FAST SETTING STEEL FIBER REINFORCED GEOPOLYMER MORTAR CURED UNDER AMBIENT TEMPERATURE

Thesis

Submitted in partial fulfilment of the requirements for the degree of

MASTER OF TECHNOLOGY

in

CONSTRUCTION TECHNOLOGY & MANAGEMENT

By

IRAMBONA THEODOSE

(172CM021)

DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY KARNATAKA

SURATHKAL, MANGALORE -575025

June, 2019

FAST SETTING STEEL FIBER REINFORCED GEOPOLYMER MORTAR CURED UNDER AMBIENT TEMPERATURE

Thesis

Submitted in partial fulfilment of the requirements for the degree of

MASTER OF TECHNOLOGY

in

CONSTRUCTION TECHNOLOGY & MANAGEMENT

By

IRAMBONA THEODOSE

(172CM021)

Under the guidance of

Dr. B.B.Das

DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY KARNATAKA

SURATHKAL, MANGALORE -575025

June, 2019

DECLARATION

By the PG (M.Tech) student

I hereby declare that the Report of the P.G. Project Work entitled "**FAST SETTING STEEL FIBER REINFORCED GEOPOLYMER MORTAR CURED UNDER AMBIENT TEMPERATURE**" which is being submitted to the **National Institute of Technology Karnataka Surathkal**, in partial fulfilment of the requirements for the award of the Degree of **Master of Technology in Construction Technology and Management** in the department of Civil Engineering, is a *bonafide report of the work carried out by me*. The material contained in this Report has not been submitted to any University or Institution for the award of any degree.

172 CM 021, IRAMBONA THEODOSE
Department of Civil Engineering

Place: NITK, SURATHKAL
Date: June, 2019

CERTIFICATE

This is to certify that the P.G. Project Work Report entitled **FAST SETTING STEEL FIBER REINFORCED GEOPOLYMER MORTAR CURED UNDER AMBIENT TEMPERATURE** submitted by **IRAMBONA THEODOSE** (Register Number: **172CM 021**) as the record of the work carried out by him, is accepted as the P.G. Project Work Report submission in partial fulfilment of the requirements for the award of degree of Master of Technology in Construction Technology and Management in the Department of Civil Engineering.

………………………

Dr. B.B.Das

Associate Professor

Department of Civil Engineering

NITK, Surathkal-575025.

………………………….

Chairman – DPGC

Department of Civil Engineering

NITK, Surathkal

ACKNOWLEDGEMENT

I would like to express my profound gratitude to my guide **Dr. B .B. Das** , Associate Professor, Department of Civil Engineering, National Institute of Technology Karnataka, Surthkal for his guidance , support , advice and help for this work.

I also take this opportunity to express my special thanks to my faculty advisor **Dr. Gangadhar Mahesh** for his guidance during this work.

I am extremely thankful to **Dr. K Swaminathan**, Professor and Head of the Department of Civil Engineering, National Institute of Technology Karnataka for granting permission to do this Project work.

I would like to extend my appreciation towards Mr**. Sivaprasad** a PHD scholar for his advice, encouragement, and help throughout this project.

Finally, I would like to thank my beloved family and friends for their all time support advice and encouragement.

…………………………

IRAMBONA THEODOSE

(172CM021)

ABSTRACT

Cement and cementitious materials are being used worldwide as the most popular multipurpose construction materials but cement is not a sustainable material and energy intensive. Greenhouse gas (CO2) produced by portland cement industries during the manufacturing process of cement causes environmental impact thus efforts have been made for alternative binders. Geopolymer technology is one of the new technologies experimented to reduce the use of portland cement in concrete industries because it shows the most hopeful green and eco-friendly alternative to cementitious materials (doesn't emit green house gases during polymerisation process).The aim of this study is to produce fast setting fly ash and Ground Granulated Blast Furnace Slag (GGBS) based geopolymer mortar reinforced with crimped steel fibers. In this research, the influence of various parameters such as steel fiber volume content, the ratio of activator/binder ratio, the effect of variation of GGBS percentage on the setting time and compressive strength were investigated. Four different alkaline liquid to binder ratio (0.5 to 0.8), three different percentage of crimped steel fibers (0.5,1 & 1.5% by total volume of binder) with Six different binder combinations of Fly ash and GGBS (100%:0%, 90%:10%, 80%:20%, 70%:30%, 60%:40%, 50%;50) were used for preparation of steel fiber geopolymer mortar. The tests conducted include setting time and flow capacity of fresh geopolymer mortar, compressive strength and structural properties (SEM) of steel fiber fly ash and GGBS based geopolymer mortar. The tests for compressive strength were carried out on 70.6x70.6x70.6 mm cube steel fiber geo-polymer mortar specimens at 3, 7 and 28 days .The results obtained from this study, show that in all mixes, the setting time (both initial and final) of geopolymer mortar increases with the increase of alkaline to binder ratio and then decreases with the increase in GGBS content .they also show that incorporation and increase of steel fibers in plain mortar have improved significantly its compressive strength. Optimum fiber content showing the maximum strength value in all mixes is 1%. The highest 28 days compressive strength was found to be 69.5 MPa at 1% fibers content for alkaline to binder ratio of 0.6 with 50%:50% FA and GGBS content. SEM images show that there is a relatively good bond between the geopolymer matrix and the steel fiber which lead to higher compressive strength.

Keywords: Fibers, Geopolymer, Setting time, Mini flow, Compressive strength and SEM.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

FA : Fly Ash

GGBS : Ground Granulated Blast Furnace Slag

B : Binder

M : Morality

B/S : Binder to Sand

Alk/B : Alkaline to Binder ratio

PM : Plain Mortar

GM_1 : Geopolymer Mix number 1

F100G0 :100% FA and 0% GGBS

F90G10 : 90% FA and 10% GGBS

F80G20 : 80% FA and 20% GGBS

F70G30 : 70% FA and 30% GGBS

F60G40 :60% FA and 40% GGBS

F50G50 :50% FA and 50% GGBS

CHAPTER 1

INTRODUCTION

1.1. BACKGROUND

In construction, cement is being used worldwide as a multipurpose material but greenhouse gas (CO2) produced during its manufacturing process causes major problems in environment. Many researchers have shown that for every ton of OPC produced; approximately one ton of CO2 is released into the atmosphere. Hence, there is a need to find an alternative type of binder to produce more environmentally friendly concrete/mortar (Porkodi.R et al.2005). Geopolymer technology has been attempted as one of the new technologies to reduce the use of portland cement in concrete because it shows the most hopeful green and eco-friendly alternative to cementitious materials (Xiaolu Guo and Xuejiao Pan ,2018).

Geopolymers are inorganic aluminosilicate polymeric material produced by polymerisation of aluminosilicate precursors with alkaline activators solutions, which set and harden at adjacent ambient temperatures (T.Williamson and M.C.G. Juenger ,2016). A geopolymer is made by activating amorphous alumino-silicate materials with an alkaline solution (a combination of NaOH or KOH and Na2SiO3 or K2SiO3) and other constituents, if necessary. Davidovits J.(1988b) proposed that to produce binder, an alkaline liquid could be used to react with the aluminium (Al) and the silicon (Si) in a source material of geological origin or in by-product materials such as blast furnace slag, fly ash, rice husk ash, etc.

There are two major constituents of geopolymers: The source materials or materials rich in silicon (Si) and aluminium (Al). The second constituent is alkaline liquids or alkaline activators such as Sodium Hydroxide (NaOH) or Potassium Hydroxide (KOH) and Sodium Silicate (Na2SiO3) or Potassium Silicate (K2SiO3). All those constituents play a significant role in geopolymer reaction and affect the mechanical properties and microstructure of the final geopolymer products. The production of geopolymer materials does not need to heat or calcine raw materials at a high temperature, only parts of raw materials need to be dried at a relative low temperature, and the process of geopolymerization can be finished at room temperature to 150 ^{C}, and CO_2 emissions are also very low (Xiaolu Guo and Xuejiao Pan ,2018)**.**The acceptance or adoption of geopolymer materials could reduce 80% of the CO_2 emissions produced during cement production. One of geopolymer construction materials is geopolymer concrete; it is obtained by activating industrial by-products material with alkaline activators solution. There the source materials or industrial by-products react with NaOH or KOH and Na_2SiO_3 or K_2SiO_3 and form a gel which holds the fine and coarse aggregates together. Many properties are there to make the geopolymer concrete more important than ordinary concrete, some of them are: less hydration heat, earlier gaining strength and higher compressive strength, higher chemical resistance, good resistance to acid, good sulfate attack resistance, etc. Geopolymer concrete also has rapid strength gain and cures very quickly. The time of hardening is very short; in first 4 hours of setting they obtain 70% of the final compressive strength.

Mostly around the world in construction industries, concrete is the most widely used structural material but for a variety of reasons, much of this concrete is cracked. The reason for concrete materials to suffer from cracking maybe attributed to structural, environmental or economic factors, but researches shows that most of the cracks are formed due to the inherent weakness of the material to resist tensile forces. It is now well established that fiber reinforcement offers a solution to the problem of cracking by making concrete tougher and more ductile. The addition of fibers to the composite depends upon volume concentration of fibers in the matrix, the fiber material and type, Length (l), diameter (d) and aspect ratio (l/d) (Porkodi R et al.2015).The essential variables that governing the performance of fiber reinforced mortar or concrete are fiber efficiency and fiber content (Plizzari andG. A, 20 04). Fiber affects the mechanical properties of concrete in all modes of failure, mainly those that motivate or influence fatigue and tensile stresses. The mechanism that toughening fibers includes transfer of stress from the matrix to the fiber by interfacial shear or by interlock between the fiber and matrix. With the augmentation of the applied load, stress is shared by the fiber and the matrix in tension until the matrix cracks then the total stress is more transferred to the fibers, till the fibers are break **(**Porkodi.R et al.2015)**.** The incorporation of steel fibers to geopolymer mortar or concrete considerably affect its workability and improves its hardened properties like flexural strength, impact strength, tensile strength, ductility and flexural toughness. Investigation done on effect of different fibre types on fibre reinforced geopolymer composite show that implementation of all fibre types improved automatically the flexural strength & compressive strength, improve the energy absorption and tensile strength of the fly ash based geopolymer (Natali A et al.2011)

In this research, fly ash and GGBS have been used together with Crimped steel fibers to produce crimped steel fiber geopolymer mortar. Setting time of geopolymer mortar, the effect of steel fibers content on flow capacity of geopolymer mortar, the compressive strength behavior and the micro-structural properties of crimped steel fiber geopolymer mortar were investigated.

1.2 OBJECTIVES

The general objective of this research is to produce fast setting steel fiber geopolymer mortar cured under ambient temperature using FA& GGBS as binder materials. The following are the specific objectives:

1. To investigate the effect of variation of binder proportions (FA& GGBS) on the setting time of geopolymer mortar for different alkaline to binder ratios.
2. To investigate the effect of steel fibers content on fresh properties (flow capacity) of FA& GGBS based geopolymer mortar.
3. To examine and analyze the impact of steel fibers on the compressive strength behavior of geopolymer mortar cured under ambient temperature for different alkaline to binder ratios.
4. To investigate the micro-structural properties of fast setting steel fiber admixed FA & GGBS based geopolymer mortar.

1.3 SCOPE OF THE WORK

This research work involved production of fast setting fiber geopolymer mortar cured under ambient temperature. The test procedures conducted for portland cement mortar were used. In the experimental work, by-products materials such as fly ash from UDUPI power plant and GGBS from Jindal steel were used as binder without any conventional cement, a commercially available crimped steel fibers and local available river sand were also used in producing steel fiber geopolymer mortar. Setting time test, mini flow table test and compressive strength development of geopolymer mortar were studied for various combinations of different parameters.

1.4 ORGANISATION OF REPORT

This section presents a brief description of five chapters arranged in order to make this Thesis clear and understandable.

Chapter1: This chapter introduces in general geopolymer and its constituents, fiber geopolymer mortar, objectives of this research and the scope of the work.

Chapter 2: Gives a brief review of geopolymer technology and materials, fibers as material to reinforce concrete or mortar and some of the previous research on fiber geopolymer mortar or concrete.

Chapter3: Describes the methodology adopted in this research such as the materials used, mixture proportions, test parameters, test procedures and equipment used for the experimental works.

Chapter 4: Presents the experimental test results, discussions and analysis of the test results.

Chapter 5: Gives general conclusions from this research work based on experimental test results obtained and scope for future research. It also shows the list of references used in this research work then finally appendices.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

This section presents the information about fibers, geopolymer (its constituents of and applications) and literature survey on fiber geopolymer mortar/concrete.

2.2 FIBERS

Fiber is a small piece of reinforcing material possessing certain characteristic properties. They can be circular, square, rectangular, flat or irregular cross-sections. Fibres vary in types, geometry, properties and availability in construction industry. Fibre geometry differs from hooked end fibres, deformed fibres, deformed wires, fibre mesh, wave-cut fibres, large end fibres, etc. Fibres are selected from their properties like effectiveness, cost and availability. The usage of fibres depends on the requirement of behavior and properties for a concrete allowing the increase of the specific effects and mechanical properties (Milind V. Mohod ,2015). Fibers have been used to reinforce brittle materials since ancient times; straws were used to reinforce sunbaked bricks, horse hair was used to reinforce plaster and more recently, asbestos fibers are being used to reinforce portland cement. Now days a variety of materials such as polypropylene, nylon, polyester, glass, carbon, basalt and steel fibers can be used in fiber reinforced concrete in many large projects like the construction of industrial floors, pavements, highway-overlays, etc. For each application it needs to be determined which type of fiber is optimal in satisfying the purpose. The addition of steel fibers to concrete considerably improves its properties of concrete in the hardened stage such as tensile strength, impact strength, flexural strength, ductility and flexural toughness. They are also able to prevent surface cracking through bridging action leading to an increased impact resistance of the concrete. The characteristics of fiber reinforced concrete depend upon many factors such as size, type, elastic properties, aspect ratio and volume fraction of fibers (Aiswarya Sukumar and Elson John ,2014).

2.2.1 Fiber types

There are various fiber types acceptable for commercial and experimental use such as steel fiber, polypropylene fiber, organic fiber, glass fiber, carbon fibers, asbestos fibers, etc. Normally in concrete, low modulus fibres such as polypropylene can reduce cracking due to shrinkage and control spalling phenomena whereas steel fibres with high modulus are used to improve mechanical properties (Sasikala K and Vimala S,2013). Different types of fibers used in concrete industry are shown in figure 2.1.

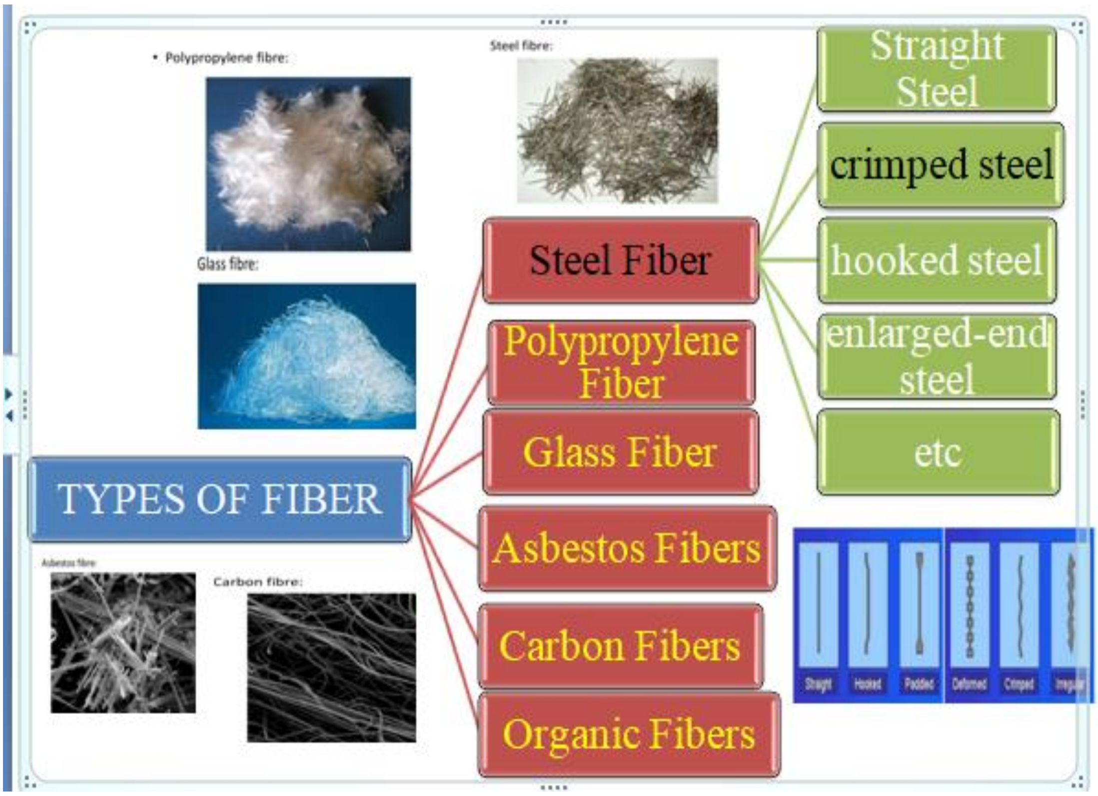


Figure2. 1 Types of fiber

2.2.1.1 Steel fibers

Steel fibers are added to concrete matrix to provide increase in flexural, compressive and tensile strength, toughness, and dynamic strength (impact resistance). The main two physical properties that are used to define steel fibers: an aspect ratio (the length to diameter ratio) and the geometry of the fiber (straight, crimped, hooked, enlarged-end, etc). In the case of square or rectangularly shaped steel fibers, an equivalent diameter is commonly used rather than the actual width to calculate the aspect ratio (James E. Shoenberger and Joe G. Tom ,1992**)**. Steel fibers have a relatively high strength and modulus of elasticity, they are protected from corrosion by the alkaline environment of the cementitious matrix, and their bond to the matrix can be enhanced by mechanical anchorage or surface roughness. Important fiber reinforcement properties are strength, stiffness and the ability of the fibers to bond with the concrete. This bond depends on the aspect ratio of the fiber ranging from 20 to 100, while length dimensions range from 6.4 to 76 mm (ACI Committee 544, 2002)**. ACI** ASTM A 820 and JSCE set up bending requirements and minimum tensile strength for steel fibers as well as tolerances for diameter (or equivalent diameter), length and aspect ratio. The minimum tensile yield strength required by JSCE is 552 MPa while for ASTM A 820 the Specification requirement is 345 MPa.

2.2.1.2 Glass fibers

Glass fibers are produced by pulling molten glass through orifices at a temperature where the glass has just the right amount of viscosity. Due to their combination of low cost, high strength and relatively low density glass fibers (commercially known as fiberglass) are most widely use reinforcements for polymer matrix composites. They are used in the manufacture of structural composites, printed circuit boards and a wide range of special-purpose products (Frederick T.Wallenberger et al.2001). ASM International (2001) classified Glass fibers into two categories: low-cost general-purpose fibers and premium special-purpose fibers. General- purpose categories occupy over 90% of all glass fibers. These fibers are known by the designation E-glass and are subject to ASTM specifications. The remaining glass fibers are premium special-purpose products. S-glass, D-glass, A-glass, ECR-glass, ultrapure silica fibers, hollow fibers, and trilobal fibers are special-purpose glass fibers.

The physical properties and major classification of glass fiber are shown in table below:

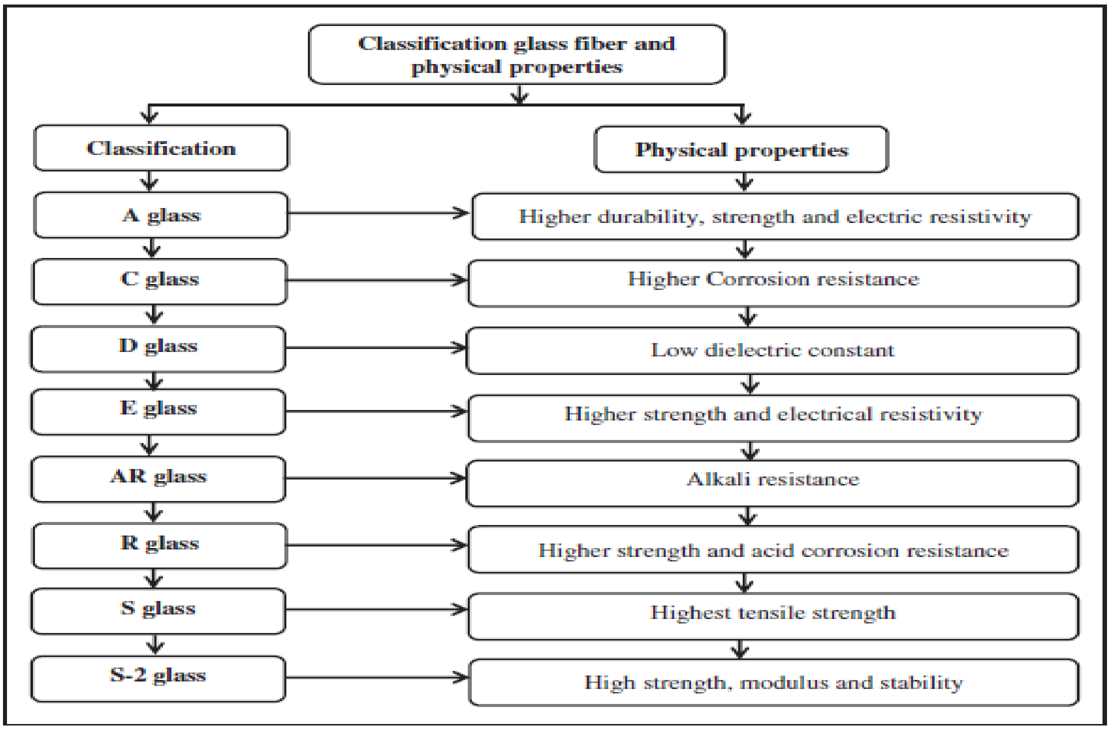


Figure2. 2 Classification and physical properties of various glass fibers

Table 2. 1 Characteristic and use of various glass fiber grades

Letter designation	Property or characteristic	Use
E	electrical Low electrical conductivity	Electrical Insulation
S	strength High strength	High Strength Composites
C	chemical High chemical durability	Chemical Applications
M	modulus High stiffness	-
A	alkali High alkali or soda lime glass	Thermal Insulation
D	dielectric Low dielectric constant	-

2.2.1.3 Polypropylene fibers

Polypropylene is a synthetic hydrocarbon polymer material. Polypropylene is accessible in two forms (monofilament and film fibers). Monofilament fibers are manufactured by an extrusion process through the orifices in a spinneret and then cut to the desired length. The process of newer film is similar but the only difference is that the polypropylene is expelled through a die -that produces a tubular or flat film (James E. Shoenberger and Joe G. Tom, 1992) **.**Monofilament fibers were the first type of polypropylene fiber introduced as an additive in PFRC. Monofilament fibers are available in lengths of 1/2, 3/4, and 1-1/2 inches (Milind V. Mohod , 2015)**.** Polypropylene has a melting point of 165 degrees C and can resist temperatures of over hundred degrees Celsius for short periods of time before softening. It is chemically inert and any chemical that can damage these fibers will probably be much more harmful or unfavorable to the concrete matrix. The fiber is susceptible to degradation by **UV** radiation (sunlight) and oxygen; however, in the concrete matrix this problem is eliminated (James E. Shoenbergerand Joe G. Tom, 1992)**.** Polypropylene fiber has some special characteristics such as high strength, ductility and durability, abundant resources, low cost, and easily physical and chemical reformations according to certain demands, thus it can be broadly utilized in the field of concrete products.

2.3 GEOPOLYMER

The term geopolymer was coined by Davidovits in 1978 to represent a broad range of materials characterized by chains or networks of inorganic molecules. Geopolymers achieve structural strength by utilizing the polycondensation of silica and alumina precursors. Source materials or by-product materials (materials rich in aluminium (Al) and silicon (Si) such as fly ash, silica fume, slag, rice-husk ash, red mud, etc) and alkaline liquids are the two main constituents of geopolymers.

2.3.1 Geopolymerisation

The geopolymerisation is an integrated process for the synthesis of geopolymer, which involves the reactions between two parts of raw materials: Alumino-silicates and alkaline activators. The exposure of aluminosilicate materials such as fly ash, blast furnace slag, etc to high-alkaline environments (hydroxides, silicates) gives rise to the formation of a geopolymer. These materials represent a new order of cementitious products able to provide ceramic and zeolitic properties not normally present in traditional cement materials (Petermann et al.2010).

2.3.1.1 Mechanism of geopolymerization

Geopolymerization is complex process accompanied by an exothermic production; the following are the stages of geopolymerization: Destruction to coagulation, coagulation to condensation, condensation to crystallization. To produce geopolymer concrete, two main stages are carried out as shown in Figures 2.3. Stage one is aluminosilicate dissolution and formation of polymer species, stage two includes growth of polymeric particles through nuclei achieve critical size (which give crystals) also crystals start to create. Dissolution stage begins when Si-Al from raw materials contacts alkaline solution, to produce Si and Al species. Many variables influence formation of Si and Al species, like alkaline metal type (Na+ or K+), alkaline solution concentration, rate, and time mixing. Reorientation stage includes Si and Al diffused into the oligomers after dissolution. Oligomers into aqueous phase form many networks by condensation to gel formation, filtration of reactive Al and Si species from the raw materials is happening at Al+3 and Si+4 dissolving on surface of source Si-Al materials are removed. Solidification stage incorporates for formation of continuous gel including rearranging and reorganization. Three stages lead to produce geopolymer with amorphous, or semi-crystalline, three-dimensional aluminosilicate, network (Hameed AM et al. 2017).

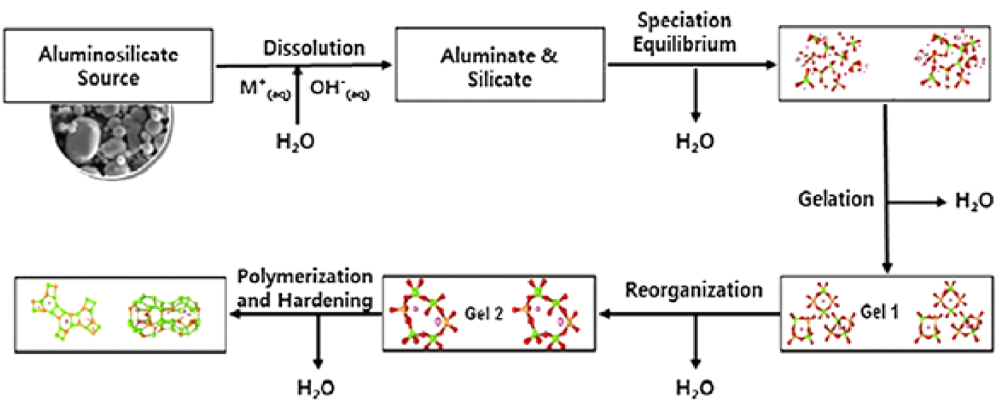


Figure2. 3 Stages of geopolymerisation process

2.3.2 Constituents of Geopolymer

2.3.2.1 Source Materials

Source materials are materials that mostly contain Silicon (Si) and Aluminium (Al) in amorphous form for the manufacture of geopolymer. Various materials or industrial by-product materials like low-calcium (Class F) fly ash, slag, rice husk ash, metakaolin, natural Al-Si minerals, combination of fly ash and metakaolin, and combination of granulated blast furnace slag and metakaolin and etc, can be used for assembling geopolymer. This section focuses on Fly ash and Ground-Granulated Blast-Furnace Slag (GGBS) as source materials because they have been proved to be the potential source materials for development of geo-polymer mortar or concrete (Xu et al. 2000).

2.3.2.1.1 Fly ash

Fly ash is the finely divided residue that results from the combustion of pulverized coal and is transported from the combustion chamber by exhaust gases. Fly ash consists primarily of oxides of silicon, aluminum iron and calcium; Magnesium, potassium, sodium, titanium, and sulfur. ASTM (American Society for Testing and Materials) classifies fly ash into two main types for various applications. They are class F and class C which are categorized depending upon chemical properties of fly ash. Class C ashes are generally derived from sub-bituminous coals and consist primarily of calcium alumino-sulfate glass, as well as quartz, tricalcium aluminate, and free lime (CaO). Class C ash is also referred to as high calcium fly ash because it typically contains more than 20 percent CaO and it is mostly used in situations where higher early strengths are important. Class F ashes are typically derived from bituminous and anthracite coals and consist primarily of an alumino-silicate glass, with quartz, mullite, and magnetite also present. Class F or low calcium fly ash contains less than 10 percent CaO. This type is a solution to a wide range of summer concreting problems and where concrete may be exposed to sulphate ions in soil and ground water (American Coal Ash Association ,2003). Low-calcium (class F) fly ash is accepted as a source material than high calcium (class C) fly ash since the high amount of calcium may interfere with the polymerisation process and modify the microstructure (Xu et al. 2000).

Chemical composition of Fly ash

The chemical compsition of fly ash depends upon the type of coal used and the methods used for combustion of coal.

Table 2. 2 Chemical composition of fly ash of different coals

Component	Bituminous coal	Sub Bituminous coal	Lignite Coal
SiO2 (%)	20-60	40-60	15-45
AL2O3 (%)	5-35	20-30	20-25
Fe2O3 (%)	10-40	4-10	4-15
CaO (%)	1-12	5-30	15-40
LOI (%)	0-15	0-3	0-5

Benefits of fly ash to concrete vary depending on the type of fly ash, proportion used, other mix ingredients, mixing procedure, field conditions and placement. Fly ash improves concrete's workability, pumpability, cohesiveness, finish, ultimate strength, and durability as well as solves many problems experienced with concrete today and all for less cost. Good quality fly ash generally improves workability or at least produces the same workability with less water (A.Alekhya and Y.Mahesh ,2017**).** Fly ash also has significant environmental benefits such as improving concrete durability, net reduction in energy use and greenhouse gas and other adverse air emissions when fly ash is used to replace or displace manufactured cement, reduction in amount of coal combustion products that must be disposed in landfills, and conservation of other natural resources and materials (American Coal Ash Association ,2003)**.**

2.3.2.1.2 Ground-Granulated Blast-Furnace Slag (GGBS)

Ground granulated blast furnace slag (GGBFS) is a by-product of the iron production process, primarily made up of silica, alumina, calcium oxide, and magnesia (it mostly consists of 95% of alumino-silicates and calcium silicates). Other elements like manganese, iron, sulfur, and trace amounts of other elements make up about other 5% of slag .The exact concentrations of each element vary slightly depending on where and how the slag is produced. Ground granulated blast furnace slag has a lower heat of hydration and thus during concrete production and curing generates less heat. As an outcome, GGBFS is a desirable material to apply in mass concrete placements where control of temperatures is an issue (David N. Richardson ,2006).

The major benefits of GGBS include better workability, making placing and compaction easier, lower early age temperature rise, reducing the risk of thermal cracking in large pours, high resistance to chloride ingress, reducing the risk of reinforcement corrosion, high resistance to attack by sulphate and other chemicals and other considerable sustainability benefits (D. Suresh and K. Nagaraju ,2015). All above benefits can extend the service life of structures and reduce the overall maintenance costs of concrete. Ground granulated blast furnace slag is also used for cement replacement to reduce the maximum temperature rise in mass concrete. It has a positive effect on both the flexural and compressive strength of concrete after 28 days. The research showed that the real gain in strength is noticed after the 28 day while in the first 7 days the compressive strength is generally slightly lower than pure 100% portland cement mixtures (V. Cervantes and J. Roesler ,2007). Proportions of GGBFS in a mix depend on the different parameters such as the purpose for which the concrete is being used, the grade (activity) of the slag, the characteristics of the cement or activator and the curing temperature (David N. Richardson ,2006).

2.3.2.2 Alkaline liquids

Alkaline liquid mostly used in geopolymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate (Na2SiO3) or potassium silicate (KSiO3). However, sodium hydroxide and sodium silicate are the most common alkaline liquid used in geo-polymerization. The Research showed that generally NaOH solution caused a higher extent of dissolution of minerals than the KOH solution. Polymerization occurs at a high rate when the alkaline liquid contains soluble silicate as compared to the use of alkaline hydroxides only. Alkaline liquid prepared by adding sodium silicate solution to the sodium hydroxide solution upgraded the reaction between the fly ash and the solution (S. V. Joshi and M. S. Kadu ,2012).

2.3.3 Factors affecting strength of Geopolymers.

Shriram Marathe et al.(2016) in their research discussed in brief the major factors affecting the fresh and hardened properties of GPC.

- **Molarity:** The molarity of alkali (NaOH solution) plays an important role in the strength of GPC with a higher concentration of NaOH solution a higher compressive strength can be achieved.
- **Sodium silicate to Sodium hydroxide ratio:** The GPC mix produced by maintaining the ratio as 2.5 gives a higher compressive strength. For producing optimum results, a ratio of 1.5 has been suggested.
- **Water to geopolymer solids ratio:** In this parameter the total mass of water is the sum of the mass of water contained in the sodium silicate solution, the mass of the water use in the making of the sodium hydroxide solution and the mass of extra water, if any present in the mixture.
- **Fly ash (Binder) and alkaline activator ratio***:* Higher fly ash contents with a higher alkaline activator content gives a high compressive strength and vice versa.
- **Rest Period***:* Rest period increases the compressive strength of geopolymer concrete. Rest period is time between casting and curing and is of 3 hour to 2 days, inclusion of a 24 hour period before curing.

2.3.4 Fields of Applications of geopolymer materials.

The application of geopolymeric materials is determined by the chemical structure in terms of silica to alumina atomic ratio (Si: Al) in the polysialate. J.Davidovits (1999) classified the type of application according to the ratio Si: Al as shown in table below.

Table 2. 3 Applications of geopolymeric materials based on Si: Al atomic ratio.

Si: Al ratio	**Applications**
1	• Bricks • Fire protection • Ceramics
2	• Low CO2 cements and concretes • Radioactive and toxic waste encapsulation
3	• Tooling for aeronautics titanium process • Fire protection fibre glass composite • Foundry equipments • Heat resistant composites, 200°C to 1000°C
>3	• Tooling for aeronautics • Sealants for industry, 200°C to 600°C
20-35	• Fire resistant and heat resistant fibre composites

Geopolymer materials can also be used to develop building products such as fire resistant wall panels, masonry units, protective coatings and repairs materials, Shotcrete, sewer pipeline products ,etc.

2.4 LITERATURE SURVEY

Geo-polymer concrete is generally a mix of binder and alkali solution with a replacement of some percentage of fly-ash with Ground Granulated Blast Furnace Slag (GGBS) shows a good result. The alkali solution is the mixture of Sodium Hydroxide (or Potassium Hydroxide) and Sodium Silicate (or Potassium Silicate) to a different ratio. Other ingredients such as Naphthalene based Super Plasticizer and glass powder can also be added to improve the fresh and hardened properties of GPC (Mithanthaya I.R and Bhavanishankar Rao N. ,2015).

Vishnu Ramesh and Annie Joy (2017) in their review on the study of fly ash based geopolymer concrete concluded that compressive strength of geopolymer concrete is sufficient enough to be used in construction activities. Main consideration should be given to the curing process. It means proper oven curing leads to good strength properties; otherwise the strength attainment may consume time. This geopolymer concrete technology proves to be an alternative to cement and it can reduce or eliminate the harmful effects caused by cement by reducing the emission of CO_2; at the same time fly ash as a byproduct material which is largely available can be effectively utilized for construction. The authors also said that factors such as sodium silicate to sodium hydroxide ratio or potassium silicate to potassium hydroxide ratio, molarity of sodium hydroxide or potassium hydroxide (according to alkali used), alkali to binder ratio, curing temperature and curing period must be considered .

Mohammed Haloob Al-Majidi et al.(2014) studied experimental investigation on the mechanical and micro-structural properties of geopolymer concrete mixes prepared with a combination of fly ash and slag cured under ambient temperature. User friendly' geopolymer mixes were produced using fly ash (FA) and Ground Granulated Blast furnace Slag (GGBS) mixed together with potassium silicate with molar ratio equal to 1.2 (as the activator) and water. Five different mixtures of geopolymer mortar proportions were examined with various ratios of GGBS to total binder (10%, 20%, 30%, 40% and 50 %. The results indicated that increasing the GGBS content in the fly ash-based geopolymer mortar decreases the workability and accelerates the setting times (initial and final) and hardening and heat curing treatment can be avoided by partial replacement of fly ash with slag. The results also showed that the compressive strength was considerably affected by blend composition. Improvements in compressive strength have been observed by increasing the GGBS to total binder ratio in geopolymer mortar mixtures. Increasing GGBS content from 10% to 50 % of the total binder increased the compressive strength from 18.45 to 48MPa at 28 days. The compressive strength of the examined mixes was found to be in the range of 40-50MPa for 40 % and 50 % GGBS replacement mixtures respectively. Moreover, the flexural and direct tensile strengths of geopolymer mixes are considerably improved as the GGBS content is increased. Based on FTIR and SEM/EDS analysis, the inclusion of a higher content of GGBS resulted in a denser structure by formation of more hydration products.

2.4.1 Effect of fibers on the properties of Geopolymer mortar/Concrete.

Porkodi.R et al.(2015) carried out research on experimental study on fiber reinforced self-compacting geopolymer mortar. The study focuses on evaluation of mix proportions, self compacting and strength properties of geopolymer mortar for various mix proportions with different fiber. Experiments were performed using Low-calcium (class F) Fly ash (with specific gravity of 2.36 and fineness of 4%), natural river sand, sodium hydroxide in the form of pellets with 99% purity and sodium silicate solution (Grade 53A with Sio2= 29.43%, Na2O= 14.26% and Water = 56.31%), a commercially available Superplasticizer (Conplast SP430 and Glenium SKY 8233 from BASF) and polypropylene fiber (length =12mm, diameter= 18µm, specific gravity= 0.91 and aspect ratio of 0.67) , E-glass fiber (length =11mm, diameter= 18µm, specific gravity= 0.91 and aspect ratio of 0.67) ,steel fiber (length =12.5mm, diameter= 450µm, specific gravity= 0.91 and aspect ratio of 0.91 27.77) were used . The alkaline solution to fly ash ratio was kept at constant as 0.45 whereas the ratio of sodium silicate to sodium hydroxide solution was kept 1:1 and fly-ash to sand ratio was 1:1 for mix proportion. Mortar cubes of size 70.6x70.6x70.6 mm were casted and cured at 70°C for 24 hours in the oven. The workability of fresh mortar was determined using slump flow, V-funnel, U-Box, J-Ring, and V-funnel at T5 minutes as per EFNARC guidelines. Authors concluded that geopolymer mortar with polypropylene fiber gives more compressive strength when compared with cement mortar of same mix proportion. Self-compacting geopolymer mortar with polypropylene fiber having 0.45 solution/binder ratio shows more compressive strength and also satisfies the workability properties of self-compacting mortar as per EFNARC guidelines, when compare with cement mortar of same mix proportions.

Atteshamuddin S. Sayyad and Subhash V. Patankar (2013) investigated the effect of steel fibres and low calcium fly ash on mechanical and elastic properties of geopolymer concrete composites (GPCC). The study also analyses the impact of steel fibres and low calcium fly ash on the compressive, flexural, split-tensile, and bond strengths of hardened GPCC. Geopolymer concrete mixes were prepared using low calcium fly ash and activated by alkaline solutions (13M NaOH and Na_2SiO_3) with solution to fly ash ratio of 0.35. Crimped steel fibres having aspect ratio of 50 and modulus of elasticity (E) of 210GPa with volume fraction of 0.0% , 0.1%, 0.2%,0.3% ,0.4% and 0.5% by mass of normal geopolymer concrete were used. The inclusion of steel fibre showed the excellent improvement in the mechanical properties of fly ash based geopolymer concrete. The experimental results showed that the wet and dry densities of geopolymer concrete composites increased continuously with increase in fibre content, whereas the workability of geopolymer concrete composites reduced with increase in fibre content. The maximum percentage increase in compressive strength, flexural strength, split tensile strength, and bond strength is 29.98%, 30%, 30.05%, and 16.11%, respectively.

P.Eswaramoorthi and G.E.Arunkumar (2014) conducted a study on properties of geopolymer concrete reinforced with polypropylene fibers. The aim of the study was to develop a mixture proportioning process to manufacture low-calcium fly ash based geopolymer concrete, to identify and study the effect of salient parameters that affects the properties of low-calcium fly ash based geopolymer concrete and to study the short-term engineering properties of fresh and hardened low calcium Fly ash- based geopolymer concrete. Materials used to perform experiments were fly ash (specific gravity of 2.2, fineness of 310 m^3 /kg) , fine aggregate (specific gravity 2.6),coarse aggregate(size =12mm,specific gravity of 2.6) , water (ordinary portable water) , polypropylene fibers (aspect ratio= 1800 , specific gravity 8) , sodium silicate solution(Na_2O =15.9% , SiO_2= 31.4% and H_2O= 52.7%) , sodium hydroxide (of the lowest cost).The results show that , the compressive strength of the geopolymer concrete with fibers has increased by 10.70% than conventional concrete. Split tensile strength of geopolymer concrete with fibers has increased by 13.62%, than conventional concrete. They also concluded that low-calcium fly ash-based geopolymer concrete has excellent compressive strength and is suitable for structural applications. As per load deflection test, strain energy absorbed, ductility factor and, toughness index, are considerably increases in GPC with addition of polypropylene fibers. Due to geopolymer concrete the consumption of cement, emission of carbon di -oxide and greenhouse effect are reduced.

Banda Rohit Rajan and K.Ramujee(2015) investigated the properties of geopolymeric binder cured under ambient and oven temperature prepared using the source materials such as Fly Ash and Ground Granulated Blast Furnace Slag (GGBS) without using any conventional cement. The individual properties of the mortar such as setting time, normal consistency, slump test, compressive strength, were determined. The various combinations of fly ash (class F) and GGBS 90% & 10%, 80% & 20%, 70% & 30%. The alkaline activator liquid which is a combination of sodium silicate solution (Na_2O = 14.7%, SiO_2 =29.4% and 55.9% water) and 6M, 8M, 10M,& 12M sodium hydroxide in pellets form (NaOH with 98% purity). The ratio of Na_2SiO_3 /NaOH was taken as 2 and 2.5 and the alkaline liquid to binder ratio as 0.45. The fine aggregate was river sand with specific gravity of 2.54 and fineness modulus of 2.65. The test results have shown that the geopolymer mortar develops the strength even at ambient conditions. Compressive strength increases with an increase in the quantity of GGBS. It was also found that geopolymer mortars made with Na_2SiO_3 /NaOH ratio as 2.5 & alkaline liquid to binder ratio as 0.45 produces higher strength. They also concluded that the results of geopolymer mortars are high when compared with conventional mortars in terms of strength.

Dr. S. A. Bhalchandra and Mrs. A. Y. Bhosle (2013) carried out research on experimental program to determine mechanical properties of glass fibre reinforced geopolymer concrete, they studied also the effects of inclusion of glass fibers on density, compressive strength & flexural strength of hardened geopolymer concrete composite (GPCC). Experimental materials were fly ash (low calcium dry fly ash), alkaline liquids (sodium silicate is Na_2O=16.37%, SiO_2=34.35%, water=49.28% and NaOH with 98% purity), fine & course aggregates and glass fibres (of 12mm length & 14µm diameter). Alkaline liquids to fly ash ratio were fixed as 0.35 with 100% replacement of ordinary portland cement by fly ash. For alkaline liquid combination ratio of sodium hydroxide solution to sodium silicate solution was fixed as 1.00. Glass fibers were added to the mix in 0.01%, 0.02%, 0.03% & 0.04% by volume of concrete. Based on the test results it was observed that the glass fibers reinforced geopolymer concrete have relatively higher strength in short curing time (3 days) than geopolymer concrete & Ordinary Portland cement concrete. They concluded that geopolymer concrete is an excellent alternative to Portland cement concrete ;Density of Geopolymer concrete is similar to that of ordinary Portland cement concrete; low calcium fly ash based geopolymer concrete has excellent compressive strength within short period (3 days) & suitable for structural applications. The results also showed that additional of glass fibres in geopolymer concrete shows considerable increase in compressive & flexural strength of GPCC with respect to GPC without fibres. Compressive strength &flexural strength of glass fibre reinforced geopolymer concrete increases with respect to increase in percentage volume fraction of glass fibres from 0.01%, 0.02%, 0.03% &0.04%. Addition of 0.03% volume fraction of glass fibres shows maximum increase in compressive strength & flexural strength by 20.2%, & 57% respectively with respect to GPC mix without fibres.

Based on experiments study conducted on a comprehensive study of the polypropylene fiber reinforced fly ash based geopolymer by Ranjbar et al.(2016), the results have shown that the workability of the composite reduced significantly by increasing the percentages of fiber inside because of higher shear resistance to flow. Moreover, setting time was affected and compressibility of the materials increased. Shrinkage of the composite can be controlled based on the fiber content which was the best for 3% addition of PPF into the geopolymer matrix. Based on the fiber content, shrinkage effects might appear in the form of geometrical deformation with or without visible cracks. The mechanical properties of the composites are governed by the strength development of the geopolymer matrix itself. Experiments were performed using class F fly ash obtained from local industry, alkaline activators (sodium silicate and sodium hydroxide solutions). Sodium hydroxide (NaOH) was prepared in pellet form with 99% purity while sodium silicate (Na2SiO3) was used in liquid form with about 1.5gr water per milliliter at 20°C with a modulus ratio of 2.5 (SiO2/Na2O, SiO2 = 30% and Na2O = 12%). The ratio of Na2SiO3: NaOH: H2O was 2.5:1.0:0.7. The content of PPF (with 12.19 mm in length, ~40 μm in diameter and 0.9 as specific gravity) in geopolymer paste varied in the range of 0.5%, 1%, 2%, 3%, 4%, and 5%. It was observed that both compressive and flexural strength of the pure geopolymer specimens, without PPF content, was increased by time. However, incorporation of the PPF into the geopolymer nullified the effects of geopolymer matrix strengthening because of weak fiber-matrix interfacial contact and breaking the geopolymer bonds.

G.Ramkumar et al.(2015) studied the effect of steel fibres on mechanical and elastic properties on geopolymer concrete. The materials used for making fly ash geopolymer concrete composite specimens are low-calcium fly ash, course and fine aggregates, steel fibres, alkaline solution, and water. Three GPC mixes of fly ash (50%) and GGBS (50%) in the binder stage were considered. with control GPC mix, GPC mix with added stainless steel fibre and mild steel fibres. The alkaline activator solution (AAS) used in GPC mixes was a combination of sodium silicate solution (Na_2SiO_3, SiO_2/Na_2O=2.2), sodium hydroxide pellets (NaOH) and distilled water. Crimped stainless steel fibres and crimped mild steel fibres of aspect ratio (a/d) 60 were used. The studies showed that the load carrying capacity of most of the GPC mix was in most cases more than that of the conventional OPCC mix. The deflections at diverse stages including service load and peak load stage were higher for GPC beams. The studies also have shown that with the addition of steel fibres in GPC diminished the workability of concrete mix and also diminish the crack propagation in concrete and can achieve higher peak value. There is no need of exposing geopolymer concrete to higher temperature to achieve most extreme strength.

A.Alekhya and Y.Mahesh (2017) have carried out an experimental study consists of geopolymer concrete composites by using glass fibers with volume fractions of 0.01%, 0.02% and 0.03% of concrete. The study was designed to evaluate the mechanical properties of glass fiber reinforced geopolymer concrete composites consisting of 85% fly ash, 10% cement and 5% of GGBS, alkaline liquids (specific gravity of NaOH = 1.47& specific gravity of Na_2Sio_3= 1.6), fine aggregate (with specific gravity of 2.66) & crushed granite coarse aggregate (size of 20mm & specific gravity of 2.70) as per IS 383-1970 2.8 were used. Results showed that the additional of glass fibers reduces the slump values due to the resistance of fibers for the free flow of concrete. At the age of 28 days with the increase in fiber dosage from 0.01% to 0.03% compressive strength values are falling down by 2.86% and 6.56% compared to the GPCC mix with 0.01% dosage. Hence, optimum dosage of fibers is found to be 0.01%. Results showed also that split tensile strength values are increased from 8.5% to 25.5% with the increase in volume fraction of fibers from 0.01% to 0.03% the compared to the GPCC mix without fibers at the age of 28 days. As the volume fraction of fibers increased from 0.01% to 0.03% flexural strength values are increased from 5% to 15% compared to the GPCC mix without fibers at the age of 28days.

Milind V. Mohod (2015) has carried an experimental study to explore effects of polypropylene fiber on compressive, tensile, flexural strength under different curing condition. His main aim was to study the effect of polypropylene fiber mix by varying content: 0%, 0.5%, 1%, 1.5% & 2% and finding the optimum polypropylene fibre content. Materials used in this experimental investigation were pozzolana Portland cement with 3.11 as specific gravity, The coarse aggregate (20mm size) and fine aggregate , polypropylene fibres (with an aspect ratio of 139.33 with respect to varying fibres content of 0%, 0.5, 1%, 1.5%, 2%). The study showed that PPF reduce early age shrinkage and moisture loss of the concrete mix even when low volume fractions are used. It was also found that the use of fiber in the concrete decreases the workability of the fresh concrete, high volume dosage rate above 1.0% exhibited that the concrete was significantly stiff and difficult to compact. However it also reduced the bleeding and segregation in the concrete mixture. Compressive strength of concrete increases with increase in fiber dosage up to 0.5%, then it starts decreasing. He concluded that the optimum value of fibre content is 0.5% for both tensile strength and flexural strength.

Lidia Rizzuti and Francesco Bencardino (2014) analyzed the effects of fibre volume fraction on the mechanical properties of SFRC (Steel Fibre Reinforced Concrete), evaluate and compare the experimental behaviour in terms of peak load, post-peak behaviour, and residual strength. The hooked ends steel fibres of 400 as aspect ratio and 350-400 MPa as tensile strength with volume fraction of 1%, 1.6%, 3% and 5% were used. The authors ended that, the addition of fibres does not significantly affect the compressive strength of concrete but the increase in fibre content improves the post-peak behaviour and a more extended softening branch is observed. Steel fibres give to the concrete a sizable post-peak residual strength. Based on the study, they suggest the use of SFRC with medium-high fibre content for many structural applications with and without traditional internal reinforcement, thus they are particularly suitable for structures subjected to loads over the serviceability limit state in bending and shear and when exposed to impact or dynamic forces as they occur under seismic or cyclic action.

Xiaolu Guo and Xuejiao Pan (2018) conducted experimental study with the aim of recycling solid wastes, and developing a sustainable alternative to Portland cement. Their paper studies the effects of fibers on mechanical properties of geopolymer. Scanning electron microscope (SEM) and Brunauer-Emmett-Teller (BET) have been conducted to investigate the reinforcing mechanism. Fly ash(the specific surface about 369 m2/kg) and steel slag(with specific surface area of steel slag of 400 m2/kg;) were used as the main raw materials to prepare the geopolymer binder then mixed with the sand (with a fineness modulus of 3.1.). The precise composition of the 2 alkali solutions was 91.34% of sodium silicate solution and 9.66% of NaOH by mass. Polypropylene fiber (12 mm in length and 18–30 µm in dia.), basalt fiber (length of 12 mm and a diameter of 7–30 µm and steel fiber (SF) with a length of 13 mm & a diameter of 0.2 mm were also used .The results show that polypropylene fiber and basalt fiber can improve the mechanical properties at the late age, and steel fiber shows excellent toughening and reinforcing effects on geopolymer. SEM and BET results indicate that fibers could relieve the stress concentration, increase the specific surface area and significantly decrease the average pore diameter of geopolymer.

Arya aravind and Mathews M Paul (2014) carried out research on mechanical properties of Geopolymer concrete reinforced with steel fiber. The study was focused on the compressive strength and split tensile strength of geopolymer concrete reinforced with steel fiber. Experiments were performed using the Box–Behnken experimental design. They concluded that compressive strength of geopolymer concrete was gradually increased with prolonged curing period and also with the increase of sodium silicate to sodium hydroxide liquid ratio by mass. Split tensile strength of geopolymer concrete increased as percentage of steel fiber increased.

Another important observation was obtained that curing under normal sunlight yielded strength of 16 N/mm2.

2.4.2Effect of alkaline activators the properties of Geopolymer mortar/Concrete.

Sanumuri Parth (2017) in his review reported that increase of concentration of NaOH increases the compressive strength of geopolymer. This is mainly because of the concentration of NaOH solution is directly affecting the dissolution of the metakaolinite particulates, which affecting the formation of the geopolymer framework. To have strong inter-molecular bonding strength of the geopolymer, more reactive bond for the monomer is needed. This can be achieved by a better dissolving ability to metakaolinite particulates. To obtain a better dissolving ability to metakaolinite particulates, a higher concentration of NaOH solution is required.

Saloma et al.(2016) have carried out a experimental study on Geopolymer Mortar with Fly Ash. The purpose of the research was to analyze the effect of activator liquid concentration on geopolymer mortar properties. Fly ash (class F) was used as binder, (NaOH) 98% purity flake & sodium silicate (Na2SiO3), and river sand as fine aggregate. Molarity variation of NaOH are 8, 12, 14, and 16 M with ratio of Na2SiO3/NaOH = 1.0. Ratio of sand/fly ash = 2.75 and ratio of activator/fly ash = 0.8. The cube-shaped specimen 50 x 50 x 50 mm is cured by steam curing with a temperature of 60oC for 48 hours. The experimental result of fresh mortar reported that the molarity of NaOH affect the slump flow and setting time, higher the molarity of NaOH produces the smaller value of slump and the faster time of setting. Thereby it reduces the workability of the mixture. The result of compressive strength showed that the maximum value is obtained on geopolymer mortar 14 M in the amount of 10.06 MPa and the minimum value is obtained on geopolymer mortar 8 M which is equal to 3.95 MPa. In mortar mixture of 16 M, it decreases the compressive strength to 9.16 MPa. Based on these result, authors concluded that the optimum mixture to get the maximum strength is NaOH 14 M.

Arie Wardhonoa et al.(2015) reported the details of the experimental work that has been undertaken to investigate the strength of alkali activated slag (AAS) /fly ash (AASF) mortar blends cured under ambient temperature. The AASF specimens were prepared using a mix of ground granulated blast-furnace slag (GGBS) and low calcium class F fly ash activated by high alkaline solution. The mix compositions of slag to fly ash were 1:0, 0.9:0.1, 0.8:0.2, 0.7:0.3, 0.6:0.4 and 0.5:0.5, respectively. The alkaline activator solutions were formulated by blending sodium silicate with sodium hydroxide (NaOH) to achieve a Na2O dosage of 15% and activator modulus (Ms) of 1.25. A sodium silicate with alkali modulus (AM) of approximately 2.0 (Na2O = 14.7% and SiO2 = 29.4%) and a high concentration of sodium hydroxide, 15 M NaOH in liquid form were used .The results showed that the mix proportion of 0.5slag to 0.5 fly ash produced the best strength results. The standard deviation values also reduced along with the increase of fly ash content indicating an improved stability of the specimens. The authors also suggested that 0.5 slag to 0.5 fly ash blend could provide a solution for the need of heat curing for fly ash-based geopolymer.

Hardjito.D et al.(2004) reported the development of geopolymer concrete. The geopolymer paste was formed by activating low calcium (class F) fly ash as a by-product material with a combination of sodium silicate solution and sodium hydroxide solution as the activator. The experimental work showed that the compressive strength of geopolymer concrete is influenced by the higher the concentration of sodium hydroxide solution, higher the ratio of sodium silicate solution to sodium hydroxide solution, longer curing duration, and an increase in higher curing temperature. The low calcium fly ash based geopolymer concrete has excellent resistance to sulfate attack, endures low creep and drying shrinkage.

Shankar H. Sanni and Khadiranaikar R.B(2013) investigate on the variation of alkaline solution on mechanical properties of geopolymer concrete based on fly ash. The alkaline solution used for the study was the combination of sodium silicate and sodium hydroxide solution (8molarity) and the varying of Na2SiO3 to NaOH ratio ware 2, 2.50, 3 and 3.50. Specimens were heat-cured at 60°C in an oven. The investigation showed that workability is increased with the increase in the ratio of alkaline solution .The strength of geopolymer concrete can be improved by decreasing the water/binding and also aggregate/binding ratio; the curing period improves the polymerization process resulting in higher compressive strength. The obtained compressive strength was in the range of 20.64 – 60 N/mm2 and split tensile strength is in the range of 3 – 4.9 N/mm2. The authors concluded that the optimum dosage ratio for alkaline solution can be considered as 2.5 because it produces the maximum strength in compression and tension for any grade of GPC specimens.

Sofi Yasir and Gull Iftekar (2015) have concluded that the GPC gains its final strength in 7 days which is 4 times faster than ordinary plain cement concrete. In 3 days there is more than 50% gain in strength. Authors found that with increase in concentration of sodium hydroxide, strength increases and with increasing alkaline liquid to fly ash ratio, strength decreases. Optimum ratio between sodium silicate and sodium hydroxide to get maximum strength is 2.5. The study shown that for ratio below or above 2.5, the strength decreased. High temperature (about 600C) curing is necessary for the development of strength. There is decrease in strength in GPC when immersed in acid solution. Cubes with lower alkaline liquid to fly ash ratio showed large decrease in strength as compared to cubes with higher alkaline liquid to fly ash ratio. Permeability of GPC is very low; it increases with increase in alkaline liquid to fly ash ratio. With increase in alkaline liquid to fly ash ratio workability increases. Mix with alkaline liquid to fly ash ratio less than 0.3 is very stiff.

2.4.3 Effect of curing on the properties of geopolymer mortar/concrete.

The researchers suggested that the optimum curing time would be 48 hours. Curing time showed commonly a positive effect to the compressive strength of geopolymer mortar, and this effect is much more noticeable at the optimum curing temperature. Optimum curing temperature of 60 °C was suggested for the study of the geopolymer mortar with small 50 mm cub size. The suggestion is based on the fact that smaller cube is having higher surface area-to-volume ratio compared to larger cube. As a result, the smaller cube is more vulnerable to the high curing temperature and would experience loss of moisture during curing compared with the larger samples (Djwantoro Hardjito and Tsen , M.Z ,2008).

Lee N.K and Lee H.K (2013) used replacement ratio of the slag for the fly ash and the ratio of water glass to NaOH solution were 20% and 0.5 by weight respectively. The setting times of the 4 M specimens were an initial time of 55 min and a final time of 160 min, while those of the 6 M specimens were an initial time of 50 min and a final time of 114 min. Those of the 8 M specimens were faster than any of the other specimens (their initial and final times were 10 min and 50 min, respectively).At the same time he showed that the higher replacement ratio of the slag for the fly ash as an increase in the CaO content (which is the main chemical component of slag) accelerated the hydration reaction and led to a faster setting time of the mixture

Djwantoro Hardjito and Tsen, M.Z (2008) presented the engineering properties of geopolymer mortar manufactured from class F fly ash with potassium-based alkaline reactor. The results reported that as the concentration of KOH increased, the compressive strength of geopolymer mortar also increased. The ratio of potassium silicate-to potassium hydroxide by mass in the range between 0.8 to1.5 produced highest compressive strength geopolymer mortar. Geopolymer mortar specimens were tested for thermal stability for three hours under 400^{o}C, 600^{o}C and800^{o}C. When exposed to temperature of 400^{o}C for three hours, the compressive strength doubled than the one of control mixture. This indicates that the geopolymerisation process continues when geopolymer mortar is exposed to high temperature, up to 400^{o}C. Geopolymer mortar posses excellent fire resistance up to 800°C exposure for three hours. Above 800^{o}C, compressive strength of fly ash based geopolymer concrete decreases with increase in temperature.

C. Kamlesh. Shah et al.(2014) conducted research on strength parameters and durability of fly ash based geopolymer concrete. In his study, two concrete mixes were worked out; GPC Mix-1 fly ash concrete and OPC Mix-2 concrete mix having OPC equivalent to amount of cementitious material used in GPC Mix-1. Various parameters were used such as alkaline liquid to fly ash ratio of 0.40, 0.45 and 0.50, ratio of NaOH to Na2SiO3: 2.0 and 2.5, molarities of NaOH; 10M, 12M, 14M and 16M. Compressive strength test, split tensile test, pull out test and durability test were performed under ambient temperature curing conditions (at 600C, 900C and 1200C). Higher average compressive strength, tensile strength and pull out strength of 52.25, 4.10 and 10.25 N/mm2 were observed for concrete GPC Mix-1 as compared to that of concrete OPC Mix-2. The test results showed that oven cured fly ash based geopolymer concrete have an excellent resistance to sulfate attack, salt attack and acid attack as compared to ambient curing.

P.Eswaramoorthi and G.E.Arunkumar (2014) while the curing temperature increases in the range of 60^{o}C to 90^{o}C, the compressive strength of fly ash-based geopolymer concrete also increases. Longer curing time, in the range of 24 to72 hours (4 days), produces higher compressive strength of fly ash-based geopolymer concrete. However, the increase in strength beyond 48 hours is not significant. The slump value of the fresh fly-ash-based geopolymer concrete increases with the increase of extra water added to the mixture. The compressive strength of heat-cured fly ash-based geopolymer concrete does not depend on age. Geopolymer concrete has excellent properties within both acid and salt environments. Comparing to Portland cement, the production of geopolymers has a relative higher strength, excellent volume stability, better durability.

CHAPTER 3

METHODOLOGY

3.1 GENERAL.

In this chapter different engineering properties such specific gravity, fineness modulus, particle size distribution of materials have been found out .It also shows the procedures and apparatus used for each test. The following materials were used for preparation of fiber reinforced geopolymer mortar: Low calcium or class F fly ash (FA) & Ground granulated blast furnace slag (GGBS) as binder, alkaline liquids (Na_2SiO_3 & NaOH), fine aggregates, crimped steel fibers and water. This section also shows their brief descriptions.

3.2. MATERIALS

3.2.1 Fly Ash

Fly ash is a fine residual particle formed during combustion of powdered or ground coal and then transported by flue gasses from the combustion zone to the particle removal system'. Fly-ash mainly contains silica, alumina and minor amounts of oxides such as iron (Fe), sodium (Na), calcium (Ca), magnesium (Mg) and potassium (K). In this study, low calcium content or class F fly ash obtained from UDUPI Power plant was used. It confirms with grade I of IS: 3812 – 1981.

3.2.2 Ground Granulated Blast Furnace Slag (GGBS)

Ground Granulated Blast furnace Slag (GGBS) is a by-product from the blast furnaces used to make iron. The chemical composition of GGBS varies considerably depending on the composition of the raw materials in the iron production process. The GGBS used in this work is obtained from Jindal Steel and it confirms with grade I of IS: 3812 – 1981.

(a) Fly ash (b) GGBS

Figure 3. 1:2 Binder compositions (a) FA, (b) GGBS

Table 3. 1: Physical properties of Fly ash & GGBFS

Physical properties	Specific gravity	Fineness (m^2/kg)
Fly ash	2.27	315
GGBFS	2.85	337

3.2.3 Alkaline Liquid

A combination of sodium silicate solution and sodium hydroxide solution was chosen as alkaline activators for geopolymerization.

3.2.3.1. Sodium Hydroxide

The sodium hydroxide **(NaOH)** is available in solid state in falkes & pellets form. In this experimental sodium hydroxide flakes with 97% purity were dissolved in distilled water to make 10M NaOH solution. The mass of NaOH solid varies according to the molarity required. The weight of NaOH solids is 400 grams per 1 lit of solution for 10M concentration. Its specification and impurity limits given by the manufacture are shown in table 3.2.

Table 3. 2: Specification and Impurity limits of NaOH

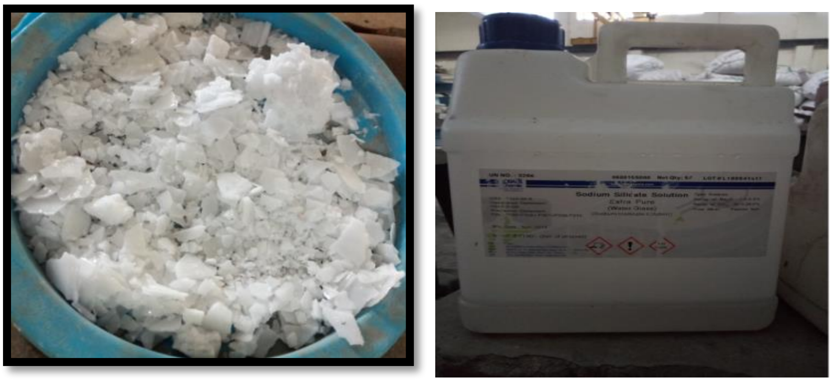
Molecular weight	40.00
Assay	Min. 97%
Insoluble matter in water	Max. 0.05%
Carbonate (Na_2CO_3)	Max. 2%
Chloride (CL)	Max. 0.05%
Sulphate(SO_4)	Max. 0.05%
Heavy metals(as Pb)	Max. 0.005%
Arsenic (As)	Max. 0.0003%
Iron (Fe)	Max. 0.005%

3.2.3.2 Sodium silicate (Na_2SiO_3)

Sodium silicate is used in alkaline solution along with sodium hydroxide; it is also known as water glass or liquid glass and available in liquid (gel) form. The pure form of sodium silicate solution is of colourless or white in colour. Commercially available (shown in fig.3.3b) sodium silicate in liquid form supplied by local manufacturer was used. Its properties specification given by the manufacture is as in table 3.3.

Table3. 3: Property specification of Sodium silicate

MF	NA
Assay (as SiO_2)	25-28%
Assay (as Na_2O)	7.5-8.5%
Free alkali	Passes test



(a) (b)

Figure 3.3 :Alkaline liquid (a) **NaOH** pellets, (b) Na2SiO3solution

3.2.4 Water

Water is one of the most important elements in construction industries and is required for the preparation of mortar, mixing of cement concrete and for curing work, etc. The role of water in the geopolymer mix is to make workable concrete in plastic state and do not contribute towards the strength in hardened state. Similarly the demand of water increases with increase in fineness of source material for same degree of workability. According to the common specifications water used for making geopolymer concrete should be clean and free from deleterious impurities like acids, oil, alkalinities, etc. Potable water was used for making sodium hydroxide solution.

3.2.5 Fine Aggregate

Clean and dry local river sand passing through IS 4.75 mm sieve was used as fine aggregate for preparation of mortar. Fine aggregate must be free from silt, clay, organic impurities, etc and is tested for various properties such as specific gravity and fineness modulus. This was confirming to grading zone I as per IS 383-1970 having specific gravity 2.65 and fineness modulus of 2.844.

Figure 3. 4 Fine aggregate

Sieve analysis of fine aggregate

Weight of sample taken= 1 kg=1000 gm

Table 3. 4: Sieve analysis

S/No	IS Sieve size	Weight retained(gm)	Cumulative Wt. retained	Cumulative % Wt. retained	% finer
1	10 mm	0	0	0	100
2	4.75 mm	60	60	6.0	94
3	2.36 mm	45	105	10.5	89.5
4	1.18 mm	334	439	43.9	56.1
5	600 µ	87	526	52.6	47.4
6	300 µ	194	720	72	28
7	150 µ	274	994	99.4	0.6
8	Pan	6	1000	∑ =284.40	

Fineness modulus= ∑Cumulative% Wt. retained /100

= 284.40/100

=2.844

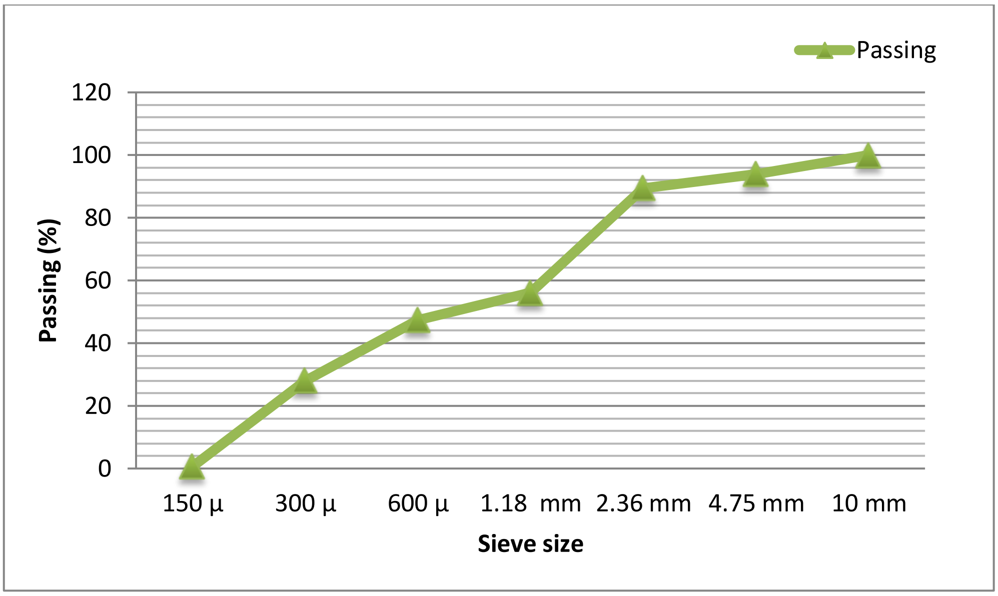


Figure 3. 5: Particle size distribution of fine aggregate

3.2.6 Steel Fibre

Mostly fibres are used in concrete industry to increase resistance against cracking and crack propagation, to increase substantially the energy absorption characteristics of the fibre composite and ability to withstand repeatedly applied shock or impact loading. Crimped steel fibres of 12.5 mm length, diameter of 0.45 mm and aspect ratio (l/d) of 27.77 were used in this study.

Figure 3. 6: Crimped steel fiber

3.3. MIXTURE PROPORTIONS

In this experimental study 72 mortar samples were prepared using the local available river sand, class F fly ash and GGBS, a combination of sodium hydroxide and sodium silicate as alkaline activators and crimped steel fibers. The details of mixture proportions of various mortar sample mixes casted in this study are given in table 3.5.

Table 3. 5: Mix proportions for steel fiber geopolymer mortar

Alk/B	**Series**	**B/S**	**B (%) [FA:GGBS]**	**Fiber Content (%)**		
	$GM1F_{100}G_0$	1:3	100:0	0.5	1	1.5
	$GM2F_{90}G_{10}$	1:3	90:10	0.5	1	1.5
	$GM3F_{80}G_{20}$	1:3	80:20	0.5	1	1.5
0.5	$GM4F_{70}G_{30}$	1:3	70:30	0.5	1	1.5
	$GM5F_{60}G_{40}$	1:3	60:40	0.5	1	1.5
	$GM6F_{50}G_{50}$	1:3	50:50	0.5	1	1.5
	$GM7F_{100}G_0$	1:3	100:0	0.5	1	1.5
	$GM8F_{90}G_{10}$	1:3	90:10	0.5	1	1.5
0.6	$GM9F_{80}G_{20}$	1:3	80:20	0.5	1	1.5
	$GM10F_{70}G_{30}$	1:3	70:30	0.5	1	1.5
	$GM11F_{60}G_{40}$	1:3	60:40	0.5	1	1.5
	$GM12F_{50}G_{50}$	1:3	50:50	0.5	1	1.5
	$GM13F_{100}G_0$	1:3	100:0	0.5	1	1.5
	$GM14F_{90}G_{10}$	1:3	90:10	0.5	1	1.5
0.7	$GM15F_{80}G_{20}$	1:3	80:20	0.5	1	1.5
	$GM16F_{70}G_{30}$	1:3	70:30	0.5	1	1.5
	$GM17F_{60}G_{40}$	1:3	60:40	0.5	1	1.5
	$GM18F_{50}G_{50}$	1:3	50:50	0.5	1	1.5
	$GM19F_{100}G_0$	1:3	100:0	0.5	1	1.5
	$GM20F_{90}G_{10}$	1:3	90:10	0.5	1	1.5
0.8	$GM21F_{80}G_{20}$	1:3	80:20	0.5	1	1.5
	$GM22F_{70}G_{30}$	1:3	70:30	0.5	1	1.5
	$GM23F_{60}G_{40}$	1:3	60:40	0.5	1	1.5
	$GM24F_{50}G_{50}$	1:3	50:50	0.5	1	1.5

3.3.1. Quantity of material per m^3 using Trial Mix design

Take an example for alkaline to Binder ratio **of 0.5 with 0.5% steel fibers.**

Unit weight of geopolymer mortar = 2200kg/m3

Aggregate to binder ratio = 1:3

Mass of fine aggregates = (2200×3) /4= **1650kg**/m3

Mass of binder = 2200-1650 = **550** kg/m3

Mass of alkaline liquid = 550×0.5= **275** kg/m3

Sodium silicate/sodium hydroxide ratio = 2.5

Mass of sodium hydroxide (NaOH) solution = 275/3.5 = 78.57kg/m3

- For 10 molar, sodium hydroxide solid = 22.45kg/m3
- Water = 56.12 kg/m3

Mass of sodium silicate(Na2SiO3) solution = 275-78.57 = 196.43kg/m3

Steel fibers= (550×0.5) /100=2.75 kg/m3. In this study the quantity of materials used for each 9 cubes casted for every sample are shown in table 3.6.

Table 3. 6 Quantity of materials for 72 samples of steel fiber geopolymer mortar

proportion of binders	**Sand (gm)**	**Fly ash (gm)**	**GGBS (gm)**	**Na2SiO3 (gm)**	**NaOH (gm)**	**Solut. (gm)**	**Steel by wt of B. (gm)**
A/B=0.5							0.5%
$GM1F_{100}G_0$	6000	2000	0	714	286	1000	10
$GM2F_{90}G_{10}$	6000	1800	200	714	286	1000	10
$GM3F_{80}G_{20}$	6000	1600	400	714	286	1000	10
$GM4F_{70}G_{30}$	6000	1400	600	714	286	1000	10
$GM5F_{60}G_{40}$	6000	1200	800	714	286	1000	10
$GM6F_{50}G_{50}$	6000	1000	1000	714	286	1000	10
							1%
$GM7F_{100}G_0$	6000	2000	0	714	286	1000	20
$GM8F_{90}G_{10}$	6000	1800	200	714	286	1000	20
$GM9F_{70}G_{30}$	6000	1600	400	714	286	1000	20
$GM10F_{60}G_{40}$	6000	1400	600	714	286	1000	20

$GM11F_{100}G_0$	6000	1200	800	714	286	1000	20
$GM12F_{90}G_{10}$	6000	1000	1000	714	286	1000	20
							1.5%
$GM13F_{100}G_0$	6000	2000	0	714	286	1000	30
$GM14F_{90}G_{10}$	6000	1800	200	714	286	1000	30
$GM15F_{80}G_{20}$	6000	1600	400	714	286	1000	30
$GM16F_{70}G_{30}$	6000	1400	600	714	286	1000	30
$GM17F_{60}G_{40}$	6000	1200	800	714	286	1000	30
$GM18F_{50}G_{50}$	6000	1000	1000	714	286	1000	30
A/B=0.6							0.5%
$GM19F_{100}G_0$	6000	2000	0	857	343	1200	10
$GM20F_{90}G_{10}$	6000	1800	200	857	343	1200	10
$GM21F_{80}G_{20}$	6000	1600	400	857	343	1200	10
$GM22F_{70}G_{30}$	6000	1400	600	857	343	1200	10
$GM23F_{60}G_{40}$	6000	1200	800	857	343	1200	10
$GM24F_{50}G_{50}$	6000	1000	1000	857	343	1200	10
							1%
$GM25F_{100}G_0$	6000	2000	0	857	343	1200	20
$GM26F_{90}G_{10}$	6000	1800	200	857	343	1200	20
$GM27F_{80}G_{20}$	6000	1600	400	857	343	1200	20
$GM28F_{70}G_{30}$	6000	1400	600	857	343	1200	20
$GM29F_{60}G_{40}$	6000	1200	800	857	343	1200	20
$GM30F_{50}G_{50}$	6000	1000	1000	857	343	1200	20
							1.5%
$GM31F_{100}G_0$	6000	2000	0	857	343	1200	30
$GM32F_{90}G_{10}$	6000	1800	200	857	343	1200	30
$GM33F_{80}G_{20}$	6000	1600	400	857	343	1200	30
$GM34F_{70}G_{30}$	6000	1400	600	857	343	1200	30
$GM35F_{60}G_{40}$	6000	1200	800	857	343	1200	30
$GM36F_{50}G_{50}$	6000	1000	1000	857	343	1200	30
A/B=0.7							0.5%
$GM37F_{100}G_0$	6000	2000	0	1000	400	1400	10
$GM38F_{90}G_{10}$	6000	1800	200	1000	400	1400	10
$GM39F_{80}G_{20}$	6000	1600	400	1000	400	1400	10
$GM40F_{70}G_{30}$	6000	1400	600	1000	400	1400	10
$GM41F_{60}G_{40}$	6000	1200	800	1000	400	1400	10
$GM42F_{50}G_{50}$	6000	1000	1000	1000	400	1400	10

							1%
$GM43F_{100}G_0$	6000	2000	0	1000	400	1400	20
$GM44F_{90}G_{10}$	6000	1800	200	1000	400	1400	20
$GM45F_{80}G_{20}$	6000	1600	400	1000	400	1400	20
$GM46F_{70}G_{30}$	6000	1400	600	1000	400	1400	20
$GM47F_{60}G_{40}$	6000	1200	800	1000	400	1400	20
$GM48F_{50}G_{50}$	6000	1000	1000	1000	400	1400	20
							1.5%
$GM49F_{100}G_0$	6000	2000	0	1000	400	1400	30
$GM50F_{90}G_{10}$	6000	1800	200	1000	400	1400	30
$GM51F_{80}G_{20}$	6000	1600	400	1000	400	1400	30
$GM52F_{70}G_{30}$	6000	1400	600	1000	400	1400	30
$GM53F_{60}G_{40}$	6000	1200	800	1000	400	1400	30
$GM54F_{50}G_{50}$	6000	1000	1000	1000	400	1400	30
A/B=0.8							0.5%
$GM55F_{100}G_0$	6000	2000	0	1143	457	1600	10
$GM56F_{90}G_{10}$	6000	1800	200	1143	457	1600	10
$GM57F_{80}G_{20}$	6000	1600	400	1143	457	1600	10
$GM58F_{70}G_{30}$	6000	1400	600	1143	457	1600	10
$GM59F_{60}G_{40}$	6000	1200	800	1143	457	1600	10
$GM60F_{50}G_{50}$	6000	1000	1000	1143	457	1600	10
							1%
$GM61F_{100}G_0$	6000	2000	0	1143	457	1600	20
$GM62F_{90}G_{10}$	6000	1800	200	1143	457	1600	20
$GM63F_{80}G_{20}$	6000	1600	400	1143	457	1600	20
$GM64F_{70}G_{30}$	6000	1400	600	1143	457	1600	20
$GM65F_{60}G_{40}$	6000	1200	800	1143	457	1600	20
$GM66F_{50}G_{50}$	6000	1000	1000	1143	457	1600	20
							1.5%
$GM67F_{100}G_0$	6000	2000	0	1143	457	1600	30
$GM68F_{90}G_{10}$	6000	1800	200	1143	457	1600	30
$GM69F_{80}G_{20}$	6000	1600	400	1143	457	1600	30
$GM70F_{70}G_{30}$	6000	1400	600	1143	457	1600	30
$GM71F_{60}G_{40}$	6000	1200	800	1143	457	1600	30
$GM72F_{50}G_{50}$	6000	1000	1000	1143	457	1600	30

3.4. EXPERIMENTAL WORKS AND SAMPLE PREPARATION.

Experimental works of this research were conducted in laboratory of concrete and material, Civil Engineering, Faculty of Engineering, NITK Surathkal. Experimental works conducted in this study include: Setting time test of geopolymer mortar, mini flow table test and compressive strength test of steel fibers geopolymer mortar and SEM analysis. The adopted procedures for the above tests were the same as the procedures adopted for cement mortar.

3.4.1 Preparation alkaline activator.

Alkaline activator is constituted of sodium hydroxide and sodium silicate. The alkaline activator solution was prepared in the laboratory by mixing sodium hydroxide (high purity 97%, dissolved in distilled water) with sodium silicate solution together just 24 hrs before their use to ensure the reactivity of solution. In this work a solution of NaOH 10M concentration (mass= 400gms) and a commercial solution of sodium silicate were combined to make an alkaline activator. Na2SiO3/ NaOH ratio was 2.5.

Figure 3. 7: Preparation of alkaline activator solution

3.4.2 Setting time test for Mortar.

Initial setting time of mortar is the elapsed time, after initial contact of cement (or other binder FA& GGBS) and water (or alkaline solution in case of geopolymer), required for the mortar(sieved through a 4.75-mm IS sieve in case of concrete) to reach a penetration resistance of 3.43 N/mm2 (35 kgf/cm2) while Final Setting Time is the elapsed time, after initial contact of binder and water, required for the mortar to reach a penetration resistance of 26.97 N/mm2 (275 kgf/cm2).

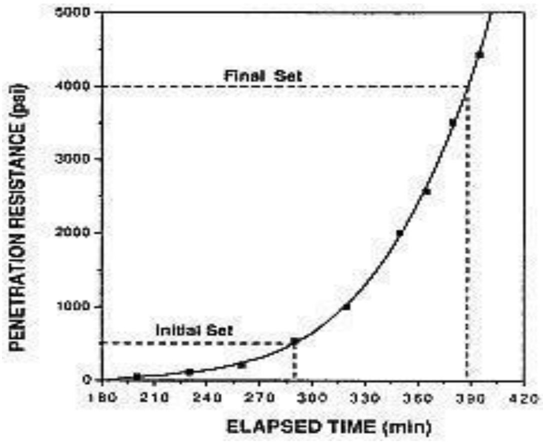
Fly ash and GGBS as binder with different proportions by weight were mixed in a dry condition in a mixing try thoroughly till the homogeneous dry mixes obtained. The homogeneous dry mixes and alkaline solution were mixed properly with hand to ensure homogeneity. The series of geopolymer mortar were prepared by varying the percentage of GGBS (from 0% to 50% of binder) as well as different alkaline to binder ratios (0.5 to 0.8).Various apparatus were used in this experiment: Rigid cube mould of 150×150×150mm ,penetration resistance apparatus - Spring reaction-type apparatus, graduated from 50 N (5 kgf) to 600 N (60 kgf) in increments of 10 ***N (*** 1 kgf), removable needles of 645,323,161, 65, 32 and 16 mm^2 bearing areas and a tamping rod of 16 mm in diameter. The following are the procedures to be followed for the setting time of mortar (concrete) as indicated by IS: 8142 – 1976.

1. Mix the mortar thoroughly with hand to ensure homogeneity and plate it in container layer by layer in 3 layers, compact each layer by tamping rod.

2. Upon completion of specimen preparation, remove the bleeding liquid from the surface. It is recommended that the mortar surface after tamping should be at least 13 mm below the top edge of the container to provide space for the collection and removal of bleeding water.

3. Attach the needle with the apparatus .Bring the bearing surface in contact with the mortar surface and gradually and uniformly apply a vertical downward force on the penetration resistance apparatus until needle penetrates a depth of 25 mm as indicated by scribe mark in 10 seconds time period.
4. Record the force required producing 25 mm penetration and also the time of inserting, from the time alkaline solution is added to the homogeneous dry mixture.
5. Repeat the above procedures/steps for the remaining needles at an hourly interval but for a subsequent penetration avoid area where mixture has been disturbed by inserting the needle at least 25 mm away from the wall of the container.

6. A minimum of 6 penetration resistance are conducted, continue until one penetration resistance of at least 26.97 N/mm2 or 275kgf/cm^2 is obtained/reached.
7. Penetration resistance is calculated in N/mm2 (kgf/cm2), by dividing the force required to cause 25 mm depth of penetration of the needle by the area of bearing force of the needle.
8. The initial and final setting time are found out by plotting a graph of penetration resistance as ordinate and elapsed time as abscissa as shown by the figure 3.8(b)
9. From the graph, draw a horizontal line from the penetration resistance of 3.43N/mm2 or 35 kgf/cm2, the point where it cuts the smooth curve read on Y axis gives the Initial setting time.
10. Similarly the final setting time is obtained by drawing a horizontal line from the point where the penetration resistance of 26.97 N/mm2 or 275 kgf/cm2 cuts the smooth curve, read on Y axis.



(a) (b)

Figure 3. 8: Penetration resistance apparatus (a), setting time plot (b)

3.4.3 Mini Flow Table test.

The flow table is used to determine the flow of hydraulic cement, mortars and cement pastes. A test specimen is molded on the flow table to a specified volume and shape. Then, with the mold removed, leaving the test specimen on the table. The flow table is dropped and raised (via a hand crank or optional motor) a specified number of cycles, after which the flow (or increase in average diameter of the specimen) is measured.

In this research the mini flow table test have been performed to determine the flow capacity of steel fiber geopolymer mortars in order to evaluate their workability and the impact of increasing the percentage or content of steel fibers. It was conducted by using the mini flow cone having a top diameter of 70 mm, bottom diameter of 100 mm and height of 50 mm.

Fly ash & GGB as binder with 50%:50% proportions by weigh were mixed in a dry condition in a mixing try thoroughly then crimped steel fibers were added till the homogeneous dry mixes obtained. The homogeneous dry mixes and alkaline solution of required quantity were mixed properly with hand for around 3min to ensure homogeneity. Sixteen (16) series of geopolymer mortar were prepared by varying the percentage of steel fibers as well as different alkaline to binder ratios. The mini flow table test was conducted as per the guidance given in IS: 4031 (part 7) -1988**.**

Carefully the flow-table top was wiped, cleaned and dried then the cone was placed on the flow table firmly. The fresh mortar was then filled in the cone and tamp 20 times with the tamping rod. Cut off the excess mortar to a plane surface of the mould. After 60 seconds the cone was carefully lifted up then immediately the table was dropped 25 times in 15seconds through a height of 12.5 mm. The flow is the resulting increase in average base diameter of the mortar mass, measured on at least four diameters at approximately equi-spaced intervals expressed as a percentage of the original base diameter.

$$\text{Flow} = \frac{\text{Average diameter} - \text{Inner base diameter}}{\text{Inner base diameter}} \times 100$$

Figure 3. 9: Mini flow table and its cone

3.4.5. Density

Density of hardened steel fiber geopolymer mortar was measured before testing the specimens for compressive strength. The density of mortar was calculated by dividing the weight of mortar cube with its volume.

3.4.6 Compressive strength Test

Compressive strength test is conducted to find the maximum amount of compressive load that can be taken by a material until failure. It is done by applying a compressive loading on specimens by using a compressive testing machine. In this research the compressive strength test was done based on IS 516-1959. Normally mortar or concrete is mixed by any of the two mixing methods (by hand & mechanical). But here hand mixing was used to obtain a uniform mixture that shows uniformity in terms of color as shown in the figure 3.10.

3.4.6.1 Mortar Preparation

The steel fiber geopolymer mortar was prepared by mixing FA & GGBS as binder and sand for 3 to 4 minutes manually then crimped steel fibers were spread and continue mixing till the homogeneous dry mixes obtained. The homogeneous dry mixes and alkaline solution of required quantity were mixed properly with hand for about 3minutes to ensure homogeneity. Series of geopolymer mortar were prepared by varying the percentage of steel fibers as well as different alkaline to binder ratios .Fresh steel geopolymer mortar was poured in cube moulds with dimensions of 70.6×70.6×70.6 mm and tempered properly so as not to have any voids then the moulds are kept on a vibrating for good compaction . After 24 hours these moulds are removed and the specimens are cured in ambient temperature as shown in figure 3.11.These specimen were tested by using hydraulic compression testing machine where two plane faces of the specimen cube were inserted between platens of compressive testing machine and load was applied gradually until the specimen fails as shown by figure 3.12.The compressive strength were determined at 3, 7and 28days.

Figure 3. 10: Steel fiber geopolymer mortar preparation and some specimens

Figure 3. 11**:** Sample subject to ambient temperature

Figure 3. 12 Sample subject to compressive machine

3.4.7 The Scanning electron microscope

The Scanning Electron Microscope (SEM) analysis was conducted in order to provide a good and deep understanding of the effect of microstructure characteristics on the mechanical performance. Eleven (11) samples for SEM analysis were corrected and cut from the broken flakes of the original sample after the end of compressive tests. Samples used for SEM analysis are all 5 samples of 0.6 alkaline to binder ratio with 1% fiber content named as 0.61 (100×0), 0.61 (80×20), 0.61 (70×30), 0.61 (60×40) & 0.61 (50×50). Other 6 samples were taken 0.5 alkaline to binder ratio with 1% fiber content named as 0.51 (50×50) & 0.51 (60×40), 0.7 alkaline to binder ratio with 0.5% fiber content named as 0.705 (50×50) & 0.705 (100×10) and 0.8 alkaline to binder ratio with 1.5% fiber content named as 0.815 (50×50) a& 0.815 (70×30). Figure 3.7 shows samples of crimped steel fiber geopolymer mortar for SEM analysis.

Figure 3. 13: Samples for SEM analysis

CHAPTER 4

RESULTS AND DISCUSSION

This chapter shows the test results, discussions and analysis of all experimental works done in this study. The test results cover the setting time results of mortar, mini flow table test results, compressive strength test results of steel fiber geopolymer mortar and its scanning electron microscope (SEM).

4.1. SETTING TIME TEST RESULTS FOR MORTAR.

Initial and final setting time of geopolymer mortar for different variation of alkaline to binder ratio and variation of GGBS content were tested using concrete penetrometer. Penetration resistance at different duration were recorded and then after plotted to the setting time graph where penetration resistance is ordinate and elapsed time is abscissa. From the graph, the point where 35 kgf/cm2 cuts the smooth curve read on Y axis gives the initial setting time (IST) and the one where 275 kgf/cm2 cuts the smooth curve, read on Y axis gives the final setting time (FST).Penetration resistance at different duration were recorded and then after plotting them to the setting time graph where penetration resistance is ordinate and elapsed time is abscissa, the following results were obtained.

Table 4.1 Setting time test results of geopolymer mortar of all Alk/B

Binder composition	Initial setting time (in minutes)				Final setting time (in minutes)			
	Alkaline to binder ratio				Alkaline to binder ratio			
	0.5	0.6	0.7	0.8	0.5	0.6	0.7	0.8
$F_{100}G_0$	94	152	201	316	172	361	429	668
$F_{90}G_{10}$	62	84	115	191	116	138	198	280
$F_{80}G_{20}$	47	63	90	119	89	101	125	196
$F_{70}G_{30}$	33	40	54	80	69	84	115	162
$F_{60}G_{40}$	26	32	49	71	64	71	95	147
$F_{50}G_{50}$	22	27	40	68	51	57	72	105

Table 4.1 and figures 4.2 up to 4.5 present the initial and final setting time test results of all alkaline to binder ration with variation of binder content (FA and GGBS). From the figures, the results indicate that both initial and final setting time largely depend on alkaline solution. This means that as the quantity of alkaline increases, the setting time also increases. It can also be seen from the figures that in all mixes while the percentage of GGBS increases both the initial and final setting time decrease; This is due to higher content of CaO (the main component of GGBS) which accelerates the hydration reaction of the mixture [22].

Figure 4. 1 Sample tested using penetrometer

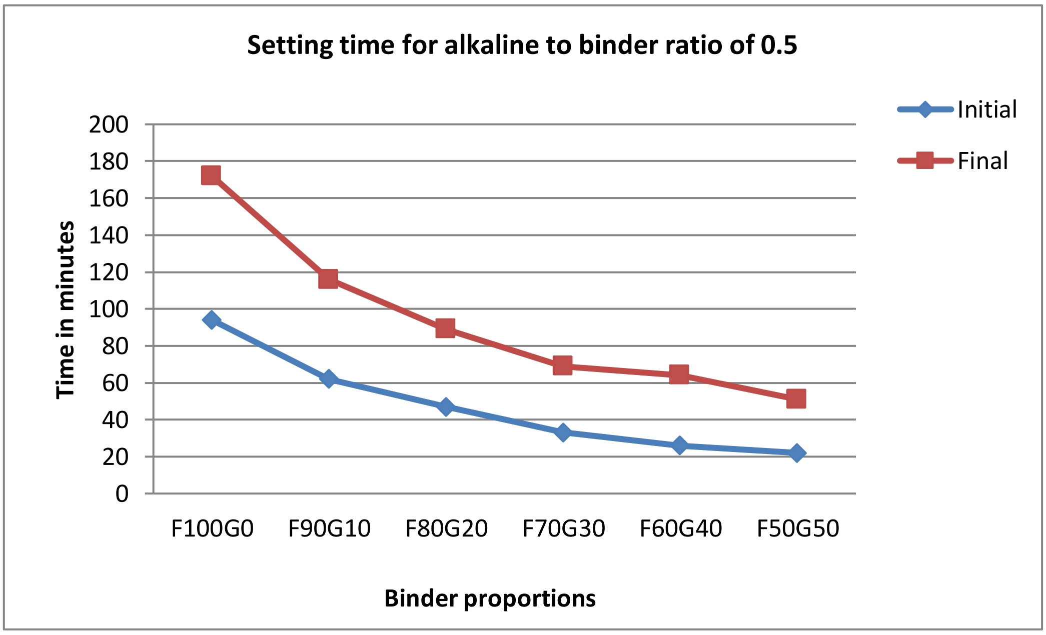


Figure 4. 2 comparison of initial & final setting Time for Alk/B ratio=0.5

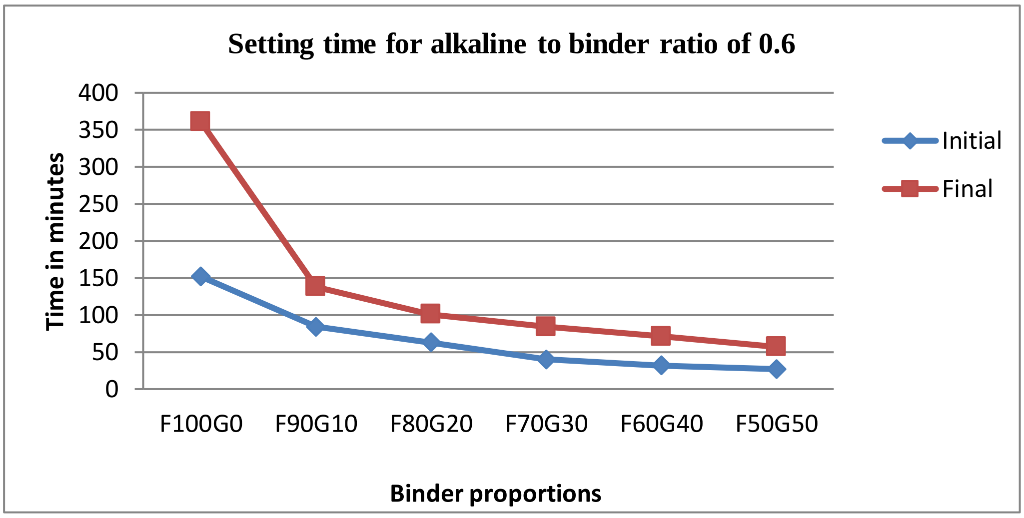


Figure 4. 3 comparison of initial & final setting Time for Alk/B ratio=0.6

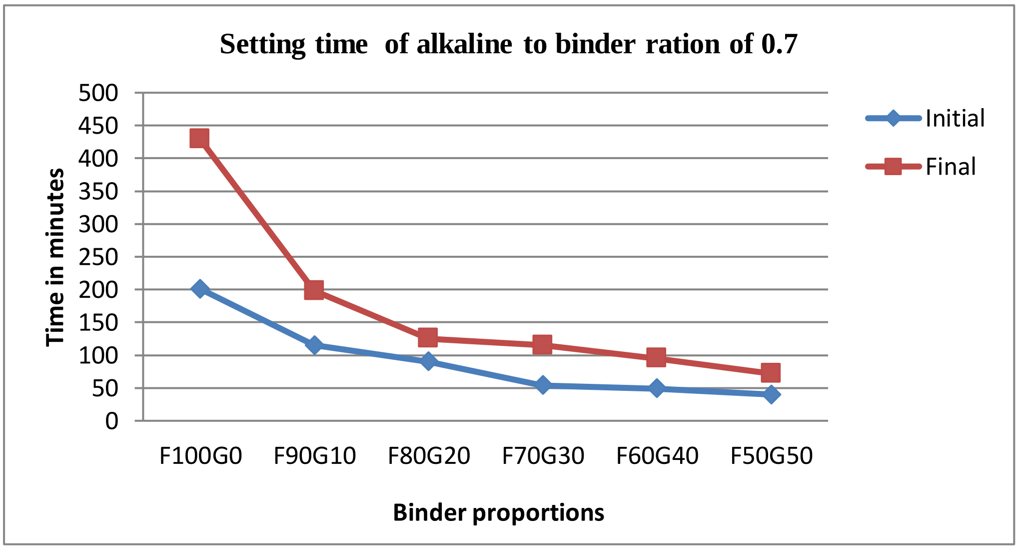


Figure 4. 4 Comparison of initial & final setting Time for Alk/B ratio=0.7

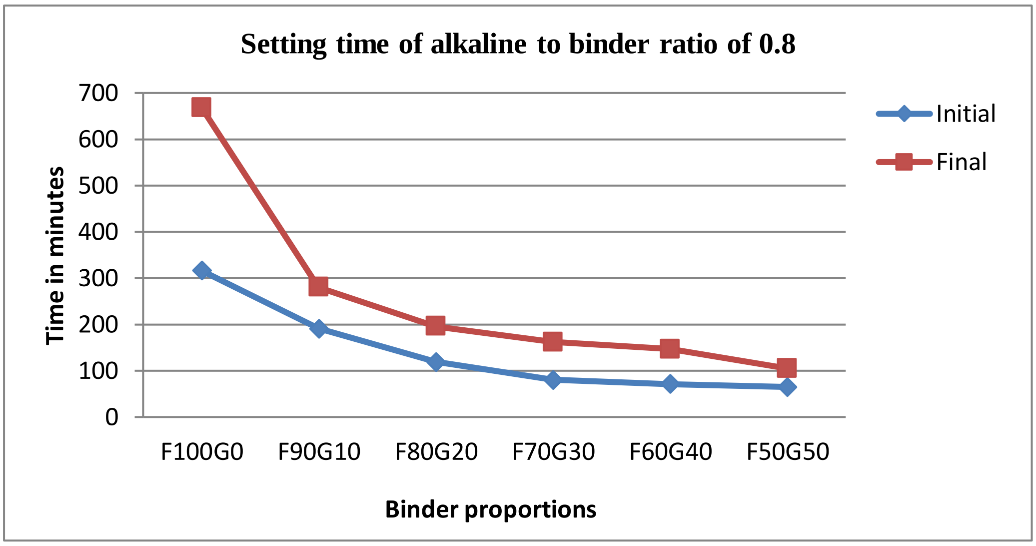


Figure 4. 5 Comparison of initial & final setting Time for Alk/B ratio=0.8

4.1.1 Comparison of setting time of all Alk/B with respect to variation of binder compositions.

Figure 4.6 shows the comparison of initial setting time of all alkaline to binder ratios with respect to the increase in GGBS content. Based on variation of alkaline to binder ratio, the figure shows an increase of about 142-236% in initial setting time when alkali to binder ratio varies from 0.5 to 0.8 with variation of slag content. Incorporation of GGBS in the mixture significantly reduces the initial setting time. The results show that the when slag varies from 0 to 50% by weight of binder the initial setting time decreased about 76-82% depending on variation of alkali to binder ratio.

Figure 4.7 presents the comparison of final setting time of all alkaline to binder ratios with respect to the increase in GGBS content. Incorporation of GGBS in the mixture significantly reduces the final setting time. The results show that the when slag varies from 0 to 50% by weight of binder the final setting time decreased about 70-84% depending on variation of alkali to binder ratio. Based on variation of alkaline to binder ratio, the figure shows an increase of about 106-288% in final setting time when alkali to binder ratio varies from 0.5 to 0.8 with variation of slag content.

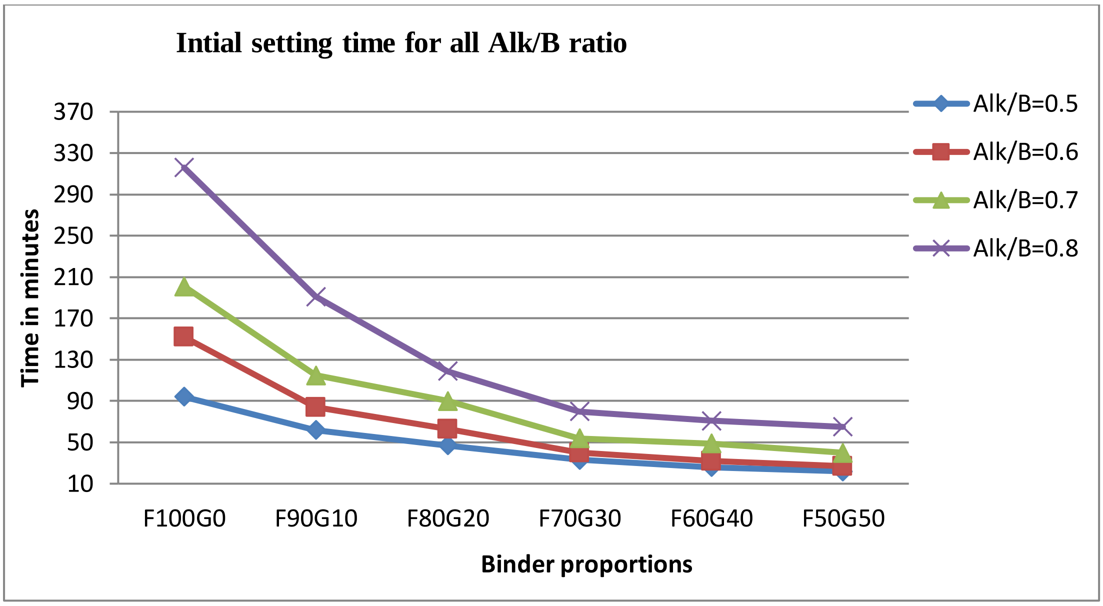


Figure 4. 6 Comparison of Initial setting time for all Alk/B with respect to variation of binder compositions.

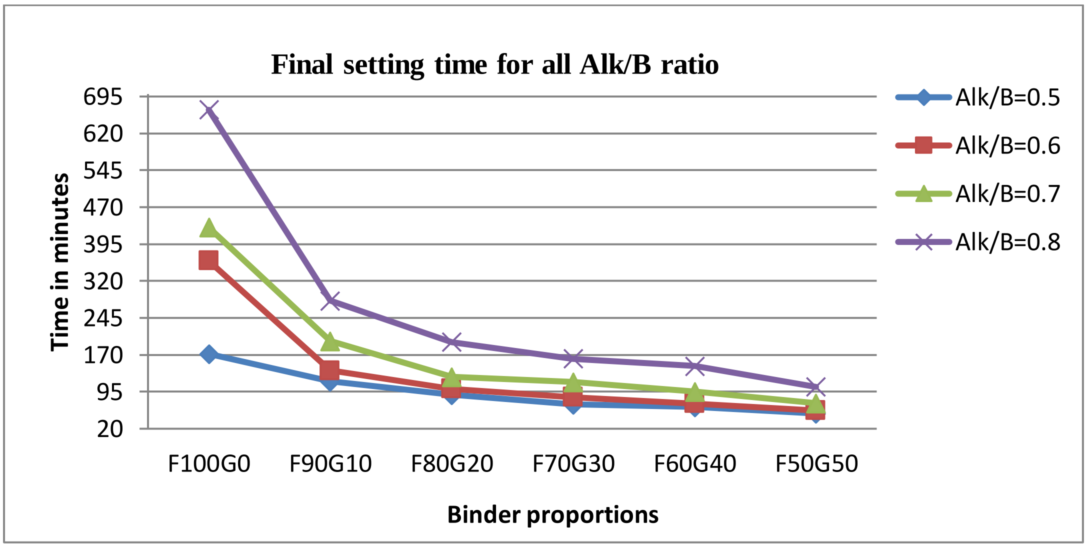


Figure 4. 7 Comparison of final setting time for all Alk/B with respect to variation of binder compositions

4.2 MINI FLOW TABLE TEST RESULTS

Mini flow table test have been performed to determine the flow of steel fiber geopolymer mortar and to evaluate the impact of incorporating and increasing the percentage of steel fibers on the flowing capacity of plain geopolymer mortar.

Table 4.2 presents the average of 4 diameters measured for alkaline to binder ratio of 0.5 to 0.8 with variation of steel percentage. It is clearly shown from the table that the flow diameter was increased as alkaline to binder ratio increased. It is easy from the table to note that incorporation and augmentation of crimped steel fibers in geopolymer mortar reduces its flowing ability. The smallest flow diameter was found at 1.5 % volume of steel fibers in all mixes.

Table 4. 2 Mini flow table Test results.

Binder Proportion (FA:GGBS)	Alkaline /Binder ratio	Steel (%)	Average Diameter (cm)	Flow (%)
		0	15.83	58.3
		0.5	13.1	31.0
50%:50%	0.5	1	12.55	25.5
		1.5	12.1	21.0
		0	19.21	92.1
50%:50%	0.6	0.5	15.65	59.5
		1	14.9	49.0
		1.5	14.45	44.5
		0	23.9	139
50%:50%	0.7	0.5	18.83	88.3
		1	18.23	82.3
		1.5	18	80.0
		0	NA	NA
50%:50%	0.8	0.5	21.25	112.5
		1	20.58	105.8
		1.5	20.28	102.8

It can be seen from the figure 4.8 that the flow diameters of geopolymer mortar were increased with respect to the increase of alkaline to binder ratio. The arrow shown in the figure indicates that the fresh geopolymer mortar was spreading beyond the diameter of mini flow table (250mm) for plain mortar of alkaline to binder ratio of 0.8. As it can be seen from the figure incorporation and increase in fiber content decreases the flow diameter , effect of crimped steel fibers on plain geopolymer mortar decreases its flow diameter between 23.56 and 30.82% for alkaline to binder ratio of 0.5, between 24.77 and 33% for alkaline to binder ratio of 0.6, between 24.7 and 32.82% for alkaline to binder ratio of 0.7 depending on the fiber percentage used for each mix.

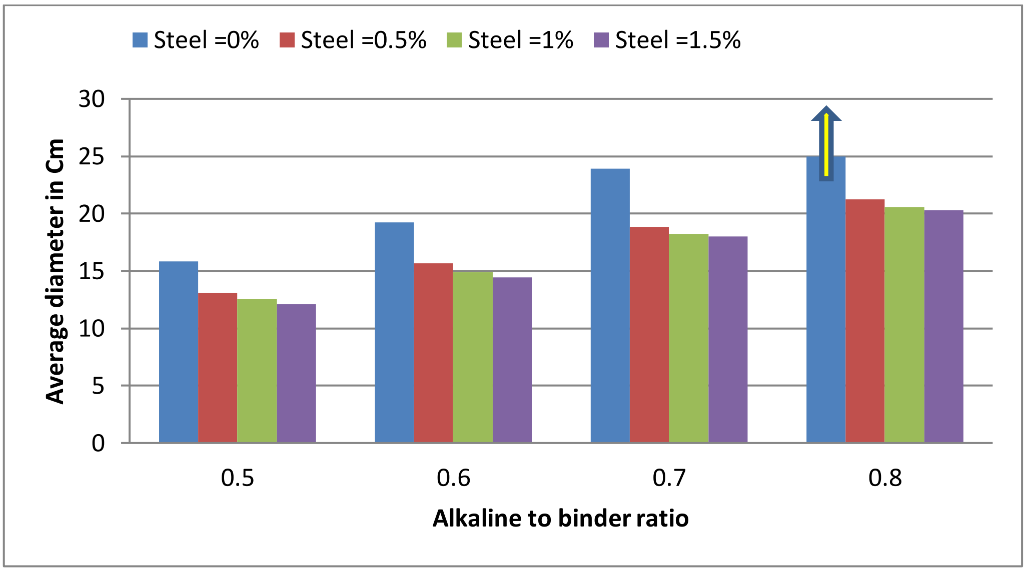


Figure 4. 8 Average flow diameter with respect to variation of fibers content

Figure 4. 9 Fresh steel fiber geopolymer mortar subjected to mini flow table test

Figure 4.10 shows the flow percentage of all alkaline to binder ratio with different variation of steel percentage. Based on alkaline to binder ratio, it can be seen from the figure that the flow percentage was increased with respect to the increase in alkaline to binder ratio. It is also clearly seen that incorporation and increase of steel fibers has a greater impact on flowing ability of geopolymer mortar in all mixes.

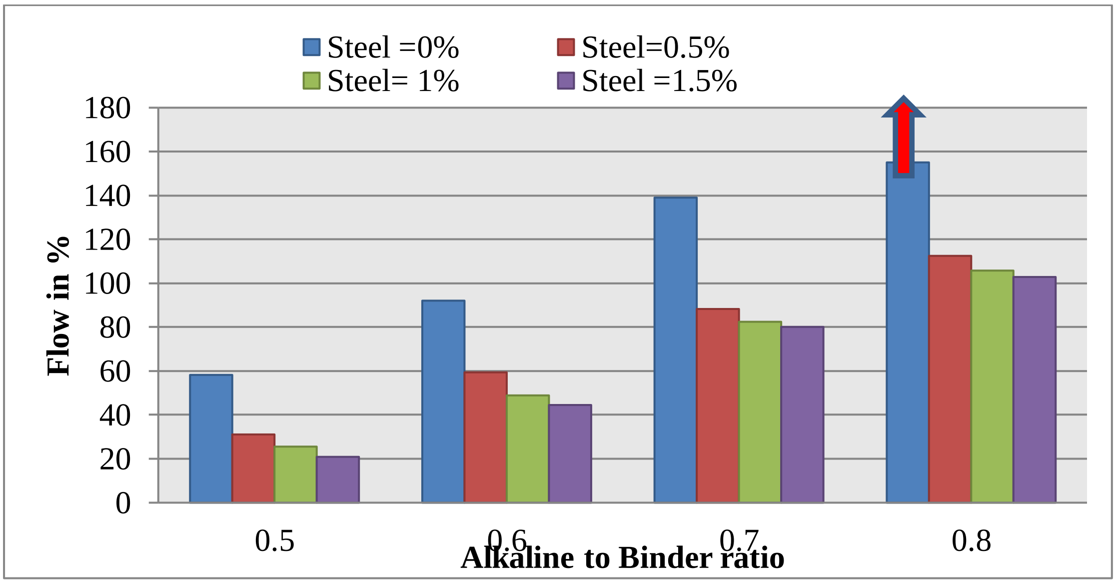


Figure 4. 10 Flow in % with respect to variation of fibers content

4.3. DENSITY

Density of hardened fiber geopolymer mortar cured at ambient temperature at the age of 3, 7 and 28 days with crimped steel fiber have been calculated in this study and the results are shown below

From figure 4.11 to 4.22, based on variation of alkaline to binder ratio (0.5to 0.8), it was observed that there is a variation in density of geopolymer mortar. The density was increase as the percentage of fiber increased. The density value ranges from 1870 kg/m3 to 2316 kg/m3 for 3 days curing, from 2106 kg/m3 to 2299 kg/m3 for 7 days and 1915 kg/m3 to 2293 kg/m3 for 28days curing depending on alkaline to binder ratio and variation of fiber content. Based on variation of fiber volume ,the results show that there is no big change in density of crimped steel fiber geopolymer mortar .The density of crimped steel fiber geopolymer mortar ranges from 2140-2316 for

0.5% fibers volume, from 1970-2290 for 1% and from 2134-2273 for 1.5% fibers volume for 3 days curing , from 2111-2299 for 0.5% fibers volume, from 2016-2290 for 1% and from 2123-2285 for 1.5% fibers volume for 7 days and from 2052-2293 for 0.5% fibers volume, from 2100-2245 for 1% and from 1915-2205 for 1.5% fibers volume for 28 days depending on alkaline to binder ratio.

Alkaline to binder ratio=0.5

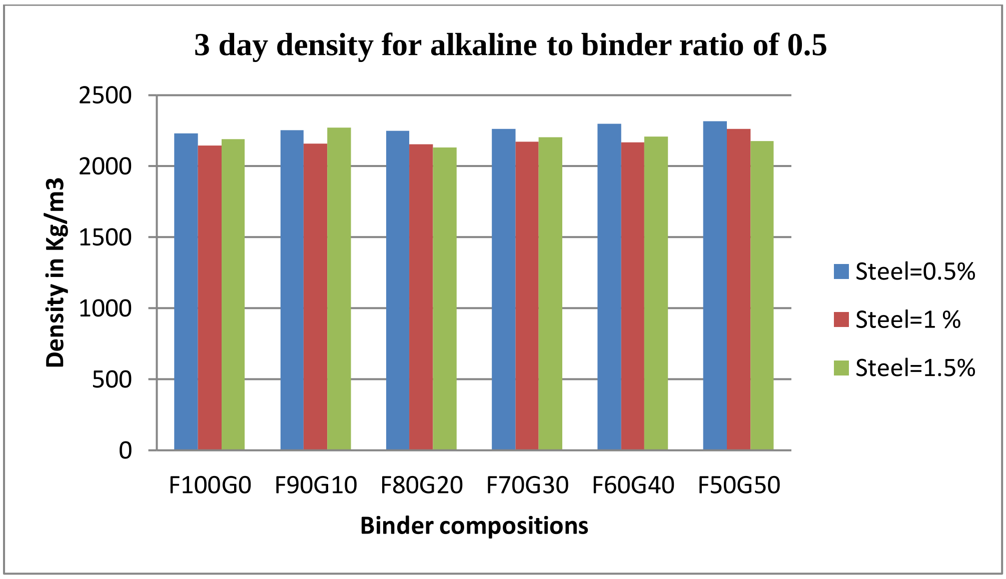


Figure 4.11 3days density for alkaline to binder ratio of 0.5

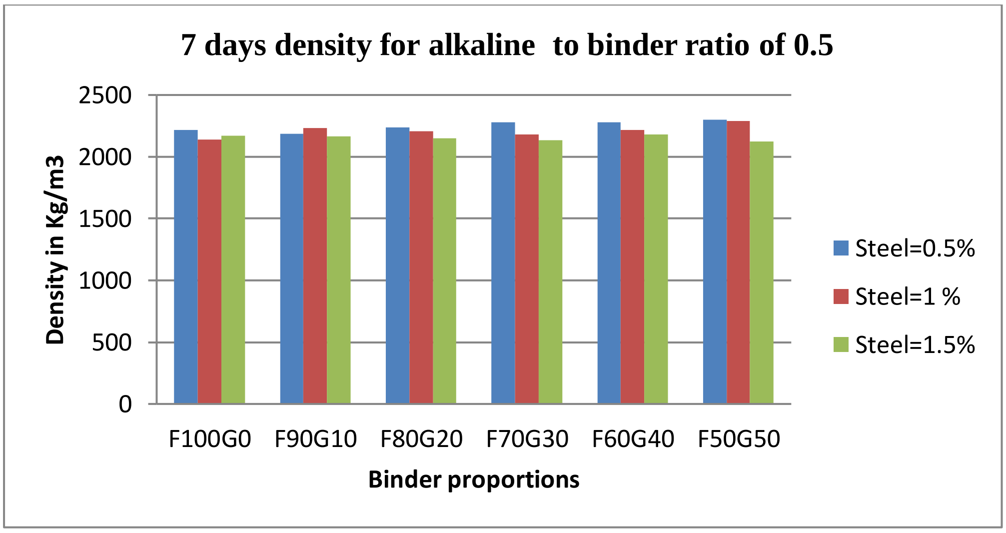


Figure 4.12 7days density for alkaline to binder ratio of 0.5

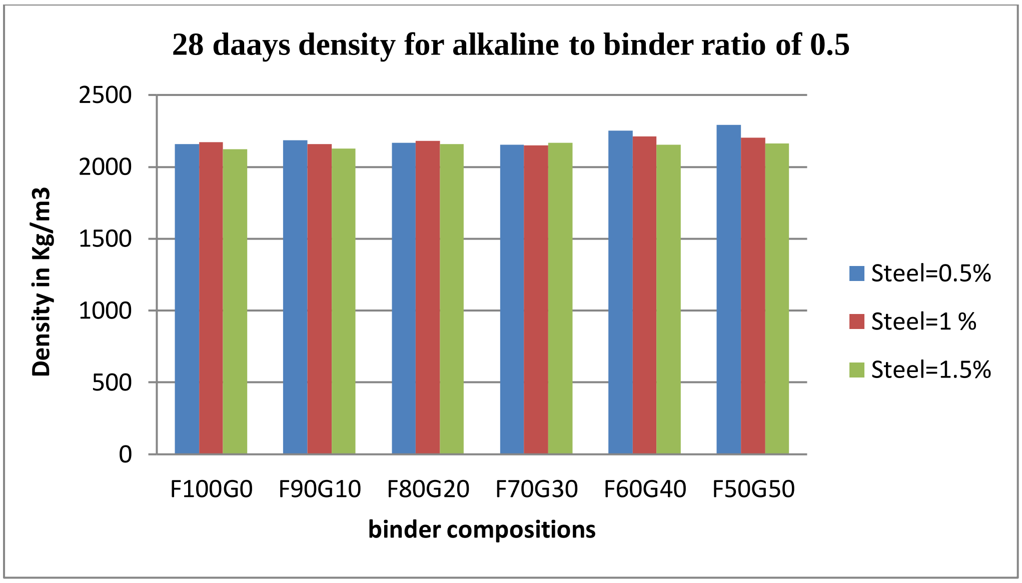


Figure 4.13 28 days density for alkaline to binder ratio of 0.5

Alkaline to binder ratio=0.6

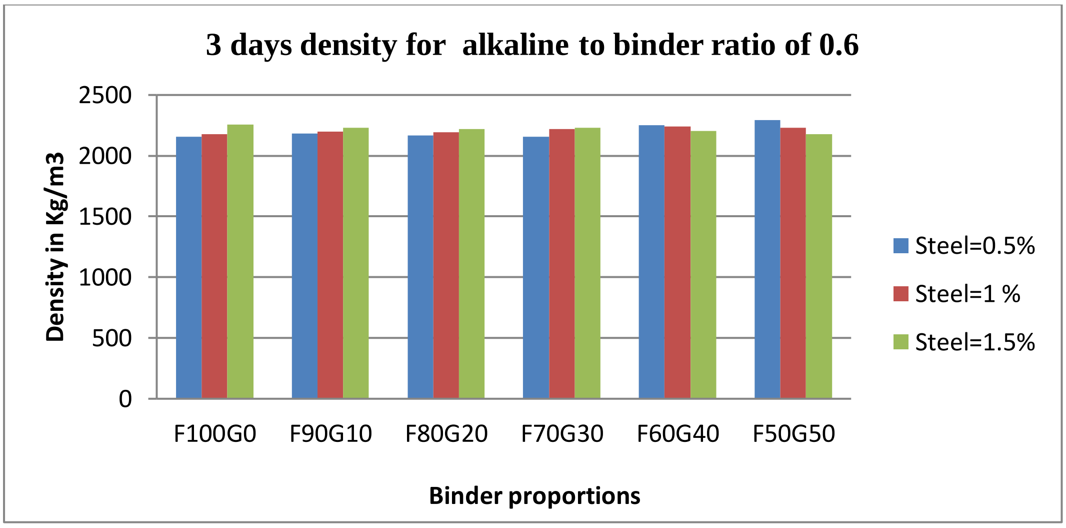


Figure 4.14 3days density for alkaline to binder ratio of 0.6

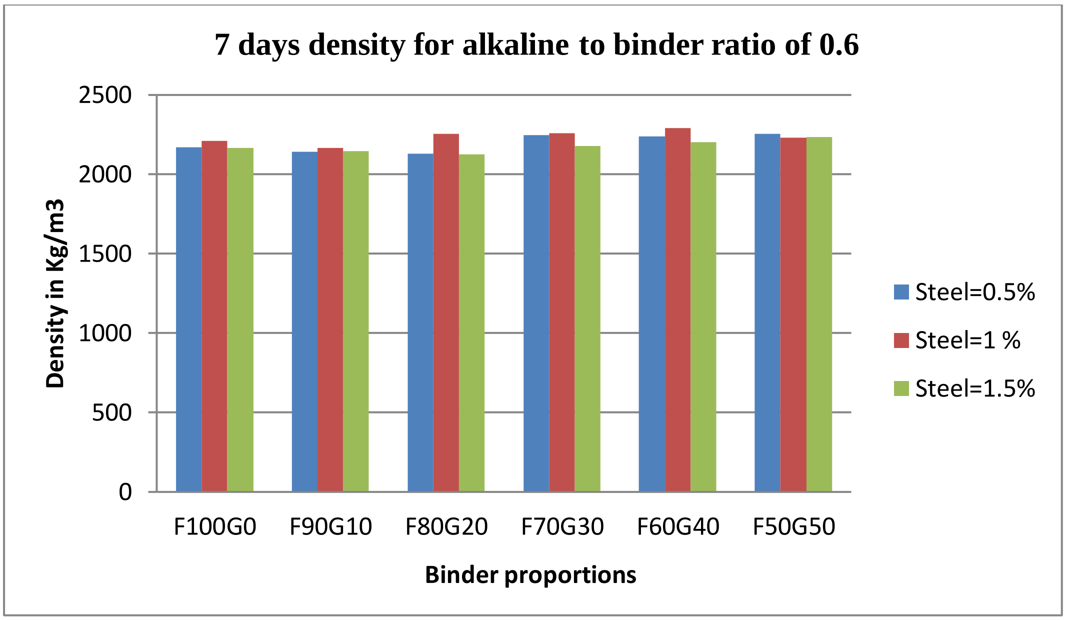


Figure 4.15 7days density for alkaline to binder ratio of 0.6

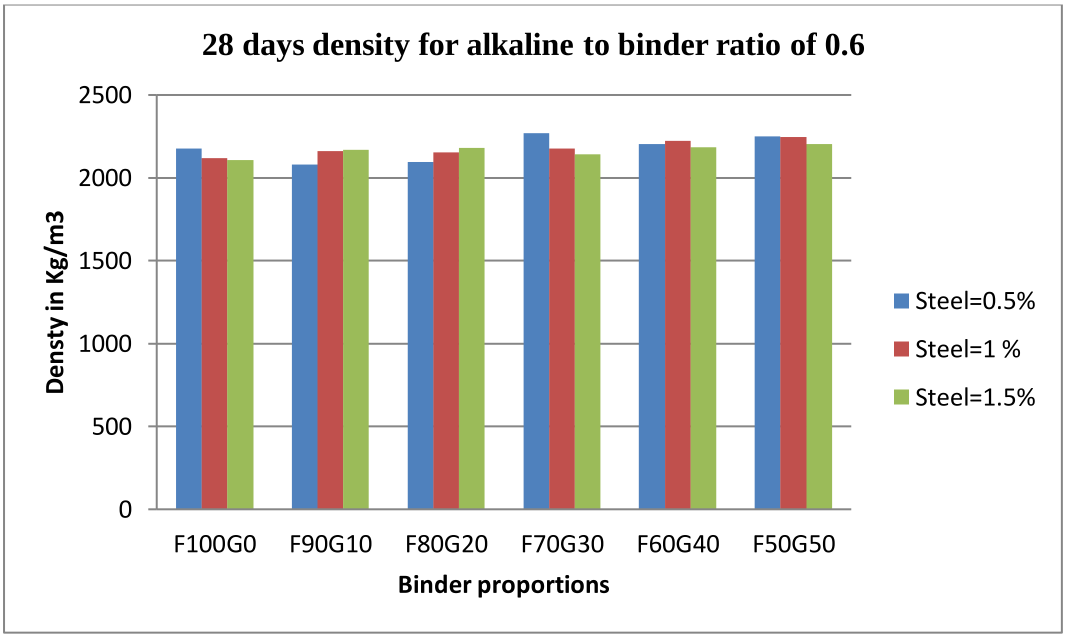


Figure 4.16 28days density for alkaline to binder ratio of 0.6

Alkaline to binder ratio =0.7

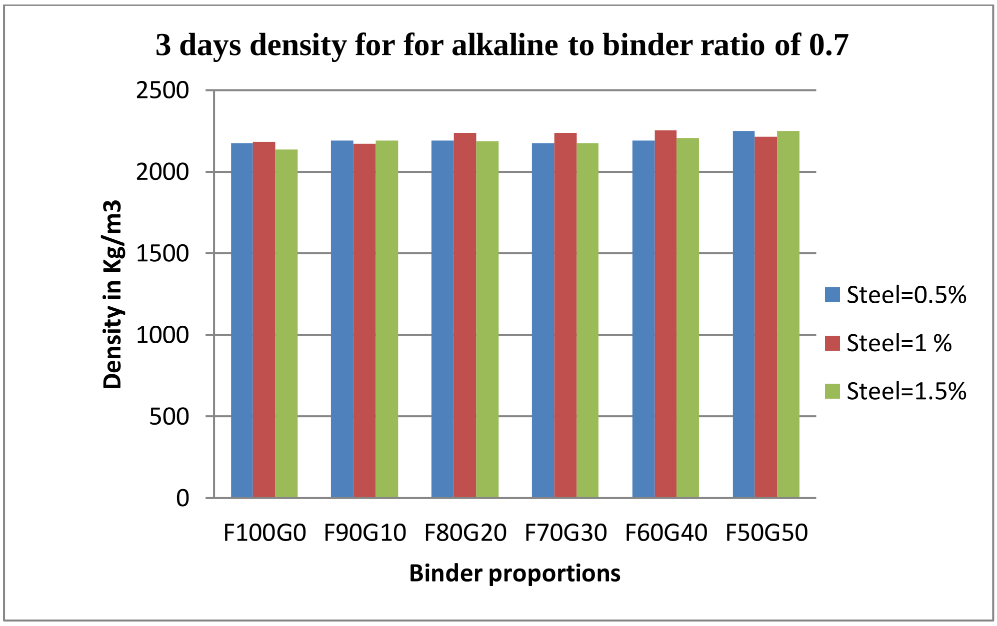


Figure 4.17 3days density for alkaline to binder ratio of 0.7

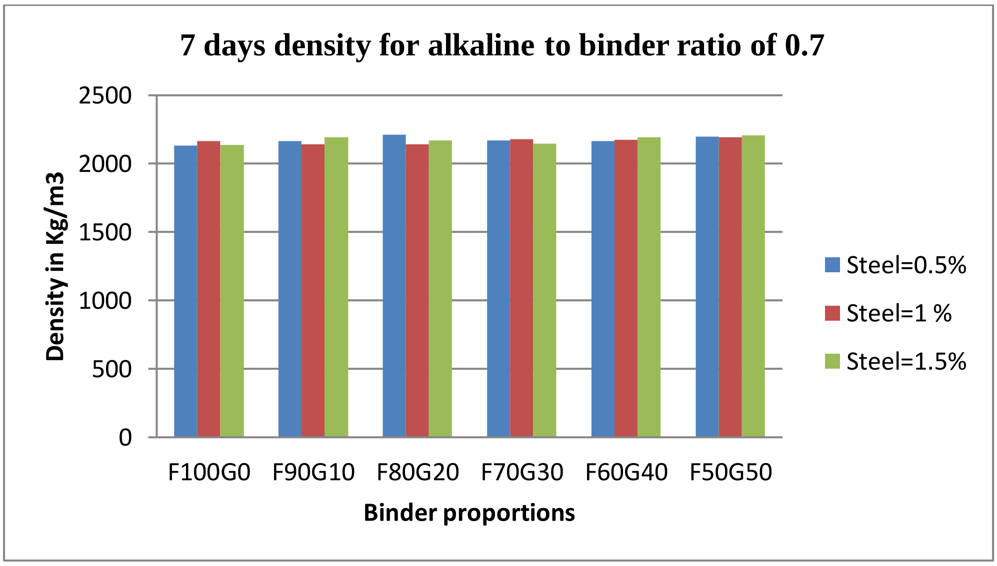


Figure 4.18 7days density for alkaline to binder ratio of 0.7

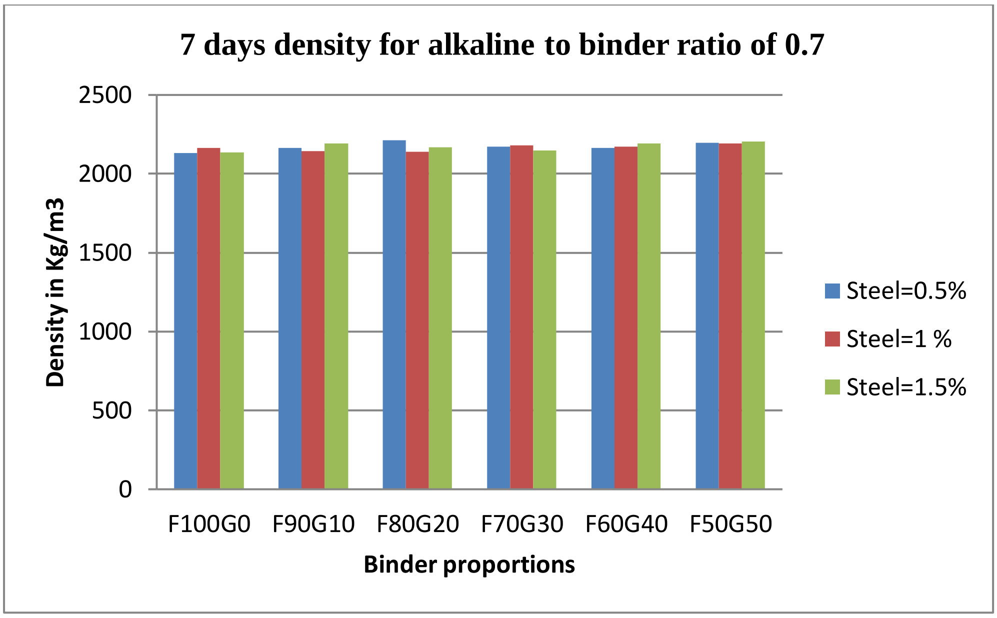


Figure 4.19 28days density for alkaline to binder ratio of 0.7

Alkaline to binder ratio =0.8

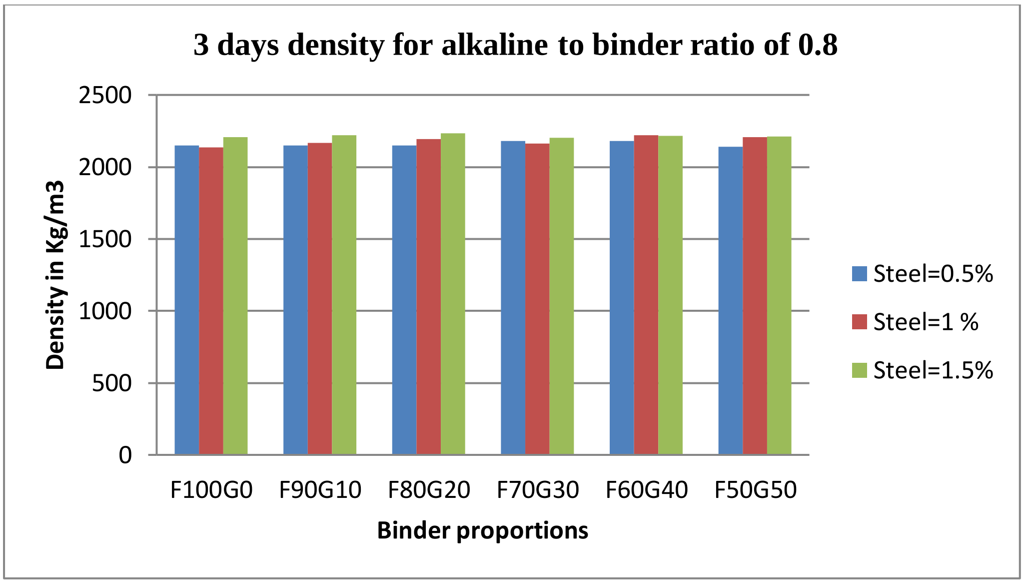


Figure 4.20 3days density for alkaline to binder ratio of 0.8

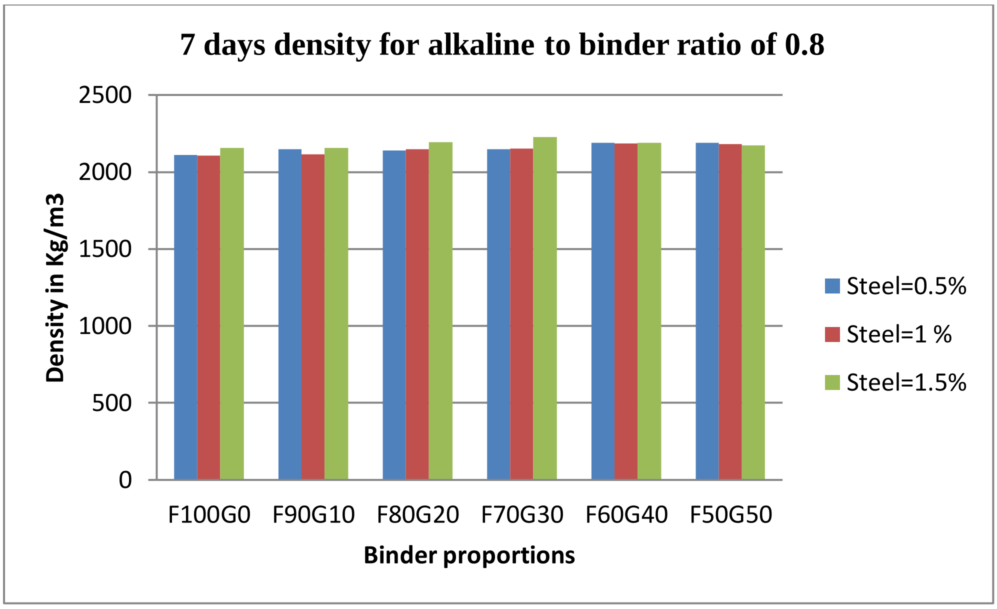


Figure 4.21 7days density for alkaline to binder ratio of 0.8

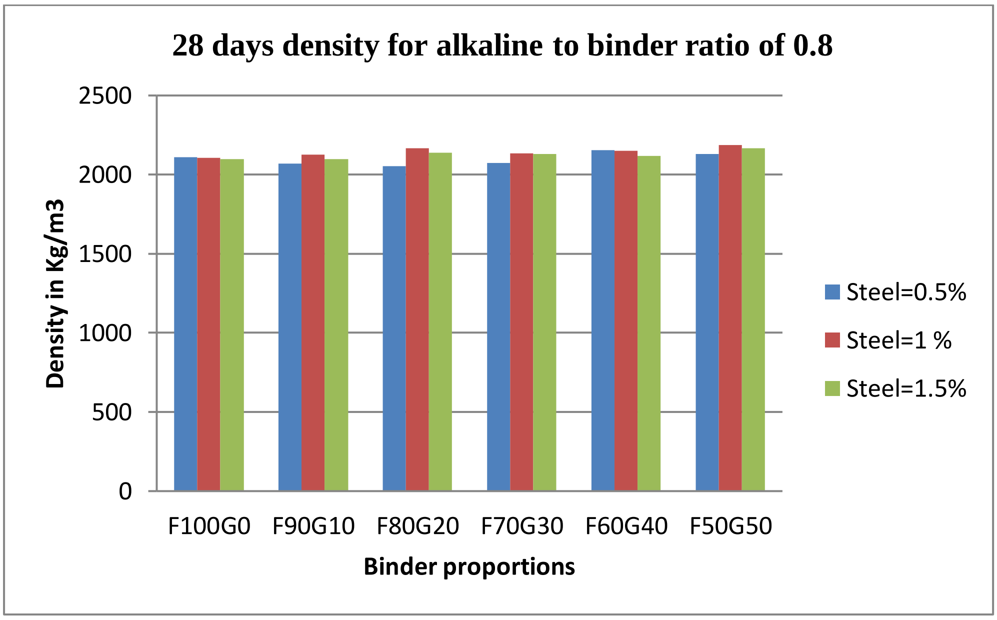


Figure 4.22 28days density for alkaline to binder ratio of 0.8

4.4 COMPRESSIVE STRENGTH TEST RESULTS

Compressive strength test is conducted to find the maximum amount of compressive load that can be taken by a material until failure. Compressive strength results for 3,7and 28 days in MPa for all alkaline to binder ratios with variation of steel content are shown in the table 4.3, 4.4 and 4.5 respectively. From compressive test results, it is observed that increasing the percentage of GGBS, the compressive strength also increased in all mixture. Variation of alkaline to binder ratio also has shown a great impact on the compressive strength but strengths values of alkaline to binder ratio of 0.6 were found to be greater than others (0.5, 0.7 and 0.8).It also observed that the increase in steel fibers volume shows an effect on compressive strength values. From tables and figures below, the following observations were made:

Figure 1 to figure 9 in the appendix III show the variation of compressive strength based on alkaline to binder ratio with different variation of fiber content (0.5, 1 and 1.5%). From the figures, it is observed that the compressive strength increased in all mixes with incorporation and increase in GGBS content from 0% to 50% due to increase in calcium content (CaO) in the mixtures which leads to a compacted microstructure and delivers high compressive strength of specimens. The alkaline to binder ratio of 0.6 was found to have greater compressive strength values than others (0.5, 0.7 and 0.8) for all variation of steel fibers content and for all curing period (3,7and 28 days). In all mixes the compressive strength increased up to 0.6, but beyond alkaline to binder ratio of 0.6, the compressive strength values decreased. The higher compressive strength values were found at alkaline to binder ratio of 0.6 in all mixes and in all curing period.

Table 4.3 presents all 3 days compressive strength test results of crimped steel fiber geopolymer mortar for alkaline to binder ratio of 0.5 to 0.8 with 0.5 to 1.5% steel content. It is found that the highest compressive strengths were obtained at alkaline to binder ratio of 0.6 at 1% steel fiber content. The highest compressive strength value is 45MPa obtained at 50×50 binder composition and 1% steel content

Table 4. 3: 3days compressive strength of all alkaline to binder ratio

	3 days	**Compressive**	**strength**		
Steel % by wt of binder	Binder proportions	Alkaline to	binder	ratio	
		0.5	0.6	0.7	0.8
0.5%	**$F_{100}G_0$**	17.2	18.5	13.3	12.5
	$F_{90}G_{10}$	21.8	22.4	16.2	14.4
	$F_{80}G_{20}$	24.1	27.6	18.6	17.8
	$F_{70}G_{30}$	28	31.3	23.6	20
	$F_{60}G_{40}$	31.5	34.6	25.5	22.5
	$F_{50}G_{50}$	35.8	40.4	28.9	26.2
1%	**$F_{100}G_0$**	22.4	23.8	18.6	17.8
	$F_{90}G_{10}$	26	27.8	21.2	20
	$F_{80}G_{20}$	28	31.4	24.2	21.7
	$F_{70}G_{30}$	33	36.3	27.8	24.5
	$F_{60}G_{40}$	37	39.8	30.5	26.8
	$F_{50}G_{50}$	40.4	45	34.5	31.5
1.5%	**$F_{100}G_0$**	21.4	22.6	16.5	15.5
	$F_{90}G_{10}$	24.3	25.5	20	19.2
	$F_{80}G_{20}$	26.3	28	22.9	20.5
	$F_{70}G_{30}$	28.5	33.1	24.9	23.5
	$F_{60}G_{40}$	33.8	36.3	29.5	26
	$F_{50}G_{50}$	36.1	42.9	32.5	29

Table4.4 shows all 7 days compressive strength test results of fiber geopolymer mortar of 0.5 to 0.8 with 0.5 to 1.5% steel content. It shows that the highest compressive strength obtained at alkaline to binder ratio of 0.6 is 52.5MPa obtained at 50×50 binder composition at 1% steel fiber content.

Table 4. 4: 7days compressive strength of all alkaline to binder ratio

	7 days	**Compressive**	**strength**		
Steel % by wt of binder	Binder proportions	Alkaline to	binder	ratio	
		0.5	0.6	0.7	0.8
0.5%	$\mathbf{F_{100}G_0}$	25.4	27	22.5	20
	$\mathbf{F_{90}G_{10}}$	27.9	29.1	25.7	22.5
	$\mathbf{F_{80}G_{20}}$	30.4	34	28.8	26.2
	$\mathbf{F_{70}G_{30}}$	35.2	38	31.2	28
	$\mathbf{F_{60}G_{40}}$	41.5	43	34.1	30
	$\mathbf{F_{50}G_{50}}$	46.4	49	39.3	34.5
1%	$\mathbf{F_{100}G_0}$	30.5	31	27.5	25.5
	$\mathbf{F_{90}G_{10}}$	33	34.8	30.5	27.2
	$\mathbf{F_{80}G_{20}}$	36.3	38	33	30.8
	$\mathbf{F_{70}G_{30}}$	39.9	42.8	36.8	32.8
	$\mathbf{F_{60}G_{40}}$	45	48.2	41	34.1
	$\mathbf{F_{50}G_{50}}$	51.8	52.5	44.5	39
1.5%	$\mathbf{F_{100}G_0}$	27.8	30.2	25.5	21.5
	$\mathbf{F_{90}G_{10}}$	29.5	31.5	27	23.5
	$\mathbf{F_{80}G_{20}}$	33	35.5	29.5	24.7
	$\mathbf{F_{70}G_{30}}$	36.1	39.5	33.3	27.5
	$\mathbf{F_{60}G_{40}}$	41.6	45	37.8	32
	$\mathbf{F_{50}G_{50}}$	47	50	42.3	37.4

Table4.5 presents all 28 days compressive strength test results of steel fiber geopolymer mortar for all alkaline to binder ratio and it seen that the highest 28 days curing compressive strength of steel fiber geopolymer mortar was 69.5MPa obtained at 1% of volume of fibers with 50×50 binder compositions for alkaline to binder ratio of 0.6.

Table 4. 5: 28days compressive strength of all alkaline to binder ratio

	28days	**Compressive**	**strength**		
Steel % by wt of binder	Binder proportions	Alkaline to	binder	ratio	
		0.5	0.6	0.7	0.8
0.5%	**$F_{100}G_0$**	35	39.6	34.8	31
	$F_{90}G_{10}$	39	40.4	36.1	32.8
	$F_{80}G_{20}$	41	42.5	39	35.5
	$F_{70}G_{30}$	45	50.2	43	37.8
	$F_{60}G_{40}$	51	56.5	48	39
	$F_{50}G_{50}$	58	65	54	45
1%	**$F_{100}G_0$**	43.6	43.6	40	34.6
	$F_{90}G_{10}$	44.2	44.2	41.6	37
	$F_{80}G_{20}$	46.4	46.4	44.4	39
	$F_{70}G_{30}$	50.8	50.8	49.5	41.5
	$F_{60}G_{40}$	55.8	55.8	53.5	44.1
	$F_{50}G_{50}$	62.7	69.5	59	49.5
1.5%	**$F_{100}G_0$**	41.5	42.2	37.5	32.8
	$F_{90}G_{10}$	43	44	39.5	35
	$F_{80}G_{20}$	44	46.5	42	37.5
	$F_{70}G_{30}$	49.3	53	48	38.9
	$F_{60}G_{40}$	53	58	51	43.2
	$F_{50}G_{50}$	60	67	57.2	48.2

4.4.1. Effect of Crimped steel fibers on Compressive strength geopolymer mortar

The main aim of incorporating fibers in plan geopolymer mortar was to examine and analyze the impact of steel fibers on the compressive strength behavior of geopolymer mortar cured under ambient temperature for different alkaline to binder ratios **(Note** that in this research all compressive strength test results of plain mortar were taken from my classmate who did plain geopolymer mortar). Based on increase in GGBS content, it is observed that increasing the percentage of GGBS, the compressive strength also increased for all mixture because of increase in calcium content (CaO) in the mixtures. This increase in CaO content leads to a compacted microstructure and delivers high compressive strength of specimens [22].Based on the compressive test results, additional and increase in steel fibers in plain geopolymer mortar increased its compressive strength values. The compressive strengths for 3,7 and 28 days of 1% volume of fibers were found to be greater than those of 0.5 and 1.5% for all variations of alkaline to binder ratio and all variations of binder proportions.

Table 4.6 shows comparison of compressive strength test results in MPa of plain geopolymer mortar and that of crimped steel fiber geopolymer mortar at 3,7and 28 curing for all alkaline to binder ratio. It can be observed in all mixes that with the incorporation and increase in percentage of crimped steel fibers up to 1%, the compressive strengths have increased but beyond 1% fiber content, the compressive strength values decreased. This increase in compressive strength up to 1% is due to the action of fibres to increase their bond with mortar thus increases the compressive strength but beyond 1% the workability was reduced due to the higher percentage of fibre content and compaction of geopolymer mortar were severely affected, hence compressive strength decrease[13].The increase in compressive strength of plain geopolymer mortar is in the range of 5.1MPa to 22.6MPa depending on the steel fiber content, binder compositions and alkaline to binder ratio. The highest 28 days compressive strength was 56, 69.5, 63 and 62 MPa for alkaline to binder ratio of 0.5, 0.6, 0.7 and 0.8 respectively obtained at 1% of steel fibers content with 50×50 binder compositions.

Table 4. 6 Comparison of compressive strength with variation of steel percentage

Binder proportions	Compressive strength in MPa											
	Curing period											
	3 days				7 days				28 days			
	Steel %											
	PM	0.5	1	1.5	PM	0.5	1	1.5	PM	0.5	1	1.5
	Alk/B=0.5											
$F_{100}G_0$	11	17.2	22.4	21.4	18	25.4	30.5	27.8	25	35	43.6	41.5
$F_{90}G_{10}$	16	21.8	26	24.3	22	27.9	33	29.5	29	39	44.2	43
$F_{80}G_{20}$	16	24.1	28	26.3	24	30.4	36.3	33	32	41	46.4	44
$F_{70}G_{30}$	21	28	33	28.5	28	35.2	39.9	36.1	39	45	50.8	49.3
$F_{60}G_{40}$	25	31.5	37	33.8	34	41.5	45	41.6	43	51	55.8	53
$F_{50}G_{50}$	30	35.8	40.4	36.1	41	46.4	51.8	47	50	58	62.7	60
	Alk/B=0.6											
$F_{100}G_0$	12	18.5	23.8	22.6	20	27	31	30.2	31	39.6	44.1	42.2
$F_{90}G_{10}$	16	22.4	27.8	25.5	23	29.1	34.8	31.5	34	40.4	46.8	44
$F_{80}G_{20}$	22	27.6	31.4	28	28	34	38	35.5	36	42.5	48.7	46.5
$F_{70}G_{30}$	25	31.3	36.3	33.1	31	38	42.8	39.5	43	50.2	55.2	53
$F_{60}G_{40}$	29	34.6	39.8	36.3	36	43	48.2	45	49	56.5	61	58
$F_{50}G_{50}$	34	40.4	45	42.9	41	49	52.5	50	56	65	69.5	67
	Alk/B=0.7											
$F_{100}G_0$	7	13.3	18.6	16.5	16	22.5	27.5	25.5	27	34.8	40	37.5
$F_{90}G_{10}$	10	16.2	21.2	20	20	25.7	30.5	27	29	36.1	41.6	39.5
$F_{80}G_{20}$	12	18.6	24.2	22.9	22	28.8	33	29.5	33	39	44.4	42
$F_{70}G_{30}$	16	23.6	27.8	24.9	25	31.2	36.8	33.3	36	43	49.5	48
$F_{60}G_{40}$	19	25.5	30.5	29.5	29	34.1	41	37.8	40	48	53.5	51
$F_{50}G_{50}$	23	28.9	34.5	32.5	32	39.3	44.5	42.3	44	54	59	57.2
	Alk/B=0.8											
$F_{100}G_0$	5	12.5	17.8	15.5	12	20	25.5	21.5	22	31	34.6	32.8
$F_{90}G_{10}$	7	14.4	20	19.2	16	22.5	27.2	23.5	25	32.8	37	35
$F_{80}G_{20}$	10	17.8	21.7	20.5	18	26.2	30.8	24.7	29	35.5	39	37.5
$F_{70}G_{30}$	13	20	24.5	23.5	18.5	28	32.8	27.5	32	37.8	41.5	38.9
$F_{60}G_{40}$	17	22.6	26.8	26	22	30	34.1	32	35	39	44.1	43.2
$F_{50}G_{50}$	20	26.2	31.5	29	27	34.5	39	37.4	38	45	49.5	48.2

1. Alkaline to binder ratio =0.5

Figure 4.23 shows the variation of 3 days compressive strength of plain mortar and crimped steel fiber geopolymer mortar for alkaline to binder ratio of 0.5. It is observed from the figure that increasing the percentage of GGBS from 0 to 50%, the compressive strength also increased. The incorporation and increase in percentage of crimped steel fibers in plain geopolymer mortar have a greater effect on its compressive strength values. Effect of fibers on 3 days compressive strength of plain geopolymer mortar increased the compressive strength about 19.33 to 75% depending on GGBS content and percentage of fibers. It can also be observed that with the increase in fiber percentage up to 1%, the compressive strength has been increased but beyond 1% fiber content compressive strength values decreased. The compressive strength increased between 19.33 to 56.36% more than that of plain mortar for 0.5% fiber content, between 34.66 to 75% more than that of plain mortar for 1% fiber content and between 20.33 to 64.38 % more than that of plain mortar for 0.5% fiber content.

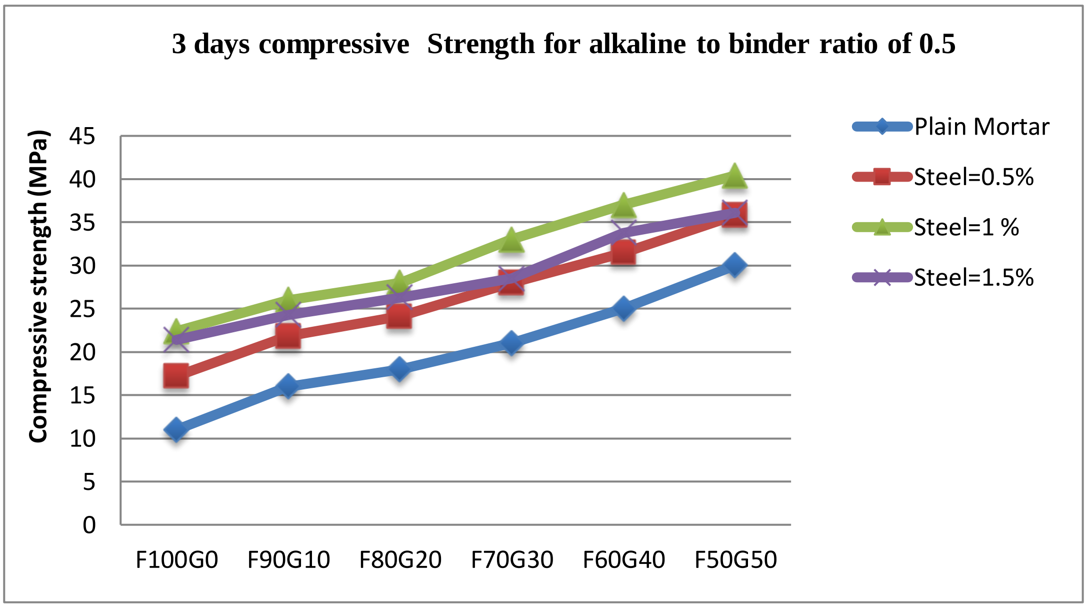


Figure 4. 23 Comparison of 3 days compressive strength for Alk/B= 0.5

Figure 4.24 shows the variation of 7 days compressive strength of plain mortar and crimped steel fiber geopolymer mortar for alkaline to binder ratio of 0.5. It is observed from the figure that increasing the percentage of GGBS from 0 to 50%, the compressive strength also increased. The figure shows increase in percentage of crimped steel fibers in plain geopolymer mortar has a greater effect on its compressive strength values. Effect of fibers on 7 days compressive strength of plain geopolymer mortar increased the compressive strength about 13.17 to 69.44% higher than that of plain mortar depending on GGBS content and percentage of fibers. It can also be observed that with the increase in crimped fiber percentage up to 1%, the compressive strength has been increased but beyond 1% fiber content compressive strength values decreased. The compressive strength increased between 13.17 to 41.11% more than that of plain mortar for 0.5% fiber content, between 26.34 to 69.44% more than that of plain mortar for 1% fiber content and between 14.63 to 54.44 % more than that of plain mortar for 0.5% fiber content.

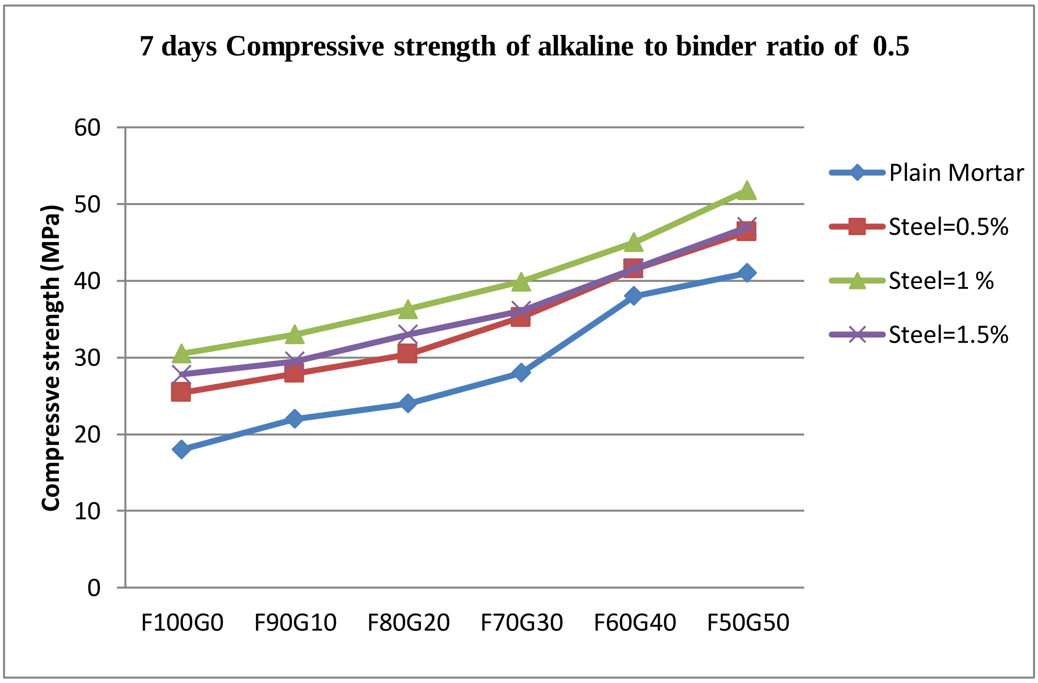


Figure 4. 24 Comparison of 7 days compressive strength for Alk/B= 0.5

Figure 4.25 shows the variation of 28 days compressive strength of plain mortar and crimped steel fiber geopolymer mortar for alkaline to binder ratio of 0.5. It is observed from the figure that increasing the percentage of GGBS from 0 to 50%, the compressive strength also increased. The figure shows that incorporation and increase in percentage of crimped steel fibers in plain geopolymer mortar have a greater effect on its compressive strength values. Effect of fibers on 28 days compressive strength of plain geopolymer mortar increased the compressive strength about 15.38 to 74.4% higher than that of plain mortar depending on GGBS content and percentage of fibers. It can also be observed that with the increase in crimped fiber percentage up to 1%, the compressive strength has been increased but beyond 1% fiber content compressive strength values decreased. The compressive strength increased between 15.38 to 40% higher more that of plain mortar for 0.5% fiber content, between 25.4 to 74.4% more than that of plain mortar for 1% fiber content and between 20 to 66 % more than that of plain mortar for 0.5% fiber content.

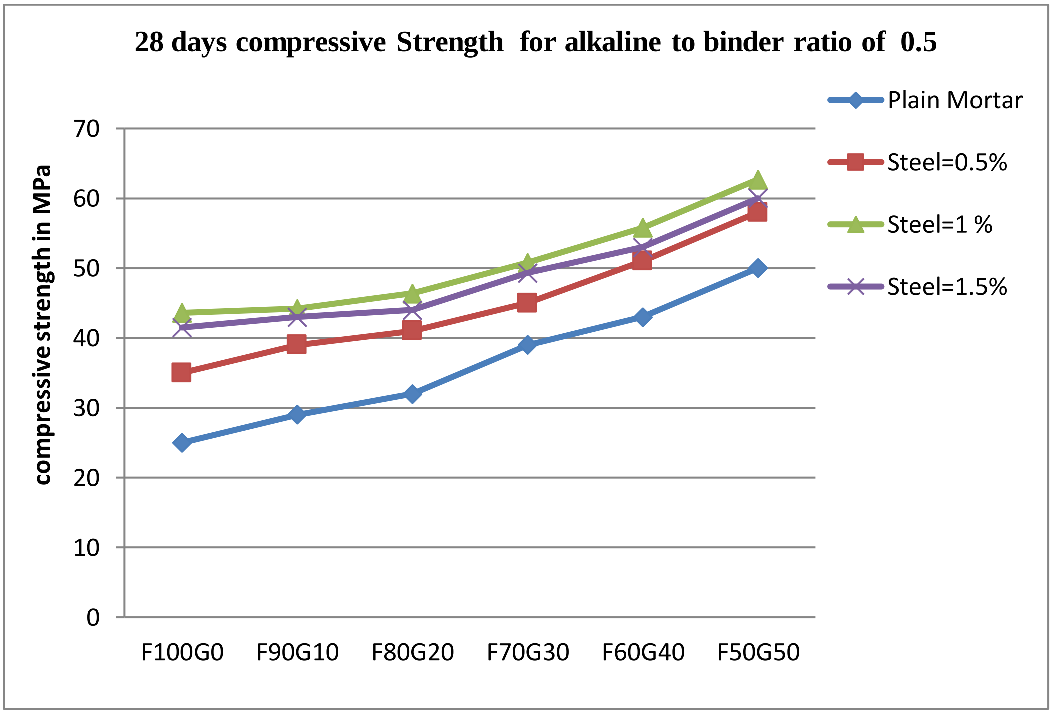


Figure 4. 25 Comparison of 28 days compressive strength for Alk/B= 0.5

2. Alkaline to binder ratio =0.6

Figure 4.26 shows the variation of 3 days compressive strength of plain mortar and crimped steel fiber geopolymer mortar for alkaline to binder ratio of 0.6. The figure shows that incorporation and increase in percentage of crimped steel fibers in plain geopolymer mortar have a greater effect on its compressive strength values. Effect of fibers on 3 days compressive strength of plain geopolymer mortar increased the compressive strength about 19.82 to 73.75% higher than that of plain mortar depending on GGBS content and percentage of fibers. It is observed from the figure that increasing the percentage of GGBS from 0 to 50%, the compressive strength also increased. It can also be observed that with the increase in crimped fiber percentage up to 1%, the compressive strength has been increased but beyond 1% fiber content compressive strength values decreased. The compressive strength increased between 18.82 to 54.16% more than that of plain mortar for 0.5% fiber content, between 32.35 to 73.75% more than that of plain mortar for 1% fiber content and between 25.17 to 19.37 % more than that of plain mortar for 1.5% fiber content.

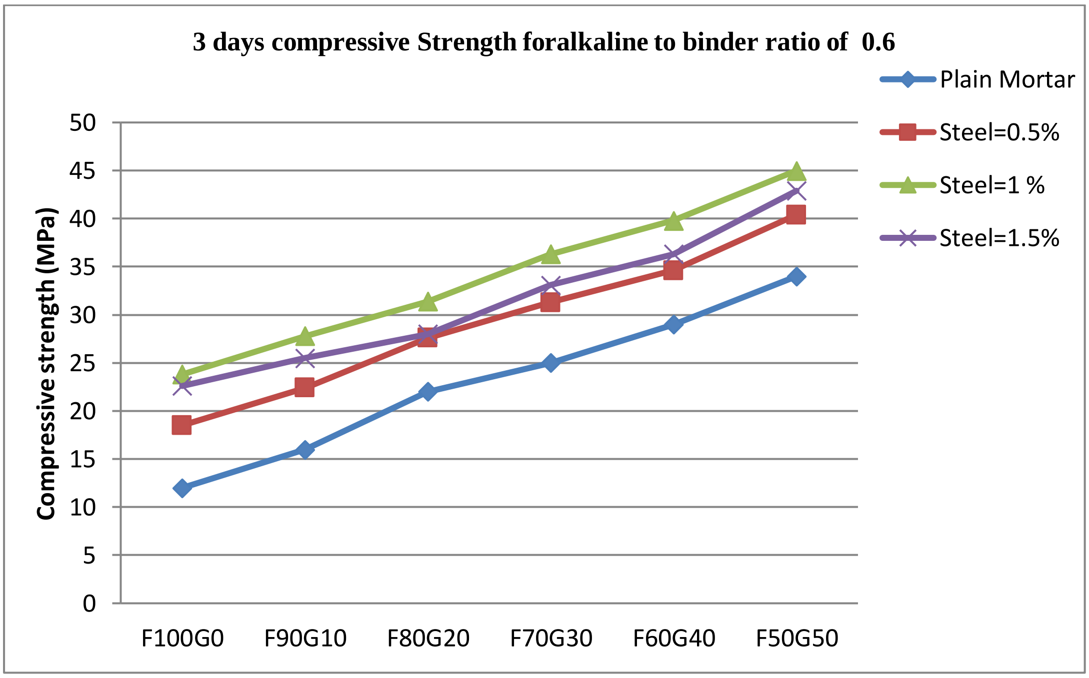


Figure 4. 26 Comparison of 3 days compressive strength for Alk/B= 0.6

Figure 4.27 shows the variation of 7 days compressive strength of plain mortar and crimped steel fiber geopolymer mortar for alkaline to binder ratio of 0.6. The figure shows that incorporation and increase in percentage of crimped steel fibers in plain geopolymer mortar have a greater effect on its compressive strength values. It is observed from the figure that increasing the percentage of GGBS from 0 to 50%, the compressive strength also increased. Effect of fibers on 7 days compressive strength of plain geopolymer mortar increased the compressive strength about 19.44 to 55% higher than that of plain mortar depending on GGBS content and percentage of fibers. It can also be observed that with the increase in crimped fiber percentage up to 1%, the compressive strength has been increased but beyond 1% fiber content compressive strength values decreased. The compressive strength increased between 19.44 to 35% more than that of plain mortar for 0.5% fiber content, between 28.04 to 55% more than that of plain mortar for 1% fiber content and between 21.95 to 51 % more than that of plain mortar for 1.5% fiber content.

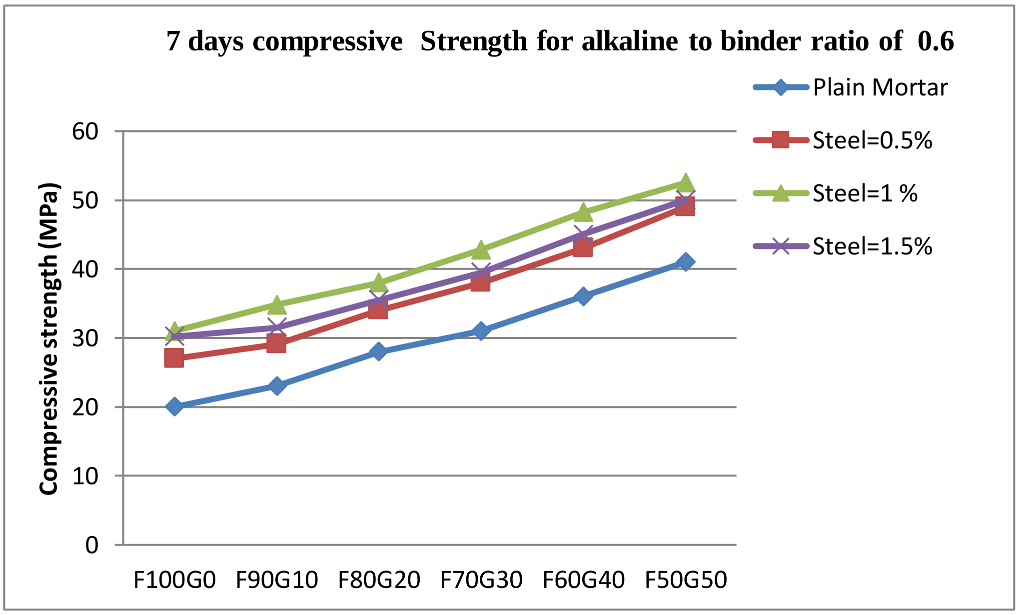


Figure 4. 27 Comparison of 7 days compressive strength for Alk/B= 0.6

Figure 4.28 shows the variation of 28 days compressive strength of plain mortar and crimped steel fiber geopolymer mortar for alkaline to binder ratio of 0.6. The figure shows that incorporation and increase in percentage of crimped steel fibers in plain geopolymer mortar have a greater effect on its compressive strength values. Effect of fibers on 28 days compressive strength of plain geopolymer mortar increased the compressive strength about 15.3 to 42.25% higher than that of plain mortar depending on GGBS content and percentage of fibers. It is observed from the figure that increasing the percentage of GGBS from 0 to 50%, the compressive strength also increased. It can also be observed that with the increase in crimped fiber percentage up to 1%, the compressive strength has been increased but beyond 1% fiber content compressive strength values decreased. The compressive strength increased between 15.3 to 27.74% more than that of plain mortar for 0.5% fiber content, between 24.1 to 42.25% more than that of plain mortar for 1% fiber content and between 18.36 to 36.12 % more than that of plain mortar for 1.5% fiber content.

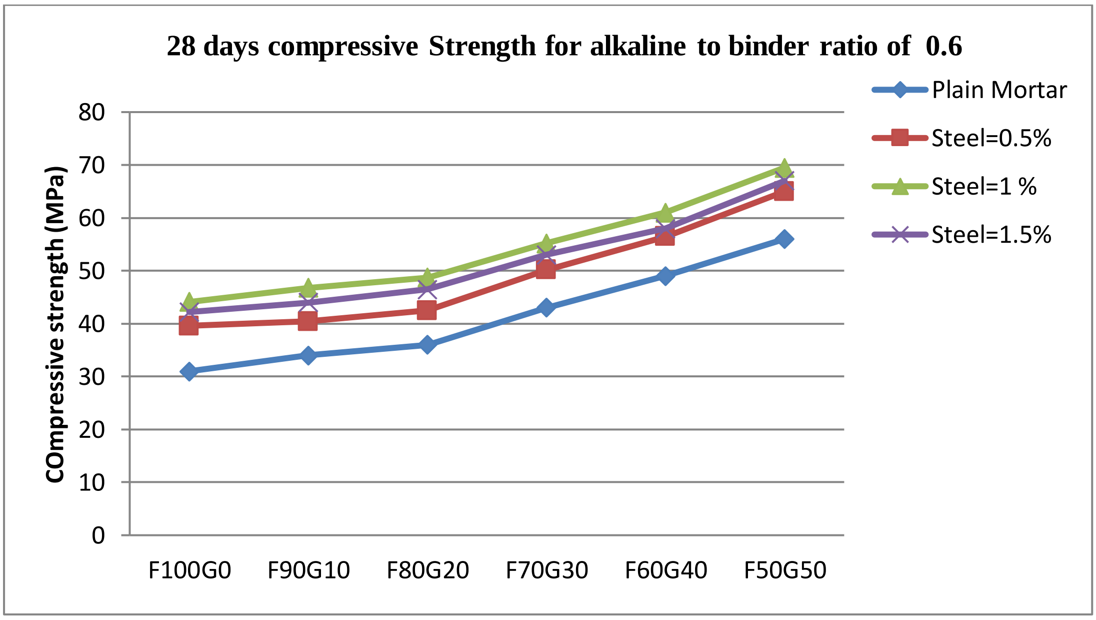


Figure 4. 28 Comparison of 28 days compressive strength for Alk/B= 0.6

3. Alkaline to binder ratio =0.7

Figure 4.29 shows the variation of 3 days compressive strength of plain mortar and crimped steel fiber geopolymer mortar for alkaline to binder ratio of 0.7. The figure shows that incorporation and increase in percentage of crimped steel fibers in plain geopolymer mortar have a greater effect on its compressive strength values. It is observed from the figure that increasing the percentage of GGBS from 0 to 50%, the compressive strength also increased. Effect of fibers on 3 days compressive strength of plain geopolymer mortar increased the compressive strength about 25 to 75.75% higher than that of plain mortar depending on GGBS content and percentage of fibers. It can also be observed that with the increase in crimped fiber percentage up to 1%, the compressive strength has been increased but beyond 1% fiber content compressive strength values decreased. The compressive strength increased between 25.65 to 62% more than that of plain mortar for 0.5% fiber content, between 50 to 73.75% more than that of plain mortar for 1% fiber content and between 41.3 to 55.62% more than that of plain mortar for 1.5% fiber content.

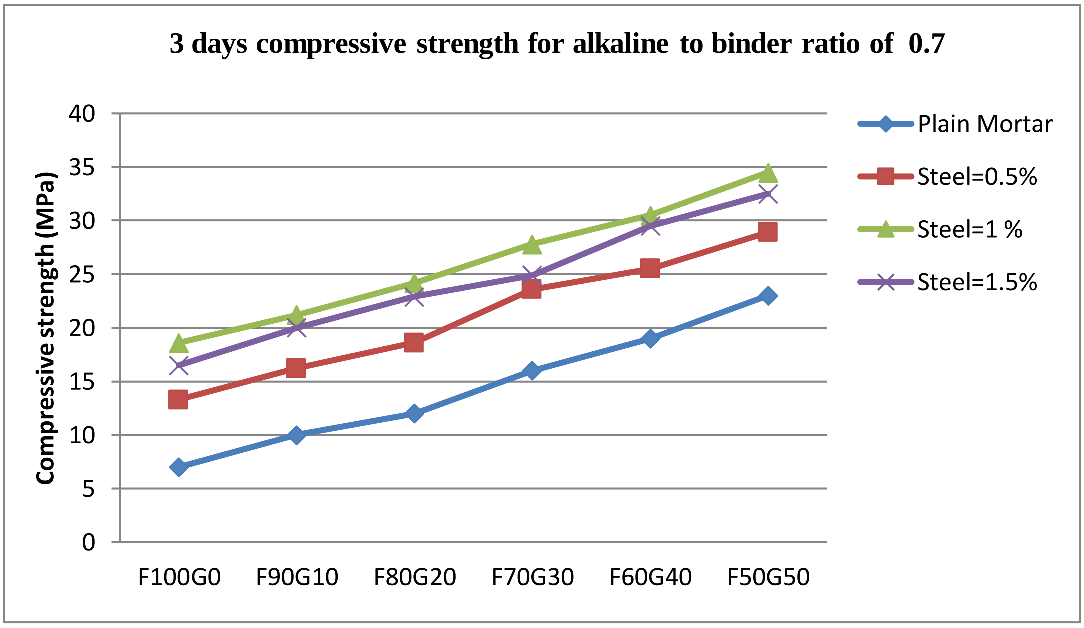


Figure 4. 29 Comparison of 3 days compressive strength for Alk/B= 0.7

Figure 4.30 shows the variation of 7 days compressive strength of plain mortar and crimped steel fiber geopolymer mortar for alkaline to binder ratio of 0.7. It is observed from the figure that increasing the percentage of GGBS from 0 to 50%, the compressive strength also increased. The figure shows that incorporation and increase in percentage of crimped steel fibers in plain geopolymer mortar have a greater effect on its compressive strength values. Effect of fibers on 7 days compressive strength of plain geopolymer mortar increased the compressive strength about 17.58 to 71.87% higher than that of plain mortar depending on GGBS content and percentage of fibers. It can also be observed that with the increase in crimped fiber percentage up to 1%, the compressive strength has been increased but beyond 1% fiber content compressive strength values decreased. The compressive strength increased between 17.58 to 40.62% more than that of plain mortar for 0.5% fiber content, between 39.06 to 71.87% more than that of plain mortar for 1% fiber content and between 30.34 to 59.37% more than that of plain mortar for 1.5% fiber content.

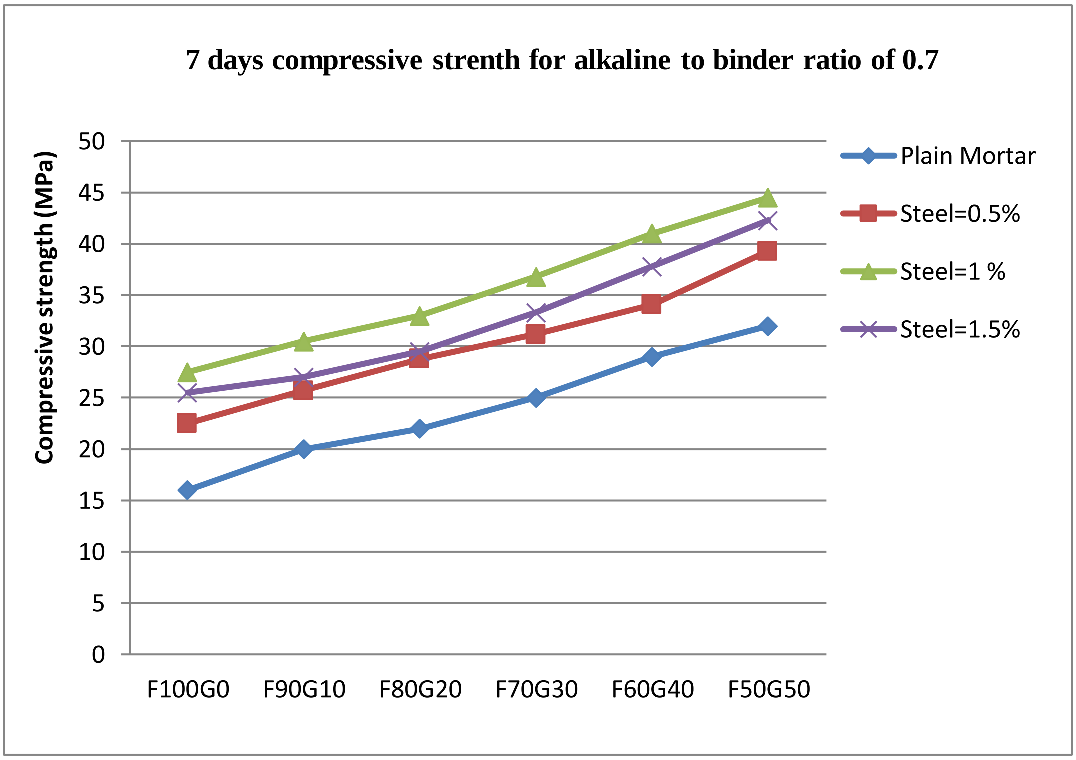


Figure 4. 30 Comparison of 7 days compressive strength for Alk/B= 0.7

Figure 4.31 shows the variation of 28 days compressive strength of plain mortar and crimped steel fiber geopolymer mortar for alkaline to binder ratio of 0.7. The figure shows that incorporation and increase in percentage of crimped steel fibers in plain geopolymer mortar have a greater effect on its compressive strength values. Effect of fibers on 28 days compressive strength of plain geopolymer mortar increased the compressive strength about 18.18 to 48.14% higher than that of plain mortar depending on GGBS content and percentage of fibers. It is observed from the figure that increasing the percentage of GGBS from 0 to 50%, the compressive strength also increased. It can also be observed that with the increase in crimped fiber percentage up to 1%, the compressive strength has been increased but beyond 1% fiber content compressive strength values decreased. The compressive strength increased between 18.18 to 28.88% more than that of plain mortar for 0.5% fiber content, between 33.75 to 48.14% more than that of plain mortar for 1% fiber content and between 27.27 to 38.88 % more than that of plain mortar for 1.5% fiber content.

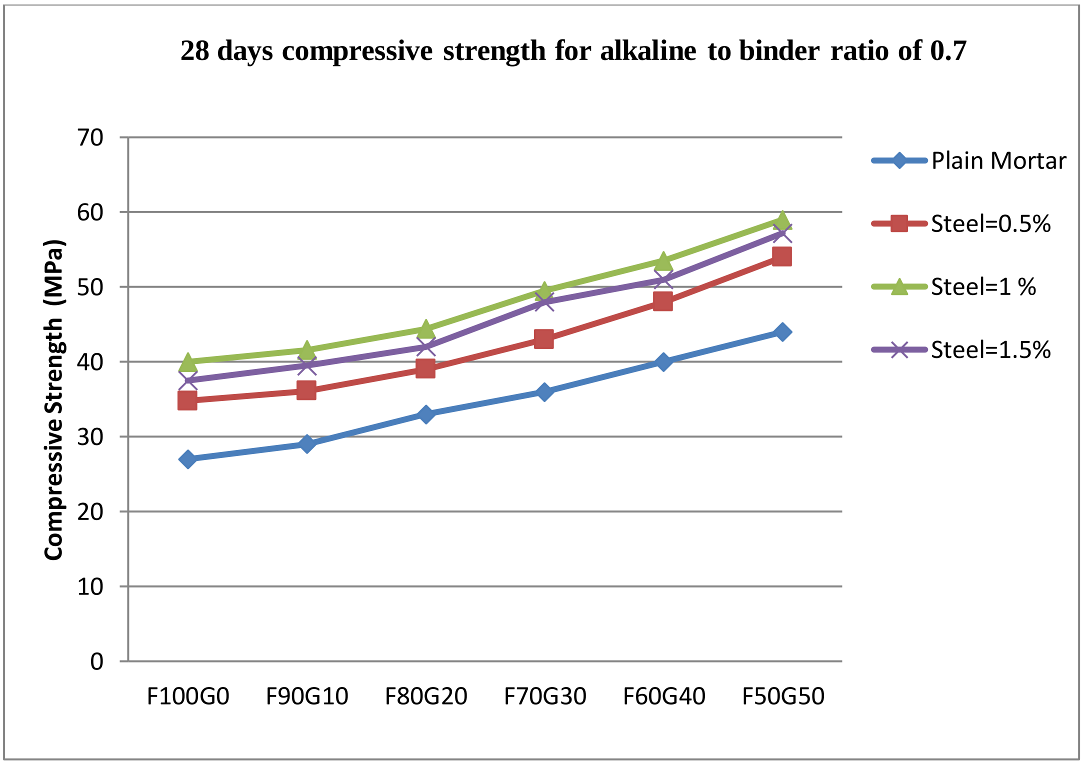


Figure 4. 31 Comparison of 28 days compressive strength for Alk/B= 0.7

4. Alkaline to binder ratio =0.8

Figure 4.32 shows the variation of 3 days compressive strength of plain mortar and crimped steel fiber geopolymer mortar for alkaline to binder ratio of 0.8. The figure shows that incorporation and increase in percentage of crimped steel fibers in plain geopolymer mortar have a greater effect on its compressive strength values. Effect of fibers on 3 days compressive strength of plain geopolymer mortar increased the compressive strength about 31 to 88.48% higher than that of plain mortar depending on GGBS content and percentage of fibers. It can also be observed that with the increase in crimped fiber percentage up to 1%, the compressive strength has been increased but beyond 1% fiber content compressive strength values decreased. The compressive strength increased between 31 to 78% more than that of plain mortar for 0.5% fiber content, between 57.5 to 88.46% more than that of plain mortar for 1% fiber content and between 45 to 80.76% more than that of plain mortar for 1.5% fiber content.

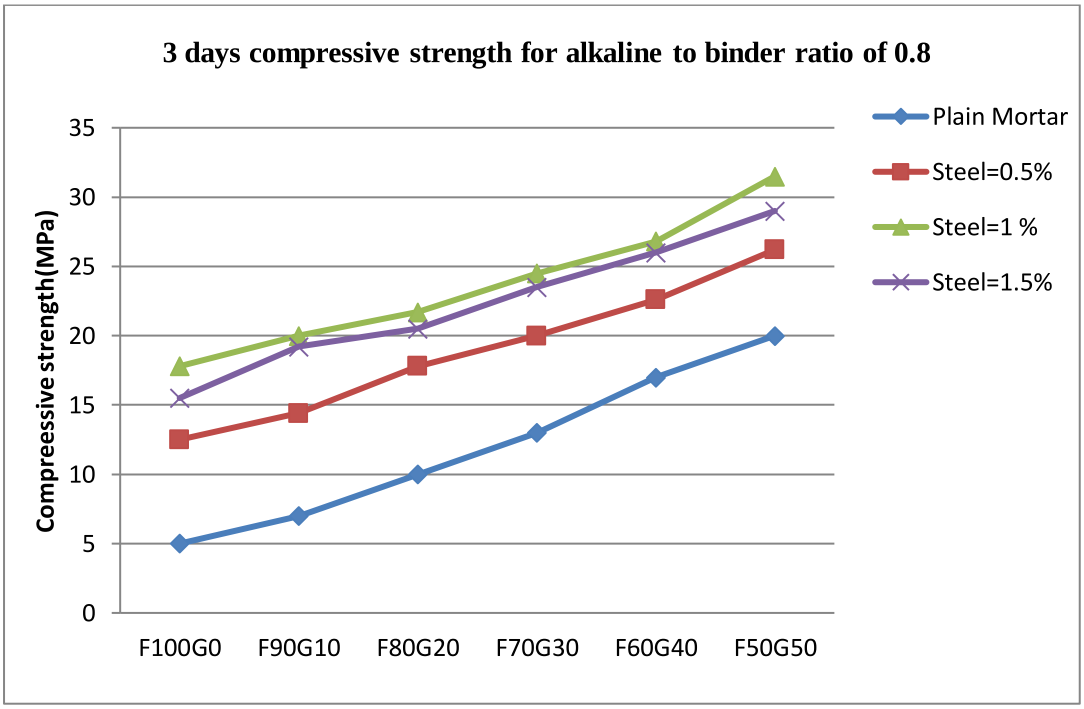


Figure 4. 32 Comparison of 3 days compressive strength for Alk/B= 0.8

Figure 4.33 shows the variation of 7 days compressive strength of plain mortar and crimped steel fiber geopolymer mortar for alkaline to binder ratio of 0.8. The figure shows that incorporation and increase in percentage of crimped steel fibers in plain geopolymer mortar have a greater effect on its compressive strength values. It is observed from the figure that increasing the percentage of GGBS from 0 to 50%, the compressive strength also increased. Effect of fibers on 7 days compressive strength of plain geopolymer mortar increased the compressive strength about 52 to 83.33% higher than that of plain mortar depending on GGBS content and percentage of fibers. It can also be observed that with the increase in crimped fiber percentage up to 1%, the compressive strength has been increased but beyond 1% fiber content compressive strength values decreased. The compressive strength increased between 66.66 to 77.27% more than that of plain mortar for 0.5% fiber content, between 58 to 83.33% more than that of plain mortar for 1% fiber content and between 52 to 78.51 % more than that of plain mortar for 1.5% fiber content.

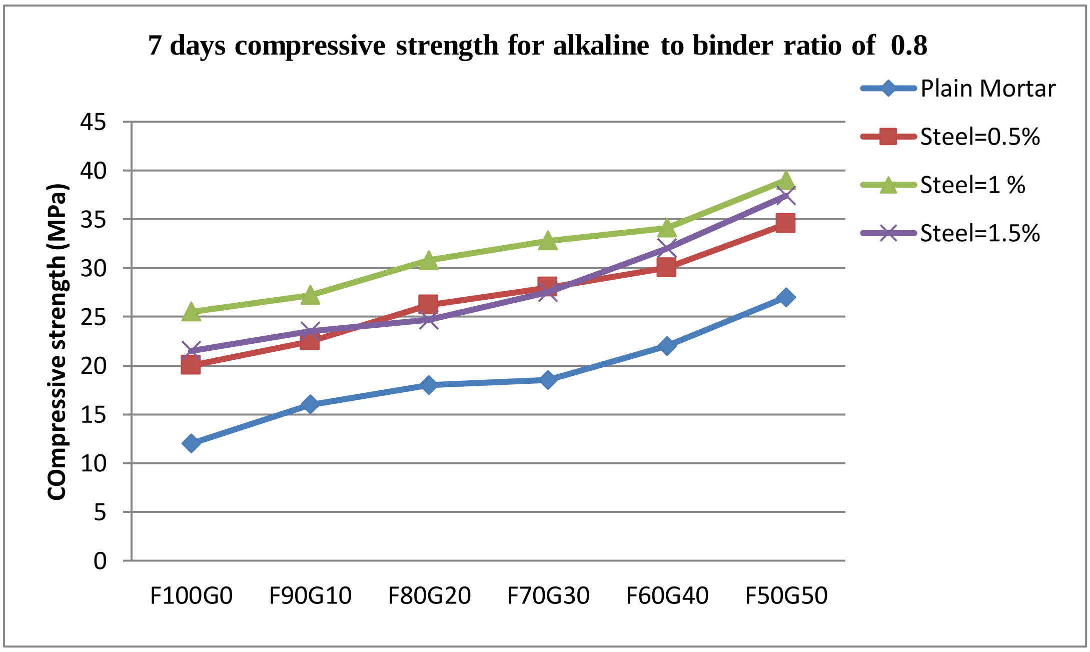


Figure 4. 33 Comparison of 7 days compressive strength for Alk/B= 0.8.

Figure 4.34 shows the variation of 28 days compressive strength of plain mortar and crimped steel fiber geopolymer mortar for alkaline to binder ratio of 0.8. The figure shows that incorporation and increase in percentage of crimped steel fibers in plain geopolymer mortar have a greater effect on its compressive strength values. Effect of fibers on 28 days compressive strength of plain geopolymer mortar increased the compressive strength about 18.42 to 67.27% higher than that of plain mortar depending on GGBS content and percentage of fibers. It is observed from the figure that increasing the percentage of GGBS from 0 to 50%, the compressive strength also increased. It can also be observed that with the increase in crimped fiber percentage up to 1%, the compressive strength has been increased but beyond 1% fiber content compressive strength values decreased. The compressive strength increased between 18.42 to 40.90% more than that of plain mortar for 0.5% fiber content, between 26 to 67.27% more than that of plain mortar for 1% fiber content and between 21.56 to 49.09 % more than that of plain mortar for 1.5% fiber content.

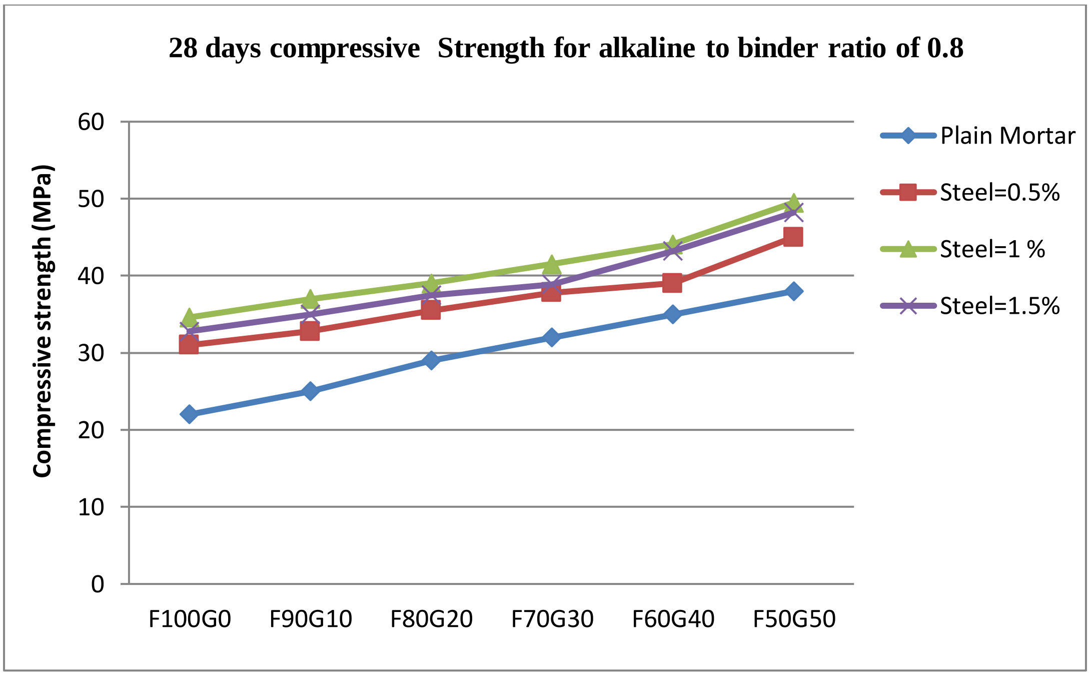


Figure 4. 34 Comparison of 28 days compressive strength for Alk/B= 0.8

4.4.2. Optimum compressive strength for all alkaline to binder ratio

In all mixes, 1% volume of steel fibers was shown the greatest compressive values than those of 0.5 and 1.5%. This makes 1% fiber the optimum fiber volume in all mixes.

Figure 4.35 presents the optimum compressive strengths for 3, 7 and 28 days obtained at 1% fiber volume with 50×50 binder compositions in all alkaline to binder ratio. It can be seen from this figure that alkaline to binder ratio of 0.6 has the highest compressive values among others. The highest compressive strength values at 1% fiber content are 45, 52.5 and 69.5MPa for 3, 7 and 28 days curing respectively obtained at alkaline to binder ratio of 0.6 with 50×50 binder compositions.

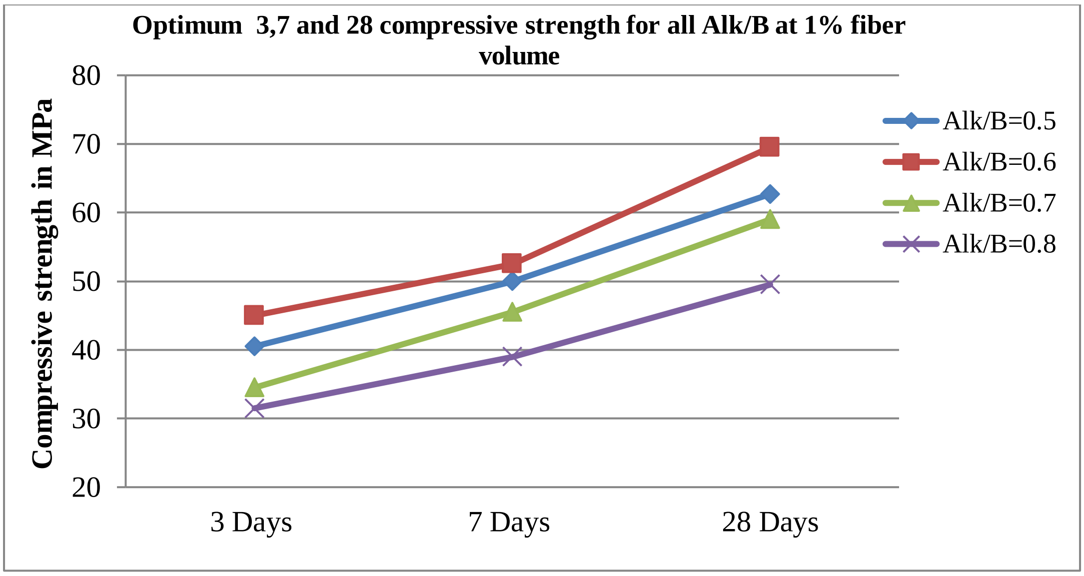


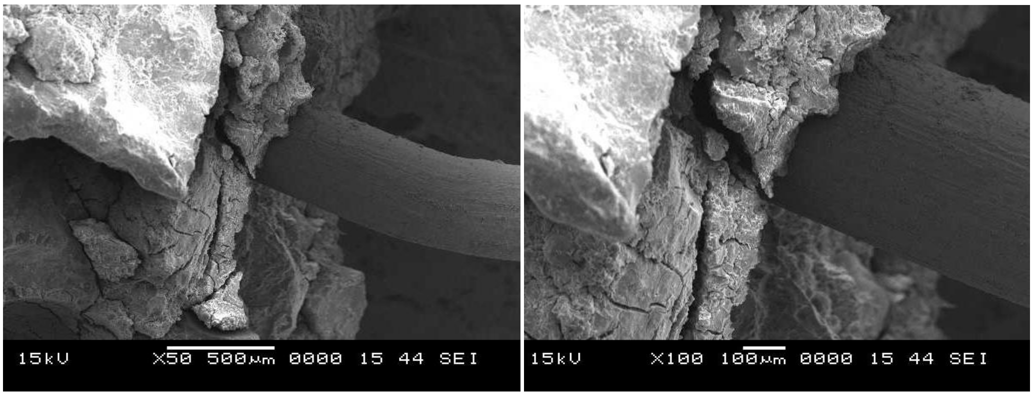
Figure 4. 35 The optimum compressive strengths for 3,7 and 28 days for all Alk/B obtained at 1% fiber volume with 50% GGBS

4.5: SCANNING ELECTRON MICROSCOPE (SEM)

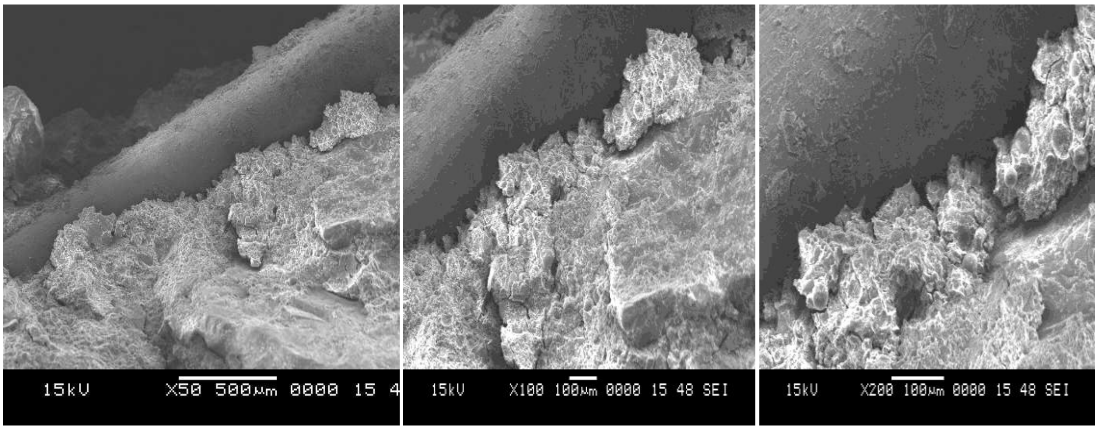
SEM images of steel fiber geopolymer were conducted in order to assess the effect of steel fiber geopolymer mortar micro-structural characteristics on mechanical performance. SEM images of selected samples of geopolymer mortar reinforced by steel fibres are in figure 4.36. These samples were corrected and cut from the broken flakes of the original sample after the end of compressive tests

From the figiure.4.36, it can be seen that the steel fiber surface is affected considerably by the geopolymer interfacial properties. Increase in GGBS content leads to enhanced interfacial properties as shown by figure 4.36b &36c). Those properties have a direct effect on the compressive strength characteristics. The smooth steell fibre surface is seen the gopolymer sample containing 0% GGBS (See fig.4.36a).But for high GGBS Content (50%) samples (fig.4.36e) the steel fiber surface is covered with geopolymer matrix thus increase the compressive strength.

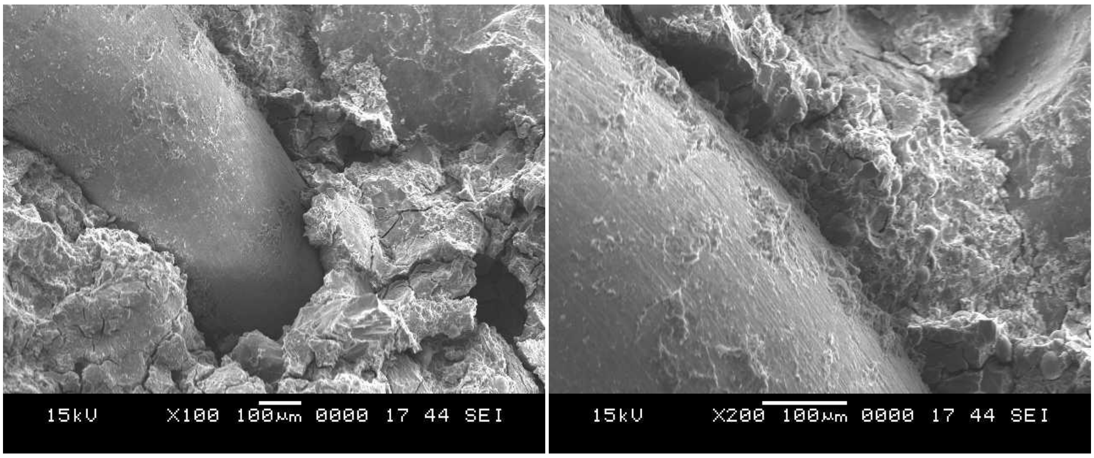
Figure 4.36d & 36e also present the SEM images of gopolymer samples containing 40% & 50% GGBS. It can be observed from the figure a relative steel fibre surface with attached geopolymer hydration products .This observation is attributed to the relatively good bond between the geopolymer matrix and the fibers and the pull-out failure of the examined specimens. This good bond between the geopolymer matrix and the surface of fibers is responsible of high compressive strength values as discused in previous section. Also the figures indicate the negligible degradative effect of the allaline geopolymer matrix on the steel fibers due to the unchanged diameter of the crimped steel fibers and the clean exposed surface of crimped steel fibers.



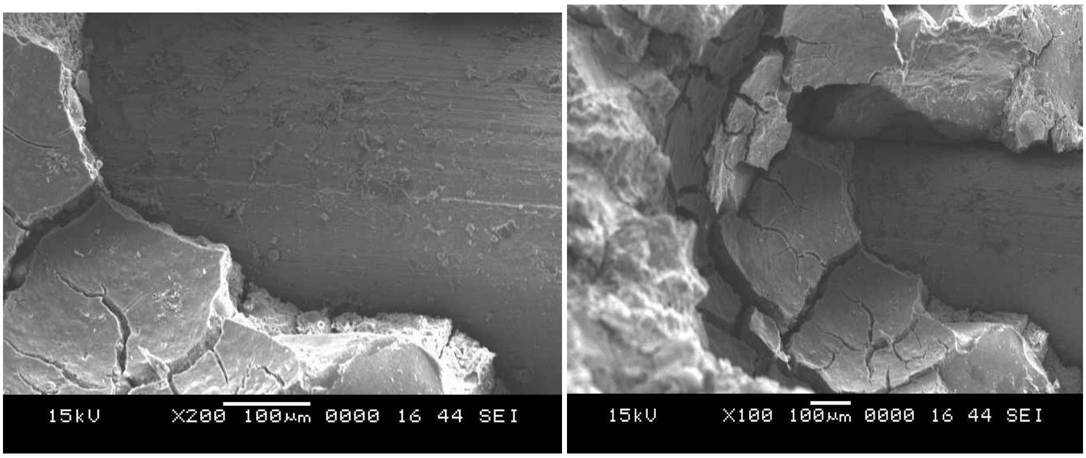
a (100×0)



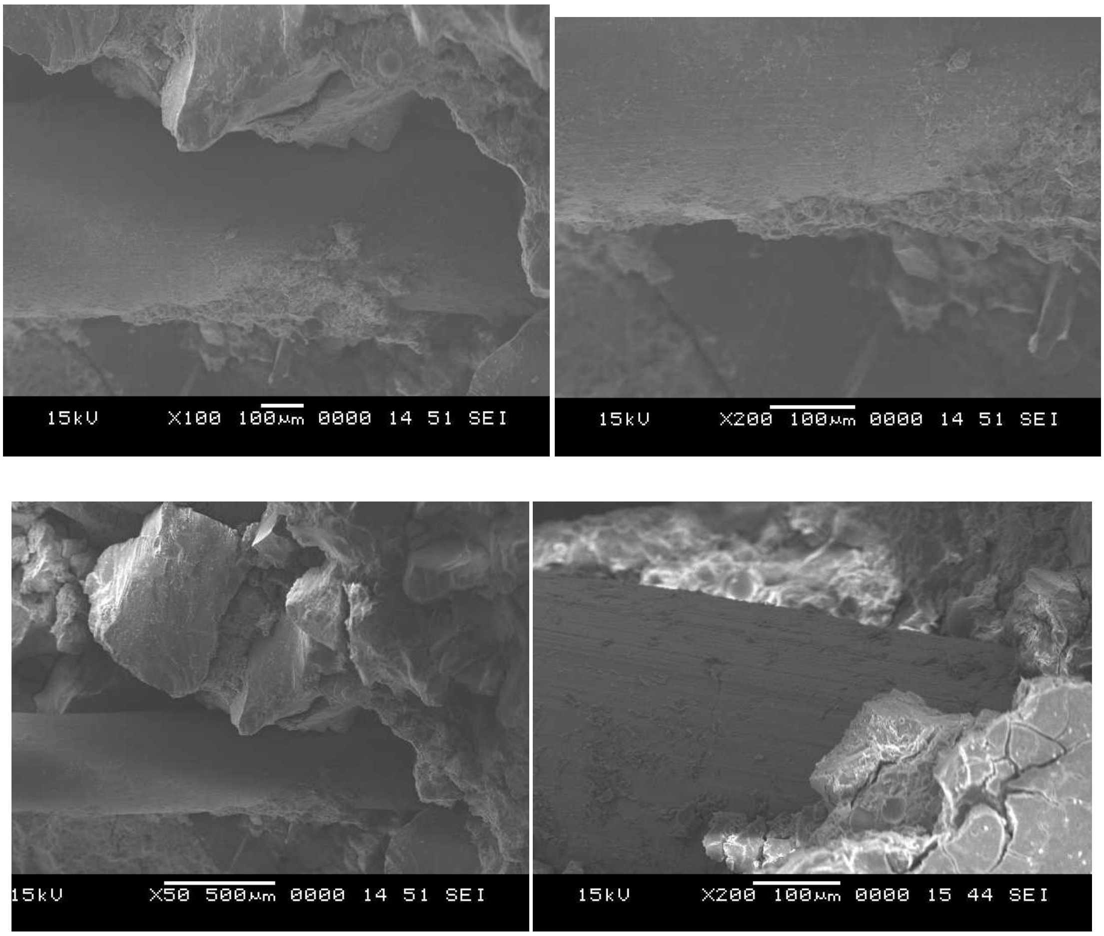
b (80×20)



c (70×30)



d (60×40)



e (50×50)

Figure 4. 36 SEM images (a) 0% GGBS, (b) 20%GGBS, (c) 30% GGBS, (d) 40% GGBS and (e) 50%GGBS

CHAPTER 5

CONCLUSIONS AND SCOPE FOR FUTURE RESEARCH

5.1 CONCLUSIONS

FA and GGBS based geopolymer mortar reinforced with crimped steel fibers cured under ambient temperature have been examined in this study. Effects of GGBS on setting time of mortar, Effect of steel fibers on flow capacity and compressive strength have been investigated. The microstructure of steel fiber geopolymer mortar specimens was determined using SEM. Based on experimental work results obtained; the conclusion can be summarized in this chapter.

1. In all mixes, setting time of geopolymer mortar (both initial and Final) were decreased with incorporation and increase in GGBS percentage. So to produce the fast setting geopolymer mortar, partial replacement of FA by GGBS can be a possible solution.
2. With the addition and increase in percentage of crimped steel fibers in plain geopolymer mortar diminished the flow diameter and flow capacity of mortar mixes in all alkaline to binder ratio. Decrease in flow diameter is between 23.56 and 32.94 %.
3. Alkaline to binder ratio of 0.6 shows the highest compressive strength values in all variation of steel fiber content and curing period.
4. Incorporation and increase in fiber volume increased the compressive strength values of plain geopolymer mortar in the range of 5.1MPa to 22.6MPa depending on the steel fiber content, binder compositions and alkaline to binder ratio.
5. The compressive strength of steel fiber geopolymer mortar increases with increase in GGBS percentage, so to deliver geopolymer mortar with high compressive strength and also fast in setting under ambient curing condition, replacement of FA with GGBS can be a good possible solution.

6. Optimum fiber content showing the maximum strength value in all mixes is 1%. The Optimum compressive strength values at 1% fiber content are 45, 52.5 and 69.5MPa for 3, 7 and 28 days curing respectively obtained at alkaline to binder ratio of 0.6 with 50×50 binder compositions.

7. The SEM results indicate that the presence of rough surface of steel fibers and geopolymer hydration products appeared on the surface of steel fibres in the specimens is an evidence of a relatively good bond between the geopolymer matrix and the steel fiber which increased the compressive strength values.

5.2 SCOPE FOR FUTURE RESEARCH

The suggested future work of this study is many but I am suggesting the following ones:

1. The present study can be continued by caring out the investigation and effect of crimped steel fiber on flexural and tensile strength of geopolymer mortar cured under ambient condition.
2. The study can be continued by using other types of fibers to found out which type of fiber giving the maximum compressive strength.
3. The effect of variation of morality on fresh and hardened properties of fiber geopolymer mortar can be carried out.

REFERENCES

1. Davidovits J. "Geopolymer Chemistry and Properties. Paper presented at the Geopolymer ’88." First European Conference on Soft Mineralurgy. Compiegne, France, 1988 b.

2. J.Davidovits . "Chemistry of geopolymeric systems terminology." Proceedings second international conference, Geopolymer 99, Davidovits J, Davidovits R, James C (Eds.), Geopolymer Institute. Saint-Quentin, France, 1999. 9-39.

3. A.Alekhya and Y.Mahesh. "Experimental Investigations on Properties of Glass Fiber Reinforced Geopolymer Concrete Composites." IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 14. Issue 6 Ver. III (2017): 01-3.

4. Aiswarya Sukumar and Elson John. "Fiber addition and its effect on concrete Strength." International Journal of Innovative Research in Advanced Engineering (IJIRAE) Volume 1 Issue 8.ISSN: 2349-2163 (2014): 144-149.

5. American Coal Ash Association. "Fly ash facts for highway engineers (as engineering material)". Technical Report. Washington,DC 20590, 06-13-2003.

6. Arie Wardhonoa, David W. Lawb and Anthony Stranob. "The strength of alkali-activated slag/fly ash mortar blends at ambient temperature." The 5th International Conference of Euro Asia Civil Engineering Forum (EACEF-5). Surabaya 60231, Indonesia, 2015. 650 – 656.

7. Arya aravind and Mathews M paul ,2014. "Study of Mechanical Properties of Geopolymer Concrete Reinforced with Steel Fiber." International Journal of Engineering Research and Technology Vol. 3,ISSN: 2278-0181.Issue 9, (2014).

8. Atteshamuddin S. Sayyad and Subhash V. Patankar. "Effect of Steel Fibres and Low Calcium Fly Ash on Mechanical and Elastic Properties of Geopolymer Concrete Composites." Indian Journal of Materials

Science(Hindawi Publishing Corporation) Volume 2013, Article ID 357563, 8 pages (2013).

9. Banda Rohit Rajan and K.Ramujee. "Strength & Development of Fly ash and GGBS Based Geopolymer Mortar." International Journal of Recent Advances in Engineering & Technology (IJRAET) Volume-3. Issue -1 (2015): 42-45.

10. C. Kamlesh. Shah, A. R. Parikh and K. J. Parmar. "Study of Strength Parameters and durability of Fly ash based Geopolymer Concrete." Indian Journal of Research Vol. 3, ISSN - 2250-1991.Issue 7 (2014).

11. D. Suresh and K. Nagaraju. "Ground Granulated Blast Slag (GGBS) In Concrete – A Review." IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)e-ISSN: 2278-1684,p-ISSN: 2320-334X Volume 12.Issue 4 Ver. VI (2015): PP 76-82. <www.iosrjournals.org>.

12. David N. Richardson. Strength and Durability Characteristics of a 70% Ground Granulated Blast Furnace Slag (GGBFS) Concrete Mix. Final Report RI99-035/RI99-035B. University of Missouri-Rolla. Jefferson City, MO 65102, February 2006.

13. Deepthi D and Dumpa.Venkateswarlu. "Studies on Behaviour of Crimped Steel Fibre Reinforced Concrete with Wood Waste Ash asan admixture." SSRG International Journal of Civil Engineering (SSRG - IJCE) Volume 3 .Issue 1 (2016).

14. Djwantoro Hardjito and Tsen, M.Z . "Strength and Thermal stability of fly ash based geopolymer mortar." The 3rd International Conference -ACF/VCA. 2008. 144-150.

15. Dr. Mrs. S. A. Bhalchandra and Mrs. A. Y. Bhosle. "Properties of Glass Fibre Reinforced Geopolymer Concrete." International Journal of Modern Engineering Research (IJMER) Vol. 3. Issue. 4 (2013): 2007-2010. <www.ijmer.com>.

16. Frederick T. Wallenberger, James C. Watson, and Hong Li, PPG Industries, Inc. ASM Handbook,Glass Fibers. Vol. Vol. 21: Composites (#06781G). 2001. <www.asminternational.org>.

17. G.Ramkumar, S.Sundarkumar and A.Sivakumar. "Development of Steel Fibre Reinforced Geopolymer Concrete." International Journal of Advance Research In Science And Engineering(IJARSE) Vol. No.4.Special Issue 01 (2015): 1718-1725. <http://www.ijarse.com>.

18. Hameed AM, Rawdhan RR and Al-Mishhadani SA. "Effect of Various Factors on the Manufacturing of Geopolymer Mortar." Archives of Science(Arch Sci 1: 111.) Volume 1 . Issue 3 • 1000111 (2017): 1-8.

19. Hardjito. D, Wallah, S.E., Sumajouw, D.M.J., and Rangan, B.V. "Properties of geopolymer concrete with fly ash as source material: Effect of mixture composition." Presented at the Seventh CANMET/ACI International Conference on Recent Advances in Concrete Concrete Technology. Las Vegas, USA, 2004. pp.109-118.

20. James E. Shoenberger and Joe G. Tom. Polypropylene Fibers in Portland Cement in Concrete Pavements. Final Report. Washington, DC 20591, 1992.

21. James E. Shoenberger,Joe G. Tom,. "Polypropylene Fibers In Portland Cement Concrete Pavements,Research and Development ServiceWashington, DC 20591,." 1992.

22. Lee N.K and Lee H.K. "Setting and mechanical properties of alkali-activated fly ash/slag concrete manufactured at room temperatue." Construction and Building Materials 47, Elsevier (2013): 1201–1209.

23. Lidia Rizzuti and Francesco Bencardino. "Effects of Fibre Volume Fraction on the Compressive and Flexural Experimental Behaviour of SFRC." Contemporary Engineering Sciences,HIKARI Ltd 2014: 379 - 390.

24. Milind V. Mohod. "Performance of Polypropylene Fibre Reinforced Concrete." IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)

e-ISSN: 2278-1684,p-ISSN: 2320-334X Volume 12.SIssue 1 Ver. I (Jan- Feb. 2015): 28-36.

25. Mithanthaya I.R and Bhavanishankar Rao N. "Effect of Glass Powder and GGBS on Strength of Fly Ash Based Geopolymer Concrete." International Journal of Engineering Trends and Technology (IJETT) V19(2). ISSN:2231-5381. (2015): 66-71.

26. Mohammed Haloob Al-Majidi, Andreas Lampropoulos and Andrew B. Cundy c. "Steel fibre reinforced geopolymer concrete (SFRGC) with improved microstructure and enhanced fibre-matrix interfacial properties." Construction and Building Materials (2017): 286–307. < www.elsevier.com/locate/conbuildmat>.

27. Mohammed Haloob Al-Majidi, Andreas Lampropoulos , Andrew Cundy and Steve Meikle. "Development of geopolymer mortar under ambient temperature for in situ applications". University of Brighton,. Brighton BN2 4GJ, UK, Nov-2014.

28. Natali, A., Manzi, S. & Bignozzi and M. C. . " Fiber-Reinforced Composite Materials Based On Sustainable Geopolymer Matrix." Novel- Procedia Engineering, 21. 2011. 1124-1131.

29. P.Eswaramoorthi and G.E.Arunkumar. "Fibers Study On Properties Of Geopolymer concrete With Polypropylene." International Refereed Journal of Engineering and Science (IRJES) Volume 3. Issue 2 (2014): 60-75.

30. Petermann, Jeffrey C., Saeed, Athar,Hammond and Michael I. Aklali-Activated Geopolymers- A Literature. Final Technical Report. Panama City, FL 32401: Applied Research Associates, 20-JUL-2010.

31. Plizzari and G. A. Experimental Study of Fracture Behavior of Concrete Reinforced with Steel Fibers. Research Report for Officine Maccaferri. Bologna, Italy, 2004.

32. Porkodi.R , Dharmar.S and Nagan.S. "Experimental study on fiber reinforced Self-compacting geopolymer mortar." International Journal of Advance Research In Science And Engineering IJARSE, Vol. No.4. Special Issue (01) (2015): 968-977. <http://www.ijarse.com>.

33. Rangan, B. Vijaya, Fieaust Cpeng,and Hon Fici. " International Workshop on Geopolymer Cement and Concrete." 2010.

34. Ranjbar, Navid; Mehrali, Mehdi; Behnia, Arash; Javadi Pordsari, Alireza; Mehrali, Mohammad Alengaram, U. Johnson; Jumaat and Mohd Zamin. "A Comprehensive Study of the Polypropylene Fiber Reinforced Fly Ash Based Geopolymer." PLOS ONE | DOI:10.1371/journal.pone.0147546 (2016).

35. S. V. Joshi and M. S. Kadu. "Role of Alkaline Activator in Development of Eco-friendly Fly Ash Based Geo Polymer Concrete." International Journal of Environmental Science and Development Vol. 3, No. 5 (2012): 417-421.

36. Saloma, Anis Saggaff , Hanafiah and Annisa Mawarni. "Geopolymer Mortar with Fly Ash." MATEC Web of Conferences 78,01026 . South Sumatra,Indonesia., 2016.

37. Sanumuri Parth. "Study on the Behaviour of Fly Ash Based Geopolymer Concrete with 20molar NaOH Activator." Project Report. Pace Institute of Technology and Sciences, Vallur, 2017.

38. Sasikala K. and Vimala S. "A comparative study of polypropylene, recron and steel fiber reinforced engineered cementitious composites." InternationalJournal of Engineering Research & Technology (2(4) (2013)): 1136-1142.

39. Shankar H. Sanni and Khadiranaikar R.B. "Performance of alkaline solutions on grades of geopolymer concrete." International Journal of Research in Engineering and Technology (2013): 366-371.

40. Shriram Marathe, Mithanthaya I R, N Bhavani Shankar Rao. "A Review on Strength and Durability Studies on Geopolymer Concrete." International

Journal of Innovative Research in Science,Engineering and Technology(IJIRSET) Vol. 5. Special Issue 9 (2016): 917-921.

41. Sofi Yasir and Gull Iftekar. "Study of Properties of Fly Ash Based Geopolymer Concrete." International Journal of Engineering Research Vol. 3. Issue 1, ISSN: 2321-7758 (2015.).

42. T. Williamson and M.C.G. Juenger. The role of activating solution concentration on alkali–silica reaction in alkali-activated fly ash concrete, Cem. Concr. Res. 83Cem. Concr. Res. 83. 2016.

43. V. Cervantes and J. Roesler. "Ground Granulated Blast Furnace Slag." Center of Excellence for Airport Technology 26 July 2007: 1-2.

44. Vishnu Ramesh and Annie Joy. "Review on the study of fly ash Based geopolymer concrete." IJARIIE-ISSN(O)-2395-4396 Vol-3.Issue-2 (2017): 1311-1315.

45. Xiaolu Guo and Xuejiao Pan. "Mechanical properties and mechanisms of fiber reinforced fly ash–steel slag based geopolymer mortar." Construction and Building Materials-Shanghai 201804, China (2018): 633-641. <www.elsevier.com/locate/conbuildmat>.

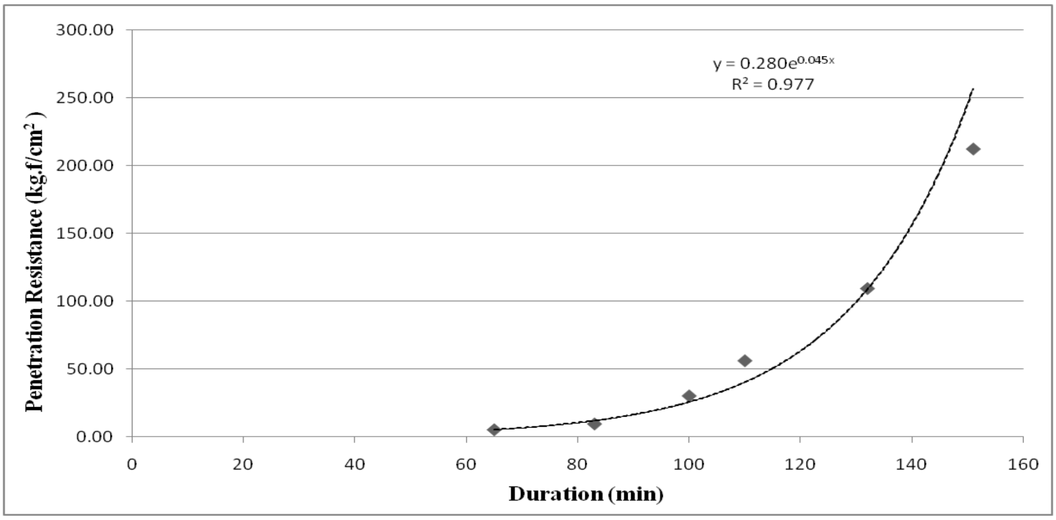
46. Xu, Hua and J.S.J.Van Deventer. "The Geopolymerisation of Alumino-Silicate Minerals." International Journal of Mineral Processing 59.3 (2000): 247-266.

APPENDICES

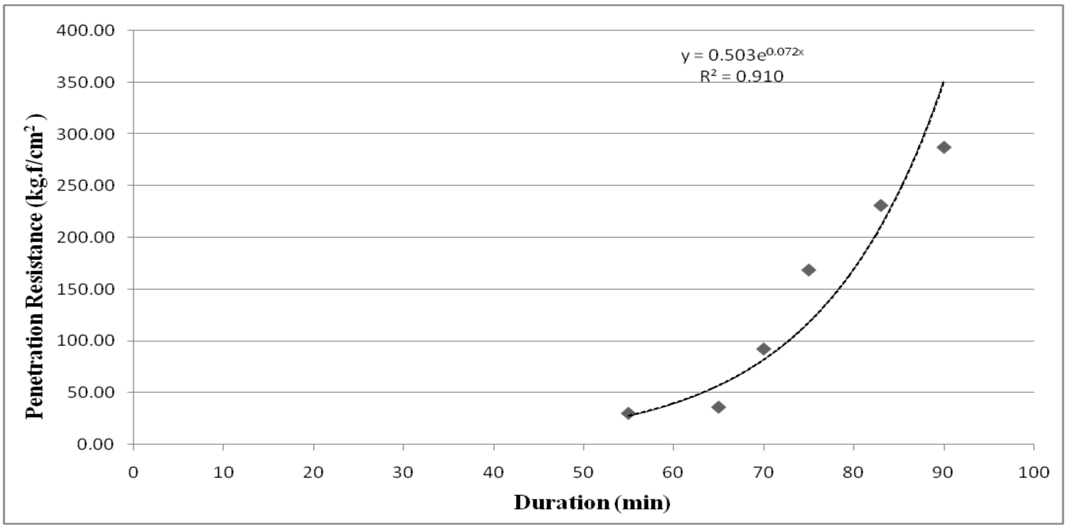
Appendix I

Curves for penetration resistance vs. duration for all alkaline to Binder ratios

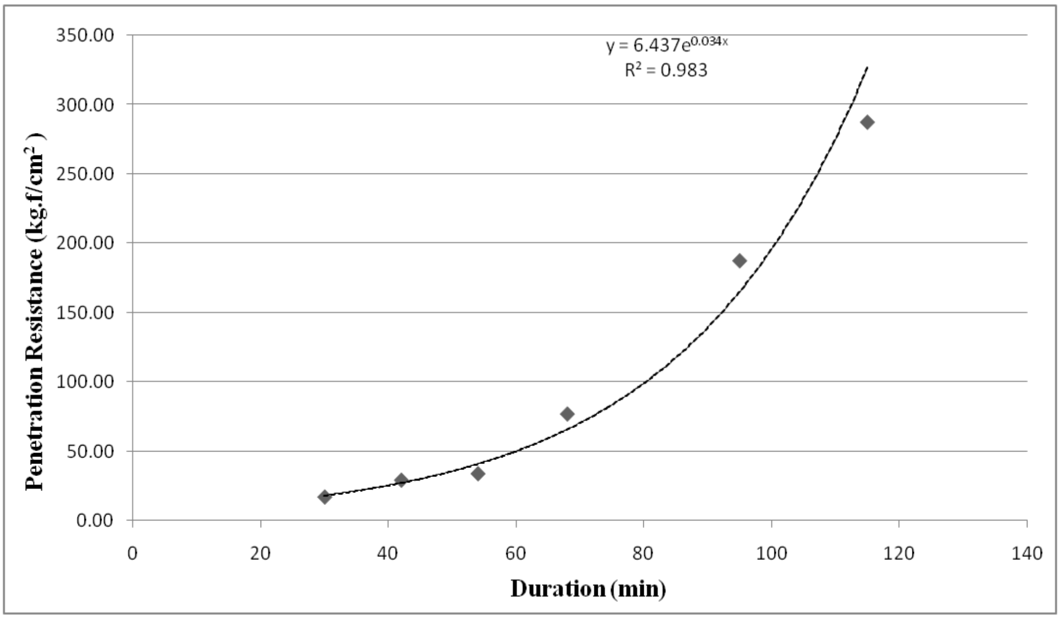
1. Alkaline to Binder ratio=0.5



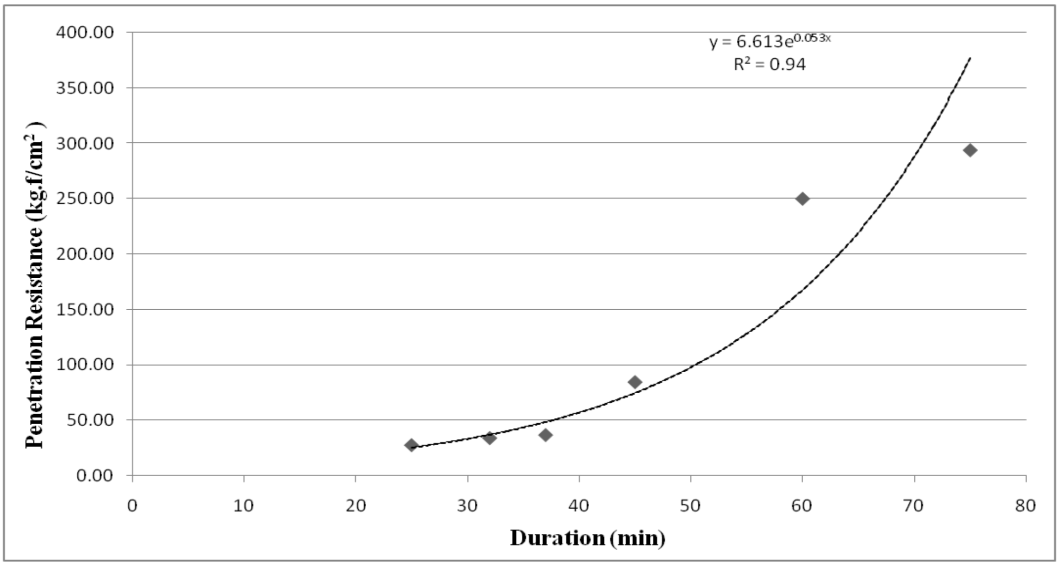
Penetration resistance curve of $F_{100}G_0$



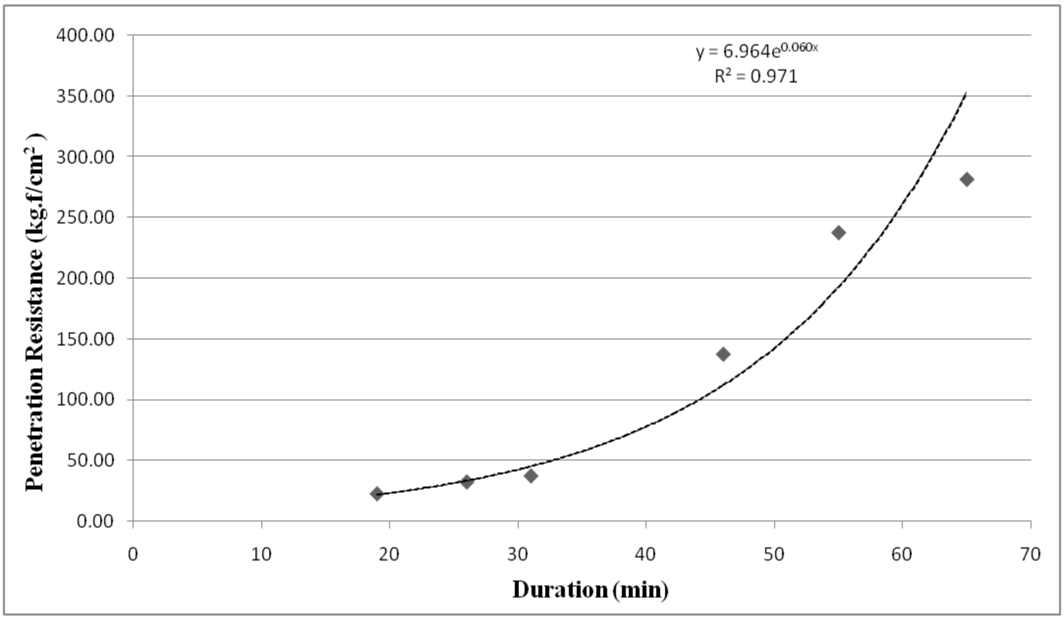
Penetration resistance curve of $F_{90}G_{10}$



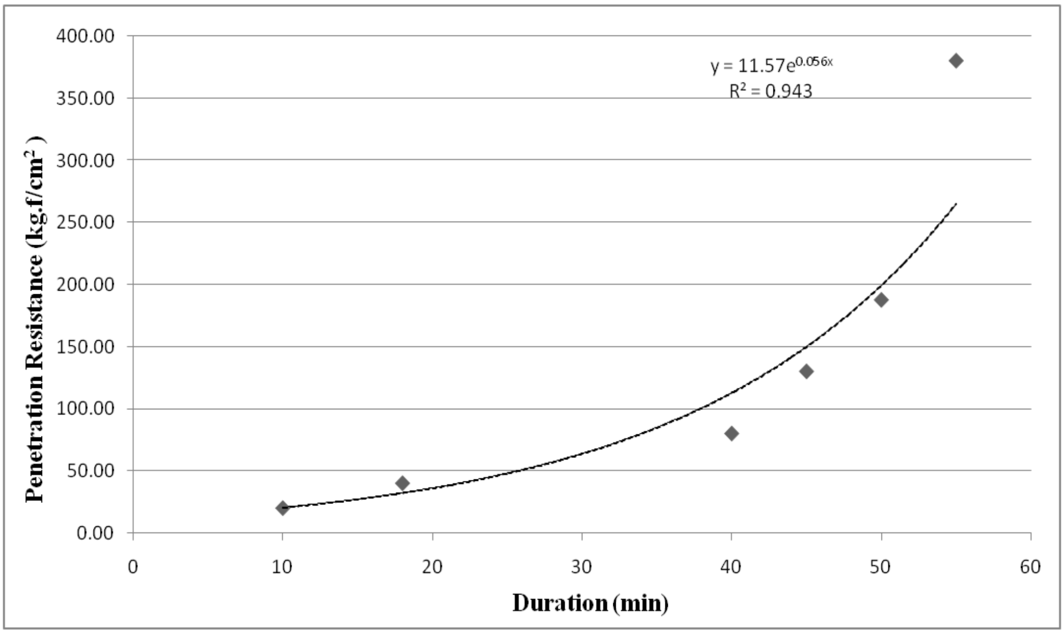
Penetration resistance curve of $F_{80}G_{20}$



Penetration resistance curve of $F_{70}G_{30}$

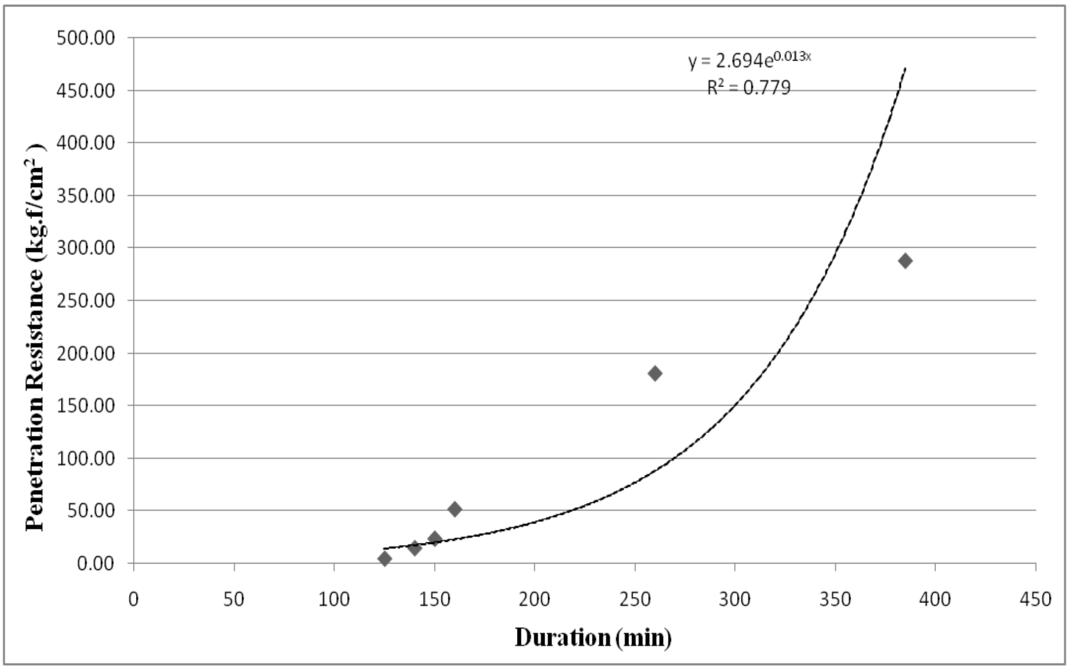


Penetration resistance curve of $F_{60}G_{40}$

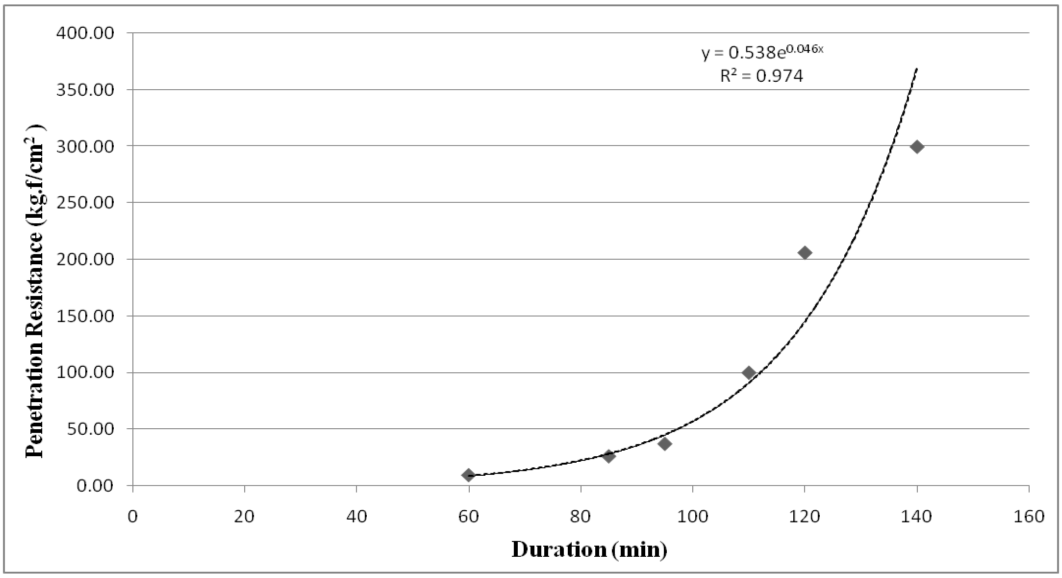


Penetration resistance curve of $F_{50}G_{50}$

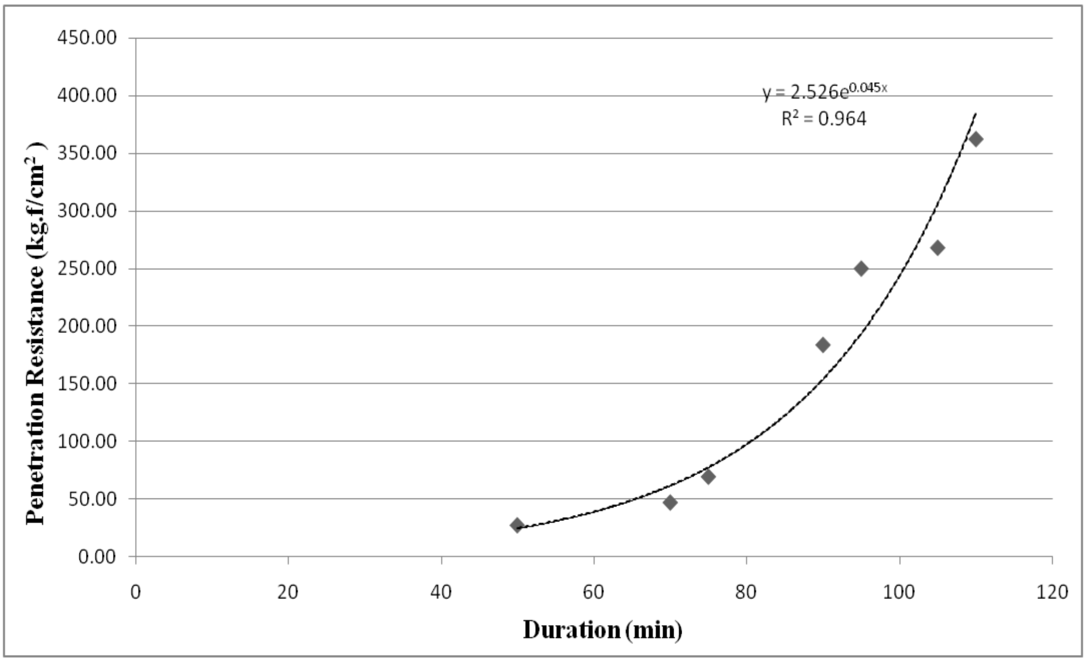
2. Alkaline to Binder ratio=0.6



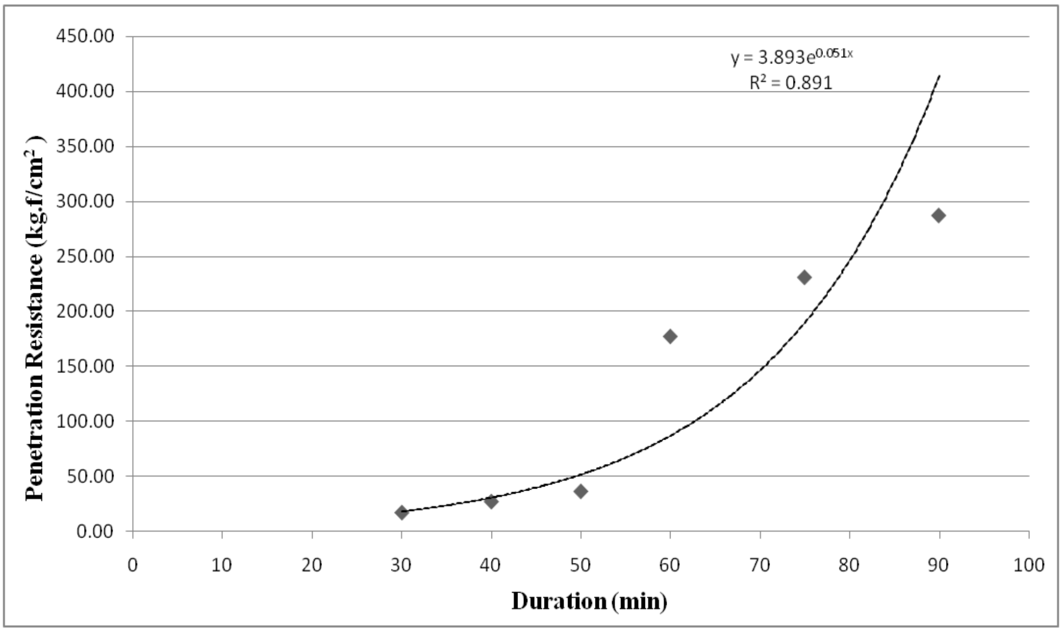
Penetration resistance curve of $F_{100}G_0$



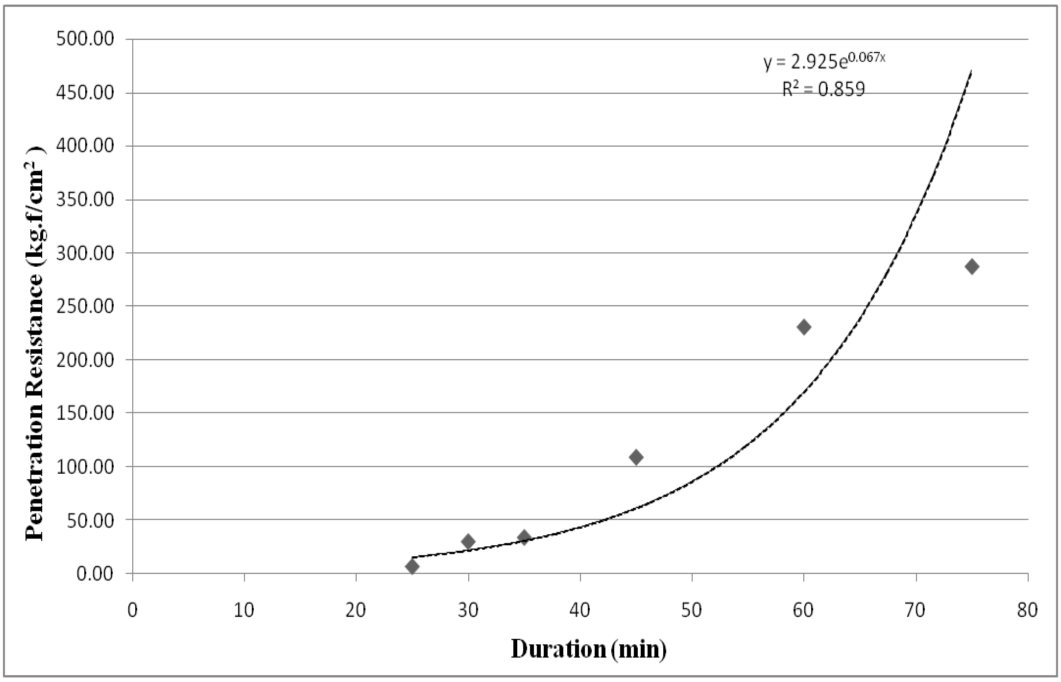
Penetration resistance curve of $F_{90}G_{10}$



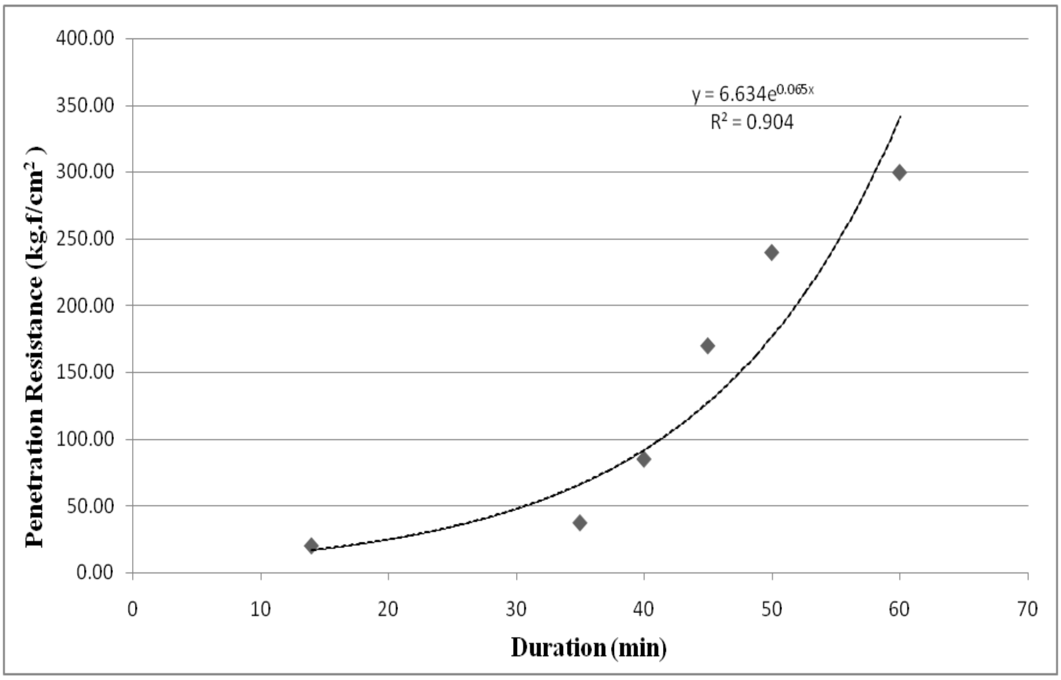
Penetration resistance curve of $F_{80}G_{20}$



Penetration resistance curve of $F_{70}G_{30}$

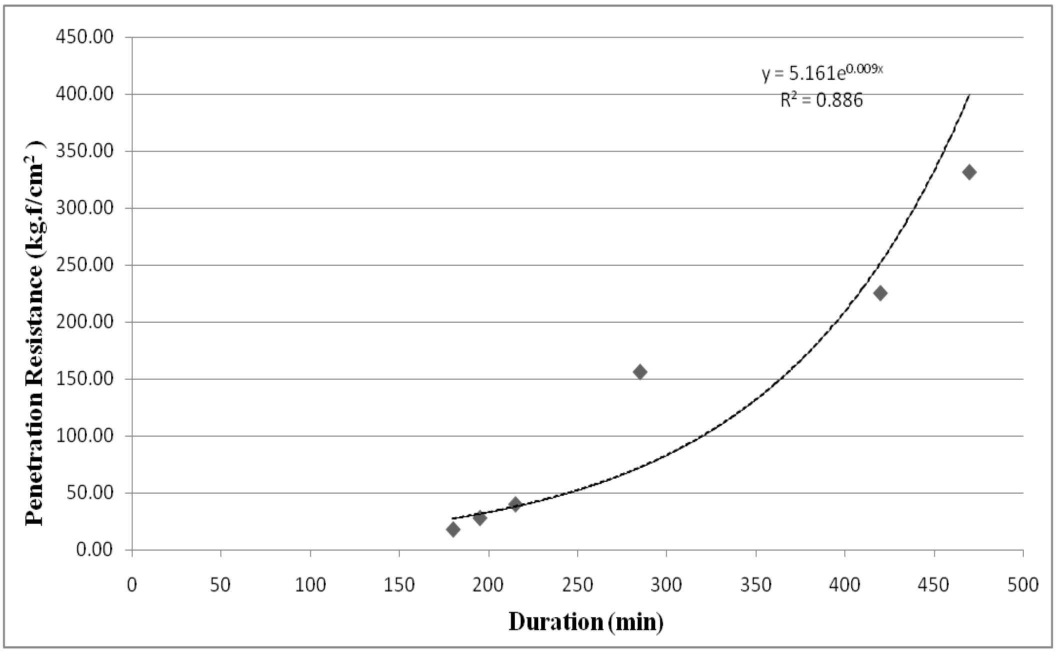


Penetration resistance curve of $F_{60}G_{40}$

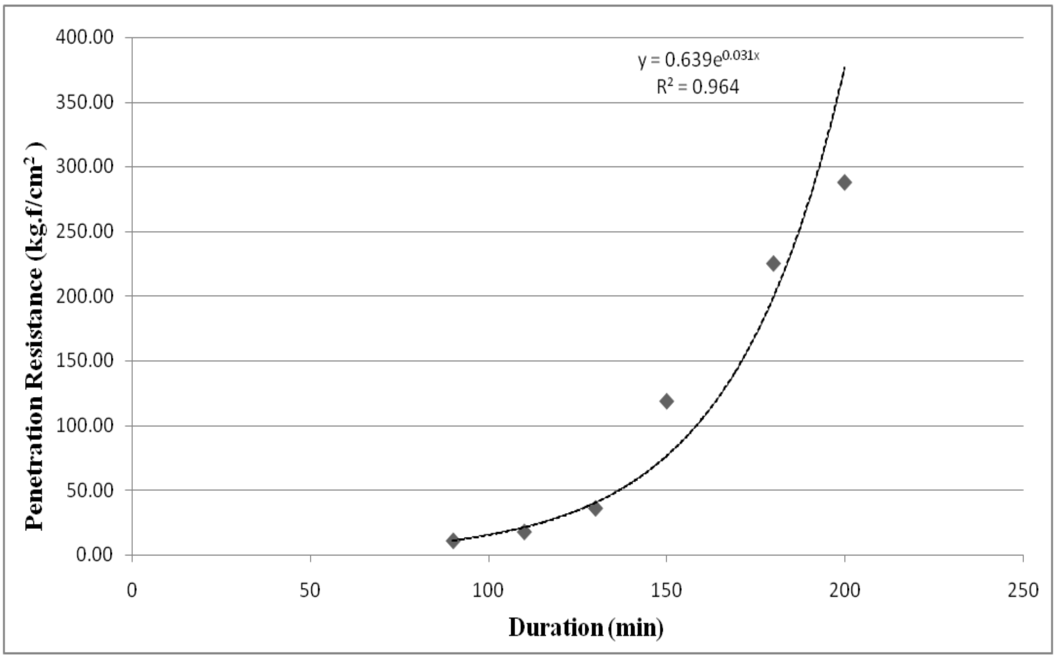


Penetration resistance curve of $F_{50}G_{50}$

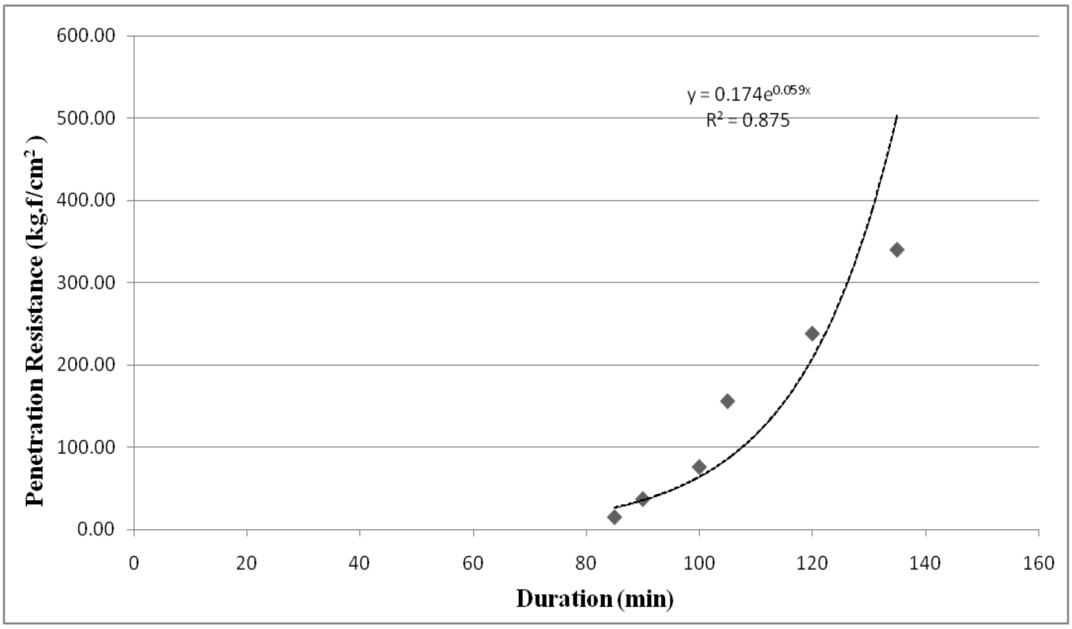
3. Alkaline to Binder ratio=0.7



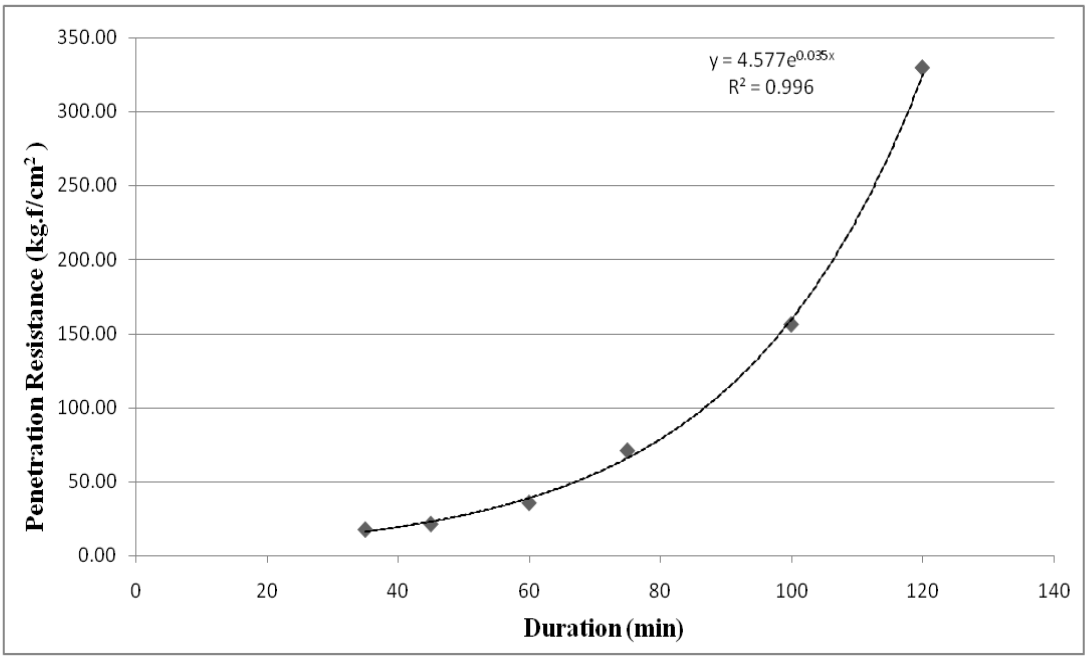
Penetration resistance curve of $F_{100}G_0$



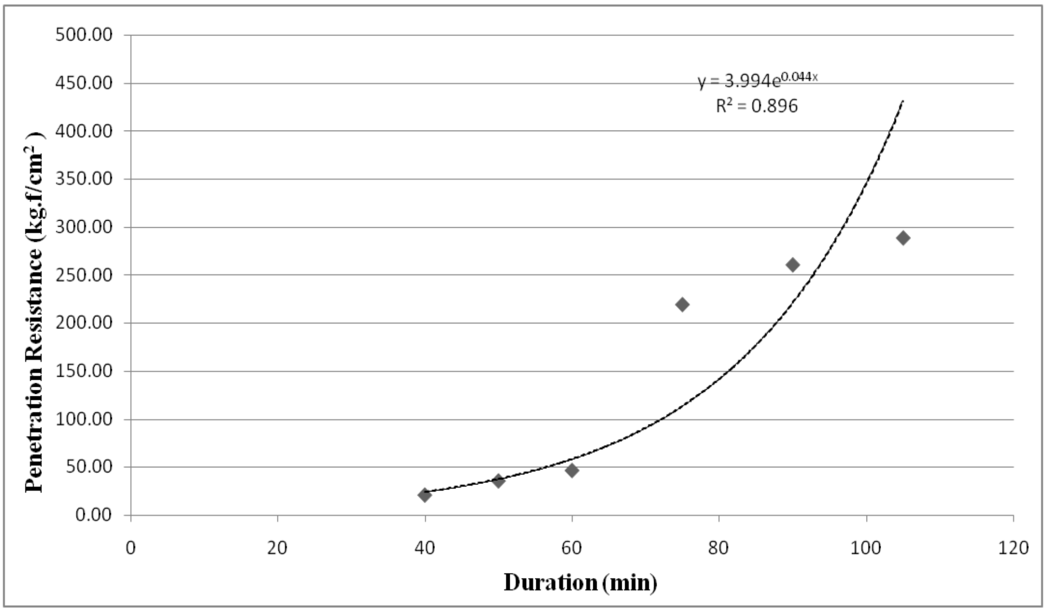
Penetration resistance curve of $F_{90}G_{10}$



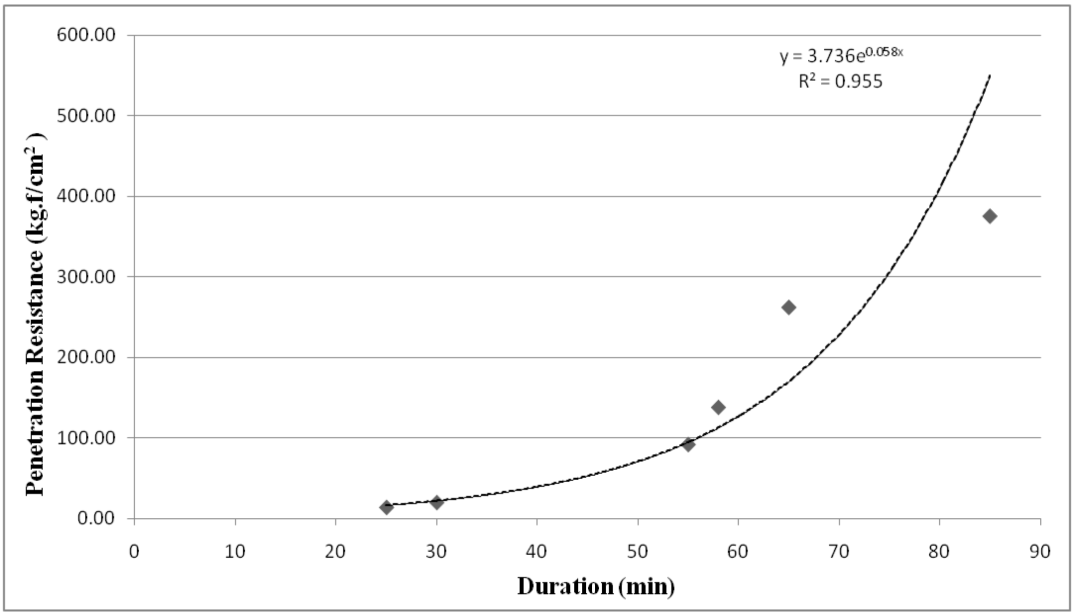
Penetration resistance curve of $F_{80}G_{20}$



Penetration resistance curve of $F_{70}G_{30}$

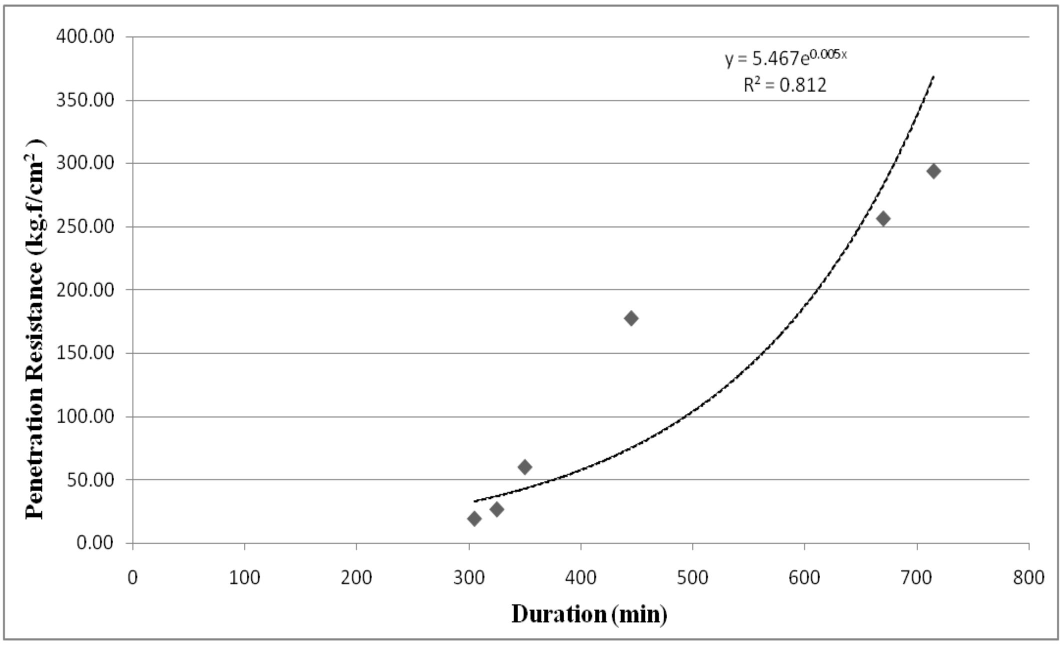


Penetration resistance curve of $F_{60}G_{40}$

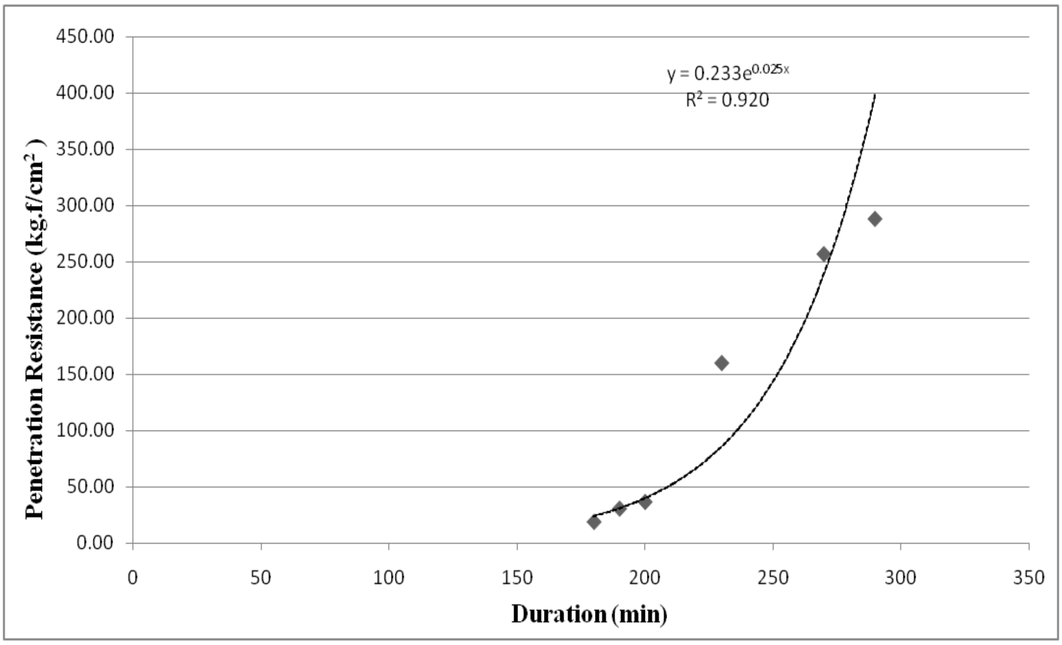


Penetration resistance curve of $F_{50}G_{50}$

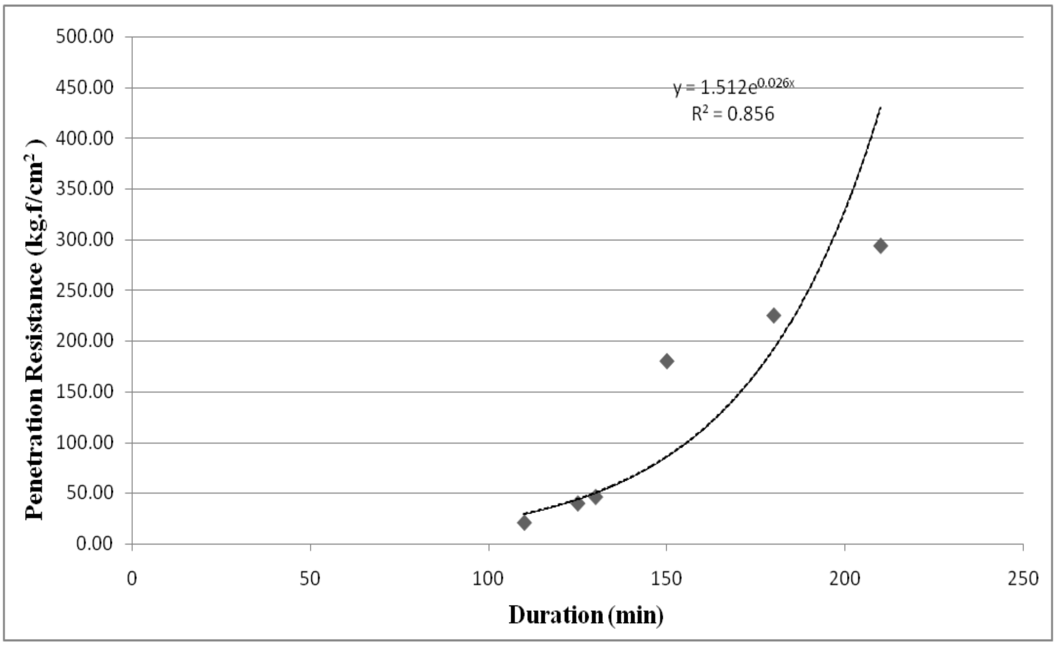
4. Alkaline to Binder ratio=0.8



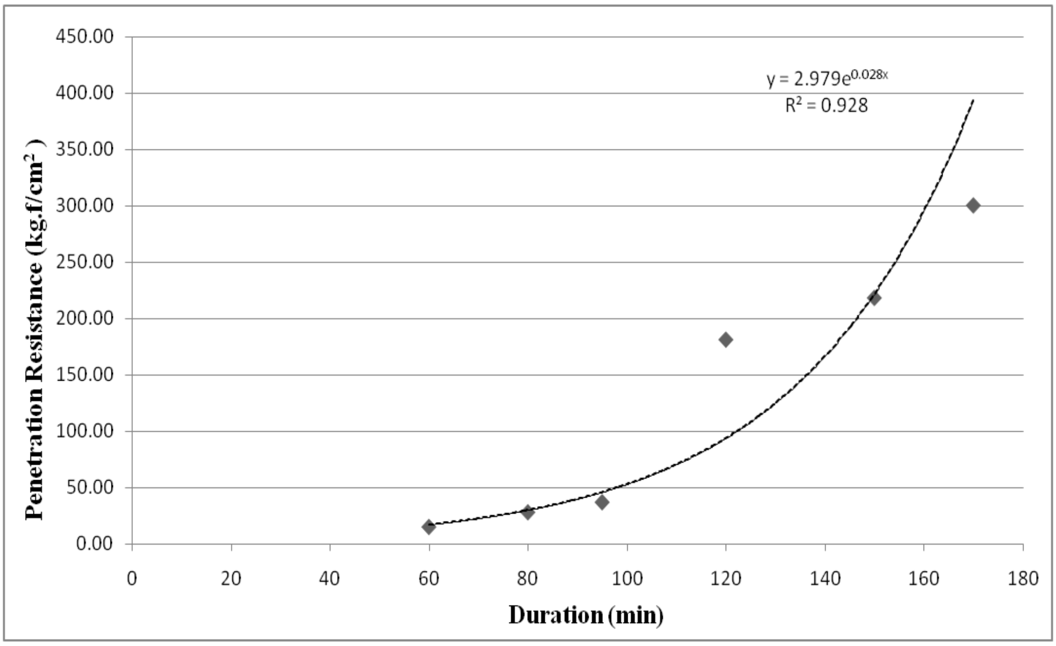
Penetration resistance curve of $F_{100}G_0$



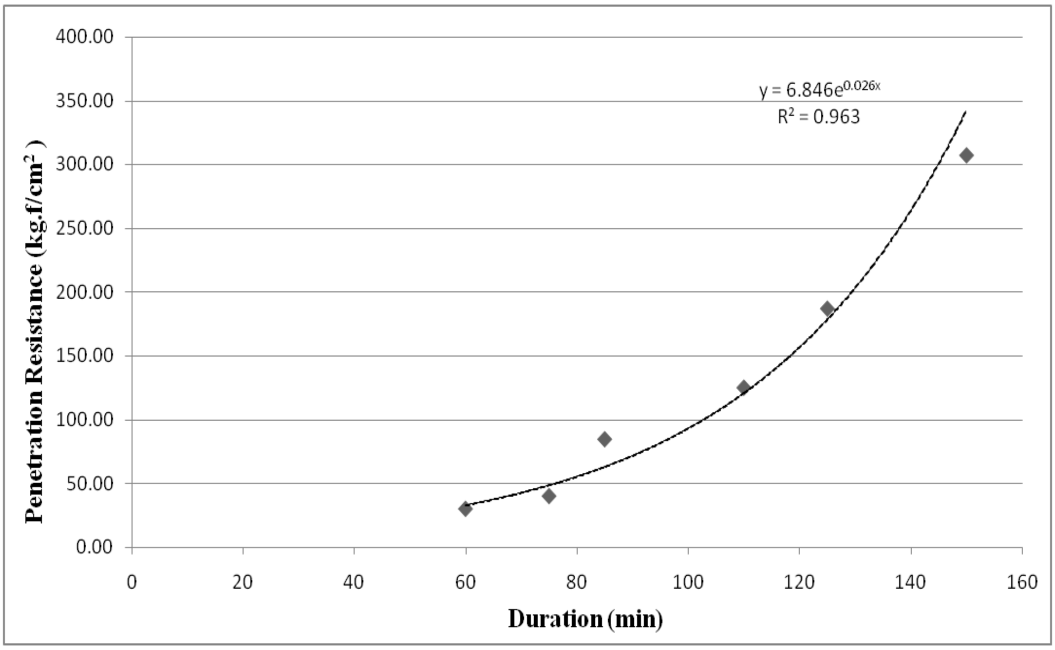
Penetration resistance curve of $F_{90}G_{10}$



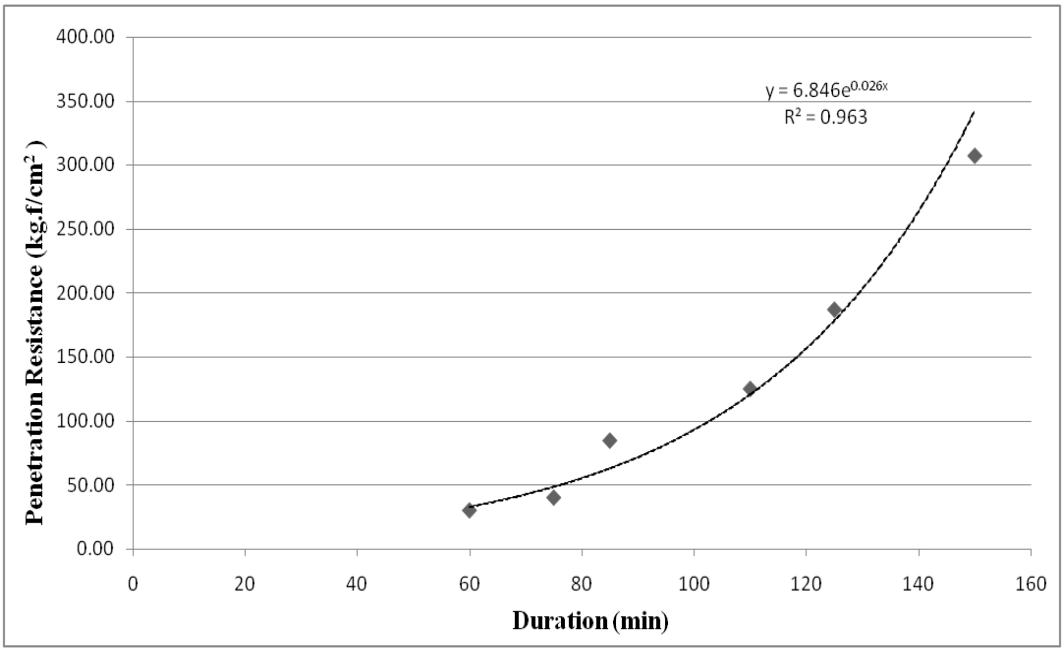
Penetration resistance curve of $F_{80}G_{20}$



Penetration resistance curve of $F_{70}G_{30}$



Penetration resistance curve of $F_{60}G_{40}$



Penetration resistance curve of $F_{50}G_{50}$

Appendix II

3, 7 and 28 day's compressive strength of all alkaline to Binder ratio with variation of steel content.

1Alkaline to binder ratio =0.5

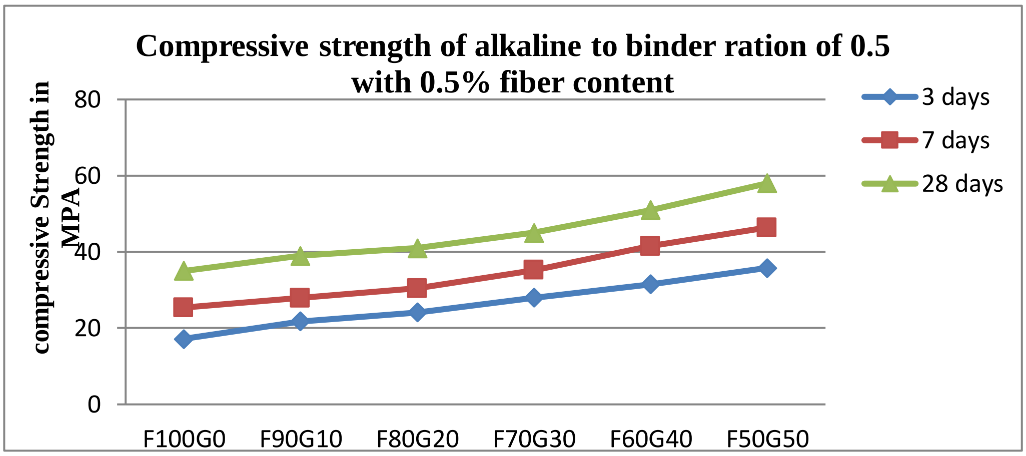


Figure 1.Variation of compressive strength for Alk/ B of 0.5 with 0.5% steel fiber content

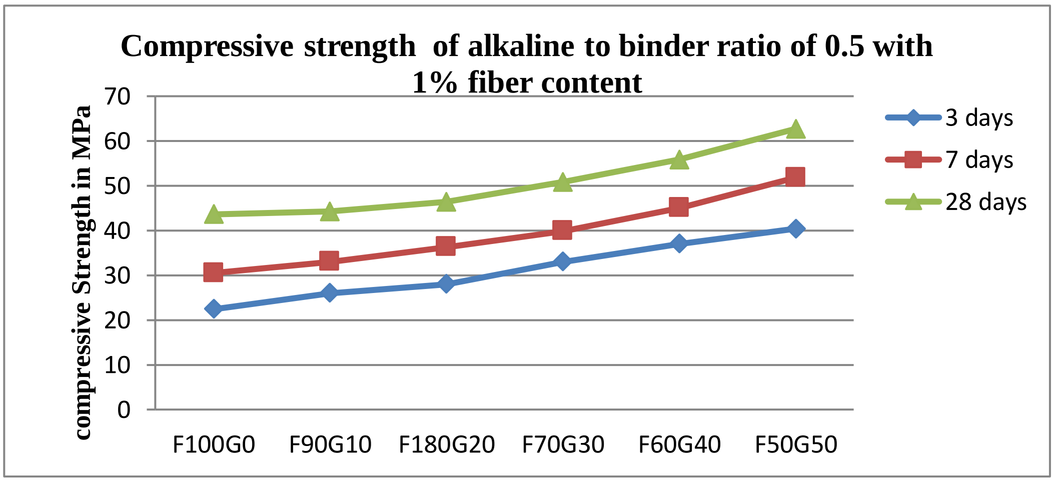


Figure 2.Variation of compressive strength for alkaline to binder ratio of 0.5 with 1% steel fiber content.

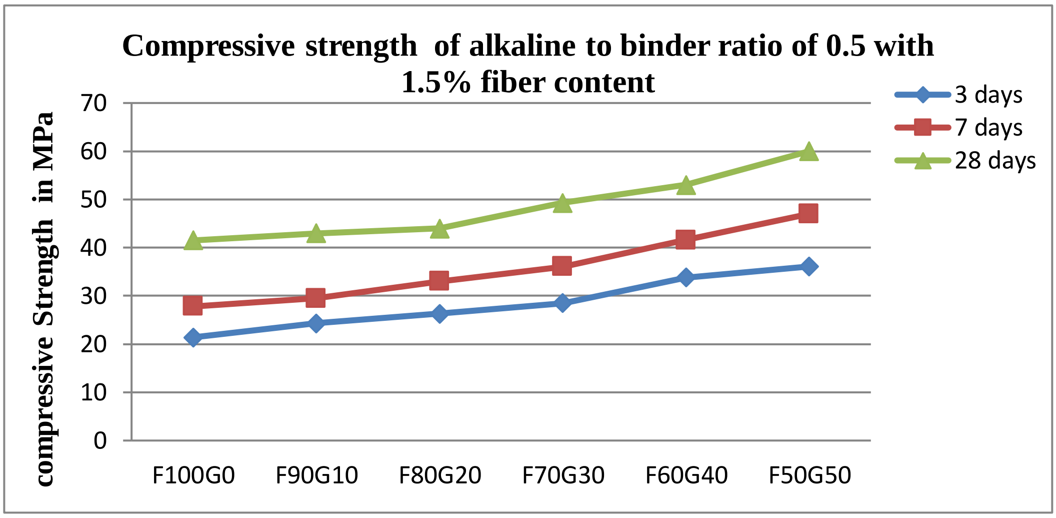


Figure 3.Variation of compressive strength for alkaline to binder ratio of 0.5 with 1.5% steel fiber content

2. Alkaline to binder ratio =0.6

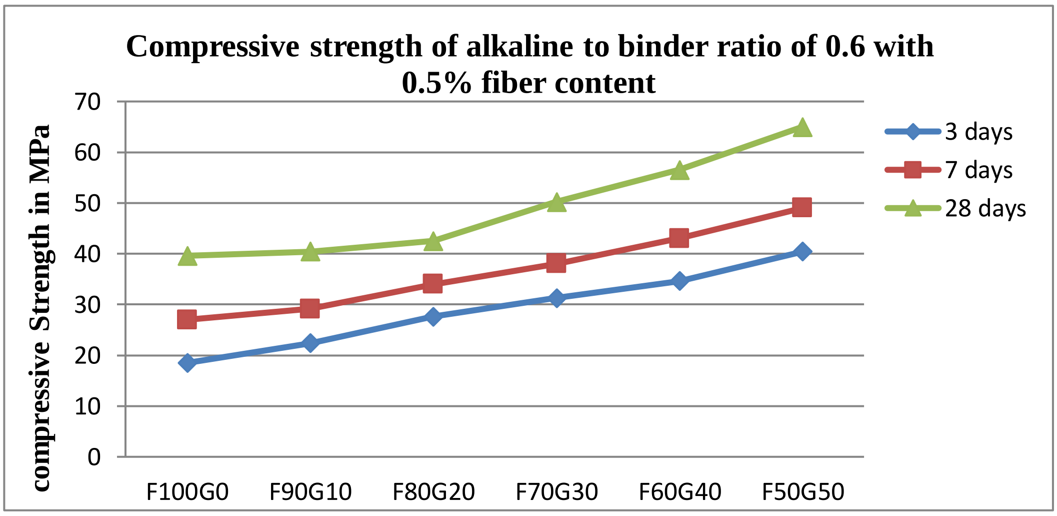


Figure 4.Variation of compressive strength for alkaline to binder ratio of 0.6 with 0.5% steel fiber content.

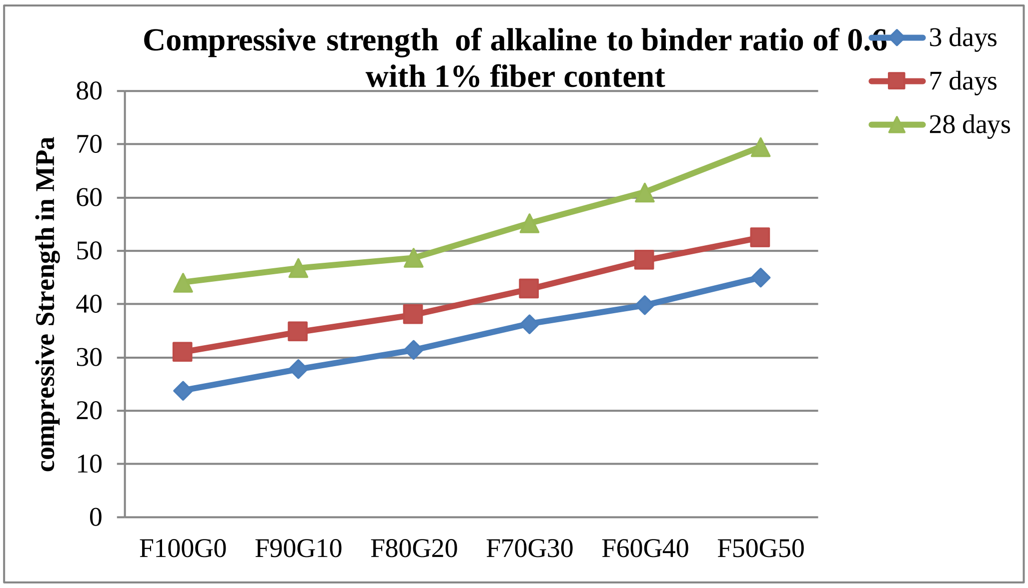


Figure 5.Variation of compressive strength for alkaline to binder ratio of 0.6 with 1% steel fiber content.

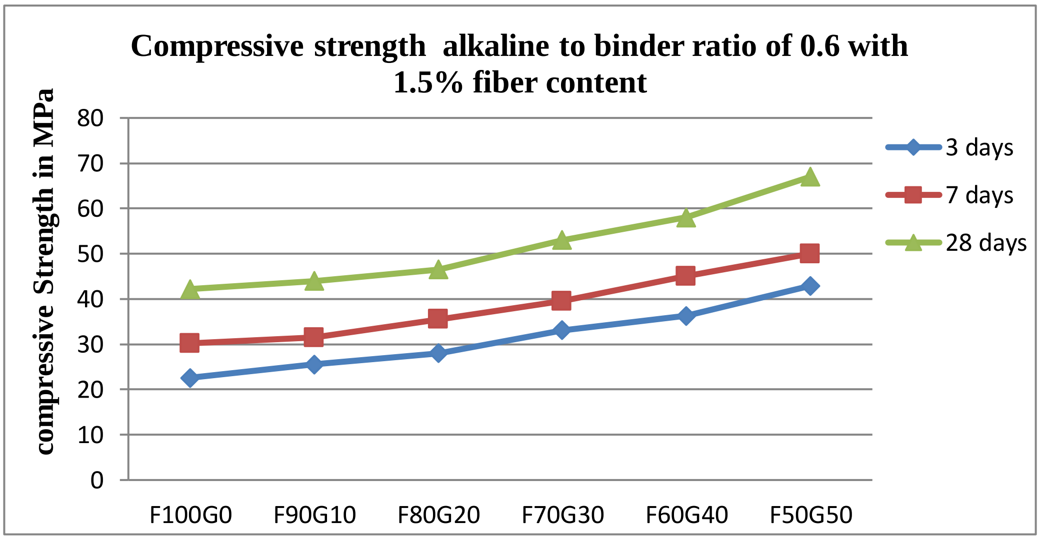


Figure 6.Variation of compressive strength for alkaline to binder ratio of 0.6 with 1.5% steel fiber content

3. Alkaline to binder ratio =0.7

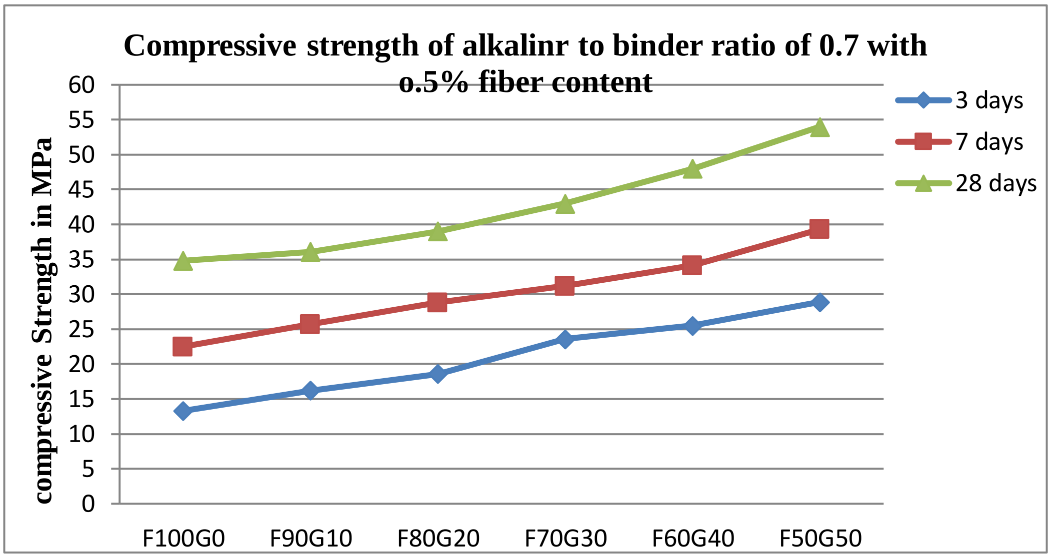


Figure 7.Variation of compressive strength for alkaline to binder ratio of 0.7 with 0.5% steel fiber content.

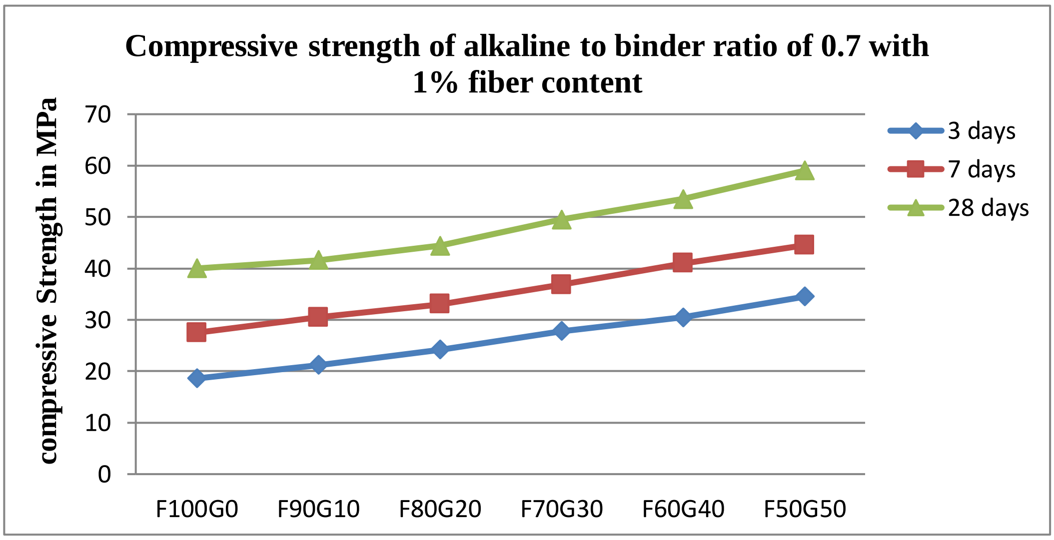


Figure 8.Variation of compressive strength for alkaline to binder ratio of 0.7 with 1% steel fiber content.

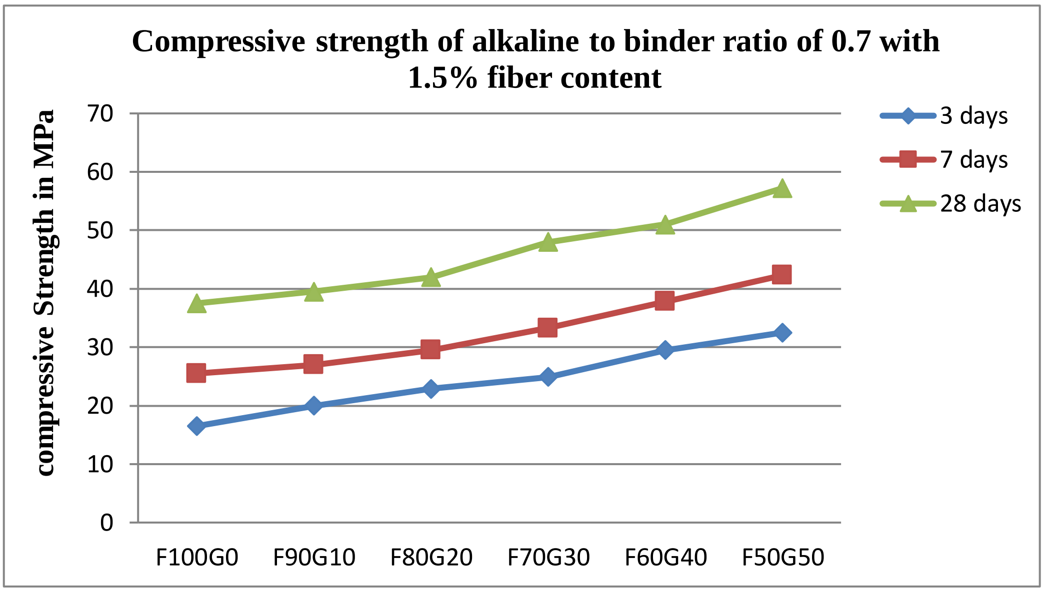


Figure 9.Variation of compressive strength for alkaline to binder ratio of 0.7 with 1.5% steel fiber content

4.Alkaline to binder ratio =0.8

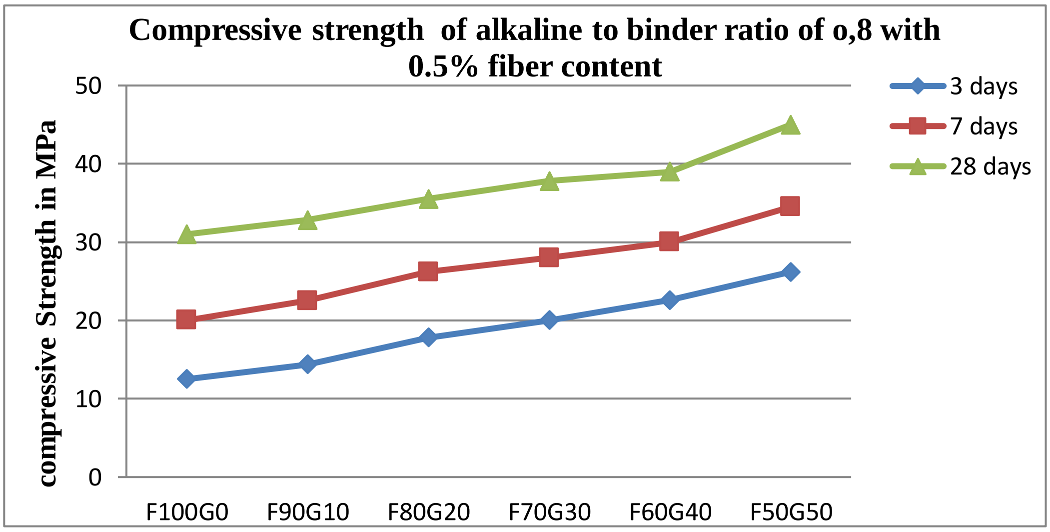


Figure 10.Variation of compressive strength for alkaline to binder ratio of 0.8 with 0.5% steel fiber content.

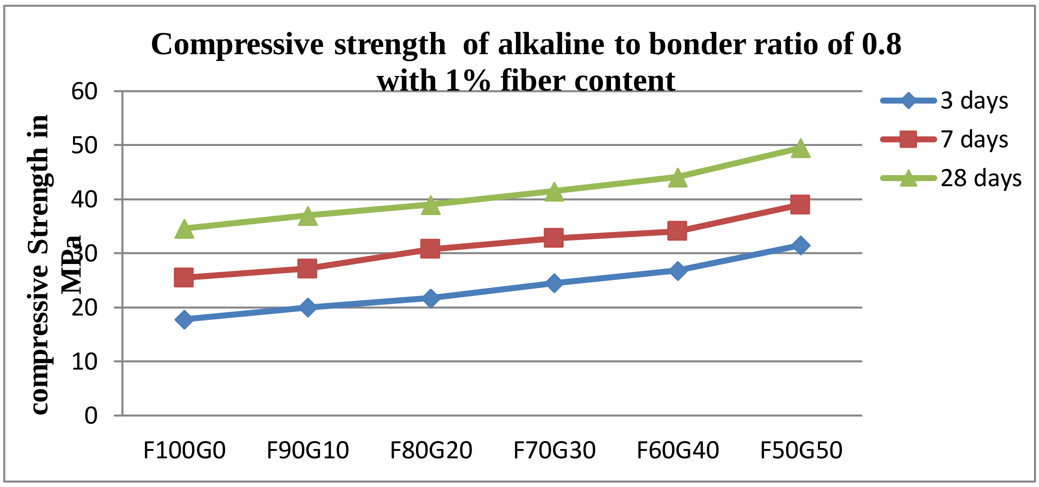


Figure 11.Variation of compressive strength for alkaline to binder ratio of 0.8 with 1% steel fiber content.

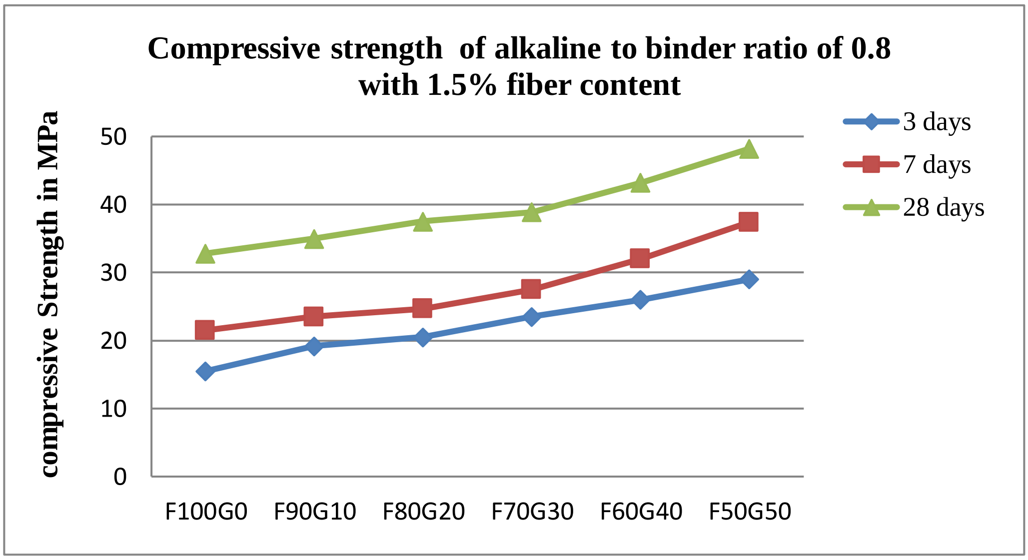


Figure 12.Variation of compressive strength for alkaline to binder ratio of 0.8 with 1.5% steel fiber content

Appendix III

Variation of compressive strength Based on Alkaline to Binder ratio

1. Steel fiber content =0.5%.

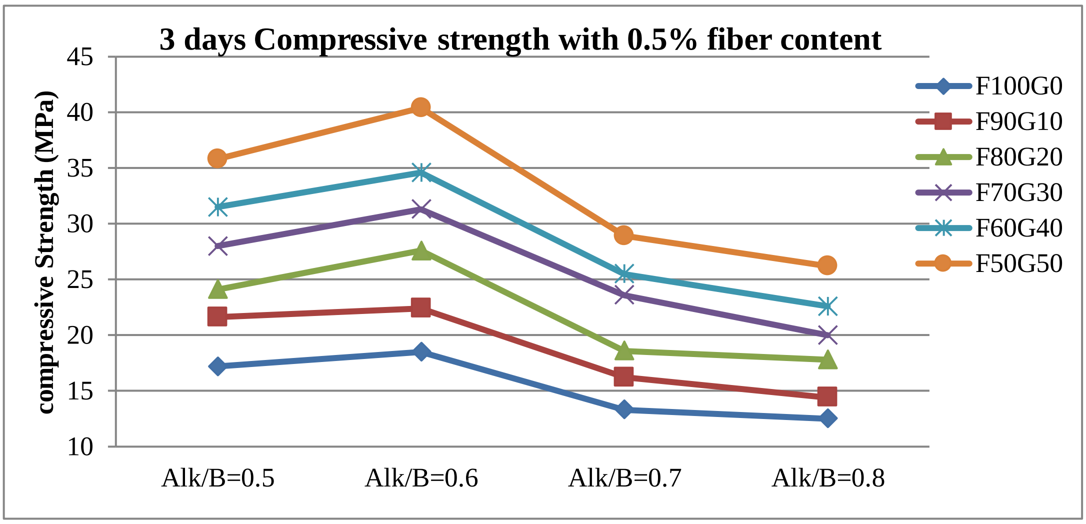


Figure 1: 3 days compressive strength for all Alk/B with steel content of 0.5%

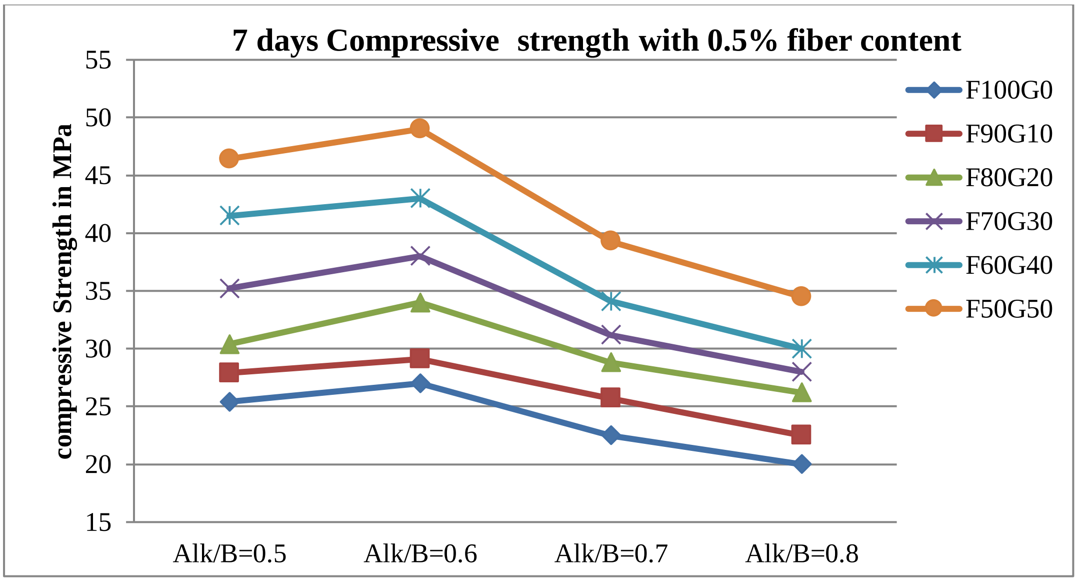


Figure 2:7 days compressive strength for all Alk/B with steel content of 0.5%

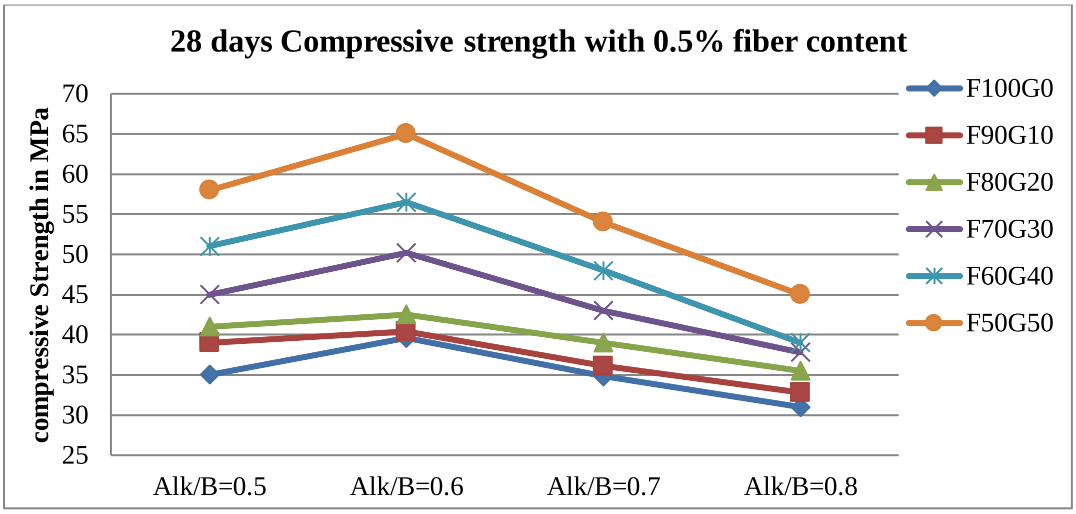


Figure 3: 28 days compressive strength for all Alk/B with steel content of 0.5%

2. Steel fiber content =1%

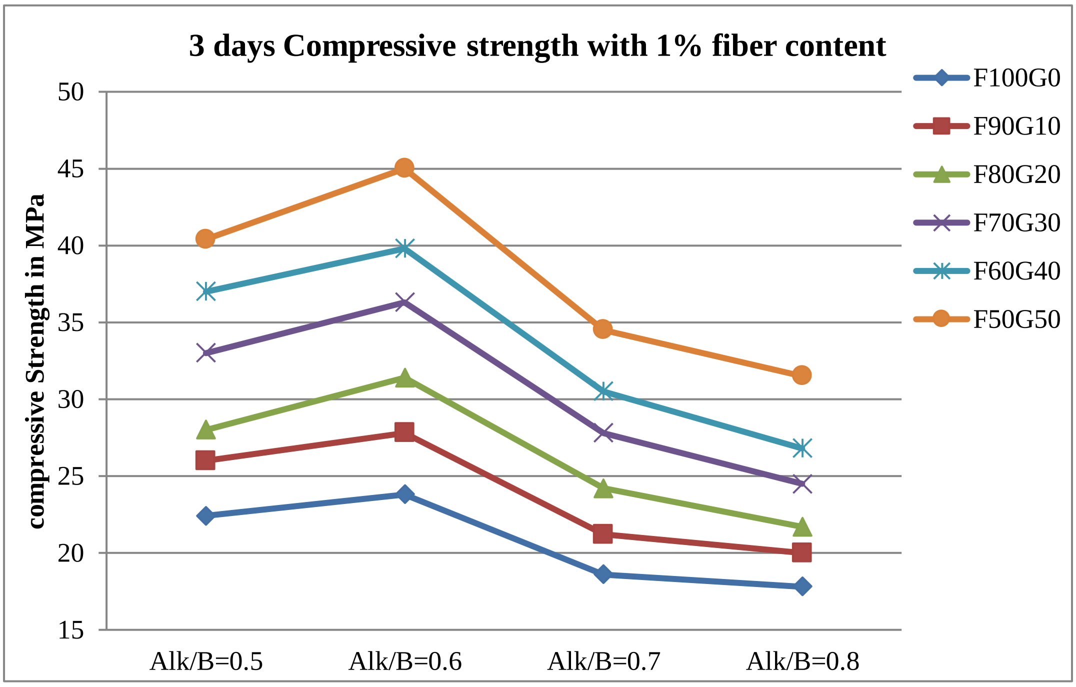


Figure 4: 3 days compressive strength for all Alk/B with steel content of 1 %

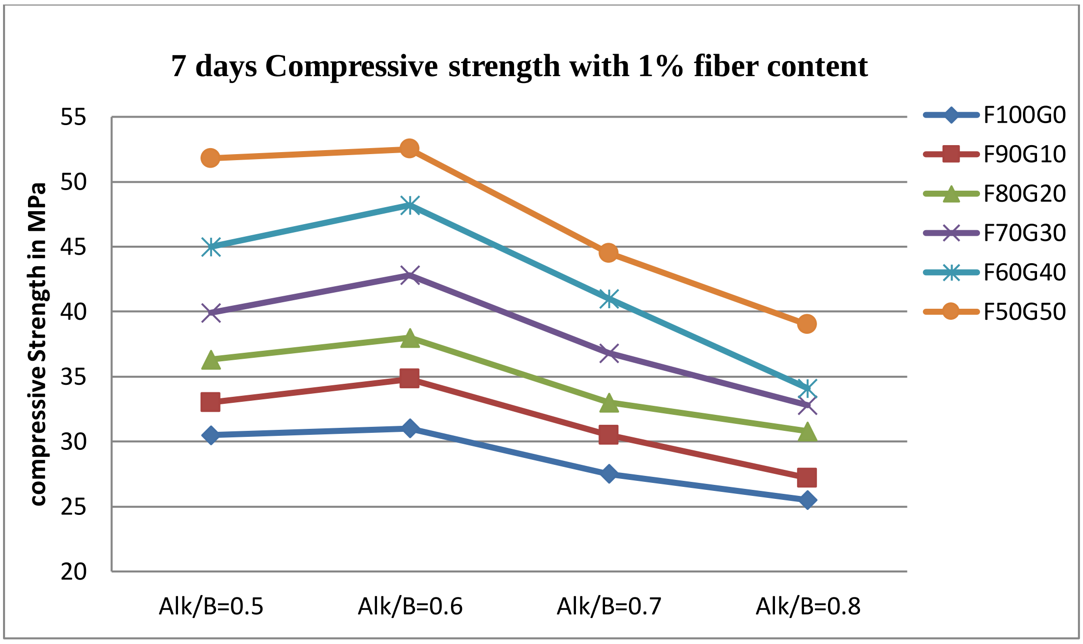


Figure5: 7 days compressive strength for all Alk/B with steel content of 1%

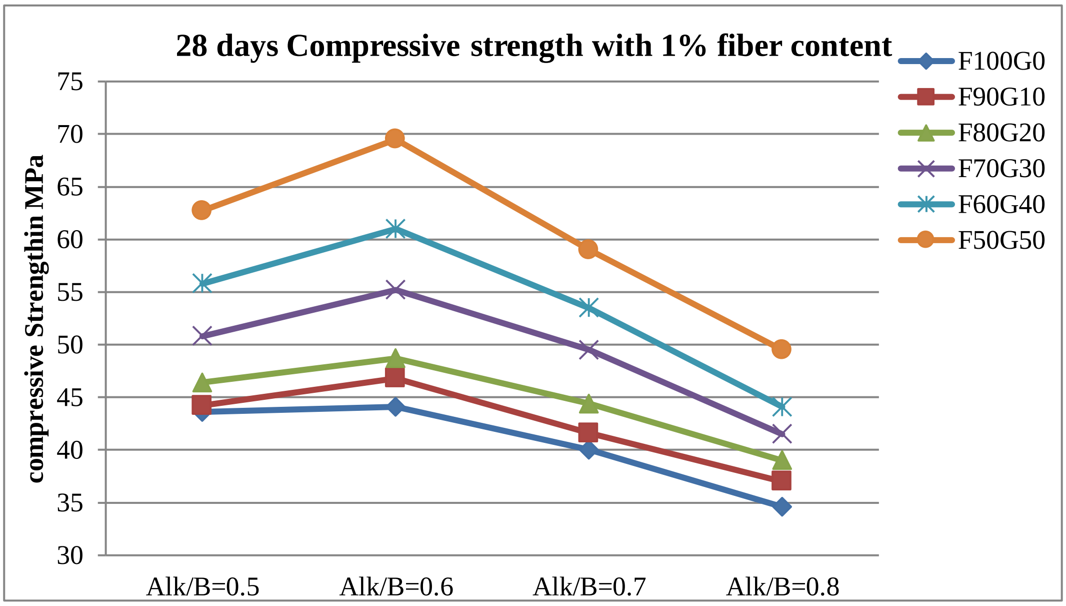


Figure 6: 28 days compressive strength for all Alk/B with steel content of 1 %

3. Steel fiber content =1.5%

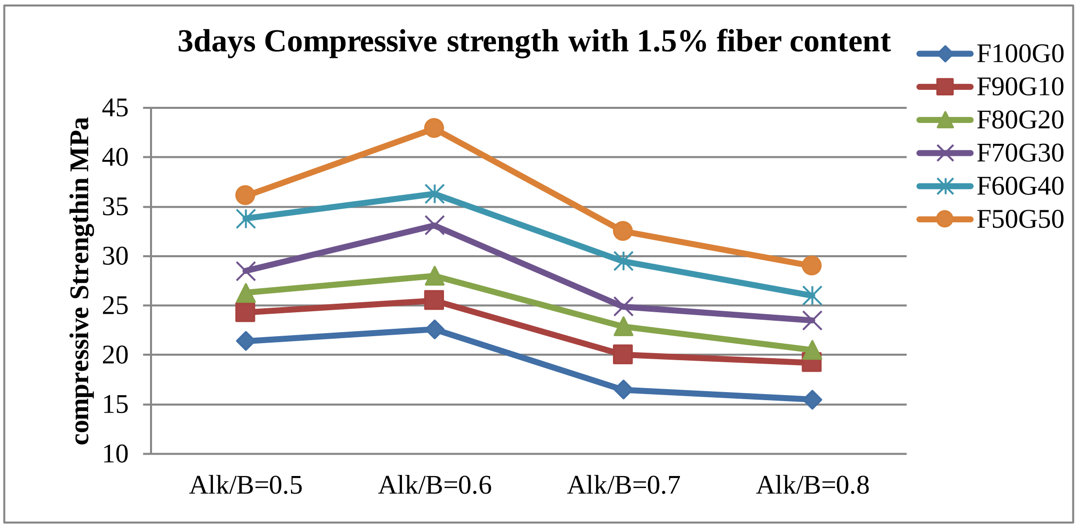


Figure7: 3days compressive Strength for all Alk/B with steel content of 1.5%

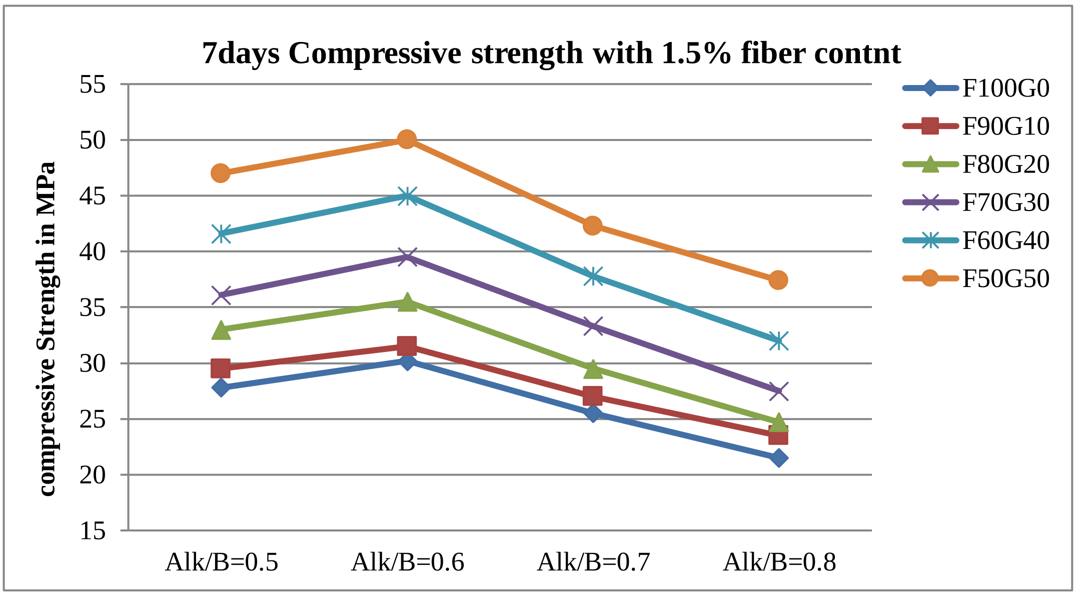


Figure 8: 7 days compressive strength for all Alk/B with steel content of 1.5%.

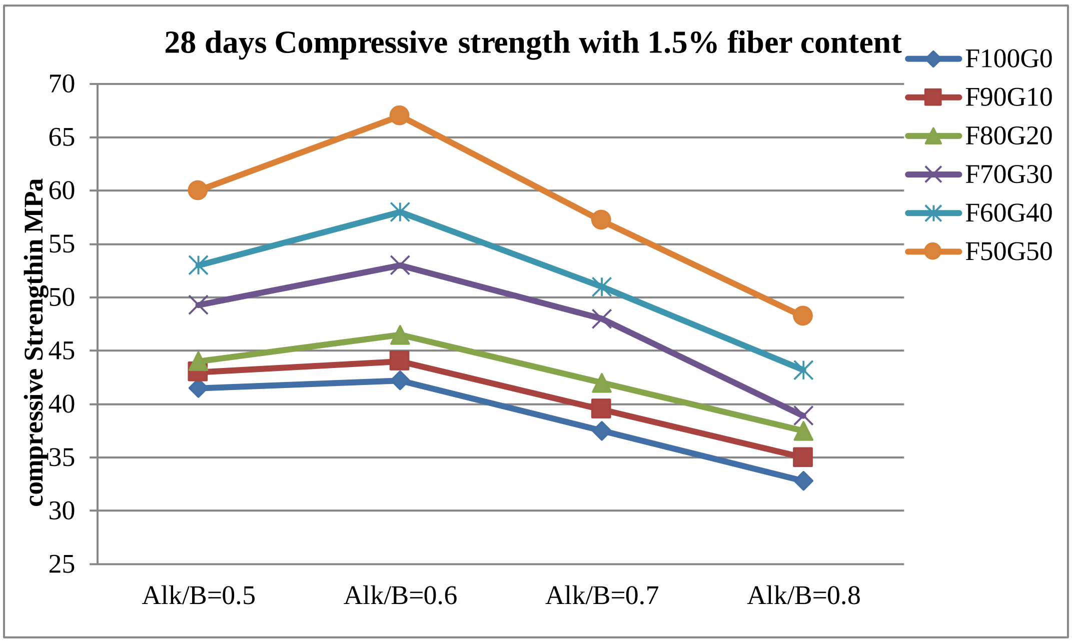


Figure 9: 28 days compressive strength for all Alk/B with steel content of 1.5%

BIO-DATA

<u>Personal Profile</u>

NAME: IRAMBONA THEODOSE

Date of Birth: 25th August 1987

Gender: Male

Nationality: Rwandan

Address: UNIVERSITY OF RWANDA, College of Science and Technology, School of Engineering, Department of Civil Environmental and Geomatics Engineering.

P.O. Box: 3900 Kigali-Rwanda

Pin Code: 000250

E- Mail address:irambodose21@yahoo.com

<u>Educational Qualification:</u>

Degree: Bachelor Degree (B.Tech. in Civil Eng)

Discipline: Building and Construction Technology

Year of passing: 2014

University: UNIVERSITY OF RWANDA, College of Science and Technology