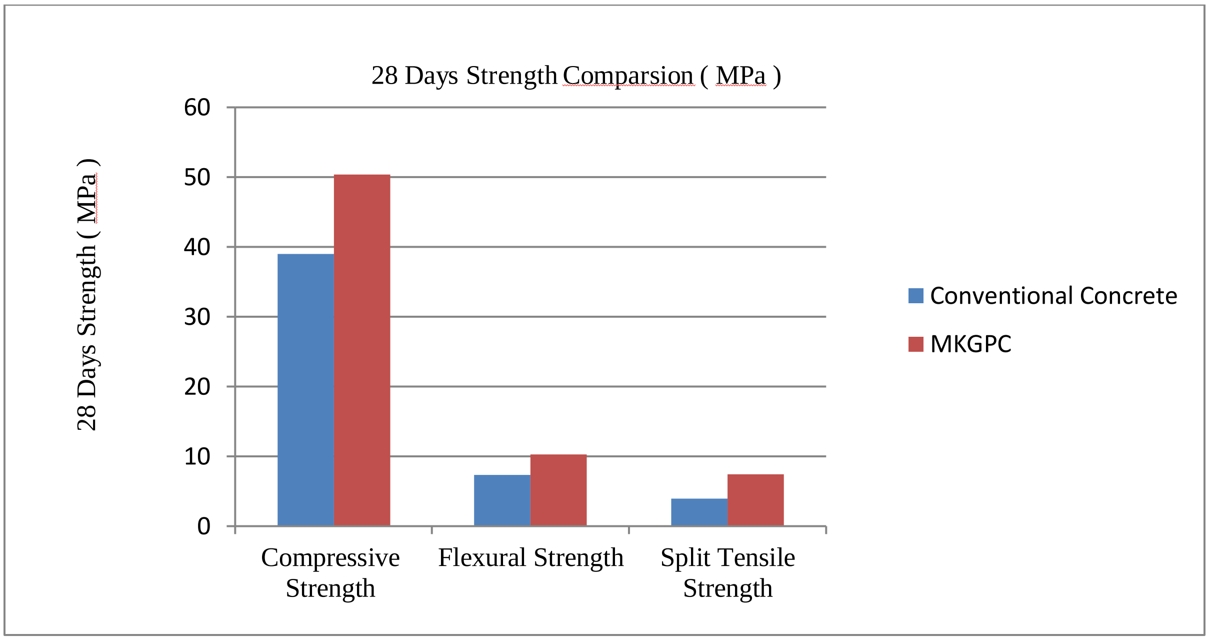
Molarity of AAS	Sodium silicate : sodium hydroxide	Flowing diameter (mm)
10 M	1:1	35
	1.5:1	33.33
	2:1	29.3
	2.5:1	26.8
12 M	1:1	29
	1.5:1	29
	2:1	28
	2.5:1	27
14 M	1:1	27
	1.5:1	27
	2:1	25
	2.5:1	25
16 M	1 :1	24.8
	1.5:1	23.6
	2:1	23
	2.5:1	23

The table shows the relationship between molarity of AAS and flow diameter for different ratios. The molarity is increased from 10M to 16M, flow diameter is found to be reduced. Also,the flow diameter reduces with increase in mixing ratio of alkali solution. The high molarity and high mixing ratio of AAS, shows significant loss in workability of meta-kaolin GPC. The flow diameter of GPC is inversely dependent on the sodium hydroxide molarity as well on the mix ratio of sodium silicate solution and sodium hydroxide solution in AAS.

Table 4.2 : Table of observation for M30 Meta-kaolin GPC compressive strength

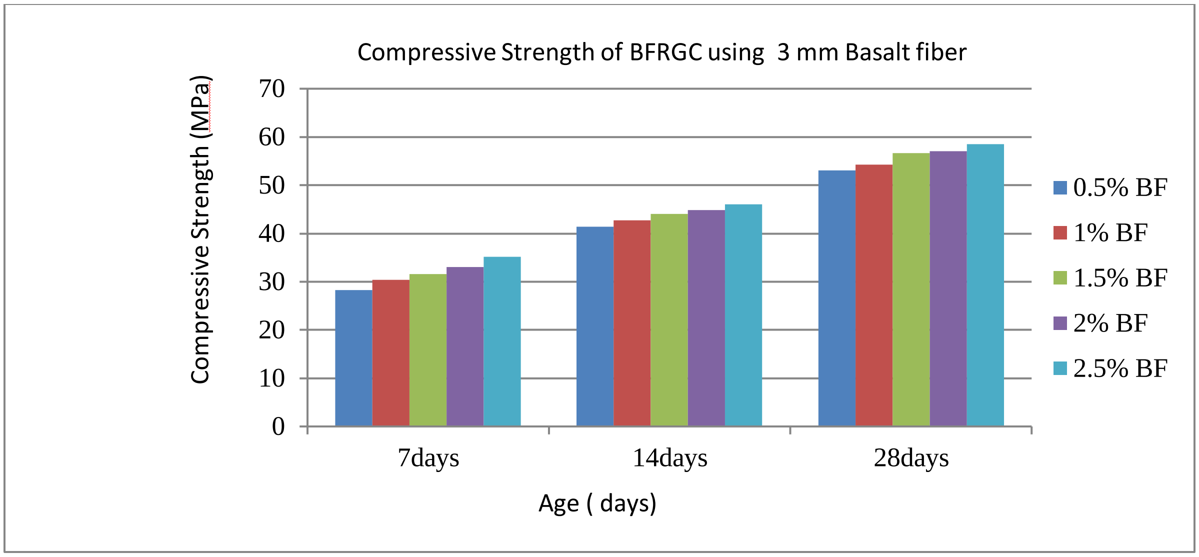
Molarity	Sodium silicate : sodium hydroxide	7 days	14 days	28 days	90 days
10 M	1.0:1	21.2	33.7	45.8	47
	1.5:1	21.6	34.2	46.1	48.2
	2.0:1	22.4	34.8	46.7	48.9
	2.5:1	23.1	35.3	48	50.3
12 M	1.0:1	21.9	34.9	45.4	46.9
	1.5:1	22.3	35.7	47.1	49.2
	2.0:1	22.8	38.1	48.8	50.1
	2.5:1	23.5	38.8	49.2	51.6
14 M	1.0:1	22.7	35.5	46.2	49.3
	1.5:1	23.4	37.1	48.1	50.8
	2.0:1	23.9	39.4	49.3	51.2
	2.5:1	24.1	39.9	50.4	52.5
16 M	1.0:1	21.4	32.1	39.3	40
	1.5:1	21.7	32.6	39.8	40.2
	2.0:1	22.3	33.4	40.2	41.9
	2.5:1	23.5	33.7	40.7	42.3

A rising trend in compressive strength was recorded for increase in molarity of NaOH solution upto 14M after which the strength was decreased. Similar trend was also observed with rise in the mixing ratio of AAS. It showed no further increment in the strength of concrete.



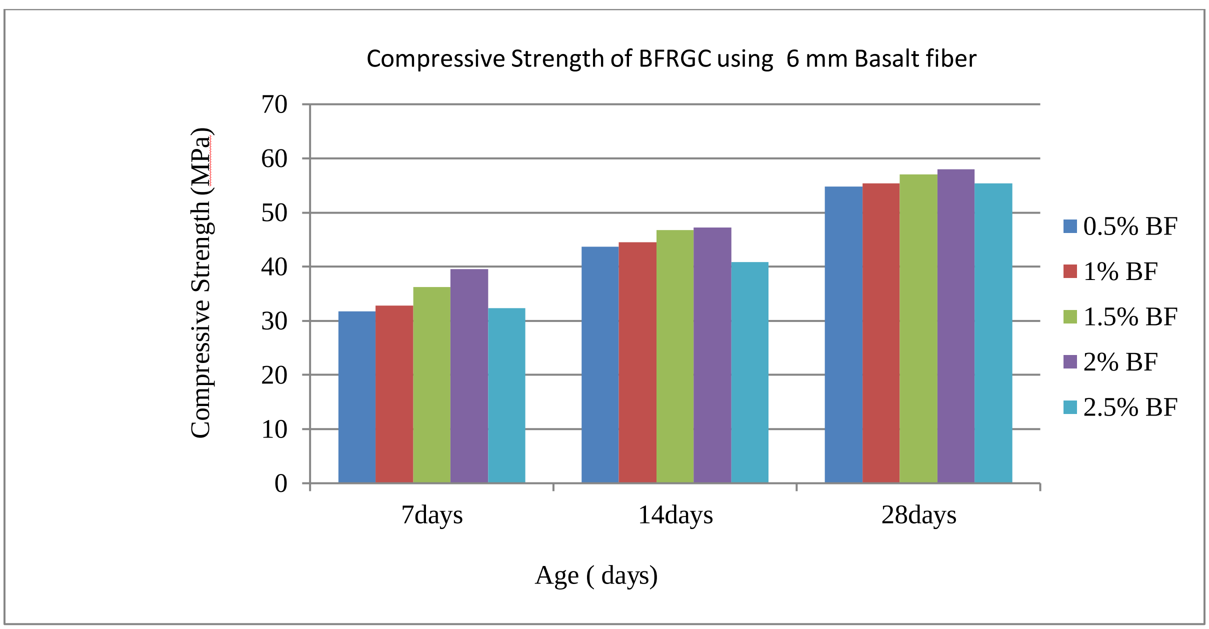
Graph 4.1. Comparison of 28 days strength of Metakaolin geopolymer concrete with Conventional concrete

Compressive strength of Metakaolin geopolymer concrete was higher than cement concrete by 77.4 %. Split tensile strength and Flexure strength of Metakaolin geopolymer concrete was higher than cement concrete by 76.22 % and 54.23% .



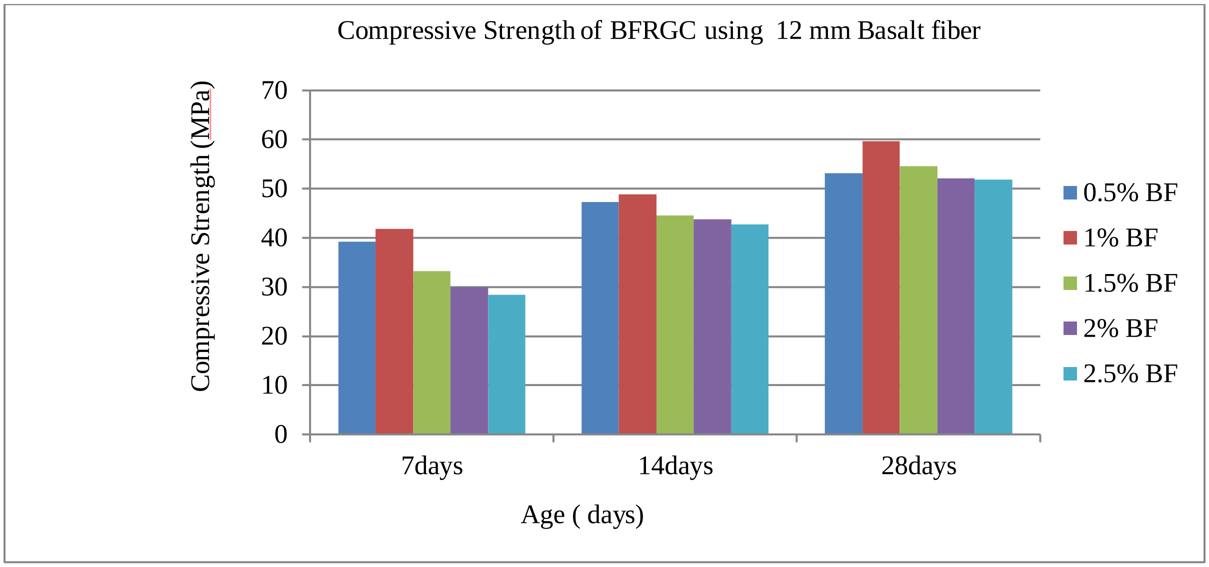
Graph 4.2. Compressive strength of BFRGC using 3 mm Basalt fiber length

The strength of concrete was discovered to be increased with increase in basalt fiber addition of length 3mm. 2.5% fiber volume addition provided excellent results.



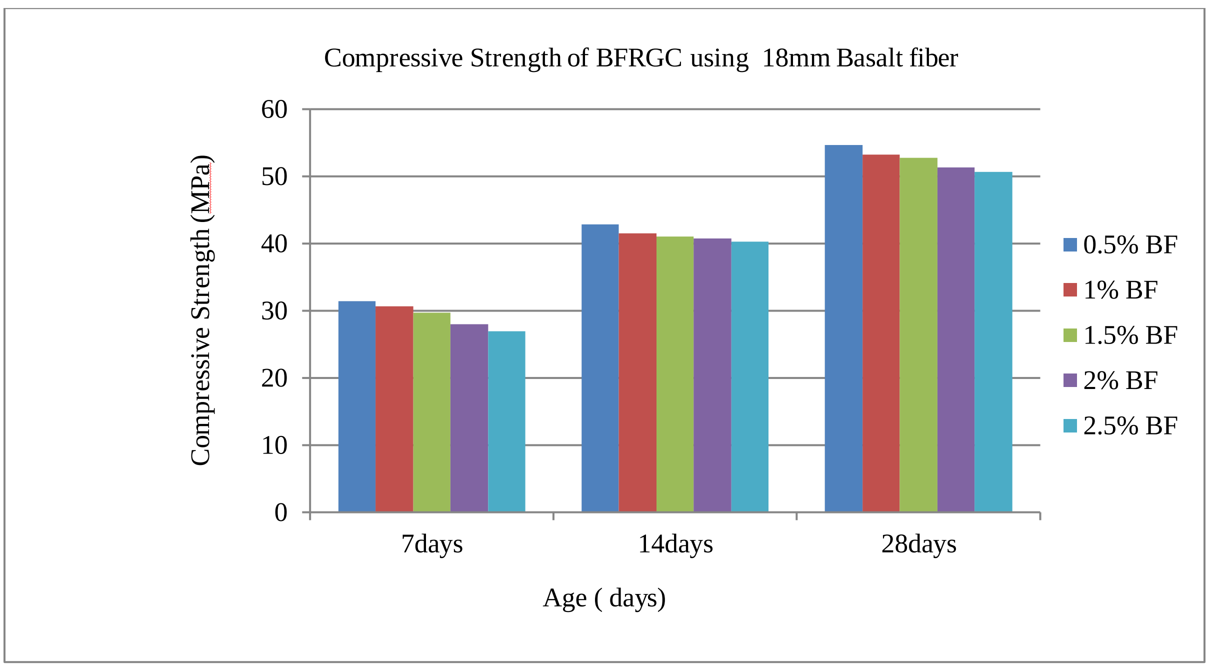
Graph 4. 3. Compressive strength of BFRGC using 6 mm Basalt fiber length

2% of 6 mm fiber length addition in metakaolin geopolymer concrete, the maximum strength was achieved. The compressive strength increased upto 2% , after which further addition of fiber resulted in strength decrement.



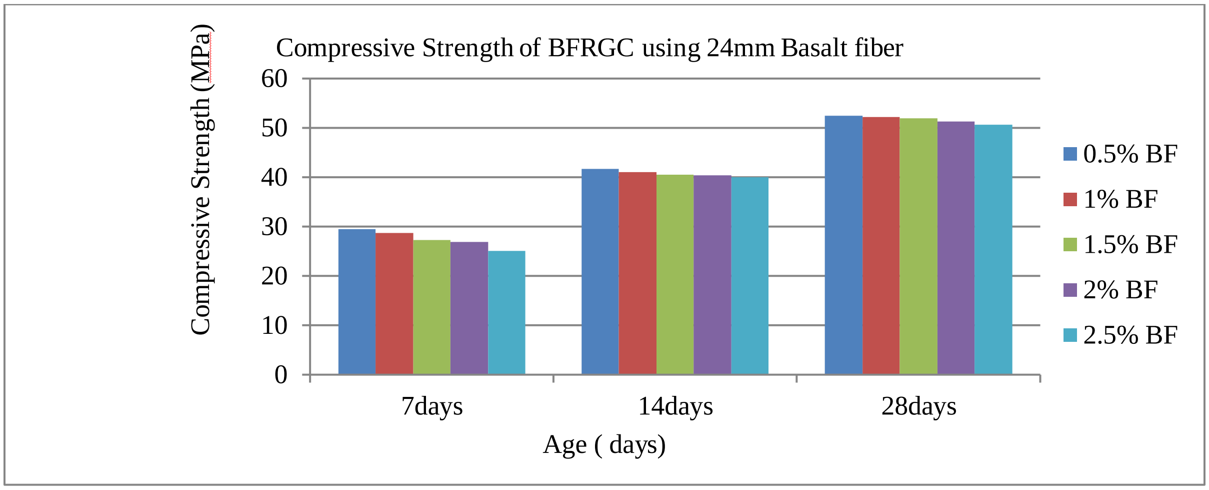
Graph 4.4. Compressive strength of BFRGC using 12 mm Basalt fiber length

The compressive strength was found maximum at 1% fiber inclusion in meta-kaolin geo-polymer . The compressive strength increased upto 1% , after which further addition of basalt fiber does not significantly increased strength.



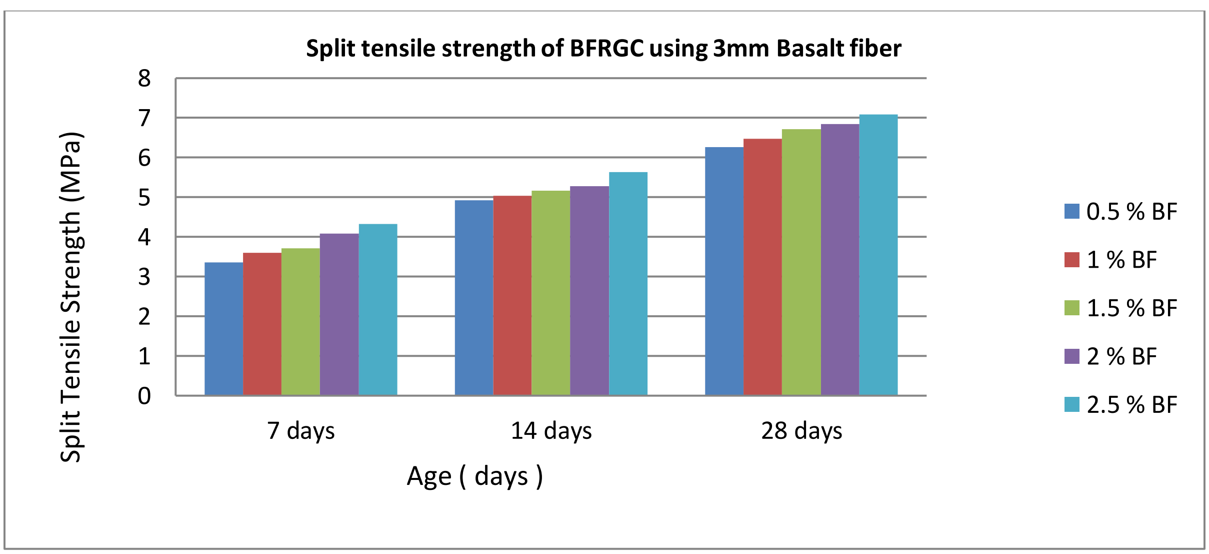
Graph 4.5. Compressive strength of BFRGC using 18mm Basalt fiber length

For 18 mm basalt fiber addition in meta-kaolin geo-polymer concrete,0.5% addition of fiber provided maximum compressive, after which further addition of fiber resulted in decrease of strength.



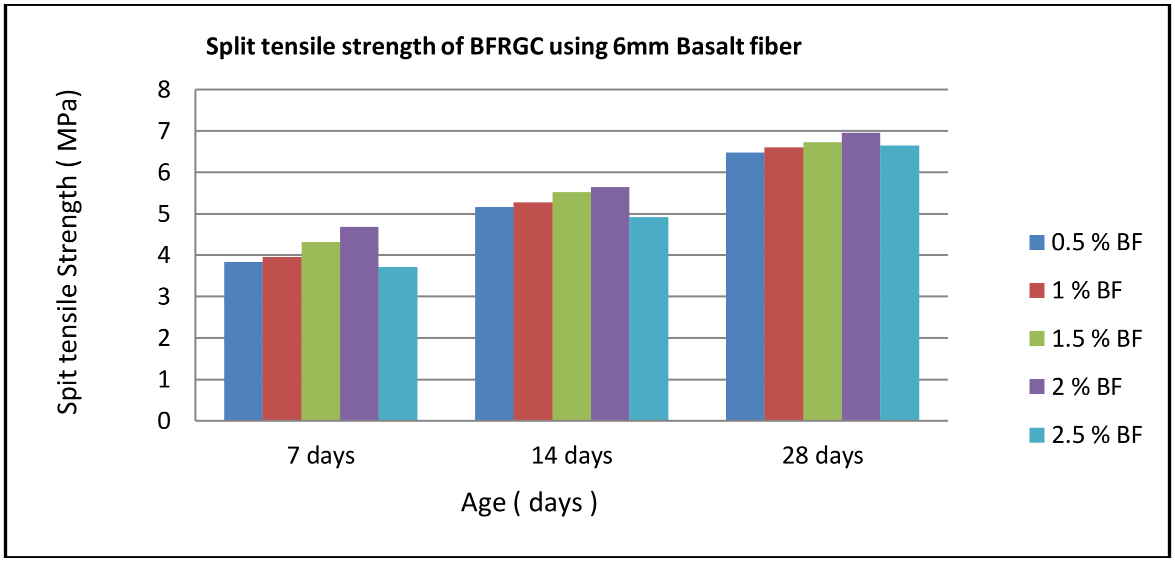
Graph 4.6. Compressive strength of BFRGC using 24 mm Basalt fiber length

For 24 mm basalt fiber addition in meta-kaolin geo-polymer concrete, the compression strength recorded was more than that of cement concrete. But dosage of Basalt fiber addition should be kept less than 0.5%.



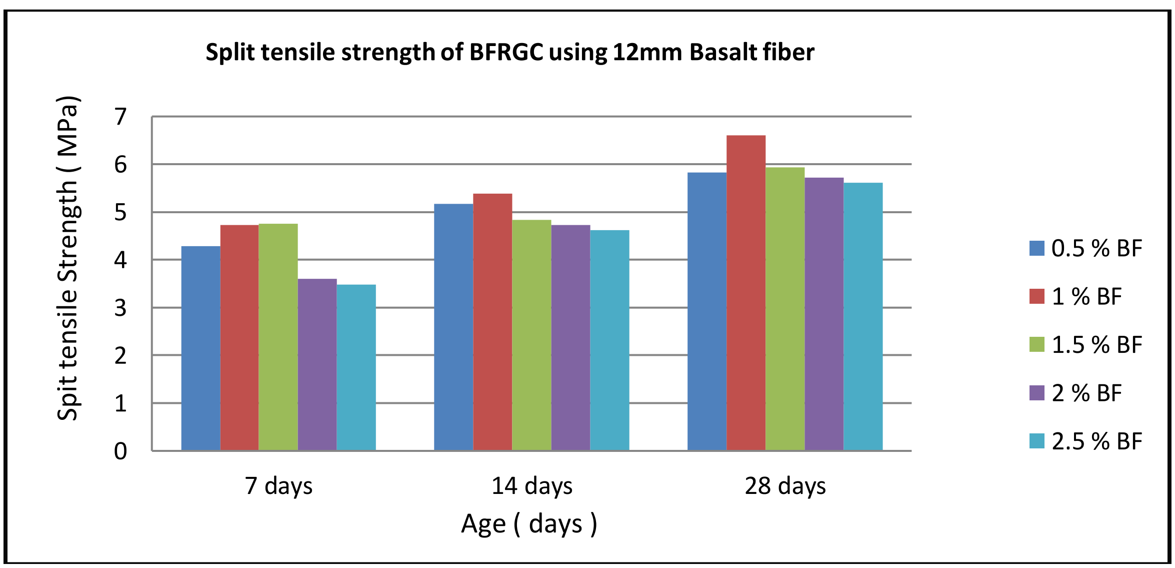
Graph 4.7. Split tensile strength of BFRGC using 3 mm Basalt fiber length

The split tensile strength was found to increase maximum upto 2.5% basalt fiber inclusion in geo-polymer concrete if fiber length was kept 3mm.



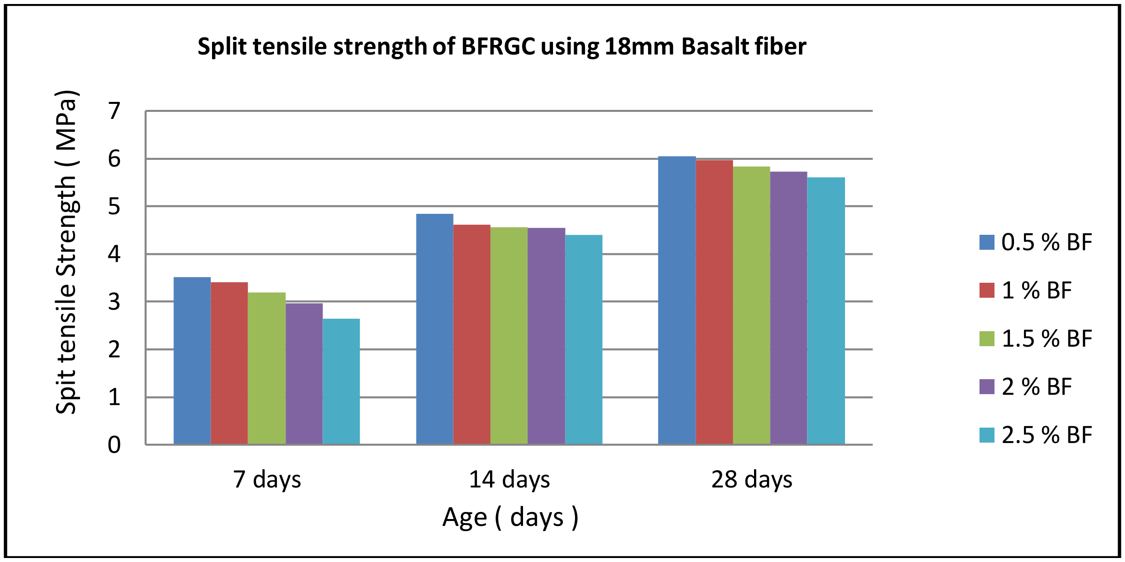
Graph 4.8. Split tensile strength of BFRGC using 6 mm Basalt fiber length

When 6mm basalt fiber in length was added in geo-polymer concrete, split tensile strength increased upto 2% increment in basalt fiber afterwards decrease in trend was noticed.



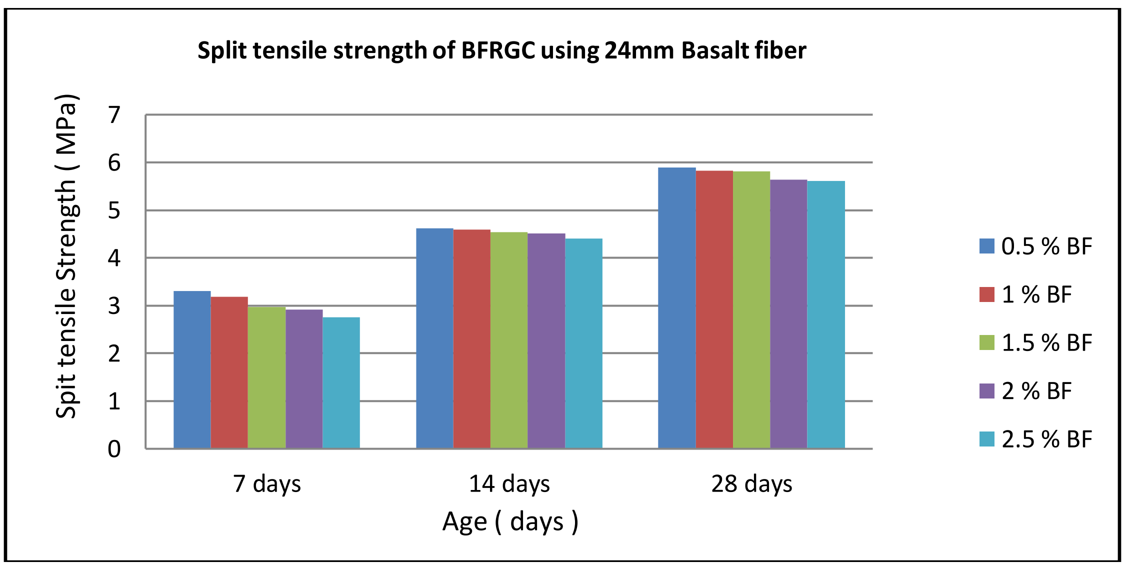
Graph 4.9. Split tensile strength of BFRGC using 12 mm Basalt fiber length

For 12mm length of basalt fiber , the maximum split tensile strength was recorded at 1% addition of basalt fiber in geo-polymer concrete, after which strength decreased.



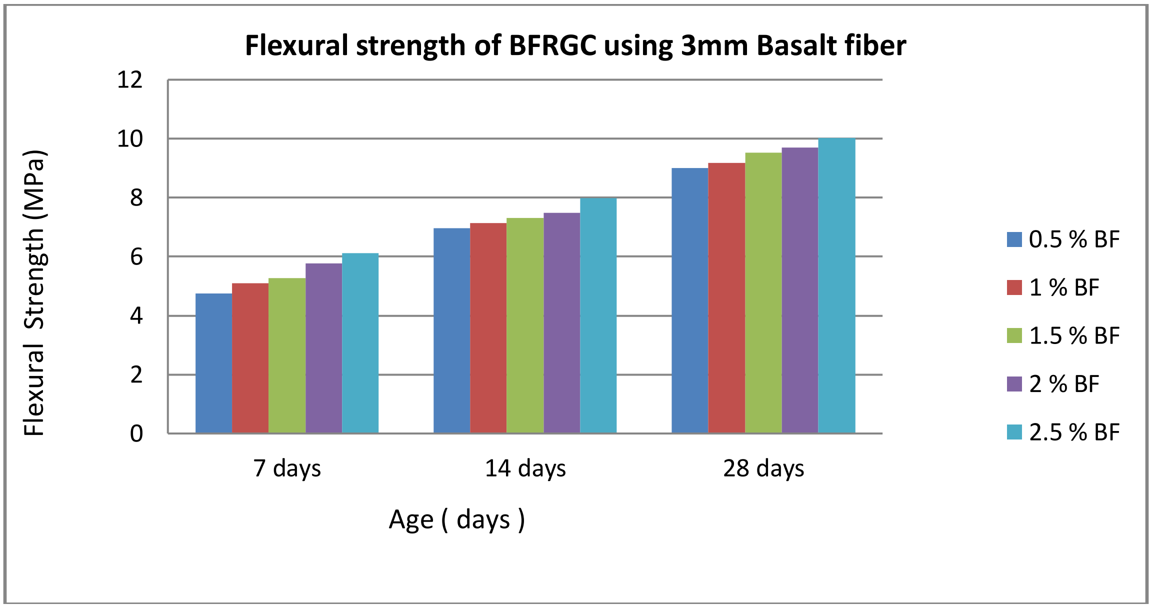
Graph 4.10. Split tensile strength of BFRGC using 18 mm Basalt fiber length

0.5% addition of 18mm length of basalt fiber produced the highest split tensile strength which decreased with the increase in volume addition of basalt fiber.



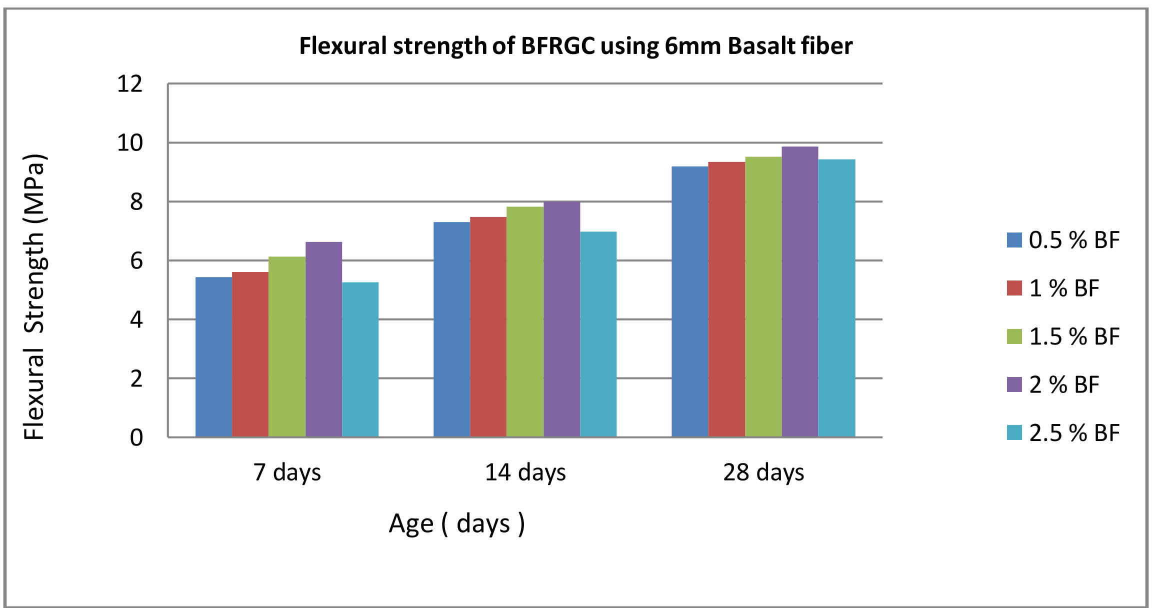
Graph 4.11. Split tensile strength of BFRGC using 24 mm Basalt fiber length

When 24mm length of basalt fiber was added in geo-polymer concrete, the split tensile strength was greater than the cement concrete if the dosage of fiber addition is kept less than 0.5%.



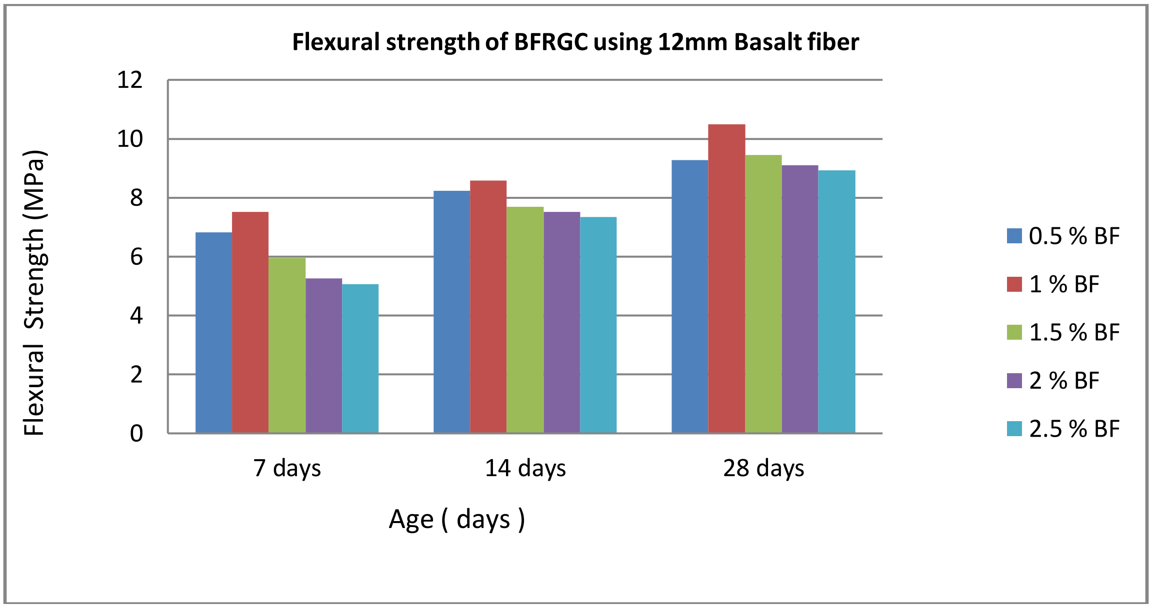
Graph 4.12. Flexural strength of BFRGC using 3 mm Basalt fiber length

Using 3mm basalt fiber length in geo-polymer concrete provided great results , the flexural strength increased with the increase in percentage addition of fiber upto 2.5%.



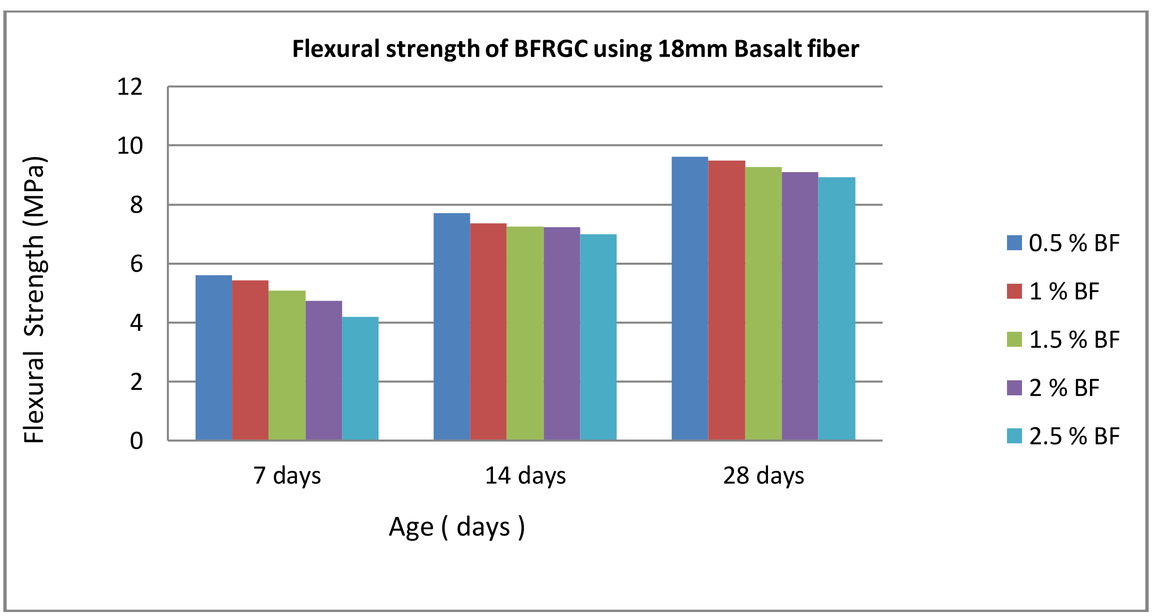
Graph 4.13. Flexural strength of BFRGC using 6 mm Basalt fiber length

The geo-polymer concrete was included with basalt fibers of 6mm in length, satisfactory results were obtained at 2% fiber addition for flexure strength test.



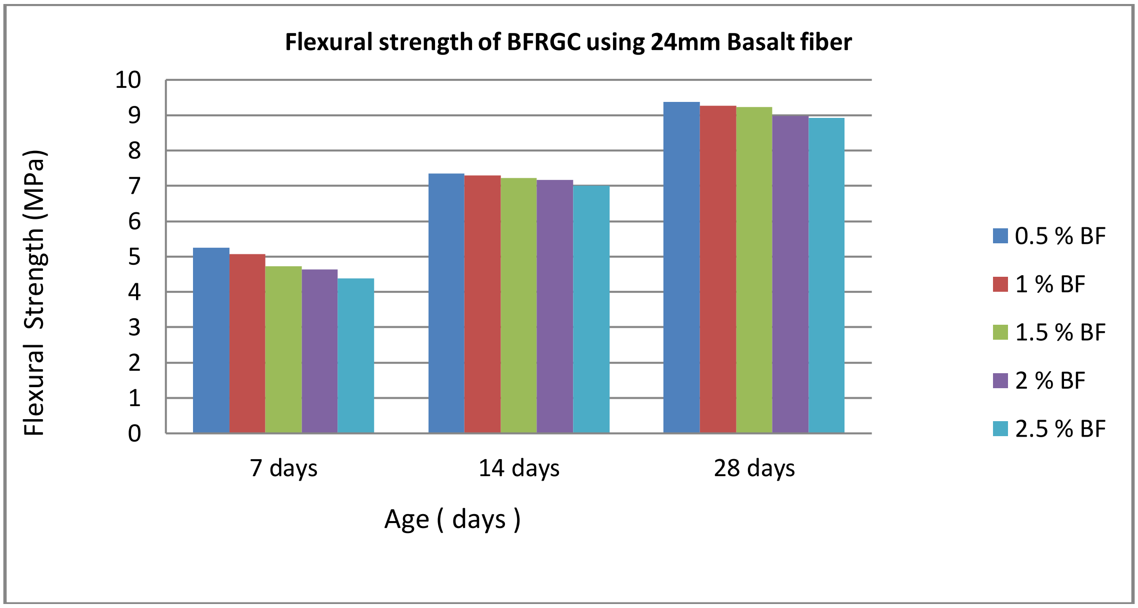
Graph 4.14. Flexural strength of BFRGC using 12 mm Basalt fiber length

The increment in flexural strength was seen at 1% basalt fiber addition of 12mm in length, which further showed decrease in strength with the increase in basalt fiber concentration.



Graph 4.15. Flexural strength of BFRGC using 18 mm Basalt fiber length

0.5% addition of 18mm basalt fiber length in geo-polymer concrete produced maximum flexural strength, which was decreased further with increase in fiber content.



Graph 4.16. Flexural strength of BFRGC using 24 mm Basalt fiber length

Using 24mm basalt fiber length in geo-polymer concrete provided flexural strength greater than the cement concrete, as the concentration of basalt fiber increased, strength reduction was noticed, hence the optimum percentage of basalt fiber addition should be less than 0.5% .

CHAPTER 5: CONCLUSION

Geo-polymer concrete can be effectively replaced with cement in concrete. Basalt fibers can be incorporated to produce high strength geo-polymer concrete. The research work describes the importance of meta-kaolin in geo-polymer and the effect of fiber length in geo-polymer concrete. It was concluded from the research work that embodiment of meta-kaolin and short length fibers increased the strength of concrete significantly.

Workability of meta-kaolin geopolymer concrete is affected by the molarity of alkali activated solution. Increase in molarity decreases the workability.Addition of fibers also have effect on workability on geo-polymer concrete.

High compressive strength can be obtained by increasing the molarity of alkali activated solution upto 14 molar, after which the compressive strength has found to be decreased. The geo-polymer concrete workability was modified by addition of fibers. Addition of high volume of fiber can cause the clumping of fiber, which results in low strength.

Optimum basalt fiber length of 12mm at 1% fiber incorporation in meta-kaolin geo-polymer concrete demonstrated high strength. The dosage of basalt fiber addition was found to be decreased with the increased basalt fiber length. The mixing ratio of 2.5 of alkali activated solution provided satisfying results.

The reduction in pore size of the concrete improved the strength. The XRD analysis showed the amorphous nature of concrete. The microstructure of the concrete was studied through SEM images, showing dense structure of the concrete with very less large pores. Micro-cracks were present in the structure which prevented rupture of concrete under stress.

The investigated properties test results were helpful in developing a better understanding of metakaolin based geopolymer concrete. The mechanical properties were found to be increased with the addition of basalt fibers and also the early shrinkage cracks decreases with addition of basalt fiber volume fraction. Basalt fibers when used in concrete can act as crack arrestors. The increase in all mechanical properties of geopolymer concrete with the addition of basalt fiber were also confirmed with the results of work previously done by authors [81, 82 ,83,84].

Future Scope

The future work should include the effect of meta-kaolin and basalt fiber on different aspects like durability strength, shrinkage, effect of freeze thaw cycles and longetivity of the concrete. New methods of production should be developed to achieve more properties and reduction in the cost. Cost analysis should be done. More studies should be conducted which will help in improving performance of concrete. Mix proportions of higher ratios could be developed. Basalt fibers in different forms such as sheets can be added into the concrete and further investigated. High grade metakaolin based geopolymer concrete can be developed and studied.

Upto a certain extent basalt fibers can be added to achieve great strength. Increase in fiber length decreased the strength. XRD, SEM, EDS and FTIR provided a better understanding of composition and structure of concrete.

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LIST OF PUBLICATIONS

S.No	Title of the paper with author names	Name of Journal / Conferences	Published date	Issue No/ Volume No	Indexing
1	A critical review on basalt fibre geo-polymer concrete Rashmi Pantawane and Dr. Pushpendra Kumar Sharma	Journal of Physics, Conference Paper in RAFAS	3/6/2022	2267(1)	Scopus
2	Evaluation of Mechanical Properties of Metakaolin Geo-Polymer Concrete Rashmi Pantawane and Dr. Pushpendra Kumar Sharma	Lecture Notes in Civil Engineering ,Conference Paper	9/11/2022	281, pp 273-278	Scopus
3	Basalt Fiber Reinforced Geo-polymer Concrete Rashmi	Africal Journal of Biological Sciences	6/5/2024	vol 6,issue 5	Scopus

	Pantawane and Dr. Pushpendra Kumar Sharma				
4	Conventional concrete reinforced with basalt fiber Rashmi Pantawane and Dr. Pushpendra Kumar Sharma	American Institute of Managemen t and Technology	2022	vol2,no 1	UGC
5	Effect of Concentration of Sodium hydroxide solution on Geo-polymer Concrete Rashmi Pantawane and Dr. Pushpendra Kumar Sharma	Journal of Systems Engineering and Electronics	2024	vol 34, issue 5	Scopus

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Evaluation of Mechanical properties of Meta-kaolin Geo-polymer Concrete

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Abstract. In this present work, the mechanical properties of metakaolin based geopolymer concrete is worked out. It has been found out that geopolymer concrete gives high early strength to the concrete. It has high strength, heat resistance and better performance than the ordinary Portland concrete. The compressive strength and tensile strength achieved by geopolymer concrete is improved, whereas the flexural strength is satisfactory. This study proves metakaolin as an effective replacement of cement, and will also promote sustainable material in the construction industry.

Key Words: Meta-kaolin, geo-polymer, concrete, mechanical properties.

1. Introduction

Geo-polymer concrete is the new age concrete, it is heavily accepted worldwide due to its sustainability and eco-friendly properties. It has reduced carbon emission content. It includes very less cement content or it has no cement in its manufacturing process. It has its properties very familiar to the traditional concrete and perform better than the traditional one.

The extensive industrialization happening in this century is having great demand to utilize its by- products or waste products which are dumped, causing hazardous distress to the surrounding environment leading to the causes such as ozone layer depletion, climate change, global warming etc. The waste products used in the manufacturing of geo-polymer are fly ash, rice husk ash, blast furnace slag which are pozzolanic in nature and can be replaced with cement.

Geo-polymer concrete is basically the mixture of its source materials like pozzolanic material which are rich in silica and aluminia, aggregates, and activating them with the alkaline solutions such as sodium silicates or potassium silicates and sodium hydroxide or potassium hydroxide in proper proportions. The reaction leads to the process of polymerization, formation of Si-O-Al bonds which is crucial for the achievement of strength.

The significance of using geo-polymer is to reduce the rapid destruction of lime stone mines and carbon footprint. To introduce a material which is creating less nuisance and can be regularly used in bulk quantity. As there is no proper design or code practice for the geo-polymer, it is hence required to find out its mechanical properties.

The mechanical properties are very important for using any construction material, as the strength provides an idea about the performance of the material. The most important test to determine the mechanical property is the compressive strength. The compressive strength determination process is the same as conventional concrete but there is a difference in the curing process to the geo-polymeric concrete. It requires ambient curing or oven curing. Depending upon the availability , any of the mentioned method of curing can be adopted.

The concentration of alkali activated solution influences the compressive strength of geo-polymer concrete [3]. Increasing the concentration of sodium hydroxide improves the compressive strength [3]. Usage of metakaolin has been found to have high achievement in mechanical properties of geopolymer [4]. High performance, high strength, high grade and lightweight concrete is achieved by using metakaolin in geopolymer [4].

Table 1. Physical properties of metakaolin

Property	Value
Specific gravity	2.60
Bulk Density (g/cm3)	0.3 to 0.4
Physical form	Powder
Colour	Off-White
GE Brightness	79–82
D10	< 2.0 µm
D50	< 4.5 µm

Table 2. Chemical composition of metakaolin

Types	% by mass
SiO2	51.52
Al2O3	40.18
Fe2O3	1.23
CaO	2.0
MgO	0.12
K2O	0.53
SO3	0.0
TiO2	2.27
Na2O	0.08
L.O.I	2.01

2. Specimen Preparation

Alkaline solution is prepared by dissolving the sodium hydroxide pellets in the water to make one litre solution of the required molarity. The ratio of sodium silicate and sodium hydroxide solution is taken as 2.5. This prepared solution is stored at room temperature for about 24hours before mixing it with other source materials to prevent exothermic reaction.

In this experimental work, the source material used to make geo-polymer was meta kaolin clay as binder. Geo-polymer contains 75% to 80% combined aggregates as per mass. The activators used in the study were sodium silicate and sodium hydroxide as they are cheaper than the potassium based activators. The molarity of the sodium hydroxide solution prepared was kept in the range of 18.

Meta kaolin clay and aggregates were first mixed together thoroughly and then the prepared alkali activated solution was added and mixed for about four minutes. Flow test, initial setting time and final setting time tests were performed. The prepared fresh geo polymer was then casted into moulds for testing strengths. The specimens were compacted three times by tamping rod after placing each layer and vibrated using vibrating table.

Specimens prepared were then placed in the oven for 24 hours at 60°C. After providing initial heat curing to the specimens, they were kept in open air till the day of testing. In this experimental work both the methods of curing, heat and ambient were used. An UTM machine was used to test the compressive strength and tensile strength of the specimens prepared.

Table 3. Mix Design of Metakaolin based geopolymer concrete

Constituents	Weight (Kg/ m³)
Meta kaolin clay	405
Coarse aggregates	1268.66
Fine aggregates	683.13
Sodium silicate	95
Sodium hydroxide	47
Water	108.35

The mechanical strengths were calculated according to Indian standards. Direct compressive load was applied to the specimens of size 150mm*150mm*150mm. The load at which the specimen shows surface crack was noted down and average of three specimen were recorded. Tensile strength was taken by placing the cylindrical specimen of size 150mm diameter and 300mm long in a manner that longitudinal axis is perpendicular to the load. The maximum applied load indicated by testing machine at failure is recorded.

3. Observations

Table 4. Compressive strength

Days	Strength (MPa)
7	42.7
14	43.6
28	46.7
90	51.4
120	50.6

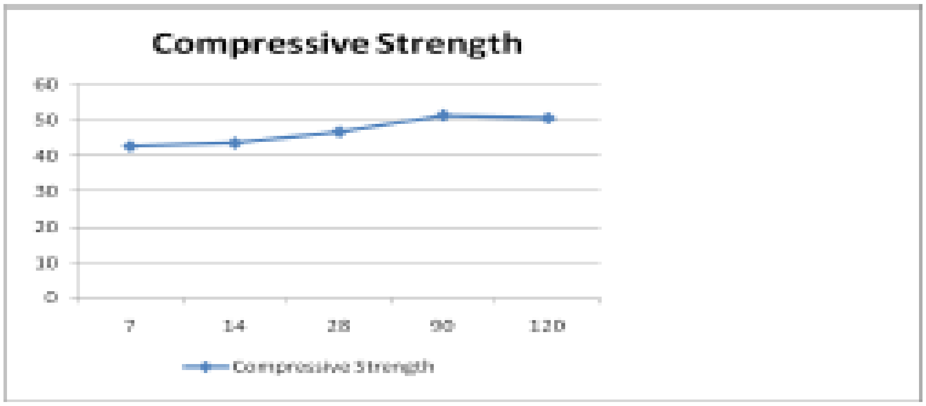

Figure 1. Compressive Strength (MPa) of Geopolymer concrete

Table 5. Split tensile strength

Days	Strength (MPa)
7	25.3
14	26.2
28	27.4
90	30
120	29.5

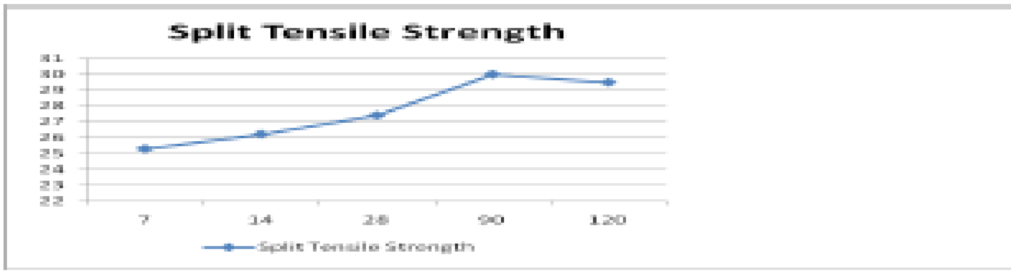

Figure 2. Tensile Strength of Geopolymer Concrete

Table 6. Flexural strength

Days	Strength (MPa)
7	9.4
14	9.5
28	10.3
90	11.3
120	11.2

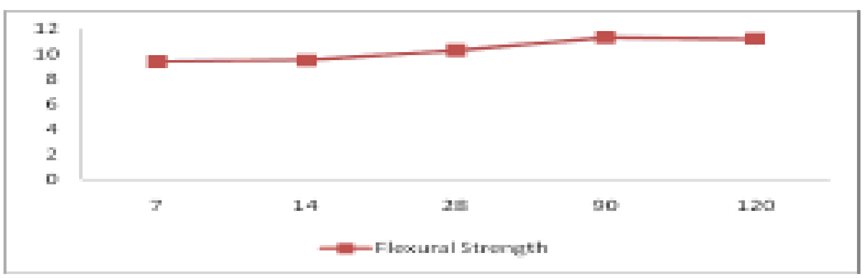

Figure 3. Flexural strength of Geopolymer concrete

4. Conclusions

From the experimental work done, it can be concluded that meta kaolin geo-polymer concrete provides high early strength, it can be due to the heat curing provided at the early stage. The early strength achieved at 7 days is nearly close to the strength achieved at 28 days. There is 83% strength achieved at 7 days. The maximum strength achieved by geo-polymer is at 90 days, after which it decreases drastically. Geo-polymer concrete can be used where high early strength is required such as in retaining walls , pavements , precast construction.

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Rashmi Pantawane / Afr.J.Bio.Sc. 6(5) (2024). 3762-3777 ISSN: 2663-2187

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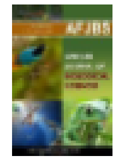

Basalt Fiber Reinforced Geo-polymer Concrete (BFRGC)

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ABSTRACT: An experimental study was carried out to develop a metakaolin-based geopolymer concrete. Meta-kaolin clay was used as the source material in the study. The alkali activator solution was prepared with sodium-based compounds such as sodium silicate and sodium hydroxide solution. The molarity of sodium hydroxide solution was taken as 10,12,14 and 16M. The ratio of Sodium silicate to sodium hydroxide solution was kept as1,1.5,2 and 2.5. The optimum results of compressive strength for M30 geopolymer concrete were found at 14 Molar sodium hydroxide solution for the ratio of 2.5:1 of alkali-activated solution. This mix was used for further investigation in which the basalt fibers were added as a percentage replacement of meta-kaolin.

INTRODUCTION:

Production of cement-based products pollutes the environmental habitat in several ways, some of them may be listed as the release of emissions such as CO2 into the atmosphere resulting in the depletion of the ozone layer, giving rise to global issues such as pollution (air and water), decrease in the quantity of natural resources such as lime deposits [1]. Geopolymer concrete is a sustainable material when compared with cement compounds[2]. Its production requires very less usage or no usage of cement, resulting in environmental protection as energy is conserved which is almost half the energy required for conventional concrete [3]and it also provides mechanical properties which are relatively higher than that of conventional concrete[4].

Natural source materials such as metakaolin which is high in aluminia and silica content or industrial by-products such as fly ash, GGBS are reacted with alkali activators which are generally sodium and potassium compounds (silicates and hydroxides), to produce geopolymer concrete[5,6]. Most of the studies done by researchers in the past have used different alternatives in geopolymer production such as fly ash [7,8,9], rice husk ash [12,13], GGBS, or kaolin [14,15].

Metakaolin-based geopolymer studies are limited, most of them are on to study the method of geopolymerization [16,19], the effect of methods of curing on strength [20,23], and the effect of temperature. Researchers studied various parameters related to metakaolin-based geplymer, some of which are noted below. Pires et al. used different source materials to prepare MK-based geopolymer and studied its fracture properties. Mohseni studied the effect of the alkaline solution ratio on the properties of GPC. Alanazi et al. studied the effect of freeze and thaw cycles on GPC. Xie et al. used recycled aggregates and varied proportions of slag and MK to study characteristics such as strength, toughness and Poisson's ratio. Pouhet and Cyr studied the effect of alkaline solution molar ratio on workability, strength, porosity and density.

By observing the above studies,it is understood that a study on MK-based GPC needs to be undertaken, as the literature is limited. The effect of various parameters needs to be studied. An attempt has been made in this study to understand the effect of mixed design parameters on GPC. Sixteen mix designs were prepared and cast to investigate the effect of the molarity of sodium hydroxide solution, and sodium silicate to sodium hydroxide ratio on workability, setting time and compressive strength at various ages. OPC mixes were also cast for comparison purposes. Basalt fibers were added in GPC to study mechanical properties. X-ray diffraction (XRD), scanning electron microscopy (SEM), and energy-dispersive X-ray spectroscopy (EDS) analysis were undertaken to study the microstructure of GPC on identified mixes.

2. Literature review

Geopolymer concrete (GPC) has emerged as a viable alternative to regular Portland cement (OPC) by the sustainable attention it deserves. GPC utilizes processed tailings rich in silica plus alumina or natural aluminosilicate as a replacement for OPC as the binder. By using this process, CO2 gas emissions that are usually tied to OPC production are reduced, making GPC more climate-friendly. One of the main producers that the geopolymer industry uses is Metakaolin which is made by calcining purified kaolin clay at 650-850°C. It is characterized by high reactivity [4].

Metakaolin is the main component of the geopolymerization process which produces an alkaline solution with rapid polymerization that creates a hardening matrix [5]. In the past, the effect of several parameters of metakaolin-based GPC has been researched in depth to evaluate its end properties. A curing regime – ambient curing, oven curing, or steam curing – would result in a much greater compressive strength. Curing in the oven and the steam autoclave shows improvement in strength by up to 2.5 times than the ambient curing condition [6]. The greater the molarity of the alkaline activator solution of NaOH results in faster setting and heating but it reduces the amount of workable time. The compressive strength of the corrosion data is linear up to 16 M NaOH [7]. The presence of sodium silicate acts as a retarder and improves the workability of concrete, also delaying the setting time, yet it might weaken the strength at higher ratios (>2.5-9\". Whereas researchers have managed to combine basalt fibers and plastic aggregates as reinforcements to improve mechanical properties [9, 10].

Experimental pieces of evidence about alkali-activated blast furnace slag cement have shown that milling the minerals before geopolymerization leads to the enhancement of the reaction intensity [11, 12]. The majority of work carried out on mechanical activation has commonly focused on fly ash-based geopolymers. Yet, we have not noticed much literature on mechanically operated MK GPC which focuses on how milling affects the geopolymer properties. According to Yao et al. [13], metakaolin was ball milled for 5-60 min then activated for 60 min and it was optimally effective for durability. The other important research would focus on the optimization of milling parameters (length, speed) too. Besides, a lot of researchers have employed SEM, EDX, XRD and NMR analyses to determine the microstructural modification of the metakaolin system [14, 15]. However, the influence of microstructural modification on the mechanical activation process is still poorly understood.

In addition, gainings should be made between MK-based GPC and OPC in terms of all fresh, hardened and durable properties using a standardized curing regime. Over the years many studies of the metakaolin geopolymer have shown that with heat curing they can match and even exceed OPC compressive strengths. [4, 16] However, not many studies are available on the action of the ambient temperature curing after which the infrastructure development-associated behavior is determined [3]. The absence of literature in this area requiring attention precludes the use of metakaolin GPC at the pilot scale. This review revealed that metakaolin has achieved its great promise in the field of geopolymer synthesis. What is more, valuable research may be needed to show how microstructure development and properties are affected by treatments like mechanical activation and bench curing. This may help in bringing such practices into common use.

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3. Experimental Program

3.1 Materials

3.1.1 Source material

Locally available metakaolin (MK) was used in the study as source material which is an alumiosilcate precursor. The chemical composition of MK is in Table 1. Alkali activators used in the study comprised of sodium silicate and sodium hydroxide solution. Sodium silicate solution was lab certified gel based solution whereas sodium hydroxide solution was prepared by mixing 98% pure NaOH pellets in tap water to solve the required molarity.

3.1.2 Aggregates

Coarse aggregates of size 20mm and fine aggregates of size less than 4.25mm are used in the study. The physical properties are listed in Table 2.

3.2 Test Matrix

An investigation was made to study the parameters like the molarity of prepared alkali-activated solution, sodium silicate to sodium hydroxide ratio, and workability on GPC. A reference mix was selected from a series of trials and was combined with basalt fiber to provide high strength. The design variables of MK-based GPC are listed in Table 3.

3.3 Casting and curing

Ingredients such as MK, coarse aggregate, and dry aggregate were mixed separately for about 2-4 minutes. Liquid ingredients such as sodium silicate solution, sodium hydroxide solution, and water were added to the dry compounds and mixed properly till a homogeneous mixture was formed. The concrete mixture thus formed is molded into standard specimens and vibrated using a vibrating table. Samples are cured at room temperature (air temperature).

4. Results obtained from the study

Table 1 includes the details of the chemical composition of meta-kaolin (MK) that is added to concrete as a supplement. The three most important components are appended - fine aggregate, coarse aggregate, and meta-kaolin clay. For fine aggregate the specific gravity is 2.70, the fineness modulus is 3.48 and the water absorption percentage is 0.5%. The aggregate has a lower specific gravity of 2.59 and a higher water absorption of 1.0%. Therefore, the coarse aggregate is composed of more material and contains less water. The fine aggregate gradation does not include the coarse aggregate nozzle. Lastly, kaolinite clay is the clay with the lowest specific gravity, 2.5. The fineness modulus for this material is at 1.11 which means it has a very fine distribution of the particles. Unfortunately, no water absorption percentage is shown for the meta-kaolin clay modifier.

Table 1. Chemical composition of MK

Property	Fine Aggregate	Coarse Aggregate	Meta-kaolin clay
Specific gravity	2.70	2.59	2.5
Fineness modulus	3.48	---	1.11
Water absorption (%)	0.5	1.0	--

Table 2 exemplifies the mix design which is for alkaline concrete, and it shows the proportion of the components that are required to get 1 cubic meter of concrete. Among other data, the Specification lists the target value of the MK ratio as 0.4, the coarse aggregate content as 405kg/m3, the fine aggregate ratio as 0.35, the fine aggregate amount range from 1255kg/m3 to 1252kg/m3 depending on activator ratios, the sodium silicate amount range from 8 Consequently the sodium silicate to sodium hydroxide grows from 1.0 to 2.5, resulting in increased amounts of sodium silicate and decreased amount of sodium hydroxide. Another more minute and less essential particle characteristic of the aggregate content is decreasing along with the increase of the activator ratio. This suggests mixed design modifications to consider the fact that greater water is created by a greater sodium silicate inclusion. In the end, the table presents a complete mix of alkali-activated concrete with a weight of coarse aggregate ranging from 405 to 405 kg/m3 and that of fine aggregate varying from 675 to 675 kg/m3. A variable amount of alkaline activators ranges from 125 to 160 kg/m3 together with additional water

Table 2. Mix Design physical properties of M30 Meta-kaolin based Geo-polymer concrete

The solution to the MK ratio	MK (Kg/ m^3)	Fine to Total agg. ratio	CA Kg/ m^3	FA Kg/ m^3	Sodium silicate to sodium hydroxide ratio	Sodium silicate Kg/ m^3	Sodium Hydroxide Kg/ m^3	Extra water Kg/ m^3
0.4	405	0.35	1255	675.77	1	81	81	30.22
0.4	405	0.35	1254	675.24	1.5	97.2	64.8	31.72
0.4	405	0.35	1253.38	674.89	2	108	54	32.71
0.4	405	0.35	1252.91	674.64	2.5	115.71	46.28	33.43

Table 3 shows the relationship between the molarity of aqueous sodium silicate (NaOH: Volumetric Concentration (EDTA) solutions and the mull diameter in mm for different volumetric ratios. With the increase of the molarity from 10M to 16M, a large flow diameter will be seen as opposed to a small flow diameter for a given mixing ratio. For example, at a 1:Varying the molarity from 10M to 16M (NaOH: SiO2 ratio) makes the diameter change from 35 mm at 10M to 24.8mm at 16 M. Along with this, the opposite behavior of the diameter with the varying content of SiO2 and NaOH occurs in the process. The most extreme example is 16M concentration - the diameter ranges from 24.8mm at a 1:SiO2 to NaOH ratio and has reduced from 1:23 to 1:2.5 at the same time, the NaOH (sodium hydroxide) component is not increased in any dramatic way. In summary, especially the high molarity and large silicon dioxide concentration compared to sodium hydroxide cause a small flowing diameter. The data shows that this trend holds for aqueous solutions of varying sodium silicate molarity and composition.

Table 3. Workability of meta-kaolin-based geo-polymer concrete

Molarity of AAS	Sodium silicate: sodium hydroxide	Flowing diameter (mm)
10 M	1:1	35
	1.5:1	33.33
	2:1	29.3
	2.5:1	26.8
12 M	1:1	29
	1.5:1	29
	2:1	28
	2.5:1	27
14 M	1:1	27
	1.5:1	27
	2:1	25
	2.5:1	25
16 M	1 :1	24.8
	1.5:1	23.6
	2:1	23
	2.5:1	23

After 10M, 12M, and 14M activators, respectively, at a higher SiO2/Na2O ratio, there is a positive trend of enhancing compressive strength of all curing ages in Table 4. For example at 14M, the 2.5. The compressive strength of the 1 binder sample was 50.4 MPa at 28 days, approximately 9% higher than the 1:1 binder, which had a compressive strength of 46.2 MPa at the same duration. Such presence means that soluble silicate renders to higher reaction with hydroxide and, therefore, generates more strength. However, at 16M concentration, the opposite trend is observed - the 1:1 element was employed, resulting in higher strength than higher silicate modulus binders. This means that in a high, hydroxide concentration regime the activation of adsorbent through the silicate species is reduced compared with that in high activator contents. In the silicates modulus ratios, a linear trend may be observed where compressive strength rises with increasing molarity from 10M to 14 M. Nevertheless, the strength of 16M slag was not observed to increase any further in the subsequent tests, and this most likely occurred due to the saturation of reactants at the 14M stage.

The greatest strength gains appear in 7 to 28 days conflicting with molarities and modulus of silicate. As the age increases up to the 90th day, only less significant extra increases in the compressive strength are found, which shows that the reactions are completed approximately as early as 28 days.

Table 4. Compressive strength of M30 Metakaolin-based Geopolymer concrete

Molarity	Sodium silicate: sodium hydroxide	7 days	14 days	28 days	90 days
10 M	1.0:1	21.2	33.7	45.8	47
	1.5:1	21.6	34.2	46.1	48.2
	2.0:1	22.4	34.8	46.7	48.9
	2.5:1	23.1	35.3	48	50.3
12 M	1.0:1	21.9	34.9	45.4	46.9
	1.5:1	22.3	35.7	47.1	49.2
	2.0:1	22.8	38.1	48.8	50.1
	2.5:1	23.5	38.8	49.2	51.6
14 M	1.0:1	22.7	35.5	46.2	49.3
	1.5:1	23.4	37.1	48.1	50.8
	2.0:1	23.9	39.4	49.3	51.2
	2.5:1	24.1	39.9	50.4	52.5
16 M	1.0:1	21.4	32.1	39.3	40
	1.5:1	21.7	32.6	39.8	40.2
	2.0:1	22.3	33.4	40.2	41.9
	2.5:1	23.5	33.7	40.7	42.3

Table 5 displays the compressive strength of the concrete in megapascals (MPa) after the varied curing times in the days below. In particular, the required compressive strength of the 7-day concrete was 5.3 MPa. Following 14 days of curing, the concrete resisted with a strength of 5.8 MPa. The strength of concrete increased more markedly at the 14-28-day interval, with the concrete being 7.4 MPa strong after 28 days were over. Concrete strength rose from 7.4 to 7.8 MPa for 28-90 days after the fermenting process. As a whole, the data points out that concrete achieves considerable strength in the first few days with the remainder of the gain to be done by the end of the 28th day. At the end of the 28 days, the gain in strength is much less than the previous comparable period and before the arrival at 90 days, it is unnoticeable. This shows that time of curing is essential in case of differential strengths between the given two concrete cubes.

Table 5. Split tensile strength of 14 M Metakaolin Geopolymer concrete.

Days	Strength (MPa)
7	5.3
14	5.8
28	7.4
90	7.8

Table 6 offshoots the correlation between the compressive strength of concrete and the number of days after it was cast. Compressive strength is given in the megapascals (MPa). At the end of the seventh day, the concrete was measured to have an unconfined compressive strength of 9.4 MPa. On the 14th day, the strength identified had a slight increase of 9.8 MPa. The reading for the concrete compressive strength was 10.3 MPa at 28 days. After 90 days, the concrete reached considerable strength with 11.3 MPa as opposed to 2.6 MPa recorded on the first day. This information indicates that the concrete continues to strengthen as the chemical hydration process works, which is the factor that causes the concrete to grow stronger. The vast amount of concrete strength is achieved after 28 days, though that process still gains tiny additional strength over time. Concretely, it has become clear that the analyzed concrete reached most of its strength potential after 90 days. Monitoring the power degree over time allows construction engineers to plan the removal of the forms and determine if the structure is ready for loading.

Table 6. Flexural strength of 14 M Metakaolin Geopolymer concrete

Days	Strength (MPa)
7	9.4
14	9.8
28	10.3
90	11.3

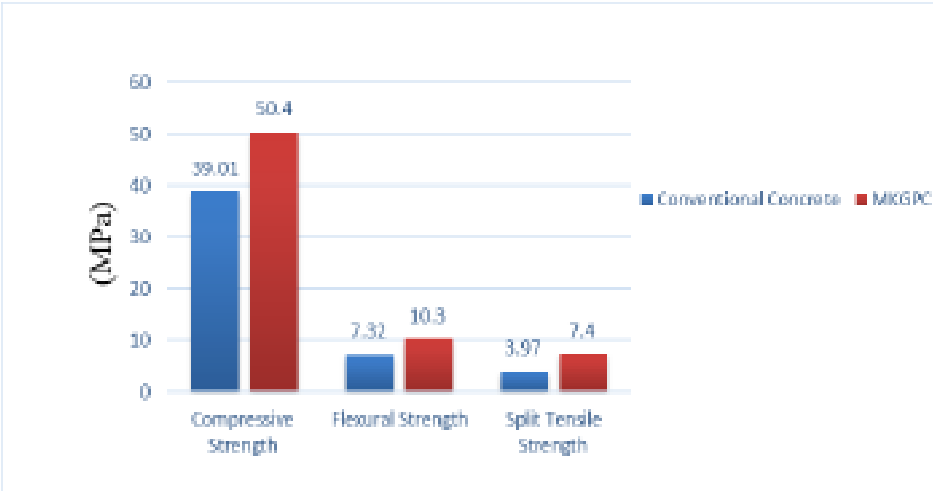


Figure 1. Comparison of 28 days strength of Metakaolin geopolymer concrete with Conventional concrete

Figure 1 provides data on three key strength properties of two types of concrete: traditional concrete and a new concrete mix called multi-component granite powder concrete (MKGPC). For standard concrete, the compressive strength is 571.5 psi, the flexural strength is 104.4 psi, and the split tensile strength is 558.7 psi. The MKGPC has a compressive strength of 150.4 MPa, flexural strength of 10.3 MPa, and split tensile strength of 7.4 MPa in contrast to conventional glass. In specific, the results from the data analysis demonstrate that the inclusion of the granite powder in the total mixture of the MKGPC concrete causes a considerable increase in the compressive, flexural, and tensile strengths which are much higher than those of the conventional concrete. The compressive strength of MKGPC is about 3 times more than normal concrete, whereas the flexural and split tensile strengths of MKGPC are around 1.4 times higher as compared to conventional concrete. The high-performance concrete as such is considered by MKGPC to be a more powerful and stable kind of concrete.

Rashmi Pantawane / Afr.J.Bio.Sc. 6(5) (2024). 3762-3777

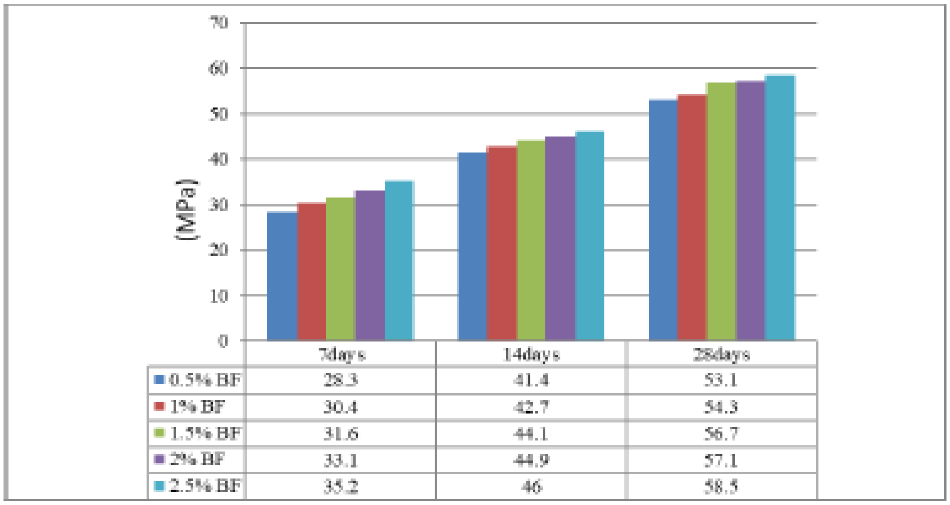


Figure 2. Compressive strength of BFRGC using 3 mm Basalt fiber length

Figure 2 illustrates the response of concrete to various BF percentages by comparing its compressive strength at different times. Basalt fiber concentrations of 0.5%, 1%, 1.5%, 2% and 2.5% were adopted in preparing concrete mixtures. The compressive strength was evaluated for three representative times, 7, 14, and 28 days for each mixture. 2 days after the introduction of BF into concrete, the compressive strength varied from 28.3 MPa to 35.2 MPa, with 0.5% BF concrete giving a lower value and 2.5% BF concrete giving a higher value. It is apparent that there is a major boost in early strength coming with the addition of greater.

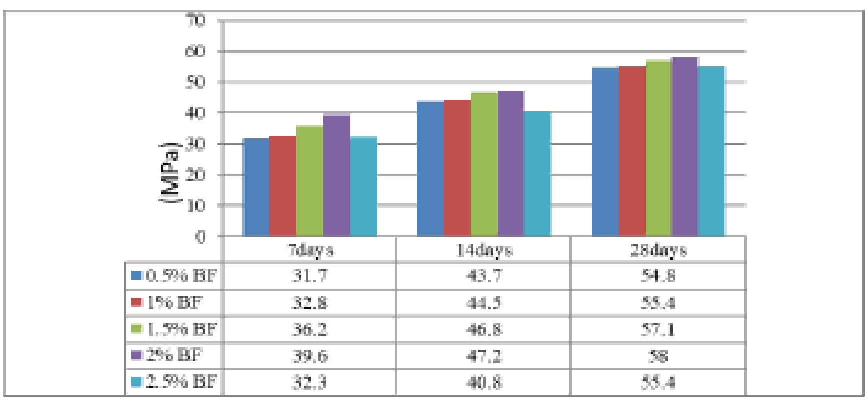
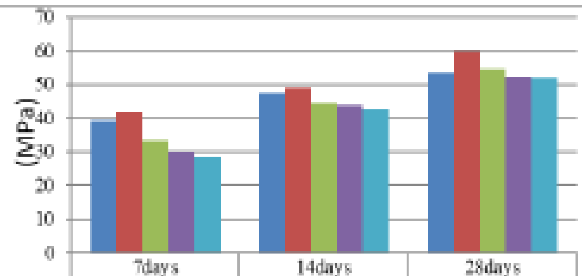


Figure 3. Compressive strength of BFRGC using 6 mm Basalt fiber length

Figure 3 gives a picture of how final compressive strength relies on the BF concrete percentage which is taken at a different point of cure. On the seventh day after casting, by adding 0.5% basalt fibers to the concrete, the strength reached 3.4 MPa, while in plain concrete it did not. The most notable enhancement in the strength of 7-day cured-time was noticed at 1.5% basalt fibers which has approximately increased the compressive strength by 28.5% or 9 MPa, compared to plain concrete. After 28 days of curing, the strongest gain was observed to be either 1.5% or 2% basalt fiber, both demonstrating similar compressive strengths of about 57 MPa which marks a 4 MPa or 7% increase from the plain concrete. Unexpectedly, the compressive strength at 30% and 50% were lower than at 25% and 20% as diagnostic of all cure times. In summary, the highly compressive strength of basalt fiber is more manifested at early ages, but some of the benefits are still there around the 28th day. The targeted amount of basalt fiber for the best combination between 28-day strength and the minimizing of the fibers appears to be in the range of 1.5% to 2.0%.

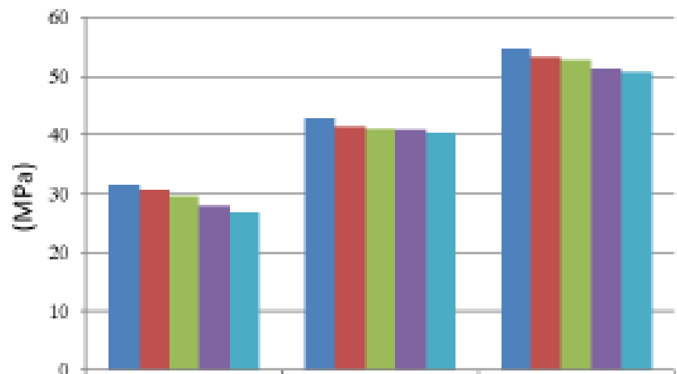


	7days	14days	28days
0.5% BF	39.2	47.3	53.2
1% BF	41.8	48.9	59.7
1.5% BF	33.2	44.5	54.6
2% BF	30	43.8	52.1
2.5% BF	28.4	42.7	51.8

Figure 4. Compressive strength of BFRGC using 12 mm Basalt fiber length

Figure 4 displays the number of days to reach the basalt fiber (BF) specific BF percentages at 0.5% increments starting from 1.5% up to 2.2% BF. This demands you to do a long term of 133 days to reach 1.5% BF. This implies that an additional 11 days would be needed to get to 2% BF if it were set as the target (i.e., 43.8 days, which is more than the 32.8 days needed for 1.5% BF as a target). And to reach 2% BF it would take 69.6 days, or about 8-9 days more than the 2.5% target. The day differentiation in targets between percentages of BF seems to decrease with increasing percent of BF. To illustrate: it needs 14 additional days to get from 1.5% to 2% BF, while only 8 days to achieve 2.5% from 2% BF. I hope to be 1.5% BF within 33 days, 51 for 2.5% BF. It is the longest period.

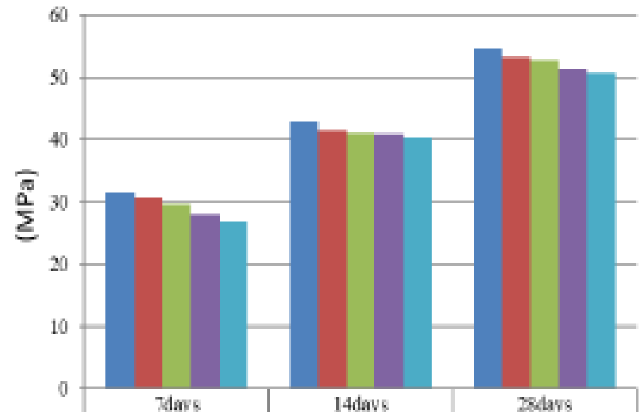
Rashmi Pantawane / Afr.J.Bio.Sc. 6(5) (2024). 3762-3777



	7days	14days	28days
0.5% BF	31.4	42.9	54.7
1% BF	30.7	41.5	53.2
1.5% BF	29.7	41	52.8
2% BF	28	40.8	51.3
2.5% BF	26.9	40.3	50.7

Figure 5. Compressive strength of BFRGC using 18mm Basalt fiber length

Figure 5 presents the BF percentage variation in the material during the certain seven-, fourteen-, and twenty-eight-days periods. The BF% begins at 1.5% to start with. By the end of 7 days, the % reduced to 1.43% which suggests the fragmentation or depletion of some of the basalt fiber has occurred. However, the speed of decrease falls after 7 days, with the BF reduction only 1.4% after 14 days. In the last stage by the end of 28 days, the BF percentage has stabilized at 1.35%, which seems to be the best-case scenario. Thus, most of the short-lived and short-term basalt fibers have abraded and have not survived in the composite. The leading finding in this study is that the BF drops by about 10% from the initial baseline of 1.5% to the final number of 1.35% at 28 days. This, therefore, implies the core of the basalt fibers remains with no observable wear and tear, while the weakest edge parts wear away at first, leaving the longest and the strongest fibers in the material.



	7days	14days	28days
0.5% BF	31.4	42.9	54.7
1% BF	30.7	41.5	53.2
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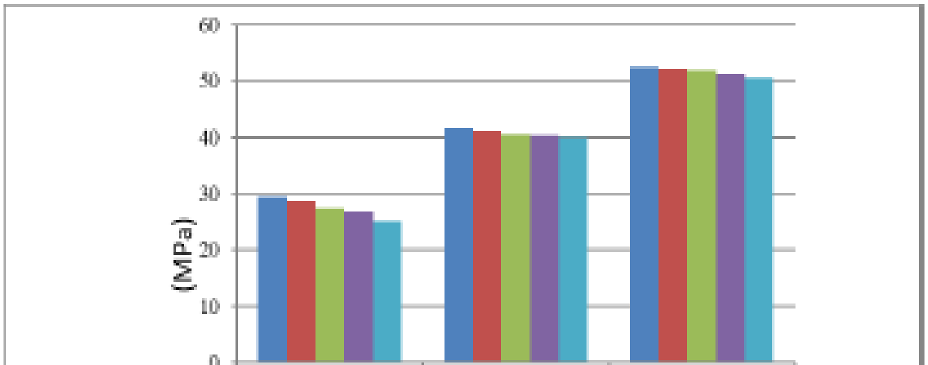

	7days	14days	28days
0.5% BF	29.5	41.7	52.5
1% BF	28.7	41	52.2
1.5% BF	27.3	40.5	51.9
2% BF	26.9	40.4	51.3
2.5% BF	25.1	40	50.6

Figure 6. Compressive strength of BFRGC using 24 mm Basalt fiber length

Figure 6 displays the effect of the compressive strength of concrete on concrete compressive strength, varying the percentage of basalt fiber (BF) added. In particular, the test result is the compressive strength in MPa after 7, 14, and 28 days for concrete mixtures for 0.5%, 1%, 1.5%, 2%, respectively. The most bending strength is found on day 7, where the 2% BF concrete compressor strength is 25.1 MPa and the 0.5% BF concrete compressor strength is 29.5 MPa. As the time increases, the range varies from 41.7 MPa (0.5% BF) to 40.4 MPa (2% BF) at day 14. On the 28th day, the 0.5% BF concrete had the highest strength at 52.5 MPa, as compared to 2% BF concrete with the least strength at 50.6 MPa.

The initial compressive strength appears to be decreased (after 7 days) with the increase of basalt fiber, conversely, a high percentage of basalt fiber brings about a strengthening effect (after 28 days). The 28-day peak compressive force is realized with 0.5% basalt fiber. Nevertheless, all the different concrete exhibits substantial strength credibility rise, thus proving the increasing strength feature of concrete material with such a percentage of added basalt fibers.

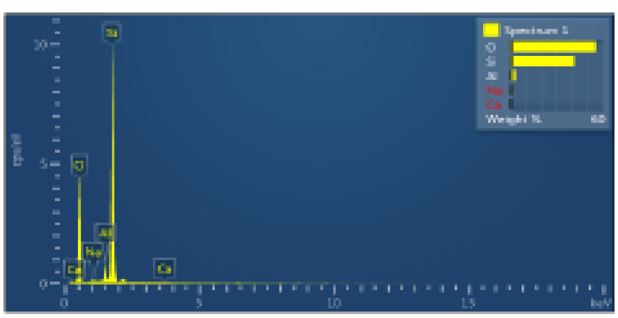

Figure 7. EDS results of 14 M Geo-Polymer concrete

Figure 7 shows that the geopolymer concrete contains a high amount of silica and provides insight into the constituent elements present in the geopolymer concrete. An EDS detector is used to separate the characteristic X-rays of different elements into an energy spectrum. A typical EDS spectrum is charted with X-ray wavelengths or counts vs. intensity or energy (in keV).

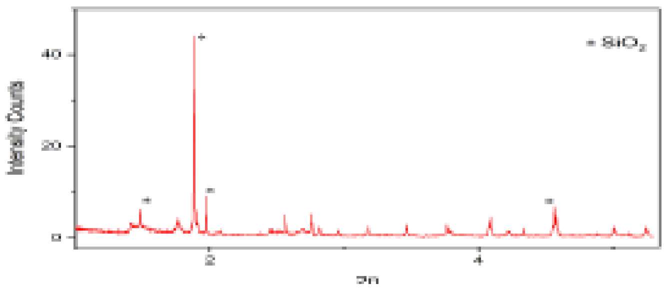

Figure 8. XRD graph of geo-polymer concrete

XRD is a technique employed to determine the underlying crystal structure of a material; it enables verification of the crystallinity and structure of a sample but gives no information of a chemical nature. The XRD characterization has been done to study the crystallinity of the nanostructured SiO_2-sensing film. Figure 8 exhibits that the changes responsible for the differences in compressive strength originate and take place within the amorphous part of the structure.

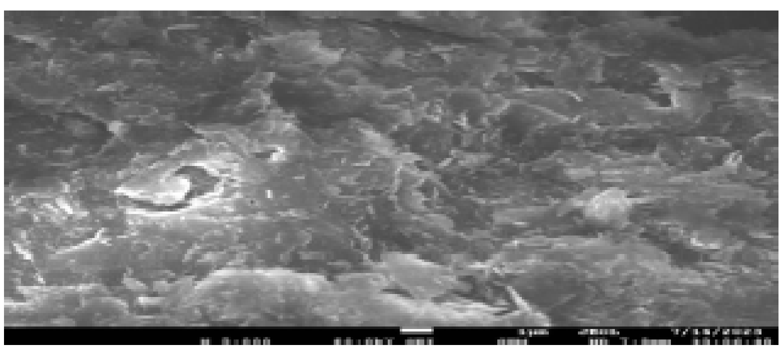

Figure 9. SEM image of geo-polymer concrete

SEM micrographs of the fracture surface of hardened GPC specimens were obtained and shown in Figure 9. This kind of microstructure without evidence of large pores is desirable for the better mechanical behavior of geo-polymer concrete (GPC). The microstructure of the GPC matrix that is visible in the micrographs is enormous with unrealized morphology, which indicates amorphous. Also, this micrograph shows minor cracks, which were probably formed to accommodate the stress fields associated with the main cracks responsible for the concrete specimen rupture under compression. It is reported that such minor cracks might contribute to keeping the integrity of the aggregate/matrix interface.

Discussion

Long-lasting, high-performance, and strong concrete is necessary for modern on-site construction. This research focused on the consequences of the incorporation of MK and variable lengths of BF into the beams of concrete specimens. Overall, it was demonstrated that the addition of MK as well as short BFs with optimal dosages increased the compressive strength.

The inclusion of this substance has received close attention among researchers as one of the most applied cementing materials. MK has high pozzolanic activity which is responsible for its reaction with calcium hydroxide that is produced from cement hydration to produce more calcium silicate hydrate (C-S-H) [16]. The C-S-H is formed in higher quantity which results in a gradual and careful pore structure evolution and better transition zone between aggregates and paste interface. In mix design, an MK replacement ratio of 0.4 was implicated as seen in Table 1. This degree addition even enhances the early and middle age compressive strengths.

Bosophate supply is being used widely as an additional component in concrete composites. In terms of strength, BFs are an inorganic material that has both a high tensile strength and a good resistance against acid, alkali, and salty solutions; they are also stable to high temperatures [17]. Surface activators, or BFs, can prevent early-age cracking and enhance the post-crack resistance of concrete (Wei & Meyer, 2016). This was accomplished by examining tables 4-6, which responded to BF treatments of different lengths and dosages. A survey of the literature, it can be concluded that shorter fibers at low volumes offer the best value of the firm compressive strength. The CPE value of 12 mm BF strength is 1% of addition, and that of 3mm BF strength is up to 2.5% of addition. A similar trend can be observed in the finding of Singha and Vinai (2020) as demonstrated by the reduction of the optical fiber volume with an increasing aspect ratio. The incorporation of BF into fresh concrete mixture modifies the mixture's workability and fiber distribution, and too high a volume of BF can cause fiber clumping, which results in uneven curing and low compressive strength [18].

The characterization techniques demonstrated in Figure 3 supply the details on the working principle delay in the mechanism of MK and BF acting in the improvement of the compressive strength. The high silica content of the geopolymer concrete provides for the formation of C-S-H which measures the pore sizes at lower values improving the strength of the concrete [16]. To make sure the concrete is mostly amorphous the XRD analysis is performed. From the SEM image, it is observed that this concrete has a dense microstructure and few large pores. In addition, microcracks are visible, which leads to the prevention of rupture using stress concentration reduction. Therefore, the microstructure phase transformation and the larger between-grains contact area are in line with the observed values of compressive strength in addition to the plain concrete.

The findings very much confirm the probability of the MK and BF routines for the strength benefit, but in-depth research is still required. The testing scope is supposed to include measurement of the effect on tensile strength, shrinkage, creep, and durability. This will help us to have better conclusions more completely and comprehensively. Moreover, the tests in field conditions can duplicate the complicated loading and the surrounding environmental exposure to some extent like the actual structures instead of the laboratory environment. On the other hand, alternative materials and production procedures could be considered to achieve multifaceted properties with lower expenditure.

In general, this study gives significant information concerning the increasing strength of concrete through MK and BF additives. By optimally choosing the additions, the microstructural and pore network refinements that followed increased the material's density and continuity leading to better strength. The results provide designers with new ways to improve the performance of concrete to apply them to the construction conditions that rule today. More trials on inclined and advanced fields can lead to the determination of the best mix proportions that would be within the cost-effective, durable, and high-strength range.

Conclusion

The data indicated that metakaolin (MK) has been a reliable additive when it comes to concrete mix solutions which increased the compressive strength and the tensile strength. Granite powder, together with the other cementitious minerals, is responsible for substantial strength gains in terms of compressive, flexural, and split tensile strengths compared with regular concrete. Basalt fibers are one of the various additives that are used to increase the compressive strength of MK geopolymer concrete up to a certain optimal level of content. Concerning the distance between the fibers (BF length of 3mm and 6mm), maximum strength was achieved at 2.5% addition and 2% addition, respectively. Increasing BF lengths in turn decreases the optimal percentage of strength increases, settling around 0.5% for 24mm diameter fiber. EDS, XRD, and SEM techniques aid the researcher in gaining a profound understanding of the amorphous microstructure and elemental composition behind the enhanced structural and mechanical performance of these concrete mixtures. Although the initial increase in strength is observed within the first 28 days, the further curing process, which unfortunately is going slow, contributes to the strength gain of concrete as well. Generally, the test results confirm the use of concrete mixes containing MK, granite powder, and basalt fibers which attain greater strengths, allowing for their application in high-performance concrete constructions.

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A critical review on basalt fibre geo-polymer concrete

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Abstract. Concrete has very less tensile strength as no reinforcement is included in its components. To increase the strength of concrete, fibers are added which acts as reinforcementsinto the concrete and basalt fibers is one of them. This paper reviews the necessity of this fiber to enhance the basic properties of the concrete. Fibers also tends to modify the physical properties of concrete as well as the hardened properties. Basalt fibers are derived from igneous rocks which makes them free from any chemical and thermal reactions. Basalt fibers have found to increase the mechanical properties of the concrete. The physical properties such as setting times have been found to increase with the increase in the fraction in volume of the fibers, dry shrinkage and workability have been found to be reduced in the concrete. Basalt fibre have proven to be efficient reinforcement material in the concrete, providing long life to the concrete. This paper will enrich the domain of structural engineering and contribute a lot to the future researchers working on fiber reinforced concrete at a glance.

1. Introduction

Fibres are continuously been used in the concrete industry as an emerging trend. Various fibres provide enormous quality to the concrete. Fibres can be produced from naturally available materials as well as they can be manufactured. Fibres are basically slender materials that can be found in variable sizes and lengths. Concrete industry is rising day to day and the resources for its production are diminishing due to degradation of natural resources by humankind.

Modern infrastructure is becoming the largest growing need of the coming generation, requiring the concrete to be of finest quality with greater strengths. The strength of concrete comprises of material strength such as tensile, flexural and compressive strengths. Development is constantly required. Addition of fibers help in achieving these strengths.

Basalt fibre is a kind of fibre which is being used extensively. Basalt fibre is derived from natural resources which are eco-friendly. It has many advantages like from igneous type rock emerging from the lava which makes it fire proof material, good resistance to environment that is chemically active like water, salt, acid and alkalis, high insulation capacity. Compared to glass, carbon and aramid fibre, they have emerged as successful and potential material. Basalt fibers are also recyclable.

Geo-polymer concrete is nowadays replacing the traditional concrete as it requires less or no cement in its manufacturing process. Making it more reliable construction material. Production of geo-polymer requires reactor and activator. Alumino silicates are reacted with user friendly alkaline agents to produce geo-polymer cement. Waste materials from industries like thermal power plants, iron and steel industry, and cement industry which uses coal in its manufacturing process, gives byproduct such as fly ash, slag, silica fumes etc. These byproducts form of waste is used to prepare geo-polymer concrete. Geo-polymer concrete is new and great alternative to ordinary Portland cement concrete as it has negligible maintenance and provides lengthy service life resulting in sustainable construction with low carbon footprint.

2. Literature review

T. Bhat et.al (2017) investigated the effect of high temperature incineration of basalt fibers on the tensile stress. When the basalt fibers are heated above 350^{0}C, its failure stress decreases with increasing temperature. There is occurrence of thermally activated surface flaw growth, which reduces the failure stress. The polymer matrix laminates were produced after thermal treatment of fibers.

Weakening of fibers and the nonappearance of fibre sizing reduced the tensile stress of recycled basalt fibers laminates when compared with the original strength.

Karthik M. P et.al (2017) carried out experimental and analytical investigation on fibre reinforced Geopolymer concrete with Flyashand Ground Granulated Blast-furnace Slag (GGBS), glass fibre and steel fibre. They investigated mainly steel fiber and glass fiber. They noticed that the steel fiber geopolymer concrete have wonderful engineering properties with a reduced carbon footprint. They proved that the fibre addition was seen to boost the tensile strength.

A. M. El-Gelani et.al (2018) experimentally investigated some basic properties of M20 concrete by using Basalt Fibre Reinforced Polymers (BFRP) .They noticed that there were positive results on compressive strength of concrete by inclusion of basalt fibers, beyond 5% there is no significant increase in strength .They also suggested that by inclusion of basalt fibers, compressive strength may be increased in the concrete. Optimum fiber length was found as 30mm and basalt fiber content was between 0.3% to 0.5%, which gave greater strengths when measured.

Michal M. Szczypinski et.al (2018) carried out the work to review the static and dynamic mechanical properties of the geoploymer when reinforced with the layers of baselfabrics.They found that the increase in flexural strength was 150 % and impact strength was over 60 %. They concluded that the mechanical properties of geopolymer composite material had great influence by using basel fabric reinforcement.

Faiz Shaikh et. al (2018) studied the effect of ambient and elevated temperature on the carbon and basalt fiber reinforced geoploymer synthesized by fly ash and activated by potassium activators. They casted six sequence ofmoulds of geopolymer by adding 0.5%,1% and 1.5% of carbon and basalt fibre by weight of fly ash. They found out that the higher strength was achieved in the geopolymer which contained 1 wt% basalt and 1 wt% carbon fibre , also there was lower volumetric shrinkage and mass loss when compared to other fibre contents. The study cojointly showed that the geopolymer containing carbon fiber was showing great achievement than the basalt fibregeopolymer despite temperature effect.

S. K. Kirthika et.al (2018) carried out a scientific study on M30 grade of concrete reinforced with basalt fiber having 0.5,0.75 and 1.00 percentage fiber volume fraction. They found out that for 0.50% dose of basalt fibre ,the compressive, splitting tensile and flexural strength magnified when compared with standard concrete. The tests of the study also implied that the basalt fibre is amorphous and hydrophilic in nature.

Mauro Henrique Lapenaa et.al (2018) performed experiments on basalt and E-glass fiber composites to find out the basic mechanical properties and located out that the composite containing high percentage of basalt fiber performed better on apparent hoop tensile strength and also on the interfacial property inter laminar shear stress.

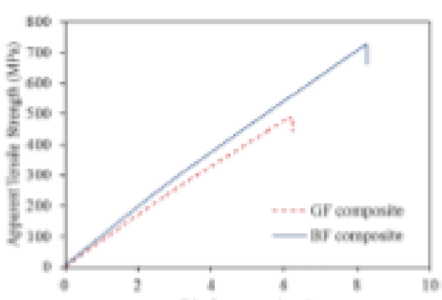

Figure 1. Split disk test tensile-displacement curves of BF and GF composite.

WonsiriPunurai et.al (2018) studied geopolymer made out of fly ash and basalt fiber to verify its mechanical properties, microstructure and drying shrinkage. They found that after replacing the fly ash geopolymeric paste with basalt fibers, it resulted in increased setting time and strength and also there was reduction in drying shrinkage. After replacement, the basalt fiber geoploymer was found to be more dense because by increasing the content of basalt fibre in fly ash geopolymer, the critical pore size and the porosity was reduced in the paste.

S.K.kirthika et.al (2018) studied durability of basalt fibre reinforced concrete (BFRC) in chemical solutions, carbonation, rapid chloride penetration and fire. They found out that the BFRC showed strong resistance to acid solutions, chloride penetration and fire. BFRC performed better than control concrete.

Yan-RuZhao et.al (2018) experimentally studied the consequence of fibre content and freeze thaw cycles on the basalt fibre reinforced concrete to verify the bending damage and failure characteristics.The check results indicated that the resistance to the elastic-plastic deformation of the concrete was increased by the fiber which restrained the bending damage and failure. They found out that the inclusion of fibers improved the bending strength whereas thefreeze-thaw cycle of fiber can lower its strength.

Michal M. Szczypinskil et.al (2018) carried out analysis on the layered basalt fabric reinforced geopolymer. They aimed to testify the enhancement of mechanical properties of the reinforcedgeoploymer to non-reinforced geoploymer. They carried out tests for finding out flexural, compressive, splitting tensile and impact strength of the specimen. They found that by reinforcing geopolymer with layered basel fabric, it showed excellent results.

XinjianSun et.al (2019) studied experimentally and numerically simulated basalt fibre reinforced concrete BFRC for execution of its compressive, splitting tensile, and bending strength.By increasing the basalt fibre content in the concrete, the strengths such as compressive and splitting tensile were found to be initially increased and then decreased, whereas there was growth in the bending strength.

Karim Attia et.al (2019) experimented one way slab concrete including basalt micro fibers reinforced with basalt fibre and glass fiber polymer bars. The ductility and load carrying capacity of the slab was found to be increased by the inclusion of basalt macro fibers, hence they can be used as substitute to other synthetic fibers for flexural concrete members.

XinWanget.al (2019) experimentally investigated the effect of salt solution on the fatigue behavior of basalt fiber reinforced polymer BFRP and found out that there was insignificant degradation in the static strength of BFRP when immersed in salt solution for long times, whereas under the fatigue loading, it showed damaging effect. The fatigue strength of BFRP was
found to be degraded but up to tolerable level due to the early interface de-bonding and concluded that the fiber to matrix interface region plays an important factor in the assessment of fatigue behavior.

Xinzhong Wang et.al (2019) studied basalt fiber reinforced concrete BFRC under then effect of fiber volume fraction ,fiber length, and compressive strength and performed physical and mechanical tests.They found that by incorporating a small amount of short basalt fibers in BFRC, it gave significant rise in compressive strength and rupture modulus .They discovered the occurrence of early shrinkage cracks were initially decreased and then increased, by increasing the basalt fibre length and the optimum basalt fiber length was found to be 18.0 mm.

Francis L Kinget.al(2019) by experimentation studied the behavior of concrete using Polylatic acid reinforced Basalt and Bagasse fibers. They determined that the weight percentage of fiber content is more responsible than the length of fibre in improving tensile, flexural, and impact strengths. The test results of water absorption test showed that by increasing the fiber content, the water absorption rate also increased.

Manibalan P et.al (2019) evaluated the performance of concrete by adding basalt fibers and determined optimum basalt fiber content. The mechanical strength of concrete was found to be increased by the addition of basalt fiber to optimum level of 0.9% in volume fraction due of the ability of fibers to arrest the cracks. Thus they confirmed that using basalt fibers at low content gives strength enhancement.

Hao Zhou et.al (2020) studied the effect of adding different basalt fiber contents in the concrete. The toughness and crack resistance performance of concrete was found to be considerably upgraded. The tensile and flexural strength were found to be increased significantly as compared to compressive strength.
MinLi et.al (2020) experimentally studied the alkali resistance of alkali resistant basalt fibre ABF and basalt fiber (BF) in the concrete. By addition of 0.1% ABF , the mechanical properties of the concrete were found to be enlarged , the fiber matrix bonding was increased.
Zoi G. Ralli (2020) reviewed the advanced topic of geopolymer concrete. The study covers various substitutes of cement for manufacturing concrete from range of industrial by products and naturally available resources abundant in needed minerals. The available minerals are prospected minutely to develop a sustainable construction material.

Eric Hughes et.al (2020) studied reinforced concrete RC structural members strengthened by using basalt fibre reinforced polymer (BFRP) fabrics. The BFRP fabrics can be used to strengthen the stationary RC members externally and proves to be favorable technique. They studied five beam samples, having 0.77% steel ratio. The layers of BFRC fabric were placed in increasing order of two, four, six, and eight. They found out that their experiment showed significant increase in strength in all specimens and also found out that the safe limit for using the BFRP fabric is six.
Mohankumarnamdeorao (2020) examined the basalt fibre reinforced concrete to the chemical attack. He structured M30 grade of concrete according to IS 10262:2009 with basalt fibres 0%,1%,2% and 3% by weight of cement. The aim of the paper was to investigate various fibre contents properties on fibre reinforced concrete. The concrete strength was found to be increased at 2% fibre content not withstanding when exposed to sulphate attack.
BunthengChhorn et.al (2020) numerically studied cohesive zone model CZM for finding the tensile bonding strength between BFRP and concrete. The early crack widths of the concrete were used to confirm the modeling results and concluded that for studying the BFRP concrete interface , CZM is best method which saves time and funds. Their results indicated the presence of finite cracks on the surface edge of specimens. Specimens which previously had 10mm initial cracks developed cracking on its whole surface.
DeendayalRathod et.al (2020) discussed the reinforcement of concrete by adding E-glass and basalt fibers. They assessed various parameters of strength of fibre reinforced concrete and then compared it to conventional concrete. Enhanced compressive strength was found in the concrete having 2% basalt and 1% E-glass fibre resulting in hybrid fibre reinforced concrete HFRC. On comparison with standarad specimen, HFRC provided great resistance to impact, deflection was less, modulus of elasticity and stiffness was higher.
ZeynepAlgin et.al (2020) investigated the basalt fibre reinforced concrete. fresh and hardened characteristics of concrete reinforced with basalt fiber (BF). They used BF with the length of 12 mm in concrete mixes at 0.2%, 0.4%, 0.6% and 0.8% of total volume together with the variation of water to cement ratio of 0.47 and 0.59. The test result showed that the mechanical properties are improved whereas the workability of concrete is remarkably deteriorated by BF incorporation. They discerned that the BF content of 0.356% provides the optimum result with the w/c ratio of 0.47.
MiroslavFrydrych et.al (2020) studied the naturally fibre reinforced geopolymer. The geoploymer composite were produced reinforcing with flax fibres in the form of non woven fabric, basalt fiber and without reinforcement. Impact bending, bending and compressive strength were found out to test the mechanical properties of concrete. Addition of natural fibers gave beneficial influence on impact bending and bending strength, but negative effect on the compressive strength.
S.N.Karaburc et.al (2020) investigated pumice lightweight concrete reinforced with basalt fibre (BPLC). Cement substitute was used namely nano ground calcium carbonate GCC at the percentages of 5 %, 10 %, 15 %, 20 % and 25 % and 6mm long basalt fibers were added 0.5% and 1% by volume content. Initially lower mechanical strength were produced by GCC added mixes, afterwards approximate strengths were achieved. Decrease in sorptivity and water absorption was observed by

adding GCC and increase in magnesiumsulphate resistance was recorded. Mechanical properties were found to be enlarged by the introduction of basalt fiber in BPLC, however the fresh properties were found to be minimized.

Table 1. Physical and chemical properties of the BF. Technical property.

Elasticity module, MPa	90
Tensile strength, MPa	4832
Melting point, C°	1452
Application temperature, C°	−220/+980
Chemical composition	Percentages (%)
SiO2	51.2−58.9
Al2O3	14.5−18.2
Fe2O3	5.7−9.6
MgO	3.0−5.4
FeO + Fe2O3	9.2−14.0
TiO2	0.8−2.25
Na2O + K2O	0.8−2.25
Others	0.08−0.14

Muhammad RiazAhmad et.al (2020) experimentally studied the resistance effect on magnesium phosphate cement MPC under high temperature and water. Different concentrations of silica fume and basalt fiber were used in study. Increasing content of silica fume and basalt fiber enhanced the water and high-temperature resistance of mortar composites. They discovered that by adding silica fume and basalt fiber, performance of magnesium phosphate cement mortar was found to be increased.
Saloni et.al (2020) studied the geopolymer which was reinforced with basalt fiber. The properties such as microstructral, hardened and fresh of the concrete so formed were studied. They discovered that introducing basalt fibers gave positive effect as there was increase in initial and final setting time. Expansion in bulk density, compressive and flexural strengths were also recorded .Basalt fibers were acting as reinforcing material thereby geopolymer characteristics were found to be upgraded.

Katharina Walbrück et.al (2021) developed fly ash fiber reinforced geoploymer which was lathered with sodium dodecyl sulfate SDS. Natural fibers used in the study were derived from Miscanthus x giganteus. By increasing the fiber size and concentration of foaming agent, an increment in thermal conductivity and compressive strength was observed.

3. Review results and discussions
In the findings of T. Bhat et.al (2017) it may be stated that the basalt fibers are derived from volcanic rocks and these rocks are formed under very high temperatures, hence exposing the fibers to temperature for thermal recycling does not affected the Young's modulus of the composite material. The thermal decomposition of fibers occurred after heating above 350°C which resulted in decreased compressive and tensile strength. Basalt and glass fibers showed similar characteristics on temperature, hence basalt fibers can be replaced with E glass fibers in polymer matrix laminates due to it slower cost.
Experimental and analytical investigation on fibre reinforced Geopolymer concrete with Flyash and Ground Granulated Blast-furnace by Karthik M. P et.al (2017) indicates that Steel fibers have high modulus of elasticity and deformation which provides them their great strength. Fibers provide tensile forces to arrest the cracks hence reduces shrinkage, improves cracking resistance and toughness to the concrete. Because of their low price and excellent characteristics, fibers have gained popularity.
Under an experimental study by A. M. El-Gelani et.al (2018) who investigated some basic properties of M20 concrete by using Basalt Fibre Reinforced Polymers (BFRP) and the results of this study could be supported as the rupture strength and average residual strength of the concrete is increased by basalt

fibers due to the characteristics of the fibres. Further the concentrations and fiber volume fractions of basalt fibers can be increased to study more significant effects.
Under the review of static and dynamic mechanical properties of the geoploymer reinforced with the layers of basel fabrics by Michal M. Szczypinski et.al (2018) it can be said that in the constructions where light weight and high strength is required; the basel fabric reinforcement can be used, which helps in reducing the mass of the concrete as compared to material without reinforcement.
Under the study of Faiz Shaikh et. al (2018) for the effect of ambient and elevated temperature on the carbon and basalt fiber reinforced geoploymer synthesized by fly ash and activated by potassium activators the reason may be the carbon fiber geopolymer provides increased compressive strength and lower volumetric shrinkage and lower mass, which makes it a better alternative than basalt fiber, that can be used as a filler material in geoploymer concrete.
Basalt fibers have great resistance to salt and water corrosion, which in turn provides dense and compact structures having good adhesion with cement matrix. Basalt fibre geo-polymeric concrete have high performance when compared with normal geo-polymer concrete, as the basalt fiber improves the strengths and toughness of the concrete under the study carried by S. K. Kirthika et.al (2018) Composites containing basalt fibers performs better than the glass fiber in the mechanical properties, hence it can be used as an substitute for glass fiber composites. More strength tests such as hydrostatic test should also be done to prove the potential of basalt fiber composites studied by Mauro Henrique Lapenaa et.al (2018).
Under the findings by S.K.kirthika et.al (2018) it can be said that Basalt fibers arrest the thermal cracks in concrete and provides good residual compressive strength due to which they perform better in elevated temperatures and show no spalling in concrete. Basalt fiber have high chemical and thermal stability which makes them a great potential building material.
Basal fabrics can be used as reinforcing material in geopolymer, which reduces the mass of material and provides great achievement in its strength. It can be used where lightweight and high strength concrete is required in case of study carried by Michal M. Szczypinskil et.al (2018).
Basalt fibers have high tensile strength and modulus of elasticity, which tends to slow the progression of cracks in the concrete and increase its energy absorption capacity resulting in enhanced strength to the concrete as in case of the study carried by XinjianSun et.al (2019).
More tests could be performed on slabs to consider its performance under long term fatigue stresses to infer quality results in the experimental study carried by Karim Attia et.al (2019).
In the experimental investigation by XinWang et.al (2019) it is clear that interface degradation and debonding leads to breaking of fibers resulting in decrease of fatigue life in saltwater immersion, but BFRP maintains suitable level of retention after degradation.
In a study by Xinzhong Wang et.al (2019) on BFRC under the effect of fiber volume fraction, fiber length, and compressive strength and performed physical and mechanical tests it is most probable that by increasing the amount of fibre volume fractions and fiber length, there is occurrence of clumping of fibers into the cement matrix, which tends to reduce its workability and compressive strength.Regarding experimental study on the behavior of concrete using Polylatic acid reinforced Basalt and Bagasse fibers by Francis L. Kinget.al(2019) it can be concluded that Fiber plays crucial part in increasing the mechanical parameters of concrete, by increasing its contents , the mechanical behavior can be increased.
Basalt fibers have high ductility as compared to other fibers, which provides increased mechanical strengths to the concrete. Furthermore research needed to be done for studying the ductile behavior in the study by Manibalan P et.al (2019).
The density of the concrete is increased by including basalt fibers which also prevents the water retention. They tends to form bridge, preventing the cracks. This property of basalt fibers provides mechanical property to the concrete. It is clear from the study conducted by Hao Zhou et.al (2020).
Regarding experimentak study conducted by MinLi et.al (2020) on the alkali resistance of alkali resistant basalt fibre ABF and basalt fiber (BF) in the concrete it is inferred that ABF tends to decrease the pore size in the concrete, resulting in greater bonding between fiber and concrete matrix when

compared with BF, which helps in imparting strength. BF can also be used to verify the acid resistance properties.
In a review on BFRC by Zoi G. Ralli (2020) the emphasis was focused on Aluminosilicate materials that could be used as binder materials in geopolymer concrete which outperforms alkali activated concretes. This concrete can be used where early strength is required.
Strengthening the beams with BFRP, prevents the flexural failure at the tensile surface but causes more stresses on the compression surface which results in cracking, leading to shear failure as studied reinforced concrete RC structural members strengthened by using basalt fibre reinforced polymer (BFRP) fabrics by Eric Hughes et.al (2020).
Mohankumarnamdeorao (2020) examined the basalt fibre reinforced concrete to the chemical attack Further basalt fibre geo-polymer concrete can be used to verify its strength characteristics against the chemical attacks.
In the study of DeendayalRathod et.al (2020) assessment of the reinforced concrete by adding E-glass and basalt fibers .Basalt fibers act as toughening materials in the concrete, which resists great impact load and provide early strength to the concrete. By increasing amount of basalt fiber, the strength is increased, also they provide higher stiffness and modulus of elasticity to the concrete.
The crack arresting mechanism of basalt fiber increases the compressive strength in concrete. By increasing the concentration of fiber incorporated in concrete, it will increase its properties. ZeynepAlgin et.al (2020) investigated.
Flax fibers have rough surface which provides good grip to the geopolymer ,whereas basalt fibers have high tensile strength and smooth surface. Hence glass fibers can be replaced with these fibers, which will result in higher strength of the composite. Extracted from MiroslavFrydrych et.al (2020) study.
Increasing the amount of basalt fiber resulted in low slump flow because of increased friction coefficient between the fiber and the mortar. Basalt fiber and GCC showed slow hydration process, hence can be used in mass concrete structures. Enhancement of physical and mechanical properties in BPLC was due to the filling of air voids in the mortar by BF and GCC, under the discussion with study done by S.N.Karaburc et.al (2020)
Increasing the content of silica fumes and basalt fiber, reduced the porosity in the mortar, leading to improved water resistivity with the discussion of Muhammad RiazAhmad et.al (2020) study.
If we comment on Katharina Walbrück et.al (2021) study we can conclude that overall surface area of the fiber was covered by the geo-polymer, there is good packing between both the surfaces, which resulted in lower thermal conductivity. This kind of fiber-geopolmer matrix can be used for thermal insulation purposes. Increasing the fiber size results in less packing structure of matrix giving rise to voids and porosity. Higher the porosity in the matrix it leads to low compressive strength and low thermal conductivity.

4. Conclusion
Basalt fibers has emerged as an effective reinforcement material in the geo-polymer composites. They enhance the fresh, hardened and microstructural properties of the concrete. They have high resistance to chemical environment. Basalt fiber reinforced geo-polymer concrete performs better than the ordinary concrete. Incorporating basalt fibers contribute to the growth of fracture properties and makes the propagation of cracks difficult. Setting times of the concrete were found to be enlarged with the increase in basalt fiber percentage and also resulted in the reduced dry shrinkage of the geo-polymer mortar. Basalt fibers enhance the resistance to sulphate and chloride attack. They increased the durability of the mortar against freeze thaw cycles.

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CONVENTIONAL CONCRETE REINFORCED WITH BASALT FIBER

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Concrete is most widely used and essential ingredient in the construction sector. Cement being one of the key component in the concrete. Its production emits carbon dioxide in the atmosphere and hence sustainable material development has become very important in today's scenario. Cement itself is very weak in tension and therefore requires extra reinforcement to bridge this gap. Nowadays fibers have gained popularity in the industry for its various utilities in fields such as construction, aeronautics, mechanical and energy emission. Basalt fibers has gained attention due to its environment friendly nature and is used in this study as reinforcement in concrete. Basalt fibers are incorporated in this study from 0.1 to 0.5% volume fraction. Strength parameters are investigated such as compressive, tensile and flexure. Addition of basalt fiber has given positive results in increasing the strength. The highest compressive strength and flexure strength was achieved at 0.3% addition of basalt fiber whereas the maximum split tensile strength was achieved at 0.2% addition of basalt fiber. The workability of the concrete has been found to be decreased with the further addition of basalt fiber.

Keywords: Basalt fiber, concrete, cement, reinforcement , strength.

Effect Of Concentration Of Sodium Hydroxide Solution On Geo-Polymer Concrete

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Abstract

Geopolymer is the new age concrete made by replacing cement in concrete by its substitute material which is pozzolanic in nature like metakaolin clay. This paper presents the effect of sodium hydroxide solution on workability of BFRGC.Mole's concentrations were used as alkaline activators. solution-to-fly ash ratio of 0.35 was considered in preparing geopolymermixes The temperature of oven curing was maintained at 80°C each for a heating period of 24 hours and tested for compressive strength. Test results show that the workability and compressive strength both increase with increase in concentration of sodium hydroxide solution.

Keywords- *Metakaolin, geopolymer concrete, molarity, sodium hydroxide and sodium silicate*

1. Introduction

Cement which is main ingredient of concrete produces emission of green house gases like co2 [1,2]. As the demand is increasing in construction industry, consumption of cement is increasing. Source material such as metakaolin clay is present abundantly. Sodium hydroxide and sodium silicate solution were used as alkaline activators. Polymerization is the process of chemical reaction to form polymer chains. Metakaolin reacts with alkaline activators to form binder.

2. literature Review

P.Udaykumar et.al 2016 used metakaolin and granulated blast furnace slag (ggbs) to produce M40 geopolymer concrete. Beams were casted using geopolymer concrete and conventional concrete. They concluded that the load deflection curves were almost similar for both the beams. However the cracking moment was lower for geopolymer beam compared with conventional beam.

Sonali et. al 2014 found out that by increasing the quantity of quarry sand upto certain limit, the compressive strength increases. The quarry sand was used 60% in place of river sand. The cement was replaced with GGBS. They concluded that the workability increased by increasing the GGBS percentage but the strength was found to be decreasing.

Rashida et. al 2016 used fly ash in the geopolymerconcrete. The samples were cured at 60°C and one ay curing time. The concentration of NaOH was taken from 4M to 18M to study the mechanical properties of geopolymer concrete. Hence the optimum concentration which exhibited satisfactory results was found out to be 12M where the best mechanical properties were obtained.

Peigang He et.al 2010 studied the effect of high temperature on microstructure and mechanical properties on unidirectional carbon fiber reinforced geopolymer composite. They found out that the mechanical properties can be improved by heat treatment in temperature from 1100 to 1300°C. for composites which were treated at 1400°C, their mechanical properties were lowered.

3. **Methodology**

3.1 Materials used

3.1.1 Metakaolin

Metakaolin is a De-hydroxylated form of the clay mineral kaolinite. The particle size of metakaolin is smaller than cement particles, but not as fine as silica fume. The quality and reactivity of metakaolin is strongly dependent of the characteristics of the raw material used. Metakaolinis produced by heating kaolin natural clay to temperature between 650-900°C .It has high performance high strength and resistance increase due to chemical attack and has increased durability.

Table 1.Physical properties of Metakaolin [3]

Specific gravity	2.40 to 2.60
Color	Off white
Physical form	Powder
Average plastic size	<2.5 μm
Brightness	80-82
Hunter L BET	15 m2/g
Specific surface	8-15 m2/g

Table 2.Chemical Composition of Metakaolin [3]

Chemical composition	Wt. %
Sulphur Trioxide (SO3)	<0.50
Alkalis (Na2O, K2O)	<0.50
Loss of ignition	<1.00
Moisture content	<1.00

Table 3. Metakaolin properties [3]

Physical Properties	Metakaolin
Specific gravity	2.5
Mean grain size	2.54
Specific area (cm2/g)	150000-18000

Color	Ivory to cream
Chemical Composition	
Silicon dioxide (SiO2)	60-65
Aluminum oxide(Al2o3)	30-34
Iron oxide (Fe203)	1.00
Calcium oxide (CaO)	0.2-0.8
Magnesium oxide (MgO)	0.2-0.8
Sodium oxide (Na2O3)	0.5-1.2
Potassium oxide (K2O)	
Loss on ignition	<1.4

3.1.2 Fine Aggregate

Fine graded aggregate was used to give minimum void ratio and free from deleterious materials like clay, silt content and chloride contamination etc. locally available river sand (coarse sand) conforming to Grading Zone II of IS 383:1970 was used as fine aggregate. The sand was washed and screened at site to remove deleterious materials and tested as per the procedure given in IS 2386:1968 (Part-3).River sand from Chandrapur is used in this study .

Table 4 . Physical Properties of fine aggregate

S.No	Property	Values
1	Specific gravity	2.63
2	Fineness modulus	2.51
3	Bulk modulus	1564

3.1.3 Sodium Hydroxide

Sodium hydroxide, also known as caustic soda, is an inorganic compound. The most common alkaline activator used is the mixture of Sodium hydroxide and sodium silicate. It is a white solid and highly caustic metallic base and alkali of sodium which is available in flakes, granules, and as prepared solutions at different concentrations. Due to its availability, it is used in various manufacturing industries such as paper industry etc.

Table 5.Specifications of Sodium Hydroxide Flakes [3]

MinimumAssay (Acidimetric)Maximum limits of impurities	96%
Carbonate	2%
Chloride	0.1%
Phosphate	0.001%
Silicate	0.02%

Sulphate	0.01%
Arsenic	0.0001%
Iron	0.005%
Lead	0.001%

3.1.4Sodium Silicate

Sodium silicate is the common name for Na_2SiO_3. Also known as water glass or liquid glass, which are available in aqueous solution and in solid form.

$Na_2CO_3 + SiO_2 \rightarrow Na_2SiO_3 + CO_2$

A chemical reaction occurs with the excess $Ca(OH)_2$(Portlandite) present in the concrete that permanently binds the silicates with the surface, making them far more durable and water repellent. This type of activator plays an important role in the polymerization process.

3.1.5 Coarse aggregate

Graded coarse aggregate of size 10mm was used in the study as per IS 383:1970.

Table 6 Physical properties of coarse aggregates

Specific gravity	2.79
Bulk density (kg/m3)	1511
Fineness modulus	7.3
Water absorption	0.41

3.2. **Methodology**

3.2.1 Preparation of alkaline solution

Sodium hydroxide pellets were used to prepare solution. The molecular weight of sodium hydroxide is 40. For example to prepare 8molar sodium hydroxide solution, 320gm of NaOH flakes were weighted and dissolved in distill water to prepare one litre solution.

3.2.2 Mixing of geopolymer concrete

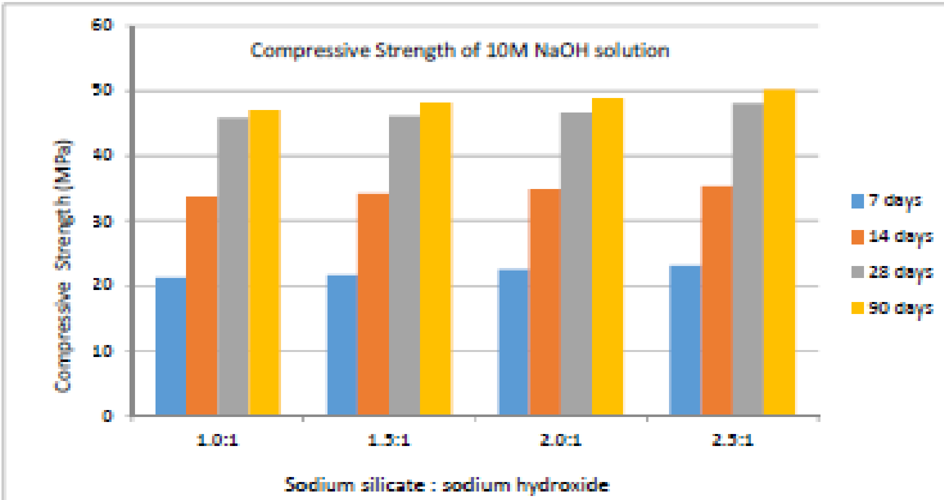
Metakaolin powder, fine aggregates and coarse aggregates were mixed properly till uniform colour was obtained. After thorough mixing, the alkaline solution which was prepared 24hours prior, was poured into the dry mix and mixed properly. The prepared concrete mix was poured into 150mm cubes and vibrated on shake table. As no code for mix design of geopolymer concrete is available , its density is assumed.

3.2.3 Curing

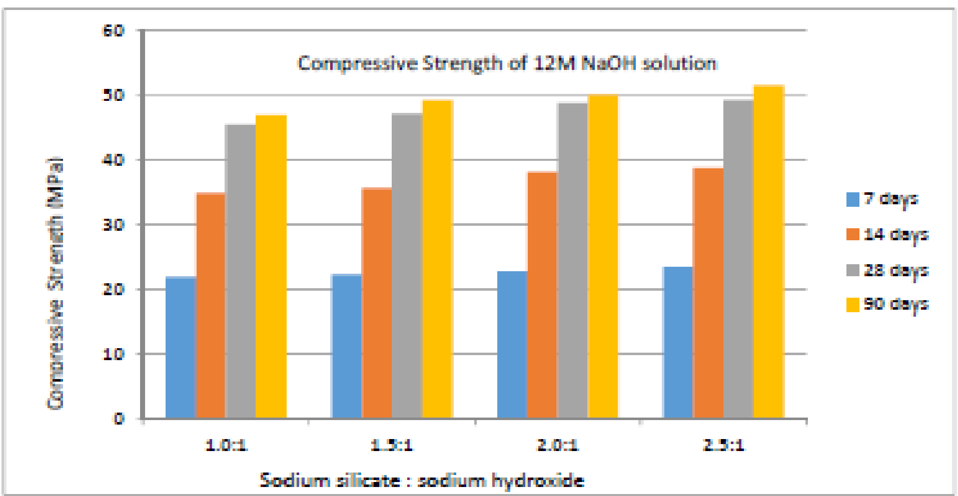
The geopolymer concrete moulds are oven cured at 80°C each for a heating period of 24 hours. Then the samples are ambient cured after demoulding and tested for compressive strengths.

4. Results

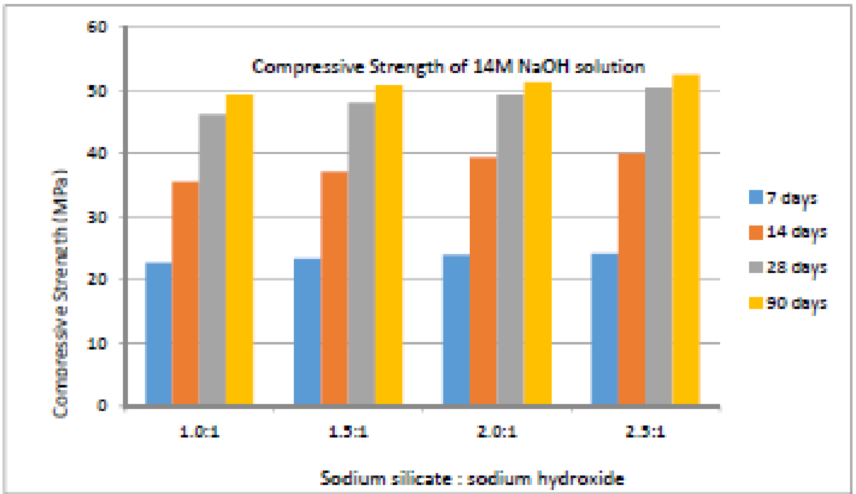
In this section, the experimental results obtained are presented.



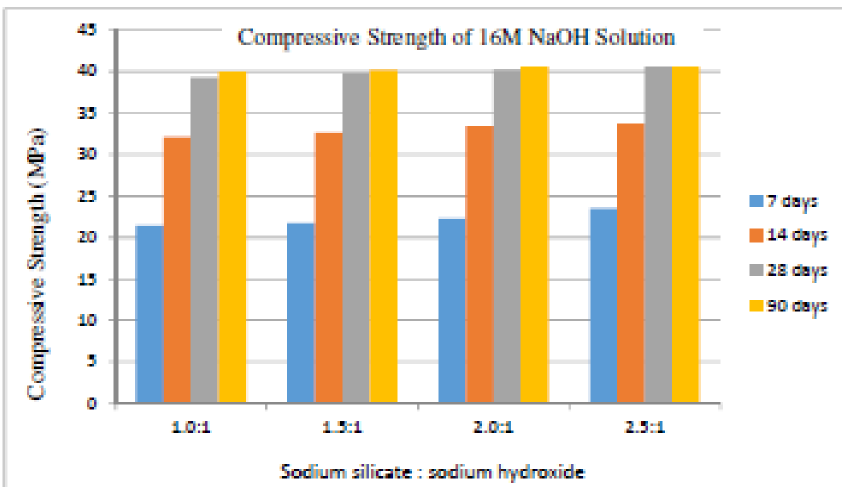
Graph 1: Compressive Strength of 10M NaOH Solution



Graph 2: Compressive Strength of 12M NaOH Solution



Graph 3: Compressive Strength of 14M NaOH Solution



Graph 4: Compressive Strength of 16M NaOH Solution

5. Conclusion

With the increase in molarity of sodium hydroxide solution, the compressive strength of geopolymer concrete strength was found to be increased upto 14 M after which is was found to be decreasing. Strength gain of geopolymer concrete increases with age upto 90 days after which there is no significant increase in strength. Ambient curing helped in attaining strength which is also practically convenient. Early compressive strength is observed in case of geopolymer concrete, hence where high early strength is required in projects, geopolymer concrete can be proved beneficial.

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