HASAN KALYONCU UNIVERSITY
GRADUATE SCHOOL OF
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DEVELOPMENT OF A NEW TYPE OF FLY ASH BASED GEOPOLYMER CONCRETE

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IN
CIVIL ENGINEERING

BY
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Development of a new type of fly ash based geopolymer concrete

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Hasan Kalyoncu University

Supervisor
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GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES INSTITUTE
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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

Development of a new type of fly ash based geopolymer concrete

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The main aim of this study is to determine the optimum mix proportion for a geopolymer concrete for different compressive strengths. This study employed the statistical analysis to find the best fit equation predicts compressive strength of geopolymer concrete from mixture proportion, where the compressive strength is one of the desired and required properties of hardened concrete. The main concept of finding the equation is derived from the feret model, all the factors that effects on the compressive strength of geopolymer concrete and related to the ingredient materials are listed. A regression analysis was done to new model to find the empirical constant of the best fit equation with a highest coefficient of determination R^2 = 0.943 and lowest loss function expressed by residual mean squares. For geopolymer concrete at 7 day age was accomplished 85-90 % rate from compressive strength. When water-to-geopolymer binder ratio between 0.16 and 0.24, as the mix was very dry and not workable. When water- to-geopolymer binder ratio between 0.24 and 0.27, as the mix was very viscous and takes more time for mixing. When water-to-geopolymer binder ratio between 0.27 and 0.33, as the mix was cohesive and viscous but flow slowly for long time. When water-to-geopolymer binder ratio between 0.33 and 0.40, as the geopolymer concrete mix was spread just like a self-compacting concrete. The rate of increment in compressive quality is fast amid the initial 24 hour of curing time, past 24 hour the pickup in quality is just direct. Statistical analysis showed that the new model is applicable to geopolymer concrete. The developed equation was validated with the experimental results.

Keywords: Geopolymer concrete, Mix proportion, Alkaline solution, Modified feret equation, Regression analysis, SPSS program.

ÖZET

Yeni bir uçucu kül bazlı jeopolimer betonu geliştirilmesi

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Çimento üretimi sırasında büyük miktarda karbondioksit atmosfere verilir. Bu salınan karbondioksit diğer sera gazları ile birlikte küresel ısınmaya sebep olmaktadır. Beton üretiminde çimento yerine geo-polimer kullanılması durumunda karbondioksit salınımı önemli ölçüde azalmaktadır. Bu çalışmanın amacı, farklı basınç dayanımları için bir geopolimer betonun optimum karışım oranını tespit etmektir. Optimum denklemin elde edilmesi için istatistiksel analiz metodu kullanılarak, beton mukavemetinin istenen özelliklerinden biri olan karışım oranıyla geo-polimer betonun basınç dayanımı elde edilmiştir. Denklem, Feret Modelinden türetilmekte ve geopolimer betonun basınç dayanımına etki eden ve bileşen malzemeleriyle ile ilgili tüm parametreleri listelenmektedir. En yüksek uygunluk katsayısına $R^2 = 0.943$ ve en düşük kayıp fonksiyonuna sahip en uygun denklemin ampirik sabitini bulmak için yeni bir regresyon analizi uygulamıştır. Geo-polimer beton için 7 günlük mukavemetinden 85-90% oranında başarı sağlanmıştır. Eğer su-geo-polimer bağlayıcı oranı 0.16 ve 0.24 arasında ise, karışım çok kuru ve kullanılmaz. Eğer su-geo-polimer bağlayıcı oranı 0.24 ve 0.27 arasında ise karışımın viskozitesi yüksek olup karıştırma süresi artmaktadır. Eğer su-geo-polimer bağlayıcı oranı 0.27 ve 0.33 arasında ise uzun süre yavaşça akma durumunda fakat karışım yapışkan ve viskozitesi yüksek olmaktadır. Eğer su-geo-polimer bağlayıcı oranı 0.33 ve 0.40 arasında ise geo-polimer beton karışımı kendiliğinden yerleşen bir beton gibi yayılmıştır. Basınç kalitesindeki artış oranı, 24 saatlik kürlenme süresinin ilk yarısında hızlıdır ve 24 saat geçtikten sonra kaliteli olarak uygulanabileceğini göstermiştir. İstatistik analizler yeni modelin geopolimer betona uygulanabileceğini göstermiştir ve geliştirilen denklem deney sonuçları ile doğrulanmıştır.

Kelimeler: Jeopolimer beton, Karışım oranı, Alkali çözelti, Değiştirilmiş feret denklem, Regresyon analizi, SPSS program.

To my Mom and Dad

To my lovely Wife

To my Brother and Sister

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LIST OF ABBREVIATIONS

ACI	American concrete institute
ASTM	American society for testing and materials
AAS	Alkali activator solution
AEA	Air-entraining admixture
ALS	Advanced light source
AMBT	Accelerated mortar bar test
ANOVA	Analysis of variance
ASR	Alkali-silica reaction
BA	Biomass ash
BTU	British thermal unit
BFS	Blast furnace slag
BASF	Baden aniline and soda factory
CA	Co-fired fly ash
CSA	Canadian standards association
ESEM	Environmental scanning electron microscope
FA	Coal fly ash
GPC	Geopolymer concrete
GPB	Geopolymer binder
GP	Geopolymer
LOI	Loss on ignition
MK	Metakaolin
OPC	Ordinary portland concrete
OP	Ordinary portland
OWC	Optimum water content
PSD	Particle size distribution
RCPT	Rapid chloride permeability test
SG	Specific gravity

SSA	Specific surface area
SP	Super plasticizers
QXRD	Quantitative x-ray diffraction
XANES	X-ray absorption near edge structure
XRD	X-ray diffraction
BS	British standard
AS	Australian standards
XRF	X-ray florescence
KN	Kilo newton
BFS	Blast-furnace slag
CH	Calcium hydroxide
C	The mass of cement per unit volume of concrete
W	The mass of water per unit volume of concrete
w/b	Water-to-geopolymer bainder ratio
w/cm	Water-to-cementitious material ratio
f_{cu}	Cubic compressive strength
f_c	Compressive strength of concrete at a given age
g/cm^3	Gram per cubic centemetr
$\gamma dmax$	Maximum dry unit weight
P	Dosage of plasticizer, as a proportion of the cement volume
g*	Packing density of the aggregate (when it is separately packe as a dry granular mixture)
g*max	Value of (g*) obtained with the best combination of the aggregate fractions
h	Height between the top surface and the bottom of a deck
x	Optimal coarse/fine aggregate ratio
φ	Function linking the water/cement ratio with the compressive strength of concrete
ηa	Apparent viscosity of the fresh concrete used as a workability index
d(t)	The kinetics parameter at age
t	The age of geopolymer concrete

V_{gs}	Volume of geopolymer solid
C-S-H	Calcium silicate hydrate (cement chemistry notation)
C-(A)-S-H	Al-substituted calcium silicate hydrate
F	Fe_2O_3 (cement chemistry notation)
H	H_2O (cement chemistry notation)
K-A-S-H	Potassium aluminosilicate gel
N-A-S-H	Sodium aluminosilicate gel
Al_2O_3	Aluminum oxide
CaO	Calcium oxide
KOH	Potassium haydroxide
K_2O	Potassium oxide
CO_2	Carbon dioxide
C_3A	Aluminate
Fe_2O_3	Iron oxide
H_2S	Hydrogen sulphide
NaOH	Sodium hydroxide
Na_2O	Sodium oxide

CHAPTER 1

INTRODUCTION

1.1 Background

Generally, concrete used as construction material plays vital role in worldwide. Later on, for cementations materials, the need is estimated by increasing it in the modern countries. It is available, PC, that stands for “Portland cement”, is still the first choice to raise it in the production of Normal concrete as much as 3% annually as the binder for concrete prompting massive Malhotra (2002). The specific role played by concrete as a greenhouse gas emission contributor is quite remarkable. The precise reason for this is that cement is seen as the second largest producer of the greenhouse gas. It is possible for any additional production of this material to further increase and reach up to 4380 million tons in 2050 from the 2540 million tons that it was in 2006, and, as such, would result in the emissions and likelihood of having great effect on the global warming indices (Pachauri et al., 2014).

In concrete production, to ensure sustainability, it has to replace it with different cementations materials of environmentally friendly supplementary and finding the alternative binder for concrete. Cement, a major constituent of concrete utilised in construction, discharges a considerable amount of CO_2 into the atmosphere during production. It has been estimated that 1 ton of OPC production leads to 1 ton of CO_2 released into the airspace. This could significantly affect the global warming and greenhouse gases. Approximately, one cubic meter of concrete per person a year is used. This amount indicated that the enormous amount of concrete used worldwide. Thus, it is estimated that cement production would contribute approximately 7% of the worldwide CO_2 emissions (Douglas et al., 1991).

Geopolymer cement, in contrast, makes use of low quantity of calcium-based raw materials as well as a mufacture with lower temperature. The number of fuel utilised is also smaller, leading to the decreased emission of carbon dioxide during production.

It was during the early 70‘s of the last century that Davidovits introduced the term geopolymer in representing their inorganic nature "Geo" and structural similarity regarding organic "polymers" as they are basically utilised today. They are all part of the material classification of activated materials, as well as their strengthening mechanism known as geopolymerisation (Davidovits, 1994a).

The geopolymer materials can be described as inorganic polymers on the basis of alumina and silica units. They are created from a broad range of de-hydroxylase alumina-silicate powders which natural porcelain that is condensed with sodium silicate in an environment that is highly alkaline is part. In spite of the fact that the manufacture of sodium silicate and alkaline hydroxide must be derived from refined products, the production of geopolymer cement has continued to have lower environmental effect compared to the production of ordinary portland concrete. Furthermore, alumina-silicates based materials are abundant in nature all over the world and can be found present in several wastes and by-products, while it is possible to produce geopolymer cement with the use of existing concrete works thus, there is no need for new expenditure (Shi et al., 2003).

The mechanical properties of these novel materials produce the competitive properties for geopolymer cement in comparison with Portland cement. Geopolymer concrete can be described as a concrete that is produced with the use of cement matrix to bind fine and coarse aggregate. There has been improvement of mechanical and physical characteristics such as elevated resistance to freeze-thaw and elevated thermal resistance, as well as elevated strength and elevated acid resistance by geopolymers (Hardjito et al., 2004a).

There has been a reference to this in the form of rock, concrete in the literature. Considering the fact of the finished product identically resembling natural rock in appearance. Producing a mixture that is capable of being poured and molded as well as worked and setting faster and harder with the use of geopolymer cement is possible compared to normal Portland cement concrete. In spite of the claims regarding the basis of this technology being on a very old construction material principle like the one that was utilised in the great Pyramids, it is only during the past 21 years that this has been discovered again and attention focused on its useful chemical and physical properties (Provis et al., 2015).

It is quite clear, based on the literature, that there has not been full comprehension of the factors governing the geopolymers formation and their setting and strengthening.

Furthermore, little is known regarding the way activated natural pozzolans behave as geopolymer cement. Thus it is worth the trouble studying these alkalis activated porcelains and the concrete constructed properties with this type of binder.

1.2 Problem statement

Some researchers have come to the consensus regarding the reduction of carbon dioxide emission by geopolymer technology to the tune of 90% in the comparison with Portland cement. Thus, in response to ecological issue, geopolymer concrete is regarded as the most suitable one than that the ordinary portland poses. Furthermore, the geopolymer concrete production, in contrast to a ordinary portland, requires the consumption of reduced natural resources like coal ash in the production of the binder.

1.3 Aim of the research

Developing suitable mixtures of geopolymer regarding the condition of ambient curing has tested many samples in properties for early age as well as an extensive trail mix design. One more thing that in the mixture, some additives to raise the quantity of calcium. A sodium silicate solution, as well as a combination of sodium hydroxide, was prepared to activate the aluminosilicate binder.

The applicability of the proposed methods, this study concentrated on producing concrete with a sufficiet compressive strength which might be used as structural components. Furnace was used as an approach of curing by finding appropriatness of geopolymer concrete.

Having proportioned different groups of mixture fly ash geopolymer put together with other additives, properties, in early age, were carried out and included the workability, compressive strength and even setting the time. Mixture varied by recognising their effect as well as recognising their properties towards the resulting geopolymer.

1.4 Research objectives

The objective of this investigation is to determine the optimum mix proportion for a geopolymer concrete for different compressive strengths.

The objectives are as follows:

- Relationship between density and compressive strength.
- Effect of age on compressive strength of geopolymer concrete.
- Effect of additional water on compressive strength of geopolymer concrete.
- Effect of size combination on compressive strength of geopolymer concrete.
- Effect of activity on compressive strength of geopolymer concrete.
- Effect of amendment molar concentration on compressive strength of geopolymer concrete.
- Effect of temperature on compressive strength of geopolymer concrete.
- Effect of water to binder magnitude relation on compressive strength of geopolymer concrete.
- Comparison between geopolymer concrete with ordinary portland concrete about CO_2.
- Modify feret model and using to geopolymer concrete.
- Illustrate the results of predicted and laboratoray compressive strength.
- Comparison between the results of theory compressive strength and laboratoray compressive strength.

1.5 Research methodology

All experiments were made nine groups. The tests were completed for every groups of five various lengths, for example 3, 7, 28, 56 and 90 days. In every length, three tests were tried for every blend, and the common outcomes were taken from these three worked examples. Add up to some moulds were 570 moulds.

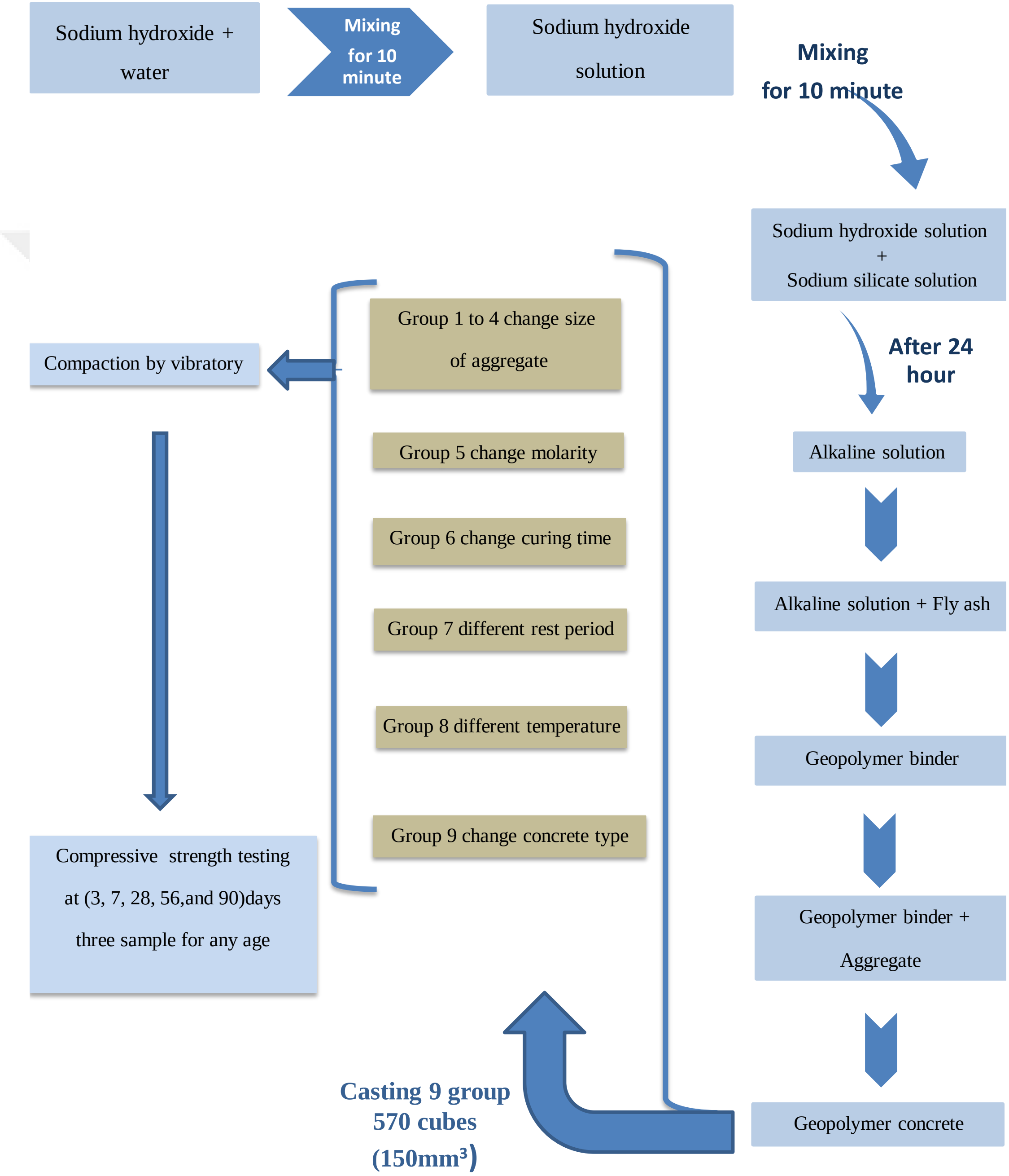


Figure 1.1 Research methodology

1.6 Dissertation outline

The thesis is divided into six chapters. Chapter 1 is a general introduction and with providing the statement of the problem, aim and objectives of the study, chapter 2 reviews the extensive literature and background about the geopolymer techniques, chapter 3 covers the highlights of the experimental test carried out in this study. The properties of the materials used, mixture design, mixing procedures, the preparation of samples, curing types, and testing procedures are also mentioned, chapter 4 includes a theoretical analysis of the test results and predicted equations for the estimation of geopolymer compressive strength, chapter 5 presents the experimental framework of results and discuss the compressive strength, the effects of compressive strength several variables about normal and geopolymer concrete, chapter 6 is conclusions about all the study expermantal and nummerical.

CHAPTER 2

LITERATURE REVIEW

2.1 Geopolymer technology

2.1.1 Brief history of geopolymer

The knowledge of geopolymer and alkali-activation technology towards the cement and concrete industry has existed for more than seventy years now. The first alkali-activated binder that utilises blast furnace slag, sodium hydroxide blast furnace slag, and sodium hydroxide was developed by Glukhovsky (1994), during the mid-1950s, started conducting investigation of the binders that ancient Roman and Egyptian structures utilised in discovering a substitute to ordinary portland concrete in the former soviet union. Glukhovsky (1994) made a production of a binder known as 'soil cement', integrating different types of slags with alkaline solutions coming from industrial waste.

The geopolymer concrete use in numerous structural applications was undertaken throughout the 1960s. Nonetheless, the mixture techniques were under patent rights, making them inaccessible. Devidovits (1991 and 1994a) during the late 1970, developed a three dimensional polysialate chains' mineral polymer, resulting from the natural minerals' hydroxylation and poly- condensation reaction like clay and slag, as well as fly ash and pozzolan, upon the activation of alkaline (Davidovits and Sawyer, 1998).

Lone Star Industries Inc of USA began the use of ordinary portland concrete blended geopolymer binders named pyrament which is strictly identical to alkali activated pozzolanic cement. This concrete accomplished an early high strength which is utilised in several structural applications that lasted until 1996 within the United States Davidovits (1994a). Acceleration of dynamic research on geopolymeric materials was made, and they began to emerge as published during the late 1990s (Provis et al., 2015).

The team from Spain and Australia such as Fernandez et al. (2006), Pacheco et al. (2007) and Sofi et al. (2007) respectively carried out several studies on geopolymer technology, in focusing on microstructural and morphological development of different types of alkali activated materials. Another group of researchers was led by rangan in curtin university australia at engineering department, studied the mechanical, structural and durability properties of fly ash based geopolymer concrete.

2.1.2 Environmental sustainability and issues

For the 21st century, it is known that the most vital challenges in the world society are the necessity for proper sustainable options. To maintain a process running on, sustain was defined as well as the terms “sustainability“ stands for life in our planet that might be sustained for the future. It is clear that the most critical concern is the environment in terms of sustainability rules followed by a civil engineer for not influencing any impact on the environment that describes as negative. Thus, both of the environmentally friendly and green technology is similar to the term sustainability (Defazio, 2007). It is known that concrete is considered as a choice material where sustainability as well as the main claims as follows:

- The material that describes as raw such as water as well as aggregates for concrete can be surrounded by much material on Earth. There are a lot of countries that are considered towards them as self-sufficient. It is not significant to deliver materials for this reason; it can get the environmental and economic costs of the project down. It is clear that limestone is considered as the most abundant mineral on the earth and the main raw material is limestone for manufacturing cement.
- For replacing recycled aggregated, ground granulated blast-furnace slag could be used. This can decrese environmental influences of manufacture of concrete and is by-products, namely secondary product.
- The concrete of Davidovits ready-mixed producers implemented to enhance efficiency and quality as well as to reduce waste. This type of concrete operates under what so called “Quality Assurance Schemes“.

They reuse concrete waste and taken materials from constructing structures could be pulverised as well as reused as aggregate besides hardcore.

- By reflecting light, concrete keeps energy because of its naturally brighter and it considered more reflective compared to asphalt. Moreover to reduce the heat-island effect by light-colored paving materials.
- Generally, they are more durable namely “pavements as well as concrete structures” A considered installed concrete has to stay in correct cases for many decades.

2.1.3 Sustainable development

The world commission clarified on environment and development 1987 as meeting the needs of the present without compromising the ability of the future generations to meet their own needs. The total environmental impact in a structure constructed during the entire cycle of life will be decresed to a minimal in a sustainable environment framework. In a suitable manner, the structure should be constructed in tailor-made regarding the right concrete for the accurate application, geopolymer concrete have the better advantagous of normal concrete like high strength, good durability, and high thermal capacity will be in action. Unluckily, two main negative sides of concrete production are exists with the regard of sustainability (Jamkar et al., 2013).

As the primary component of concrete, the process of manufacturing ordinary portland concrete is energy consuming manner and substantial resource in which about 1.5 tons of raw materials needs for every tone of cement (Glukhovsky, 1994).

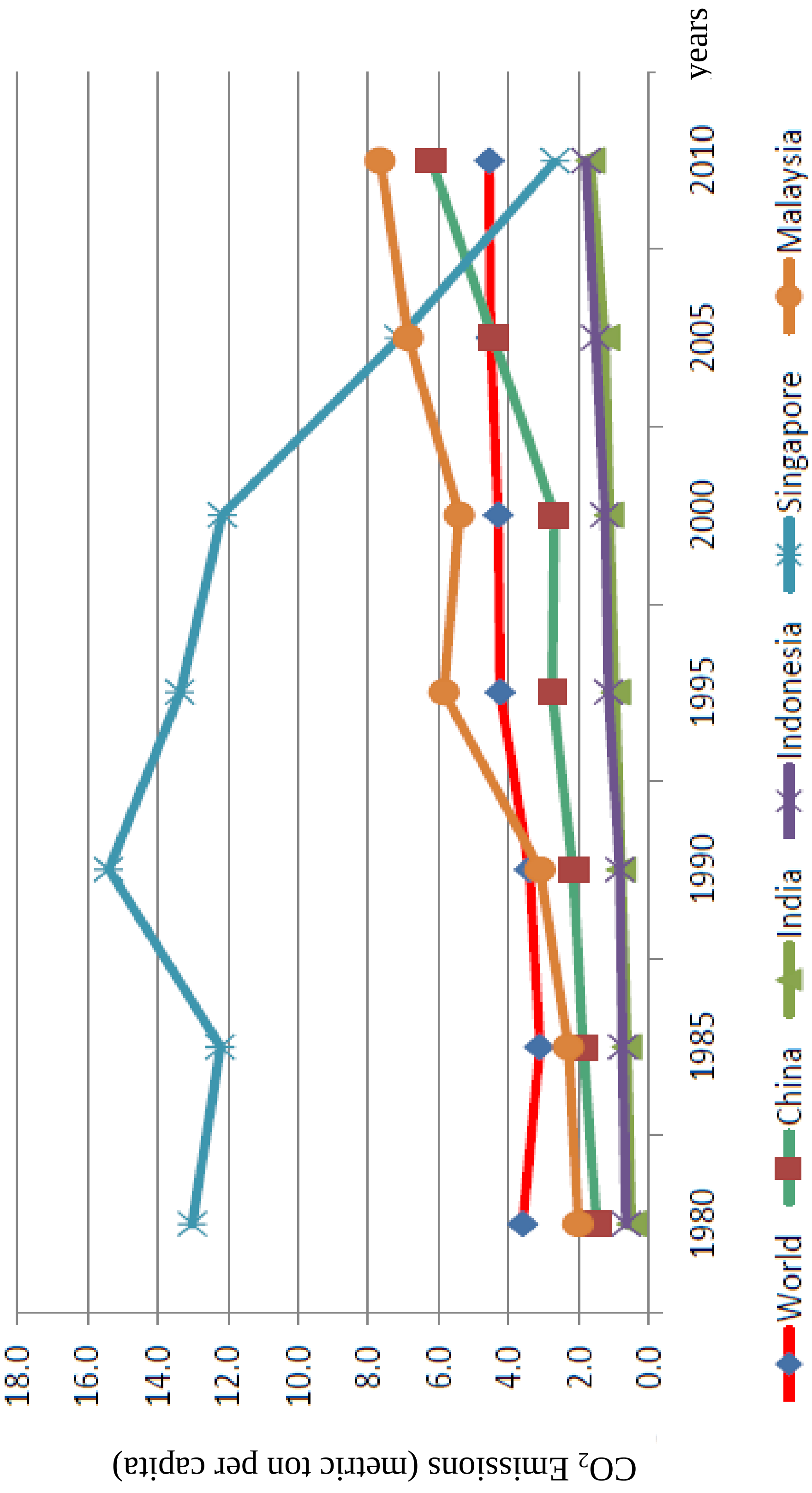


Figure 2.1 CO$_2$ emissions (Zaid et al.,2015)

An essential agent in CO_2 release and production of cement in energy use plays a vital role in this field the reason is that the generating high amounts of CO_2 from clinker production. Cembureau, the “ECA” that stands for the earth Cement Association see Figure 2.1 (Zaid et al., 2015).

It will be deteriorated when concrete exposed to the environment, which contains essential influences on its durability and serviceability. Three major factors speed the transport phenomena of aggressive agents up, such as, sulphate as well as chlorides into the concrete. It is in cracking, the quality of the cover as well as insufficient extent, and the whole quality of the overall structural concrete (Jamkar et al., 2013).

2.2 Geopolymers

Geopolymer is a term that refers to a family of mineral binders, and just like the structure of zeolites, they also have a polymeric silicon-oxygen-aluminium configuration. Occasionally, geopolymers are considered to be similar to zeolites since their aluminum to silicon raitio proportion is almost the same as zeolites and the only difference between the two is that the geopolymers have an amorphous structure while the zeolites are crystalline (Davidovits, 1994b).

The silicon and aluminium ions in the source materials are stimulated dissolve to create the geopolymer cement. For this process, highly alkaline solutions are used. This process goes through three critical steps that are identical to those used when formulating zeolites:

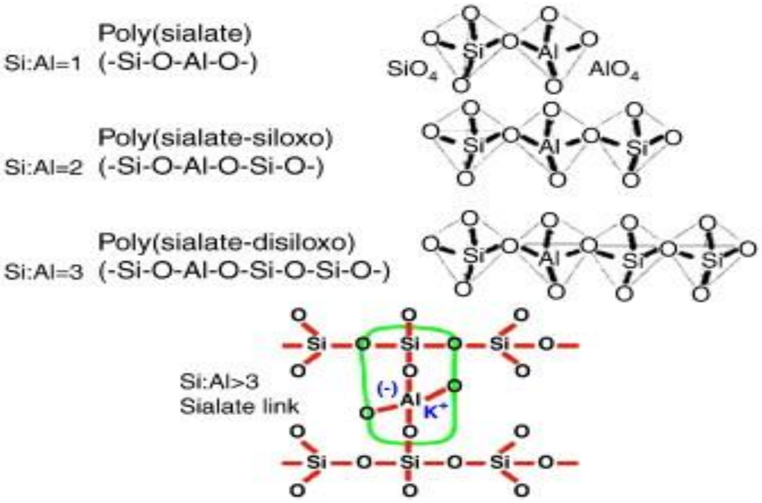
The first step involves dissolving any compound or supply that contains aluminium and silicon in alkaline solution. This is followed by the generation of moving precursors of alumina-silicate oxides. This is possible because of the reaction of hydroxide ions present in the alkaline solution.In this step, moving precursors are partially oriented, along with the partial internal reformation of the alkali poly-sialates. The particles from the preliminary solid phase are re-precipitated, and the entire system gets harder to create an inorganic polymeric structure (Davidovits, 1994a and 1994b).

Various alumina-silica wastes or natural materials like fly-ash "coal and lignite" oil, fuel ash, blast furnace and steel slag, rice husk ash, silica fume, natural pozzolans and metakaolin can be converted into building components through the process of geopolymerisation (Duxson et al., 2007).

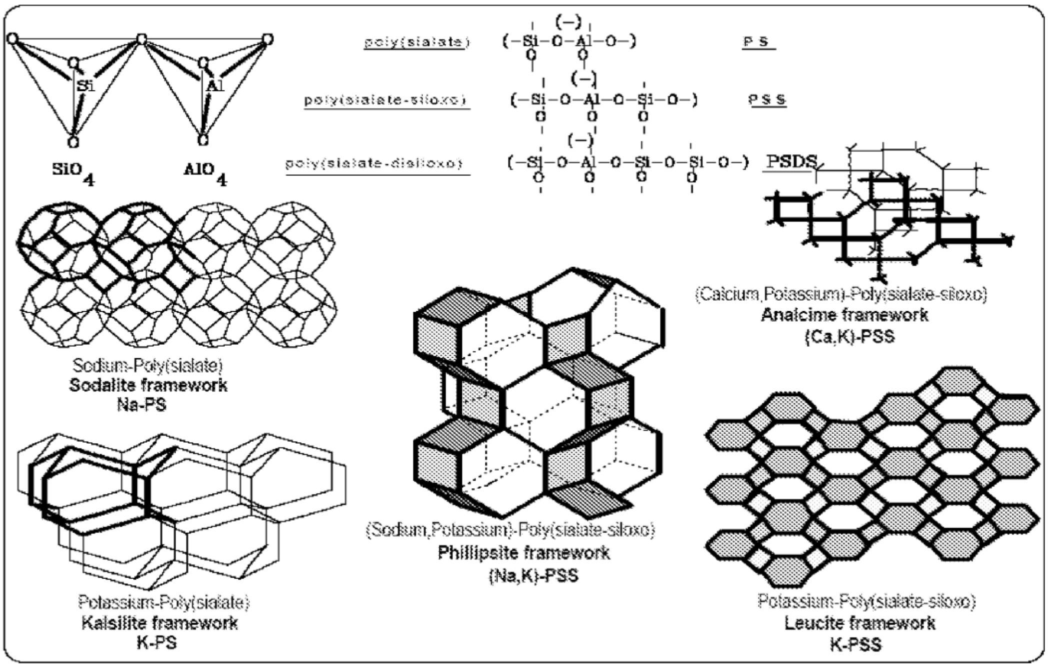
These components function as poly-condense alumina and silica, similar to organic polymers when the temperatures are less than 100°C. In geopolymerisation, there is a chemical reaction between alumina-silicate oxides and alkali poly-silicates that leads to the creation of bonds. The silico-aluminate structures are 3D amorphous or semi-crystalline structures (Hlavacek, 2014). To explain the constituents, three fundamental forms were described by Davidovits (1994a and 1994b) as shown in Figure 2.2.

- Poly (sialate), the recurring unit of which is [-Si-O-Al-O-].
- Poly (sialate-siloxo), the recurring unit of which is [-Si-O-Al-O-Si-O-].
- Poly (sialate-disiloxo), The recurring unit of which is [-Si-O-Al-O-Si-O-Si-O-].

The chemical and physical attributes of the ultimate product are influenced by the distribution and relative quantities of all the distinct aluminum and silicon building components.



(a)



(b)

Figure 2.2 Computer molecular graphics of polymeric Mn-(-Si -O-Al-O-)n poly(sial ate) and Mn-(-Si-O-Al-O-Si-O-)n poly(sialate-siloxo) and related frameworks (Davidovits, 1994a and 1994b).

2.3 Geopolymer concrete

Cement that is formed from aluminium and silicon, rather than from calcium and silicon, is denoted using the word “GEOPOLYMER CONCRETE”. This kind of inorganic polymers are called geopolymers and can be created at room temperatures. In this process, the source material is either the industrial waste or by-product. Recently, people have become more aware of the hazardous solid waste production and how they affect the health of humans. Furthermore, the impact of water disposal on the environment is also being discussed to a greater extent. Because of this, the industry players are looking for different ways in which the waste products can be reused. It is suggested that the waste materials and by-products including heavy metals can be reused to form geopolymers as a substitute to Portland cement. Geopolymers can then be used for the construction of roads and other offshore activities (Davidovits, 2005).

2.3.1 Raw materials for geopolymers

Various minerals can possibly be used as raw materials in geopolymers; however, it is critical that silica and alumina are included in these materials. These minerals may either originate from natural sources, such as kaolinite or calcinated kaolinite "metakaolin", or maybe by-products of industrial processes, such as Blast Furnace Slag from the iron-steel producing industry or fly-ash from coal combustion. BFS and fly ash are the raw materials found most commonly (Ismail et al., 2013).

2.3.2 Manufacturing geopolymers

In the process of geopolymerization, minerals comprising of naturally available silica-aluminate are chemically incorporated leading to the creation of geopolymers. There are three critical stages of geopolymerization: dissolution, condensation and polymerisation. Dissolution is the first stage in which there is a reaction within the source of silica and alumina, causing the silicon and aluminium ions to dissolve in an alkaline solution. Condensation then takes place, in which the newly formed solution reacts and creates oxygen bonds among the silicon and aluminium molecules placed alongside each other (Davidovits, 2005). Polymerization is the final stage in which there is an application of heat to the solution generally till 90°C, with firm chains of oxygen bonding being created by the molecules. Following the reaction, molecules having a structure identical to the natural building rocks are formed. These inorganic polymeric materials may be considered to be equally amorphous to geological feldspars and are known as “geopolymers” (Xu and Van, 2000).

2.4 Geopolymers properties

In contrast to the conventional cement binders in Portland cement, it has been found that geopolymers provide similar performance. A critical distinction between Portland cement and geopolymers is linked to greenhouse emissions. The Portland cement production is relying on high-energy manufacturing processes since they require extensive amounts of energy. In contrast, geopolymers do not need a lot of energy and materials, which means that the production of geopolymers is energy efficient. There is a decrease in CO_2 emission by almost 80% when compared with a typical Portland cement. Geopolymers also do not require costly raw materials and make use of by-products of other products, like fly fiery remains and BFSE (Diaz and Allouche, 2010).

2.4.1 Properties of fresh geopolymer concrete

A fresh geopolymer concrete is like a rigid paste that has a thickness and is difficult to handle (Hardjito et al., 2004a and 2004c). There have been various studies on the workability of alkali stimulated slag binders. Those studies show that the features of alkali- stimulated slag cement pastes are influenced by various factors, for example, the nature of slag and activators, fineness of slag, dosage of activator, inclusion of lime, chemical admixtures, mineral admixtures and the timing for injecting activators (AI-Otaibi et al., 2001, Shi et al., 2003). It was shown by Collins and Sanjayan (1999) and Qing-Hua and Sarkar (1994) that while slag was activated, there was a decrease in workability with an increase in the content of alkali activators sodium hydroxide. Douglas et al. (1991) also showed that when the reaction took place with sodium silicate, there was a swift decrease in workability. Furthermore, the state and the modulus of the state can also turn out to be critical for workability. There is low workability when the sample is less than 0.5, while it is very high when the sample is in the range of 0.5 to 1.0. When the sample of sodium silicate becomes higher than 1, then there is a significant decrease in the workability of the paste as the sample of silicate increases (Bondar et al., 2011, Shi et al., 2006).

Based on the finite information available on the workability of activated silicate, a significant part is played by the water content in the mixture concerning the workability of fresh geopolymer concrete. When the molar ratio of the mixture is kept constant, it is possible to adjust the water content to create the required workability for any given compressive strength of hardened concrete Hardjito et al. (2004a and 2004c). Several reserches have been performed in the past on the setting of activated slag binders; however, there is limited information on the setting of activated alumina silicate minerals. The mixture components can be modified to time a geopolymer mix to either fast or slow. On the basis of the synthesis conditions, it took very less time to achieve structural reliability and enough strength, at times, even as little as an hour (Van et aI., 1997).

It was shown by Cheng and Chiu (2003) that when granulated blast furnace slag is used as the source material, curing temperature, kind of alkaline activator and the components of the source material influenced the setting time of the geopolymer paste. According to the authors, the setting time of this geopolymer paste was between 15 to 45 minute at a temperature of 60°C. It may be more suitable to obtain the time available between the end of mixing and the beginning of casting of fresh geopolymer concrete in practical applications, while it may not be adequate to determine the setting time at higher temperatures. It was demonstrated in the laboratory experiment carried out by Hardjito et al. (2004a) that it was possible to manage the fresher geopolymer concrete for at least 120 minute following mixing before any sign of setting and deprivation in compressive strength is observed. The basis of these results is the composition of the source material; the more rapid setting is achieved when the CaO contents are higher. Besides, when the source materials include components apart from the oxides of aluminium and silicon, then the setting may take more time. In materials that originate purely from geological sources such as calcined kaolin, the dominating chemical contents are just aluminium oxide and silicon dioxide, while other compounds are also included in by-product materials, for example, Fe_2O_3. Hence, it seems that materials that are purely geological may show higher reactivity with alkaline activators and may cause a decrease in the initial setting time (Hardjito et al., 2004b). More rapid initial setting time was shown by fly ash based geopolymers when the temperatures were higher, and the eventual setting of these mortars was achieved 15 to 25 minute following the initial setting (Bondar, 2013).

2.4.2 Properties of hardened geopolymer concrete

Various views have been put forward regarding the critical parameters that influence the compressive strength and other mechanical qualities of geopolymer concrete. According to Palomo et al. (1999a), the key factors that have an impact on the compressive strength include the kind of alkaline activator the curing time and the curing temperature (Hardjito et. aI., 2004a and 2004c).

Nonetheless, according to other researchers, the significant factors for achieving effective polymerization are the comparative quantities of silicon, Aluminum, potasum, Sodium, molar ratio of silicon to Aluminum within the solution, the kind of alkaline activator, the rate of alumina silicate mineral to kaolinite after adding "kaolinite" the curing temperature and the water content (Xu and Deventer, 2000, Barbosa et aI., 2000, Rowles and O'connor, 2003).

When silicate ions are present in the alkaline solution, there is a considerable improvement in the mechanical strength and modulus of elasticity values; however, there is a slightly negative effect on the matrix/aggregate and matrix/steel bond, which is otherwise quite strong (Fernandez et al., 2006). According to the experimental findings, there is a considerable effect of the molar ratio in the mixture composition on the compressive strength of fly ash-based geopolymer concrete, while there is the less significant effect of the molar ratio of Na_2O/SiO_2 (Hardjito et al., 2004a to 2004c). The compressive strength of the geopolymer decreases when there is an increase in the H20/M20 molar ratio and water to the geopolymer solids ratio (Hardjito et al., 2004a to 2004c).

It was also shown by Van et al. (2002) that the structure of hardened material might become weaker when curing took place at high temperatures for extended time periods. According to Palomo et al. (1999b) study on fly ash-based geopolymer binding, there is a significant impact of curing temperature and curing time on the compressive strength; however, this is not always true for other alumino-silicates. The compressive strength of fly ash-based polymer concrete increases with long curing time and higher curing temperature; however, for curing at over 60°C and for periods greater than two day, this increase in strength may not be very significant. Majority of the times, 70% of the eventual compressive strength is formed within the initial 4 hour of setting. The chemical reaction of the geopolymer paste is a rapid polymerisation process, and so, there is not much change in the compressive strength with the age of concrete once 24 hour have passed since its curative. This observation is distinct from the common behaviour of open concrete in which the hydration procedure continues for an extensive period of time, and so, its durability increases with the passage of time (Hardjito et al., 2004b).

There is another distinction between Portland cement and alkaline activated substance, which is the presence of a comparatively low threshold temperature in Portland cement. A temperature over this threshold can negatively affect the mechanical growth as well as the durability of the material (Fernandez et al., 2006). On the other hand, for activated ash, when the reaction time and curing temperature is decided appropriately, a distinct reaction product can be obtained without affecting material durability. The reason for this is that the increase in curing temperature is consistent with the decrease in the quantity of aluminum added to the final product and related improvement in mechanical attributes. These improvements are consistent with the creation of a homogeneous alumina-silicate matrix (Fernandez et al., 2007).

2.5 Properties of geopolymer binders

2.5.1 Properties of fresh geopolymer binders

Geopolymer concrete produced with low water to binder ratio can be very stiff and would not have the increased flow required for better workability and ease of placement. A number of super plasticizers, water reducer and set retarders have been used in geopolymer systems to increase workability with varying extents of success (Provis et al., 2014). Previously it was reported that traditional designed for ordinary portland concrete super plasticizers, setting accelerators and setting retarders are not affected in adjusting the workability and setting of geopolymer systems (Torres and Puertas, 2017). Studied mixes with 8.4 kg of fly ash, 2 kg of water glass modulus $SiO_2/Na_2O=2$ and 0.8 kg of KOH, 7M. They showed that the improvement of workability due to the use of super-plasticizer Glenium 27 at 3% by mass of fly ash or Rheobuild 1000 at 1% by mass of fly ash was marginal while it caused a significant strength reduction the more the worse (Kong and Sanjayan, 2010).

However, few alternative methods have been tried to change the fresh properties of geopolymers. Lee (2013) tried phosphoric acid to retard the setting of fly ash and slag blended geopolymers with liquid sodium hydroxide and sodium silicate solutions. Concluded that the acid did not significantly change the initial setting time of the binder. However, observed that adjusting alkalinity and SiO_2/ Na_2O mass ratio of the liquid activator solution can change the setting of geopolymers these observations were in agreement (Nath and Sarker, 2014). Stated that increasing soluble silica in the geopolymer systems has a higher impact on the setting than increasing the alkali contents (Balczar et al., 2015). The above studies were carried out for liquid alkali activators hence they are not directly relevant for solid activator based geopolymers. Ravikumar and Neithalath (2012) used sodium silicate powder and sodium hydroxide both in powder form as alkali activators in their slag binders. The authors stated that fresh slag mixes containing powder activators shows quick setting with an initial setting below 30 minute and a final setting below 60 minute. Deb et al. (2015) also observed that the setting time and workability of the binder reduced significantly, when the GGBS content was increased in the geopolymer binder, which was in agreement with other studies (Lee, 2013, Chithiraputhiran and Neithalath, 2013, Perná and Hanzlíček, 2016).

This shows that slag reduces the setting of geopolymer binder, but due to the effect of slag on the mechanical properties, slag alone is not adequate to control the setting characteristics of geopolymer.

2.5.2 Properties of harden geopolymer binders

Compressive strength of geopolymer concrete engineering properties of geopolymers vary according to factors including source materials, alkali activator type and alkali activator content, curing parameters, water content and mixing parameters. Research has indicated that, geopolymer concrete can have comparable mechanical properties to those achieved by OPC binders. Diaz and Allouche (2010) used a variety of class F and class C fly ashes to prepare geopolymer concrete. Their results showed that class C fly ash based geopolymers achieved compressive strengths in the range 50-80 MPa while the compressive strength achieved by class F fly ash based geopolymer was 45-50 MPa, except one group of class F fly ash which has lower than 20 MPa strength. Hardjito et al. (2004c) reported that 100% Australian class F fly ash based geopolymer concrete can have a compressive strength similar or slightly higher than that of OPC concrete. Sofi et al. (2007) prepared geopolymer concrete using four types of Australian class F fly ashes and slag which achieved compressive strengths around 45-60 MPa. Geopolymers with higher alkali content, higher curing temperature and low water content can result high strength concrete 80 MPa or more.

The maximum compressive strength of geopolymer binders is achieved when samples are cured at elevated temperature (Khale and Chaudhary, 2007). Some previously research has reported that the compressive strength of geopolymer concrete containing calcium rich source materials cured at ambient temperature is comparable with elevated temperature cured fly ash geopolymer. Ismail et al. (2013) showed that addition of slag into geopolymer mix enhanced mechanical strength significantly at ambient temperature. There geopolymer concretes prepared with fly ash/slag blends gained 45 MPa in 28 day while reaching 65 MPa in 90 day. These results are in agreement with the work done by (Guerrieri and Sanjayan, 2010a). Deb et al. (2015) reported a 28-day compressive strength of around 51 MPa for geopolymer systems with 80/20 fly ash/slag at ambient curing temperature.

The above experiments were only conducted for geopolymer concrete specimens that are less than one-year-old. Flexural strength of concrete is an important parameter to evaluate which relate the behavior of structures under service load. The flexure strength of geopolymer concrete specimens with a higher compressive strength varied in the range 4-6 MPa.

Sofi et al. (2007) reported that the flexural capacity of geopolymer concrete is higher than ordinary portland concrete. Geopolymer concrete, prepared by Diaz and Allouche (2010) showed flexural strengths around 10.5% of compressive strength which is slightly higher than that of ordinary portland concrete.

2.6 Resistance to high temperatures and to fire

A weak performance is shown by concretes formed using Portland cement when they undergo thermal action and when the temperature exceeds 300ºC, they start decomposing. However, high stability is demonstrated by alkali-activated binders when they are subjected to high temperatures, up to 1000ºC .The activation of metakaolin and shale wastes was examined by other authors which showed a high mechanical efficiency following a thermal Period (Pacheco, 2014).

When the temperature is between 60 to 100ºC, a slight decrease in strength is shown by the samples. However, for specific samples, there is an increase in strength at 120 ºC. Alkali-activated metakaolin binders were examined by Kong et al. (2010) who noticed that the Si/Al ratio affects the residual strength following a thermal action of up to 80ºC. When the Si/Al ratio of the mixtures was between 1.5 and 1.7 greater residual strength was abtained.

It was shown by Shi and Krivenko (2003) that the alkali stimulated binders are highly resistant to fires which implies that this material can be used in applications involving a high risk of fire, such as tunnels and tall buildings. It was stated by Perná and Hanzlíček (2014) in this regard that alkali-activated stimulated binders may be used as a 120 minute anti-fire material, consistent with the relevant standards of the czech republic, a temperature of less than 120ºC should be shown by the anti-fire material on the other side of the fire action (Temuujin et al., 2011).

2.7 Factors affecting geopolymer reaction

2.7.1 Alkali activators

Mixtures of sodium hydroxide and sodium silicate or potassium haydroxide and potassium silicates, in liquid form, are the commonly used activator in geopolymer system that leads to improved properties (Lee and van, 2007). Since potassium haydroxide is more expensive than sodium hydroxide, most studies have been done using a mixture of Na_2SiO_3 and sodium hydroxide as the activator solution. Chindaprasirt et al. (2007) showed that the ratio between sodium silicate and sodium hydroxide has to be in the range 0.6-1.0 to get high mechanical properties in the resulting geopolymer binder. Davidovits et al. (1998) showed that when the sodium hydroxide concentration in the activator is below 5M the effect from the silicate is higher. Álvarez et al. (2008) showed that when the sodium hydroxide concentration is higher, geopolymerisation can be achieved even without soluble silicate. Hardjito et al. (2005) proposed 0.22, where molarity is alkali ions can reduce the reactivity of the alkali activated mixes as the concentration of cyclic silicate species can inhibit the further condensation of aluminium ions. Currently, common practice in geopolymer concrete research involves preparation of the activating solution by combining appropriate amounts of the two components. Sodium hydroxide and sodium silicate and allowing them to homogenize for 24 hour prior to being used for mixing of geopolymer concrete. It is argued that using dry powders and adding water does not allow for gepolymerisation reaction and the strength results may not be high as liquid based systems. However, use of geopolymer concrete for field application requires user friendly practices, and incorporation of solid activator rather than premixed solutions would be advantageous.

Ismail et al. (2013) used solid alkali activators in their research work, but the activator was first dissolved before adding into fly ash and slag blend Guerrieri et al. (2010b), also used solid sodium metasilicate activator in their work. Again, the authors first made an alkali solution and did not add into the geopolymer mix in solid form. Geopolymer concrete production using only solid source materials including alkali activator would create a pathway towards producing large scale geopolymer concrete mixes without much practical difficulty.

2.7.2 Water content in the geopolymer

Fang and Kayali (2013) stated that approximately 10.74% of added water in a geopolymer system is non-evaporable even at higher temperatures 105°C. Zuhua et al. (2009) found that this non-evaporable water content does not create any drying shrinkage, but it helps to maintain the long term strength. Also reported that water acts as a reactant in geopolymer reaction. Moreover, they identified the role of water in the three stages of geopolymerisation where in the 1st stage high water based environment facilitate transferring of ions, the 2nd stage requires water for hydrolysis and 3rd stage releases water due to poly-condensation.

The results are in line with (Weng and Sagoe, 2007). Panias et al. (2007) showed when the solid to liquid ratio in the binder is increased higher than 2.05 g/ml compressive strength of the binder starts to decrease. The authors also found that when the water content of the binder is very low, the compressive strength of geopolymer can be low due to casting defects pouring difficulty due to low workability (Bhattacharjee and Laskar, 2011). Diaz and Allouche (2010) showed that high alkaline liquid weakens the geopolymer binders due to high porous structure in the harden concrete.

2.7.3 Curing regimes

Sindhunata et al. (2006) reported that elevated temperature curing 30-75°C helps to expand total pore volume and surface area which accelerates the dissolution of precursor. They also observed that at lower temperature below 30°C, the binder is formed by precipitation of dissolved species instead of poly-condensation of silicate and aluminate. Kovalchuk et al. (2007) reported that curing in covered moulds is more beneficial for strength development than dry curing and steam curing.

Covered moulds stop water evaporation from geopolymer providing a water media to exchange silicon and aluminium ions within the synthesis. In the above study the specimen cured in sealed bags, achieved maximum strength of 102.1 MPa while, the dry cured specimen and steam cured specimen recorded 31.8 and 71 MPa respectively. Previous research has indicated several curing regimes for geopolymer. Perera et al. (2007) reported that curing temperature should be maintained in between at 40-60^{o}C temperature value to avoid cracks.

In addition Swanepoel and Strydom (2002) found that the combination of 60^oC temperature and 48 hour curing time gives the optimum strength for the binder. Memon et al. (2011) disclosed that samples cured at 70°C temperature have the maximum strength and stated that longer curing more than 48 hour is not beneficial to geopolymer. Thakur and Ghosh (2009) stated that maximum strength is obtained when their geopolymer samples were cured at 85°C for 48 hour. Yunfen et al. (2009) reported the effective curing temperature as 65^{o}C. Bakharev (2005a) found that fly ash-based geopolymers benefit significantly from pre-curing storage at 23°C before heat curing at 75-95°C. A rest period of 24 hour increased the strength equivalent to one month of continuous curing at elevated temperature. Even though, heat curing is essential for setting of pure alumina-silicate based geopolymer class F fly ash or metakaolin, calcium rich alumina-silicate source materials can be cured at room temperature ambient curing.

Ismail et al. (2013) researched on ambient cured class F fly ash and slag blended geopolymer concrete. The concrete samples show significantly higher compressive strength 65 MPa compared to ordinary portland concrete 60 MPa in 90 day. Anuar et al. (2011) also showed that ambient cured geopolymer concrete specimens have lower permeability. Nath and Sarker (2015) blended class F fly ash and ordinary portland concrete to achieve ambient cured geopolymer concrete. The authors reported that the concrete shows 40-45 MPa compressive strength after 28 day. Gao and Brouwers (2015) showed that the compressive strength of geopolymer cured at room temperature increases with the slag content in the mix. Reaction mechanisms of fly ash and slag blended geopolymer systems are discussed in chapter 4, chapter 5 and chapter 6.

2.8 Density of geopolymer concrete

The density of the geopolymer concrete is the measure of its unit weight, which includes certain aspects like entrained air, water-cement ratio and the amount and density of the aggregate. Concrete density allows us to understand the compression of the concrete with respect to an aggregate. Various researchers have discovered different densities for normal and lightweight concrete, which ranges from 1750–2400 kg/m^3, 2403–2439 kg/m^3 by Washington State Department of Transportation; Portland Cement Association reported 2320 kg/m^3 while McGuire-Hill

Encyclopaedia of Science and Technology found it to be 2400 kg/m^3 (McGuire et al., 2011). Put a variety of samples of fly ash based, geopolymer concrete to test. He examined several samples to acquire their density and compressive strength according to surrounding conditions and under special circumstances by heat-curing those for 24 hour at 60^{o}C. His discoveries concluded the densities to be equivalent to the standard concrete density, within the range of 2251 to 2400 kg/m^3. He also concluded that the age of the geopolymer and its density were directly proportional. The density of ordinary portland concrete is approximately the same as the density of the fly ash based geopolymer concrete. McGuire et al. (2011) examined geopolymer concrete samples which differed on the basis of aggregate and grading. They found that heat curing the mixtures at 60^{o}C for 24 hour resulted in a density of 2360 ±60 kg/m^3 for 28 day. Olivia and Nikraz (2012) tested low calcium fly ash geopolymer concrete and reported the densities in the range of 2248 to 2315 Kg/m^3. Hardjito and Rangan (2005a) found that the low calcium fly ash based geopolymer concrete had a unit mass ranging between 2330 and 2430 kg/m^3.

2.9 Factors affecting of compressive strength

Various parameters were identified that have an impact on the properties of geopolymers. According to Palomo et al. (1999b), curing time, curing temperature and the kind of alkaline liquid had a significant impact on the attributes of fly ash-based geopolymer concrete.

Longer curing time and high curing temperature led to higher compressive strength. In addition, alkaline liquids are composed of soluble silicates, and this increased the rate of reaction as compared to those alkaline solutions which are composed of hydroxide alone. In general, it is vital to undergo suitable curing so that advanced mechanical and durable performance can be attained. Furthermore, setting time is also critical as it describes the time that is required for placing, transporting and packing (Teixeira et al., 2002).

The concentration of sodium hydroxide as determined by Molarity second column Mixture A-3 with a higher concentration of NaOH produced greater compressive strength compared to Mixture A-1. Mixtures A-2 and A-4 show a similar trend Table 2.1.

Table 2.1 parameters on compressive strength (Hardjito et al., 2004)

Mixture	Concentration of NaOH Liquid Molarity (M)	Na_2SiO_3 / NaOH Liquid ratio by mass	7- Day compressive strength (Mpa)
A-1	8	0.4	17.3
A-2	8	2.5	56.8
A-3	14	0.4	47.9
A-4	14	2.5	67.6

Various authors use values of compressive strength to determine the effectiveness of geopolymerization because of the low cost and ease of compressive strength testing, in addition to the fact that strength development is the main method of determining the utility of materials present in various applications of the construction industry (Hajimohammadi et al., 2011).

Various factors determine the compressive strength of geopolymer, including the gel phase strength, the spread and the hardness of the undissolved aluminium and silicon particle sizes, the ratio of the gel phase/undissolved aluminium and silicon particles, the surface reaction between the gel phase and the undissolved aluminium and silicon particles and the amorphous nature of geopolymer or the degree of crystallinity. In addition, other factors like Calcium oxide, potassium oxide and the types of alkali have a significant relationship with compressive strength. It is suggested by the significance of the molar silicon to aluminium ratio during the alkaline dissolution of the separate minerals that compressive strength is attained following intricate reactions between the mineral surface, kaolinite and the concentrated sodium silicate solution. The undissolved particles stay bonded in the matrix following geopolymerization; therefore, there is a positive relationship between the hardness of the minerals and the final compressive strength (Xu and Van, 2000 to 2003).When natural minerals are being geopolymerized, after the addition of aggregate, such as granular sand, to the geopolymer mixture; an increase in compressive strength is observed (Xie et al., 2009). Certain researchers have examined the impact of curing temperature and time on the bending attributes of geopolymer focused on class C fly ash (Oh et al., 2010). It is suggested by the impact of curing time on the compressive strength that a more extended time period did not create weaker material, as was suggested by the authors (Van et al., 2002). Nonetheless, when curing periods exceed 48 hour, the increase in strength is insignificant (Figure 2.3).

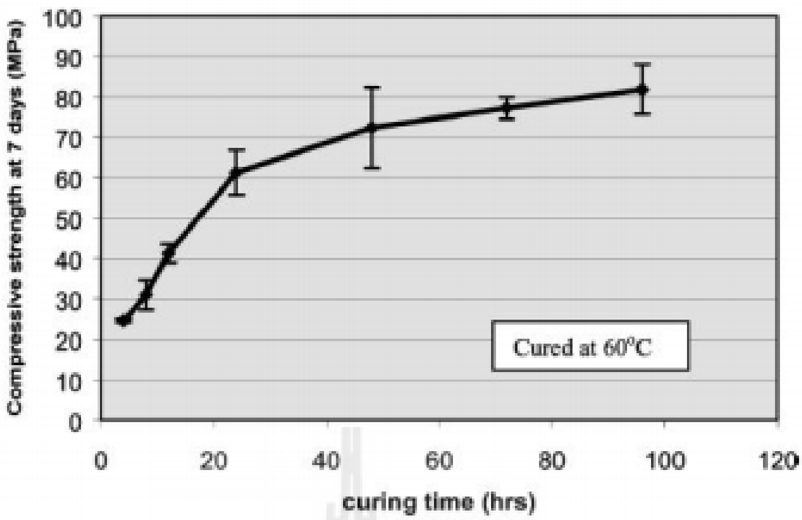


Figure 2.3 Influence of curing time on compressive strength (Hardjito et al., 2004)

It was shown by other authors Naik et al. (1994) that when curing is carried out for more significant time periods at high temperatures, the structure becomes weaker, which means that some extent of structural water should be maintained so that cracking can be prevented, and structural reliability can be maintained.

When there is extended curing at higher temperatures, the cellular structure of the geopolymer synthesis mixture decomposes, causing lack of water and great contraction, whereas lengthy procuring at room temperature is suitable for increasing strength when fly ash is used as the raw material (Bakharev, 2005b). In addition, according to Van et al. (2002) when curing initially takes place at high temperatures more than 50–80°C, compressive strength does not increase significantly over that which is obtained when curing takes place at room temperature see Table 2.2.

Table 2.2 The effect of curing conditions on the compressive strength of a matrix containing Macquarie fly ash with compositional variables: clay "kaolinite" content = 15% mass (Van et al., 2002)

Time	**Temperature (^oC)**					
	30	**50**	**70**	**30 B**	**50 B**	**70 B**
6	6	……	14	30	…..	28
12	15	26	34	7	22	21
24	20	12	33	19	24	29
48	19	……	28	21	……	15
Average (12/24 h Sample)	17	19	34	13	23	25

It was elaborated another investigation by van Jaarsveld et al. (2003) then it was specified that the characteristics of geopolymers had taken from the substance source, specifically, the ratio of water-to-fly ash as well as the content of calcium oxide.

It was concluded by Barbosa et al. (2000) information of geopolymers that the significance of parameters is the content of water as well as the molar composition. They illustrated that the amorphous microstructures were a characteristic of geopolymers hardened and bulk densities were approximately 1.3 to 1.9.

A comprehensive experiment was done by Xu and van (2000) upon natural soil geopolymers and it was listed the elements that influenced the entire strength of materials, for example, the silicon to aluminum molar ratio of the source material, the silicon to aluminium molar ratio in solution, alkali liquid, the calcium oxide and Potassium oxide content and the extent of dissolution of silicon.

2.10 Description of materials

2.10.1 Source materials

Various topics pertaining to industrial by-product materials and an extensive variety of minerals are examined by the researchers, the objective of which is to find out those materials that are most appropriate for producing geopolymers. The key factors in choosing the source materials include the demands of users and cost. Those source materials are appropriate that have natural minerals, for example, clays and metakaolin, and which are made up of oxygen silicon and aluminium (Cantarel et al., 2017). As compared to those materials that are non-calcined, for example, metakaolin clays, calcined materials like fly ash and slag showed higher compressive strength. However, to achieve high compressive strength and to decrease the reaction time, calcined and non-calcined materials can be used in combination. Natural Al-Si minerals were found to be very suitable as source materials in geopolymers. However, with respect to a quantitative suitable of a particular mineral, there have been limited studies that examine the source material due to the intricate reaction methods involved (van et al., 2000).

Metakaolin-based geopolymers were preferred for developing geopolymers because it produces greater rates of polymerisation, the regulated Si/Al and the white colour ratio; however, its by-products are cheaper (Gourley, 2003). The by-products of various industries, for example, fly ash, rice-husk ash red mud, slag, silica fume can serve as source materials (Wallah and Rangan, 2006).

2.10.2 Admixture

A superplasticiser was used after being accumulated from BASF Chemicals'. It was named as 'Rheobuild 1000'. It comprised of naphthalene sulphonic acid-based high range water, decreasing admixture, with a specific gravity of 1.2 and the solid content of 40%. The superplasticiser confirms to the Reddy et al. (2012) in the form of Class A and F admixture. An important part is played by superplasticiser in increasing the workability of ordinary portland concrete. However, it is added to geopolymer concrete mixtures where it may not function in the same way as it works in the ordinary portland concrete. It has still been used in earlier studies on heat cured geopolymer concrete without creating too many issues (Hardjito and Rangan, 2005).

Superplasticizers can be utilised alongside concrete in particular ratios and methods to achieve structures of super strength. When the slump range of the concrete is 175-225 mm, and the required amalgamation of concrete is challenging to achieve with vibrations, superplasticisers can be added to a water-cement ratio of 0.3 - 0.4 and the concrete fluid is proliferated (Lizcano et al., 2012).

The addition of superplasticisers enhances the workability of the concrete, and its addition can be administered according to the requirements.The slump range can be modified by employing super plasticisers together with concrete, by monitoring the time and quantity of the dosage, as well as the water-cement ratio and the quantity of cement.

2.11 Disadvantages of geopolymers

Numerous points of interest were said above; still, geopolymer concrete has not been effectively advertised as an advanced and supportable cover. Indeed the fundamental reason is that extensive concrete organisations are against the change from what they are proficient into what they need to realise and think that it's hazardous. From the development businesses perspective, 'green concrete' presently can't seem to set up itself as a practical, perceived or demonstrated innovation (Duxson et al., 2007).

However, no correct assessment of the price of fabricating geopolymer concrete has been accounted for. Hardjito and Rangan (2005) evaluated that low-calcium fly powder based geopolymer concrete is less expensive than ordinary cement; while Pacheco et al. (2007) stated that the 'green concrete' cost is about 62% more expensive than Portland cement. Accurate esteems for the expense of the produce of geopolymers did not exist. Monetary specialists will not spend their cash where they have no clue about the undertaking capital return. Other boundary for advertising geopolymers is that determinations have been given as satisfactory standard and these gauges cover bond-based items. Subsequently, the absence of gauges and determinations for geopolymers must be considered as a noteworthy hindrance for mass use of them (Rajesh and Mammen, 2014).

It is legitimate to say that the fabricating procedure of geopolymers is extremely perplexing for the overall population who know minimal about this innovation and need to know either this new 'green cement' is protected and sufficiently stable to trust or not. Since the 1950's, Geopolymers have been available in the Soviet Union where Professor Glukhovsky initially found geopolymers. Indeed, they utilised just slag rather than fly fiery remains to develop the more significant part of structures in ukraine back, which are yet adjusting, with no vast indications of weakening.

The creator assesses that sooner rather than later the worldwide natural guidelines concerning CO_2 preparations will force the ordinary portland concrete organisations to be changed in accordance with more feasible gauges and with no uncertainty one of the appropriate responses might be geopolymer items (Najmabadi, 2012).

They announced that many-sided quality in the system of assembling geopolymer fastener is the primary hindrance against their large-scale manufacturing. What's more, the absence of a standard and lack of talented works have stopped the first experience with the market.

CHAPTER 3

MATERIALS AND METHODS

3.1 Introduction

This part exhibits the subtle elements of advancement of the way toward making fly ash based geopolymer concrete. In 2018, no learning and knowing the way of making of fly slag based geopolymer concrete were accessible in the distributed writing. Because of this absence of data, the investigation started in view of restricted accessible writing on geopolymer glues and mortars.

The distributed papers on geopolymers accessible for the most part detailed the utilisation of metakaolin or calcined kaolin as the source material for geopolymer glue. Besides, the data available was a piece of the patent writing or financially situated research, and numerous points of interest were kept undisclosed. In spite of the fact that geopolymer cement can be made utilising different source materials, the present investigation employed just low calcium ASTM Class F fly cinder (Hardjito and Rangan, 2005a).

Likewise, as on account of ordinary portland concrete, the totals possess 70-85 % of the aggregate mass of cement. With a specific end goal to limit the impact of the properties of the totals on the properties of fly slag based geopolymer, the examination utilised totals from more than one source.

Constrained understanding on fly cinder based geopolymer concrete with no ordinary portland concrete forced a few previous test attempts to acclimate to the blend extents and system of setting up the examples. As indicated by literary works, usage of sodium silicate answers for the sodium hydroxide arrangement as the primary fluid improved the response between the source material and the arrangement (Hardjito et al., 2005b).

Along these lines, beginning blend plans for the creation of geopolymer solid utilising sodium hydroxide and sodium silicate to shape the basic arrangement were readied. Notwithstanding, the cost of potassium based arrangement was another factor that impacts the basic leadership of utilising antacid fluid. An experimental procedure was utilised for calibrating the quality of the blends, including the distinctive base fiery debris substance. In this undertaking, the compressive attributes were the fundamental parts of the examination. To acquaint with the transient quality improvement of fiery fly remains based geopolymer solid, tests were directed at 3, 7, 28, 56 and 90 days in the wake of throwing. Strategies and guidelines for assembling and testing of ordinary portland concrete were followed in the creation of geopolymer concrete (Hlavacek, 2014).

In the interim, it could help with a pertinent examination between the two items. Totals extent as a crucial factor in properties of cement was settled at 70-85 % by weight inside the blend and its size, dampness substance, shape and fineness modulus were watched precisely keeping in mind the end goal to research the impact of substitution of base powder, and the totals were utilised just from one source. Their folios accomplished compressive qualities of 18 to 46 MPa in 7 day showing potential for utilisation of this material in geopolymer frameworks (Hardjito and Rangan, 2005a).

In any case, geopolymer fasteners in the past investigation were delivered utilising high basic frameworks with molarity 8, 10, 12, 14 and 16 and high curing temperatures 70°C, speaking of preparing conditions well beyond general cementing practice (Kong and Sanjayan, 2010).

3.2 Materials preparation

It has been found that blend extent is the most essential aspect of geopolymer solid properties and quality. This meant that more attention needs to be given to the way the constituents of geopolymer are arranged instead of any other factor.

The materials used for a research facility established for the production of geopolymer concrete are shown in Figure 3.1. The ways the key constituents of the geopolymer are prepared in the experimental study are then explained. So after finshed all casting, all cubes putting in the inside of laboratory see Figure 3.2.

Figure 3.1 Materials for geopolymer concrete

Figure 3.2 After casting geopolymer concrete cubes

3.2.1 Ordinary portland cement

To create the control blend concrete, ASTM Type 1 Portland cement was used. Table 3.1 presents the substance piece and physical properties of this material, as described by the provider.

Table 3.1 Physical characteristics and chemical composition of cement.

Chemical requirements		Result	Acc. Iraq stands. 5/2016
Lime saturation factor (L.S.F)		0.96	0.66-1.02
Sluphate Tri-Oxide (SO3)		2.3	2.8 Max. %
Magnesium Oxide (MgO)		1.88	5.0 Max. %
Loss on ignition (L.O.I)		3.04	4.0 Max. %
Insoluble Residue (Ins. Res.)		0.74	1.5 Max. %
Physical Requirements		Result	Acc. Iraq Stand 5/2016
Compressive strength (MPa)	3 Day	30.1	Not less than 15
	7 Day	36.1	Not less than 23
	28 Day	47.7	Not specified
Initial Set. Time , minute		120	Not less than 45
Final Set, Time, Hour		02.38	Not less than 10
Expansion (Le-Chatelie), mm		0.6	Not less than 10
Blaine cm^2/g		3393	Not less than 2300

3.2.2 Super plasticizer

Another age superplasticizer of polycarboxilate-based write F was utilized to accomplish the enough workability indicated in ASTM C 494 (2016). Figure 3.3 Table 3.2 gives the properties of the superplasticizer.

Table 3.2 Properties of super plasticizer

Properties	Superplasticizer
Name	Glenium 51
Color tone	Dark brown
State	Liquid
Specific gravity at 20°C	1.08 ± 0.02 gm/cm3
Chemical description	Modified polycarboxylic type plymer
Recommended dosage	%1-2 (% binder content)
Alkali content (%)	≤ 1
Chloride content (%)	≤ 0.1

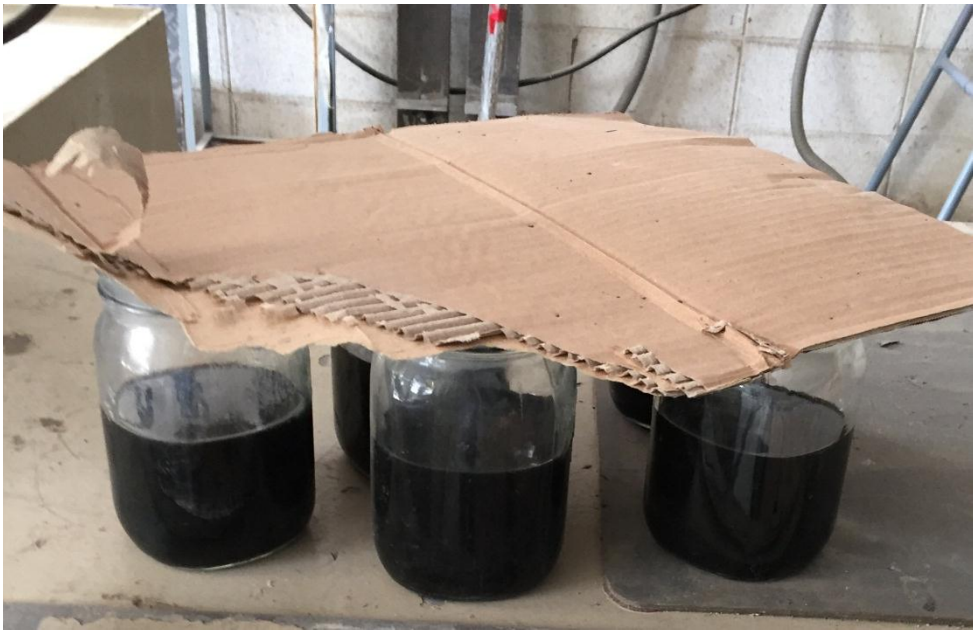


Figure 3.3 Super plasticizer befor using in mixture

3.2.3 Fly ash

Low-calcium dry fly powder ASTM Class F obtained from a Power Station was used for this purpose as understood from ASTM Committee C-09, ASTM C618 Class F, and the ACI panel 226 report given. The Rinker / Cemex Corporation obtained this fly fiery debris, delicate to class F as a powder varying from light to dark shade, based on the unburned fuel and iron oxide substance (Hardjito et al., 2005b).

To assess the substance, sieving of the fly fiery debris took place to estimate molecules less than 75µm, after which they were handed over to the Allied physicists' research facility. Table 3.3 explains the substance configuration and the physical qualities of this material, as provided by the supplier.

Table 3.3 Properties of fly ash

Property	Information (%)
Calcium Oxid (CaO)	2.2
Silicon Dioxide (SiO_2)	57.2
Aluminum Oxide (Al_2O_3)	24.4
Ferric Oxide (Fe_2O_3)	7.2
Magnesium Oxide (MgO)	2.46
Density (g/cm^3)	2.2
Potassium Oxide (K_2O)	3.48
Sodium Oxide (Na_2O)	0.43
Loss of ignition	1.5
Specific Gravity	2.14
surface (m^2/Kg)	379

3.2.4 Aggregates

Sand and rock are normally added to ordinary portland concrete and other clinker-based covers. These augmentations permit lessening the cost, the shrinkage, and the water content and expanding the ice protection of the material, see Table 3.4 for properties sand aggregate and see Table 3.5 grading limit of fine aggregate.

Table 3.4 Properties of sand aggregate size

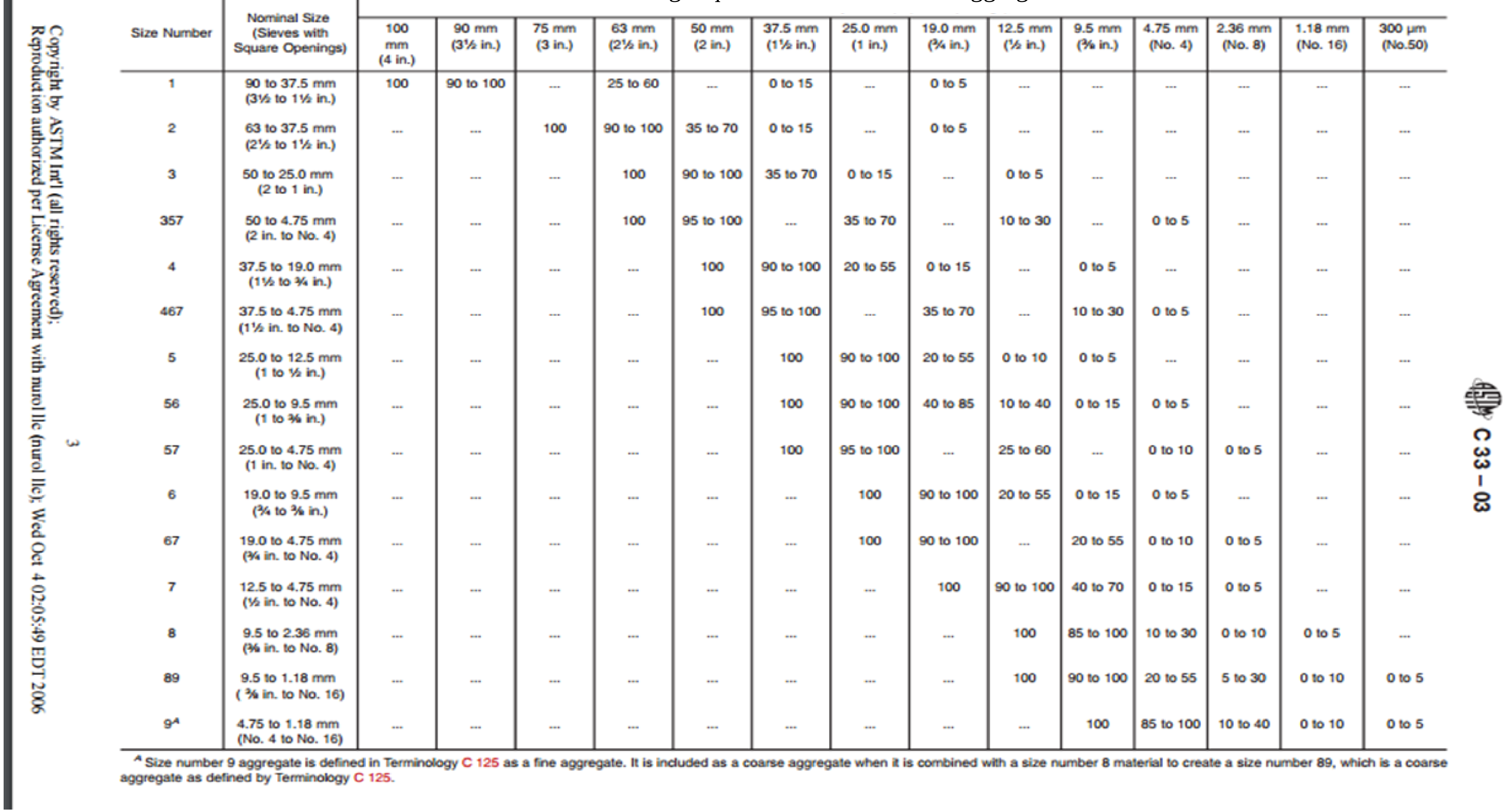
Sand		
Property	**Units**	**Average value**
Apparent Specific gravity	Dimensionless	2.72
Bulk Specific gravity at (dry)	Dimensionless	2.65
Bulk Specific gravity at (SSD)	Dimensionless	2.66
Water absorption	%	0.9
Fineness modulus	Dimensionless	3.2
Sieve analysis (grading)	Dimensionless	Cu = 9 , Cc=0.35
Bulk density of combined (Coarse & Fine) experimentally measured	kg/m^3	2.087

Table 3.5 Grading limit of fine aggregate

Sieve size (mm)	**Percentage passing for**			
	Zone 1	**Zone 2**	**Zone 3**	**Zone 4**
10	100	100	100	100
4.75	90 - 100	90 - 100	90 - 100	95 - 100
2.36	60 - 95	75 - 100	85 - 100	95 - 100
1.18	30 - 70	55 - 90	75 - 100	90 - 100
0.6	15 - 34	35 - 59	60 - 79	80 - 100
0.3	5 - 20	8 - 30	12 - 40	15 - 50
0.15	0 - 10	0 - 10	0 - 10	0 - 15

It ought to be noticed that the decision of this most extreme size of the total was likewise managed by the aftereffects of the preparatory research center work directed and revealed underneath, tending to the total size impact on the crack sturdiness, and the workability of the concrete. For this we utilized ASTM (C33-03) to grading requirements for coarse aggregates, for Properties of gravel see (Table 3.6 and 3.7).

Table 3.6 Grading requirements for concrete aggregate



Size Number	Nominal Size (Sieves with Square Openings)	100 mm (4 in.)	90 mm (3½ in.)	75 mm (3 in.)	63 mm (2½ in.)	50 mm (2 in.)	37.5 mm (1½ in.)	25.0 mm (1 in.)	19.0 mm (¾ in.)	12.5 mm (½ in.)	9.5 mm (⅜ in.)	4.75 mm (No. 4)	2.36 mm (No. 8)	1.18 mm (No. 16)	300 µm (No.50)
1	90 to 37.5 mm (3½ to 1½ in.)	100	90 to 100	...	25 to 60	...	0 to 15	...	0 to 5	...	...	...	...	...	...
2	63 to 37.5 mm (2½ to 1½ in.)	...	...	100	90 to 100	35 to 70	0 to 15	...	0 to 5	...	...	...	...	...	...
3	50 to 25.0 mm (2 to 1 in.)	...	...	...	100	90 to 100	35 to 70	0 to 15	...	0 to 5	...	...	...	...	...
357	50 to 4.75 mm (2 in. to No. 4)	...	...	...	100	95 to 100	...	35 to 70	...	10 to 30	...	0 to 5	...	...	...
4	37.5 to 19.0 mm (1½ to ¾ in.)	...	...	...	...	100	90 to 100	20 to 55	0 to 15	...	0 to 5	...	...	...	...
467	37.5 to 4.75 mm (1½ in. to No. 4)	...	...	...	...	100	95 to 100	...	35 to 70	...	10 to 30	0 to 5	...	...	...
5	25.0 to 12.5 mm (1 to ½ in.)	...	...	...	...	...	100	90 to 100	20 to 55	0 to 10	0 to 5	...	...	...	...
56	25.0 to 9.5 mm (1 to ⅜ in.)	...	...	...	...	...	100	90 to 100	40 to 85	10 to 40	0 to 15	0 to 5	...	...	...
57	25.0 to 4.75 mm (1 in. to No. 4)	...	...	...	...	...	100	95 to 100	...	25 to 60	...	0 to 10	0 to 5	...	...
6	19.0 to 9.5 mm (¾ to ⅜ in.)	...	...	...	...	...	...	100	90 to 100	20 to 55	0 to 15	0 to 5	...	...	...
67	19.0 to 4.75 mm (¾ in. to No. 4)	...	...	...	...	...	...	100	90 to 100	...	20 to 55	0 to 10	0 to 5	...	...
7	12.5 to 4.75 mm (½ in. to No. 4)	...	...	...	...	...	...	...	100	90 to 100	40 to 70	0 to 15	0 to 5	...	...
8	9.5 to 2.36 mm (⅜ in. to No. 8)	...	...	...	...	...	...	...	...	100	85 to 100	10 to 30	0 to 10	0 to 5	...
89	9.5 to 1.18 mm (⅜ in. to No. 16)	...	...	...	...	...	...	...	...	100	90 to 100	20 to 55	5 to 30	0 to 10	0 to 5
9[A]	4.75 to 1.18 mm (No. 4 to No. 16)	...	...	...	...	...	...	...	...	...	100	85 to 100	10 to 40	0 to 10	0 to 5

[A] Size number 9 aggregate is defined in Terminology C 125 as a fine aggregate. It is included as a coarse aggregate when it is combined with a size number 8 material to create a size number 89, which is a coarse aggregate as defined by Terminology C 125.

For the totals regular kalak river sand and rock were utilized. The molecule estimate conveyances and physical properties of the totals are introduced in Table 3.7 and Figure 3.4.

Figure 3.4 Sieve analyses (grading)

Table 3.7 Properties of gravel

Gravel		
Property	**Units**	**Average value**
Apparent	Dimensionless	2.72
Specific gravity (dry)	Dimensionless	2.71
Specific gravity (SSD)	Dimensionless	2.70
Rodded unit weight	kg/m^3	1733.42
Maximum size	mm	25.4
Water absorption	%	0.35
Fineness modulus	Dimensionless	5.29
Shape (roundness)	Dimensionless	Well rounded (0.7)
Shape (sphericity)	Dimensionless	Medium sphericity (0.5-0.70)
Sieve analysis (grading)	Dimensionless	Cu = 1.38, Cc=1.09
Bulk density of combined (Coarse & Fine) experimentally measured	kg/m^3	2.087

3.2.5 Alkali activators

The fly Ash was created after choosing a mix of sodium hydroxide arrangement and the sodium silicate arrangement as the soluble activator. The purpose of choosing sodium-based activators was that they were less costly as compared to Potassium-based activators. Either a specialised review sodium hydroxide in drop shape 3 mm was used, having a specific gravity of 2.130 with 98% virtue, and obtained from Sigma-Aldrich Pty Ltd, Australia, or a business review in the pellets framed having 97% immaculateness and obtained from Lomb Scientific, Australia.

3.2.5.1 Sodium hydroxide

To obtain the sodium hydroxide arrangement, either the drops or the tablets were immersed in water, as shown in Figure 3.5. The concentrations of Sodium hydroxide bonds per mole resolve the mass of the solids in the solution. As is evident in Table 3.8, the mass of Sodium hydroxide, 8M aqueous solution in chips or pellet frame, where the sub-atomic weight of Sodium hydroxide is 40gms, is calculated as 8x40 = 320 grams per litre of the arran garment.

Table 3.8 Properties of sodium hydroxide

Property	**Information**
Chemical formula	$NaOH$
Molecular weight	40 (g/mol)
Appearance (solid)	White
Density	2.13 (g/cm^3)
Freezing point	14^{o}C
Boiling point	1390^{o}C
ph	13 - 14
Melting point	318^{o}C
Specific gravity (20^{o}C)	1.52

For every kg of the 8 M solution of Sodium hydroxide bonds, the mass of Sodium hydroxide solids was assessed to be approximately 262 grams. Therefore, it was estimated that the mass of Sodium hydroxide solids for each kg for various fixations was 10 M: 314 grams, 12 M: 361 grams, 14 M: 404 grams, and 16 M: 444 grams.It could be observed that the mass of Sodium hydroxide solids was a small portion of the mass of Sodium hydroxide arrangement, where water formed most of the part refer to (Table 3.9).

Table 3.9 Characteristics of molarity solution

Molarity	**8**	**10**	**12**	**14**	**16**
(NaOH) %	26.2	31.4	36.1	40.4	44.4
Water %	73.8	68.6	63.9	59.6	55.6

Figure 3.5 Shape and type of sodium hydroxide

3.2.5.2 Sodium silicate

The sodium silicate arrangement is economically accessible in various evaluations. Alternate qualities of the sodium silicate arrangement see Table 3.10.

Table 3.10 Characteristics of the sodium silicate solution

Property	**Information**
(SiO_2 / Na_2O) ratio	2
Na_2O	14.7
SiO_2	29.4
Total solid	44.05
Water content	55.9
Water insoluble	0.05
density (g/cm^3)	2.4
Baume	50
Specific gravity at (20°C)	1.54
Color and appearance	Clear white liquid
PH	12.7

3.3 Preliminary works

Among the geopolymers, it is known that the holding or clasping attribute is the main difference between cement and Portland bond concrete. In the low-calcium fly fiery, the silicon and aluminium oxide stay with the antacid fluid to form the geopolymer glue that attaches the free coarse totals, fine totals and other substances to one another to frame the geopolymer concrete.

In the Portland bond concrete, the coarse and fine totals comprise of around 75 to 85 % of the mass of the geopolymer concrete. This part of the geopolymer solid blends can be explained with the help of the devices that are currently available for Portland bond concrete. The geopolymer concrete that has the workability and also the compressive quality is affected by the amount and the features of the materials that are made up of the geopolymer glue (Hardjito et al., 2005b).

The following were key points observed in the test:

- Greater fixation as far as molar of sodium hydroxide constitution increases the compressive quality of geopolymer concrete.
- When the relative quantity of sodium silicate configuration for sodium hydroxide configuration is higher by mass, then the compressive quality of geopolymer concrete is higher.
- When naphthalene sulphonate-based superplasticiser is increased to almost 2% of fly fiery debris by mass, the workability of the new geopolymer concrete increases. However, when the superplasticiser measurements become higher than 2%, then there is a minor degradation in the compressive quality of solidified solid.
- When the water substance of the blend increases, there is also an increase in the drop evaluation of the inflexible geopolymer solid.
- An increase in the H_2O-to-Na_2O molar proportion causes a decrease in the compressive quality of geopolymer solid.

It can be observed that it is not easy to predict the way distinct factors collaborate to create the compressive strength and workability of geopolymer concrete. As the objective is to determine the structure of low-calcium fly fiery remains based geopolymer solid blends, a single parameter is known as 'water-to-geopolymer solids proportion by mass was developed.

In this parameter, the total mass of water refers to the mass of water included in the sodium silicate configuration, the mass of water that is used to create the sodium hydroxide configuration and the mass of any other water that may be present in the blend. The mass of geopolymer solids is obtained by adding the mass of fly fiery debris, the mass of sodium hydroxide solids used to develop the sodium hydroxide configuration as well as the mass of the solids in the sodium silicate configuration mass of Na_2O and SiO_2 respectively (Hardjito et al., 2005b).

To determine the effect of water-to-geopolymer solids ratio by mass on the compressive quality and workability of geopolymer concretes, different tests were carried out. The test samples included 3D shapes of measurements 150*150*150 mm which were heated in a stove at various temperatures for 0 – 120 hours. The test results showed that there is a decrease in the compressive quality of geopolymer solid with an increase in the water-to-geopolymer solids proportion by mass (Hardjito and Rangan, 2005a).

The test results are identical to the effect of water-to-bond proportion on the compressive quality of Portland concrete cement. When there was an increase in the water-to-geopolymer solids, there was an increase in workability as the blends comprised of a higher amount of water.

3.4 Vibration

The vibration procedure is an exceptionally straightforward strategy which requires negligible gear. An open shape, which can be of different materials, is utilised to contain the fluid composite compound. Be that as it may, the shape ought to be made of a material that won't hold fast to the wet lattice. The slurry filled form is then put on a vibration table. An elastic cushion is placed in the middle of the structure and the schedule for better symphonies appropriation and to shield the shape from splitting.The shape is appropriately secured to the vibration table to guarantee it stays in coordinates contact with the table and moves the vibrations into the wet lattice see in Figure 3.6. This can be accomplished by utilising bungee strings or ties. After the shape is secured to the vibration table, the power can be turned on and left to keep running for a foreordained timeframe. This procedure takes into consideration the compound to settle and take the state of the form. Amid the vibration procedure, captured air goes through the compound and is discharged at the surface. The shape is expelled from the vibration table, and the composite is left to cure at room temperature. Notwithstanding, this procedure can prompt conflicting thicknesses if low consistency grid slurries are utilised see Figure 3.7.

(a)

(b)

Figure 3.6 Vibration table at laboratory

(a)

(b)

Figure 3.7 Before casting cubes on the vibration

3.5 Experimental details

3.5.1 Mix design

Notwithstanding the theoretical part, I depended intensely on functional parts and research centre tests. Along these lines, the subject is more cleared up and reasonable. For this reason, solid lab tests at Salahaddin university were utilised. The experiments were begun on July 1, 2017, and completed on February 17, 2018. The tests were made out of compressive quality which is completed on cubical cement 150x150x150 mm. The tests were ordered for two sorts of concrete, for example, geopolymer concrete and normal concrete. All experiments were made out of nine gatherings; they were separated between both types of cement.

Eight of these gatherings were indicated for geopolymer concrete compressive quality tests, and the other one was determined from normal concrete compressive quality tests. Each gathering had a distinctive blend outline for various points and purposes. In the first place gather the distances to the fifth gathering were made out of twenty-five blends for one gathering are five blends. The sixth gathering was composite of six blends. The seventh gathering was made out of three blends.

The eighth gathering was made out of two blends. The ninth gathering was composite of two blends. Add up to blends were thirty-eight blends; every one of them had fifteen cement cubic examples of the test.

The tests were completed for every blend of five various lengths, for example 3, 7, 28, 56 and 90 days. In every length, three tests were tried for every blend, and the common outcomes were taken from these three worked examples. Add up to some moulds were 570 moulds, they were made of iron.

The inside parts of each form were secured by a sticker or hostile to consume nylon to disallow solidly adheres to the shape See Table 3.11 to Table 3.19.The tables below show. Mix design for my experimental work on geopolymer concrete.

Table 3.11 Mix design for group 1

20	Age (Days)	3, 7, 28, 56 and 90				
19	type of sample	cube				
18	Sample (mm)	150*150*150				
17	After Curing	Ambined				
16	Curing time (hr)	24				
15	Temperature (C)	70				
14	Rest period (hr)	24				
13	Mix. size agg.(mm)	9.5				
12	Sample No.	15				
11	W/GPB	0.2404	0.2676	0.2959	0.3255	0.3565
10	SP (%) of fly ash	2%				
9	Extra Water (kg/m^3)	10	20	30	40	50
8	Alkline/Fly Ash	0.45				
7	$Na_2Sio_3/NaOH$	2.5				
6	NaOH Molarity	12				
5	Fly Ash (kg/m^3)	400				
4	Fine Agg. (kg/m^3)	660				
3	Course Agg. (kg/m^3)	1230				
2	Mix	**1**	**2**	**3**	**4**	**5**
1	**Group**	**1**				

Table 3.12 Mix design for group 2

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Group	Mix	Course Agg. (kg/m^3)	Fine Agg. (kg/m^3)	Fly Ash (kg/m^3)	NaOH Molarity	Na_2Sio_3/NaOH	Alkline/Fly Ash	Extra Water (kg/m^3)	SP (%) of fly ash	W/GPB	Sample No.	Mix. size agg.(mm)	Rest period (hr)	Temperature (C)	Curing time (hr)	After Curing	Sample (mm)	type of sample	Age (Days)
2	**6**	1230	660	400	12	2.5	0.45	10	2%	0.2404	15	12.5	24	70	24	Ambined	150*150*150	cube	3, 7, 28, 56 and 90
	7							20		0.2676									
	8							30		0.2959									
	9							40		0.3255									
	10							50		0.3565									

Table 3.13 Mix design for group 3

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Group	Mix	Course Agg. (kg/m^3)	Fine Agg. (kg/m^3)	Fly Ash (kg/m^3)	NaOH Molarity	Na_2Sio_3/NaOH	Alkline/Fly Ash	Extra Water (kg/m^3)	SP (%) of fly ash	W/GPB	Sample No.	Mix. size agg.(mm)	Rest period (hr)	Temperature (C)	Curing time (hr)	After Curing	Sample (mm)	type of sample	Age (Days)
3	**11**	1230	660	400	12	2.5	0.45	10	2%	0.2404	15	19	24	70	24	Ambined	150*150*150	cube	3, 7, 28, 56 and 90
	12							20		0.2676									
	13							30		0.2959									
	14							40		0.3255									
	15							50		0.3565									

Table 3.14 Mix design for group 4

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Group	Mix	Course Agg. (kg/m^3)	Fine Agg. (kg/m^3)	Fly Ash (kg/m^3)	NaOH Molarity	Na_2Sio_3/NaOH	Alkline/Fly Ash	Extra Water (kg/m^3)	SP (%) of fly ash	W/GPB	Sample No.	Mix. size agg.(mm)	Rest period (hr)	Temperature (C)	Curing time (hr)	After Curing	Sample (mm)	type of sample	Age (Days)
4	**16**	1230	660	400	12	2.5	0.45	10	2%	0.2404	15	25.4	24	70	24	Ambined	150*150*150	cube	3, 7, 28, 56 and 90
	17							20		0.2676									
	18							30		0.2959									
	19							40		0.3255									
	20							50		0.3565									

Table 3.15 Mix design for group 5

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Group	Mix	Course Agg. (kg/m^3)	Fine Agg. (kg/m^3)	Fly Ash (kg/m^3)	NaOH Molarity	Na_2Sio_3/NaOH	Alkline/Fly Ash	Extra Water (kg/m^3)	SP (%) of fly ash	W/GPB	Sample No.	Mix. size agg.(mm)	Rest period (hr)	Temperature (C)	Curing time (hr)	After Curing	Sample (mm)	type of sample	Age (Days)
5	**21**	1230	660	400	8	2.5	0.45	26.4	2%	0.2959	15	9.5	0	70	24	Ambined	150*150*150	cube	3, 7, 28, 56 and 90
	22				10			29.1		0.2959									
	23				12			31.5		0.2959									
	24				14			33.7		0.2959									
	25				16			35.8		0.2959									

Table 3.16 Mix design for group 6

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Group	Mix	Course Agg. (kg/m^3)	Fine Agg. (kg/m^3)	Fly Ash (kg/m^3)	NaOH Molarity	Na_2Sio_3/NaOH	Alkline/Fly Ash	Extra Water (kg/m^3)	SP (%) of fly ash	W/GPB	Sample No.	Mix. size agg.(mm)	Rest period (hr)	Temperature (C)	Curing time (hr)	After Curing	Sample (mm)	type of sample	Age (Days)
6	**26**	1230	660	400	12	2.5	0.45	10	2%	0.2404	15	12.5	0	70	0	Ambined	150*150*150	cube	3, 7, 28, 56 and 90
	27									0.2404					24				
	28									0.2404					48				
	29									0.2404					72				
	30									0.2404					96				
	31									0.2404					120				

Table 3.17 Mix design for group 7

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Group	Mix	Course Agg. (kg/m^3)	Fine Agg. (kg/m^3)	Fly Ash (kg/m^3)	NaOH Molarity	Na_2Sio_3/NaOH	Alkline/Fly Ash	Extra Water (kg/m^3)	SP (%) of fly ash	W/GPB	Sample No.	Mix. size agg.(mm)	Rest period (hr)	Temperature (C)	Curing time (hr)	After Curing	Sample (mm)	type of sample	Age (Days)
7	**32**	1230	660	400	12	2.5	0.45	10	2%	0.2404	15	12.5	0	70	24	Ambined	150*150*150	cube	3, 7, 28, 56 and 90
	33												24						
	34												48						

Table 3.18 Mix design for group 8

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Group	Mix	Course Agg. (kg/m^3)	Fine Agg. (kg/m^3)	Fly Ash (kg/m^3)	NaOH Molarity	Na_2Sio_3/NaOH	Alkline/Fly Ash	Extra Water (kg/m^3)	SP (%) of fly ash	W/GPB	Sample No.	Mix. size agg.(mm)	Rest period (hr)	Temperature (C)	Curing time (hr)	After Curing	Sample (mm)	type of sample	Age (Days)
8	**35**	1230	660	400	12	2.5	0.45	10	2%	0.2404	15	9.5	0	30	24	Ambined	150*150*150	cube	3, 7, 28, 56 and 90
	36													70					

Table 3.19 Mix design for group 9

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Group	Mix	Course Agg. (kg/m^3)	Fine Agg. (kg/m^3)	cement or flyash	NaOH Molarity	$Na_2Sio_3/NaOH$	Alkline/Fly Ash	Extra Water (kg/m^3)	SP (%) of fly ash	W/GPB	Sample No.	Mix. size agg.(mm)	Rest period (hr)	Temperature (C)	Curing time (hr)	After Curing	Sample (mm)	type of sample	Age (Days)
9	**37**	1150	720	cement	……	…….	…….	163	…….	………	15	12.50	…..	……	……	Ambined	150*150*150	cube	3, 7, 28, 56 and 90
	38	1230	660	Fly ash	12	2.5	0.45	10	2%	0.2404			24	70	24				

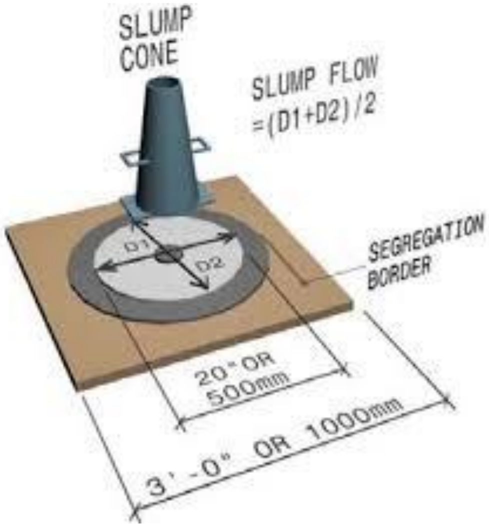
3.5.2 Mixing and casting

Geopolymer cement can be produced by embracing the customary procedures utilized as a part of fabricate of portland bond concrete. In the research facility, prepared all material expected to geopolymer solid. The fly ash and the aggregates with a little extra water were first mixed together dry in a pan mixer for about three minute.As it is shown that in saturated-surface-dry condition, the aggregates had been prepared. We mixed the alkaline liquid with dry mixture in the mixer step by step.Then super plasticizer mixed with remaining extra water. After then mixed in the pan component.

The mixing continued usually for another four minute.Without any sign of setting and degradation in the compressive strength, the fresh concrete might be handled up to reach in 120 minute.By the normal methods prepared in the case of portland cement concrete, the fresh concrete had been compacted.After casting cubes, putting another location in the laboratory for 0, 24 and 48 hours to take rest period the laboratory temperature is between 20 - 25^{o}C. It was cohesive namely the fresh fly ash based geopolymer concrete. There are means of the conventional slump test that measured the workability of the fresh concrete. Additionally, by the wet-mixing time, the compressive strength of geopolymer concrete was influenced. It was shown in the test results that as the wet-mixing time increased, the compressive strength increased.

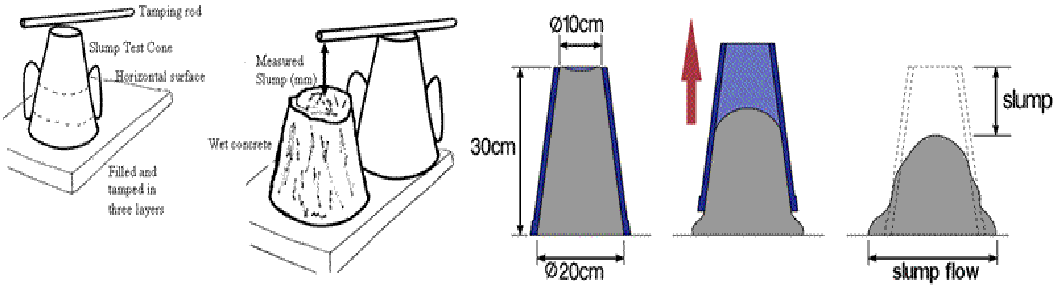
3.5.3 Workability test – Slump of concrete

The method given in AS 1012.3.1 is followed for testing the workability of fresh concrete Standards (Australia, 2014c). This technique has fundamentally been developed for OPC solid blend and may be used for the geopolymer blend as shown in the following (Table 3.20 and 3.21). To determine the droop of new concrete, a shape with measurements 300 mm in stature, 100 mm top width and 200 mm base distance is used. Initially, the droop shape, base plate and temping pole were moistened. To settle the shape as a solid, it was kept on the two plates at the base. Later on, the solid blend was poured in three equal layers in the form. Every layer was then compressed by making 25 blows with a temping pole 600 mm length and 15 mm width refer to Figure 3.8 and Figure 3.9.



(a)

(b)



(c)

Figure 3.8 Slump flow equipment

Figure 3.9 Slump test of concrete mixtures

As it can be shown above that what so called “the blow of temping rod “to be penetrated the previous layer, it was applied. The top surface would be levelled trimming excess mix because the top layer was filled. Then, about three seconds without any torsional displacements, the mould would be lifted vertically.

The slump test is suitable for slumps of low to high workability see table below. At the centre of the top surface mixture of slumped concrete, the vertical displacements would be measured from the top of the mould. The measurements have an average that in the slump value is reported. However, increase extra water to geopolymer concrete mixture caused increase workability sees (Table 3.20 and 3.21).

Table 3.20 Slump result rate

Degree of workability	Slump (mm)
Very low	0 - 25
Low	26 - 50
Medium	51 - 100
High	101 - 175
Very high	collapsed

Table 3.21 Slump result of group one

Extra water (kg/m^3)	Sample (mm)
10	51
20	59
30	71
40	98
50	114

2.5.4 Curing of geopolymer concrete

The chemical reaction that runs in the geopolymer paste was substantially assisted by heat-curing. The compressive strength of geopolymer concrete was affected by both of the curing temperatures as well as curing time for my experimental work creating an excellent rectangular oven 1*1*4 meter see Figure (3.10). The effect of curing time is illustrated in chapter 5.

The specimens that were tested are 150*150*150 mm cubes heated-cured at 70°C in an oven. The time from zero to 5 days was varied by curing time. As a result, the more the curing time will be longer, the more the polymerisation process results will be improved in higher compressive strength.

In strength, the rate of increase for curing time was rapidly up to 24 hour; more than 24 hour in strength, the gain will be just equinoctial.

(a)

(b)

Figure 3.10 Dry oven 1*1*4 meter

Accordingly, warm curing time require is not over 24 hour between viable applications. Warmth curing can be accomplished by either steam-curing or dry-curing. Dry-cured geopolymer concrete is around 15% bigger than that of steam-cured geopolymer concrete.

The required warmth curing administration can be controlled to fit the necessities of down to earth applications. In research center trials precast items were made utilizing geopolymer concrete; the plan particulars required steam-curing at 60^{o}C for 24 hour. With a specific end goal to streamline the use of formwork, also the beginning of warmth curing of geopolymer cement can be deferred for a few days. Tests have demonstrated that a deferral in the beginning of warmth curing up to two day did not create any corruption in the compressive quality. Truth be told, such a postponement in the beginning of warmth curing considerably expanded the compressive quality of geopolymer concrete. This might be because of the geopolymerisation that happens preceding the beginning of warmth curing.

3.6 Testing procedures

3.6.1 Conclusive tests

To carry out all preliminary tests on trial blends which accumulated to over 50 blend plans, and subsequently carrying out tests on the materials in their basic natural form to obtain data regarding their physical properties and compound pieces, decisive tests on the quality features of the final examples were discussed. The following strategies for tests were employed.

3.6.1.1 Density of geopolymer concrete

The thickness of geopolymer concrete was determined using the method used for ordinary portland concrete concrete. British Standards Institution (BS. 1881: Part 114: 1988) served as the training code and depicted the thickness as the mass of a unit volume of solidified concrete, which was shown as kilograms per cubic meter kg/m^3. To determine volume, measurement of 3D shapes was calculated, and weights of 3D shapes were obtained. The way weights can be obtained by modifying the indoor is shown in Figure 3.11.
For take density of Geopolymer concret to study expermentaly mix using iron cube.

Iron cube volume = (15*15*15) cm

Fresh concret without extra water

Weight cube without fresh concret = 13.5 kg

Weight cube with fresh concret = 21.75 kg

Density for one cube of fresh concret = 21.75 – 13.5

= 8.25 kg

Figure 3.11 Weight measurements for density calculation

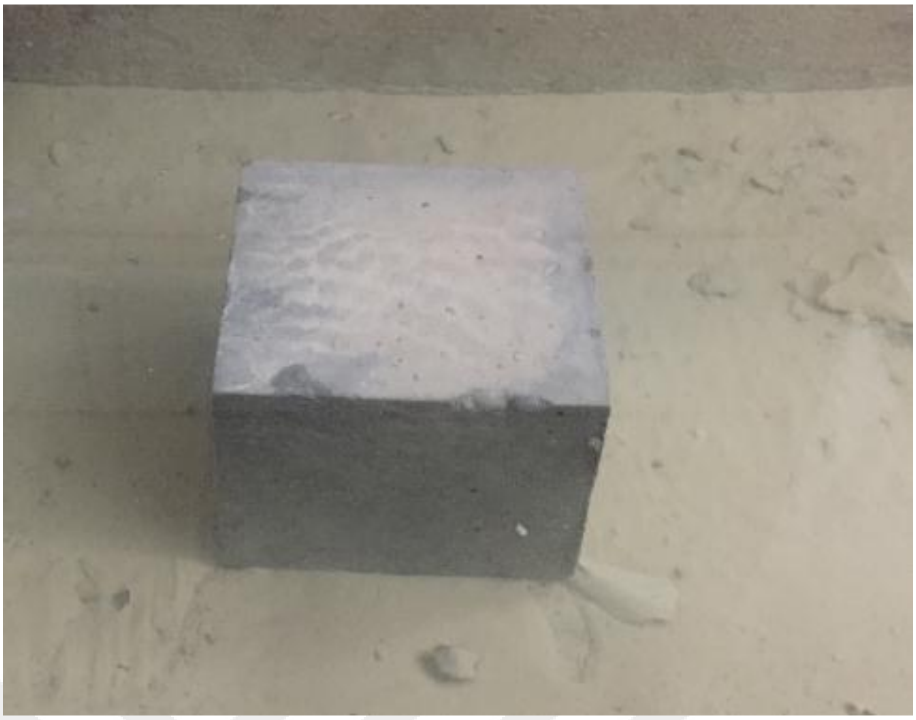
3.6.1.2 Water absorption test

Water absorption characteristic of concrete plays an important role for the durability. Water retention of fly powder based geopolymer concrete including distinct rates of base fiery remains can be determined by establishing one crystal for every blend from an identical clump, using a comparative strategy for curing. The (BS. 1881: Part 122: 1983) should be used. The test should be carried out when the duration of the test period. This suggests that at 28 day old, it has a solid shape with the measurements 150 *150*150 mm see in Figure 3.11.The (BS. 118: Part 114) was used to determine the dimensions of the samples. The midpoints were dried at this point in the broiler at a temperature of 105 ± 5 ^{o}C till the time their mass becomes constant.

Figure 3.12 Arrangement of specimens in the oven

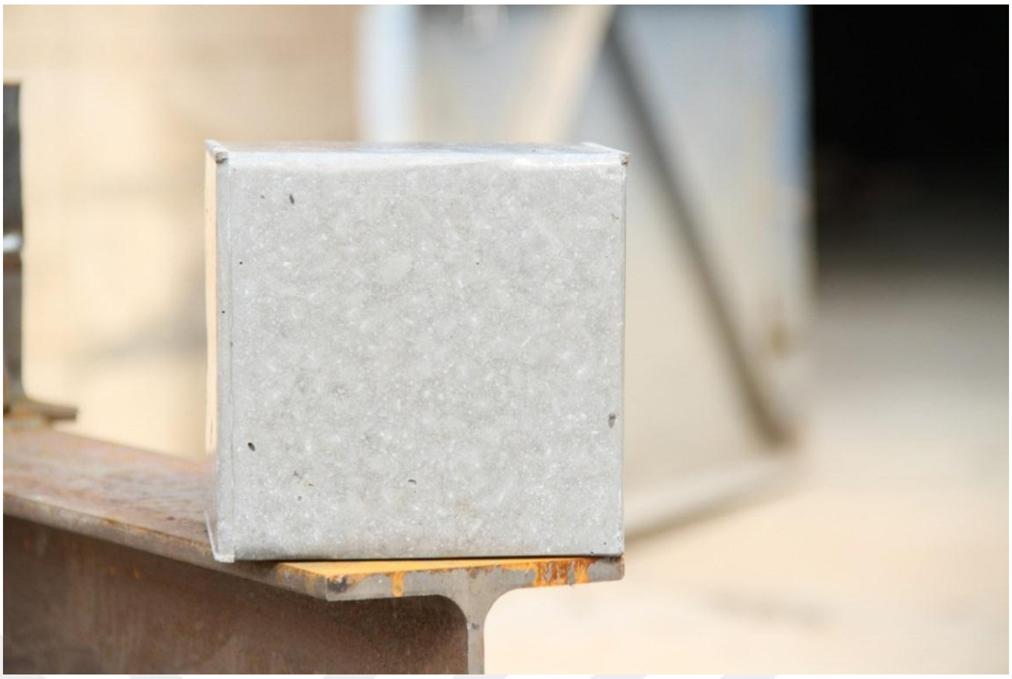
After the cores are removed from the broiler, they are kept in a vessel through which nothing can pass for 24 hour to cool down. The examples were then weighed, after which they were dissolved in water tanks for 24 hour with its longitudinal turn stage and at a depth till there was 25 mm of water higher than the maximum point of the samples. Figure 3.13 shows the process of submersion.

(a)



(b)

(c)



(d)

Figure 3.13 Immersed geopolymer concrete cubes in water

At that point, they drew out the water tank and wiped with a fabric and again they were weighted. The expansion in mass coming about because of the drenching communicated at a level of the mass of the dry example for water ingestion of geopolymer concrete. Consequences of water retention were checked with the evaluation criteria of CEB (1989) which was introduced in Table 3.22.

Table 3.22 Assessment criteria for water absorption (CEB, 1989)

Absorption (%)	**Absorption rate**	**Concrete quality**
1.3	Low	Good
1.3 to 2.5	Average	Average
2.5	High	Poor

3.6.2 Mechanical properties

3.6.2.1 Compressive strength test

The pressure test was done on the examples by a 2000 KN limit testing machine. Figure (3.14) demonstrates the compressive quality machine. As it was expressed over, the compressive qualities of geopolymer concrete were the principle focuses of this examination. In this manner, tests were led on the solidified geopolymer solid 3D squares at 3, 7, 28, 56 and 90 days while 3D squares were tried at 3, 7, 28, 56 and 90 days subsequent to throwing. The tests were explained by utilization of water driven testing machines for compressive quality tests.

Standard, B. (1881) (BS. 1881: Part116: 1983) was used to describe the compressive quality test, using three 150x150x150 mm geopolymer solid 3D shapes. To calculate their cross-sectional area, the sizes of the shapes were estimated.

The next stage involved linking the stack without stun and constantly at a rate of 0.6 N/mm²/s, which was suggested by the standard. The way stacking by water-powered quality machine takes place shown in Figure 3.15.

Figure 3.14 Compressive strength test machine

(a)

(b)

Figure 3.15 Geopolymer concrete cubes in compressive strength test machine

Compressive strength calculation of each cube was performed by dividing the maximum load applied to it by the cross-sectional area and the results were reported to the nearest 0.75 N/mm². After testing all the samples at different time and different age we can take these results see (Table 3.23 to 3.18).

Table 3.23 Result compressive strengths for maximum size particle 9.5 mm

Group1	**Compressive strength (MPa) with age (days)**				
	3	**7**	**28**	**56**	**90**
Mix 1	45.15	46.54	47.55	48.81	49.50
Mix 2	40.72	41.93	42.85	44.00	44.69
Mix 3	35.55	37.48	38.83	39.86	40.19
Mix 4	29.89	31.10	32.20	33.06	33.81
Mix 5	22.00	22.57	24.04	24.67	25.04

Table 3.24 Result compressive strengths for maximum size partical 12.5 mm

Group 2	**Compressive strength (MPa) with age (days)**				
	3	**7**	**28**	**56**	**90**
Mix 6	43.53	44.96	46.15	47.35	48.21
Mix 7	39.10	40.43	41.40	42.47	43.04
Mix 8	33.93	35.26	36.07	37.03	37.89
Mix 9	28.27	29.47	30.73	31.54	32.26
Mix 10	20.38	21.26	22.27	22.85	23.70

Table 3.25 Result compressive strengths for maximum size partical 19 mm

Group 3	**Compressive strength (MPa) with age (days)**				
	3	**7**	**28**	**56**	**90**
Mix 11	42.07	43.69	44.66	45.69	46.38
Mix 12	37.50	39.09	40.30	41.10	42.03
Mix 13	32.31	33.71	34.81	35.64	36.25
Mix 14	26.72	28.05	29.29	29.97	31.05
Mix 15	18.68	19.77	20.91	21.54	22.21

Table 3.26 Result compressive strengths for maximum size partical 25.4 mm

Group 4	**Compressive strength (MPa) with age (days)**				
	3	**7**	**28**	**56**	**90**
Mix 16	40.63	41.99	42.86	44.02	45.06
Mix 17	35.95	37.82	38.73	39.60	40.89
Mix 18	30.73	32.30	33.47	34.36	35.09
Mix 19	25.38	26.71	27.95	28.69	29.58
Mix 20	17.23	18.47	19.76	20.30	21.04

Table 3.27 Result compressive strengths for different molarity

Group 5	Compressive strength (MPa) with age (days)				
	3	7	28	56	90
Mix 21	32.21	33.63	34.87	35.66	36.86
Mix 22	36.05	37.31	39.27	40.40	41.56
Mix 23	38.59	39.50	41.52	42.56	43.36
Mix 24	37.67	38.98	40.46	41.52	42.21
Mix 25	35.57	36.79	38.59	38.59	39.83

Table 3.28 Result compressive strengths for different curing

Group 6	Compressive strength (MPa) with age (days)				
	3	7	28	56	90
Mix 26	0.00	5.09	13.05	19.44	28.65
Mix 27	38.28	40.84	43.51	44.71	45.50
Mix 28	42.02	43.23	44.46	45.21	46.05
Mix 29	43.76	44.78	46.10	46.44	46.95
Mix 30	44.91	45.95	46.89	47.45	47.89
Mix 31	45.23	46.27	47.69	48.11	48.54

Table 3.29 Result compressive strengths for different rest period

Group 7	**Compressive strength (MPa) with age (days)**				
	3	**7**	**28**	**56**	**90**
Mix 32	37.96	39.07	41.89	42.84	43.36
Mix 33	43.50	44.87	46.76	47.66	48.13
Mix 34	45.66	46.96	48.74	49.87	51.27

Table 3.30 Result compressive strengths for different temperture

Group 8	**Compressive strength (MPa) with age (days)**				
	3	**7**	**28**	**56**	**90**
Mix 35	0.00	6.15	16.37	20.77	30.27
Mix 36	36.05	38.98	41.11	42.32	42.99

Table 3.31 Compare compressive strengths for different concrete type about age

Group 9	**Compressive strength (MPa) with age (days)**				
	3	**7**	**28**	**56**	**90**
Mix 37	15.39	28.57	39.63	41.82	43.56
Mix 38	45.78	47.14	48.25	49.31	50.42

CHAPTER 4

REGRESSION MODELS AND THE PROCEDURE FOR MIXTURE PROPORTION OF GPC

4.1 Geopolymer concrete

The term “Geopolymer concrete” is considered as a sort of concrete which is made by bearing materials with a caustic activator as well as reacting aluminate besides silicate. The abbreviation “GGBS“ that stands for ground granulated blast furnace slag and fly ash can be a waste material. There are produced and generated from plants with thermal power as well as plants of steel respectively. Commonly, they have utilised by-product materials for the manufacture of geopolymer concrete. In order to activate the source materials such as silicon and Aluminum in fly ash and GGBS, there is a combination of solutions of alkali silicates, hydroxides and distilled water as a result of the necessary manner of the alkaline activator solution.

The alkaline activator solution can create the hardened binder and is used to polymerise them into molecular chains.

The alkali-activated cement or inorganic polymer cement is another name for it. The coarse and fine material aggregates are utilised by the concrete industry, which could be appropriate for the manufacture of geopolymer concrete. In concrete practice, the used grading curves at present are, in the case of geopolymer concrete (Gourley and Johnson, 2005, Hardjito and Rangan, 2005).

4.2 Composition of geopolymer concrete

This type of concrete can be composite of the following:

- A byproduct of the thermal power plant, fly ash- The distribution of grain size of the fly ash must be established to be used as well as the chemical composition or a byproduct of the steel plant, GGBS – coarse aggregates as required for normal concrete as well as Fine aggregates

- The term AAS that stands for “Alkaline activator solution.” is a sodium hydroxide solution as well as a blend of sodium silicate solution. They used them as the alkaline liquid.

4.3 Requirements for the mixture proportion

To find a suitable manner about the ingredients of concrete as well as to determine their relationship with the objective of giving a concrete of the required, durability, workability, and strength as cheap as possible, and it is termed the mix design of the concrete. With the desired performance of it in two states, the proportioning of ingredients of geopolymer concrete is dominated. In other words, the hardened states as well as the plastic if the geopolymer concrete of plastic does not have the useful trait that means that it does not look properly compact. It becomes of vital importance due to the property of followability or workability. In general, the hardened geopolymer concrete, which is the compressive strength, is considered as an index of its different features. It is as same as in conventional depending upon several elements, e.g. quantity as well as the quality of total water, geopolymer binder, aggregates; batching, geopolymer binder, mixing; placing, compaction and curing. Plant and labour are a geopolymer concrete cost made up of the cost materials for them (Balczar et al., 2015).

Different cost of materials can be raised by fly ash as well as alkaline materials. They are several times more expensive than the aggregate, so we have to produce it as lower binder content as possible. A practical point of view mixes with high alkali contents may increase the risk of alkali-aggregate reaction and negative impact on the durability of geopolymer concrete. For producing a minimum mean strength named advantages of strength which can be specified by the designer of the structure, the real cost of geopolymer concrete has a relation to the cost of materials and curing. On the quality control measures, it was eepened. On the other hand, no doubt about the quality control adds to the cost of concrete. The cost of labour depends on the flow ability of geopolymer concrete mix; inadequate flowability as well as a viscous mix may be produced at a high price of labour to get a compacting degree with the equipment that is available (Collins and Sanjayan, 1999).

To form the basis of selection and proportioning of mix ingredients, the requirements can be:

- The required from basic consideration is the minimum compressive strength.
- Due to the entire compaction, with the compacting equipment available, is the adequate necessary workability.
- With a minimum cost, the maximum water-to geopolymer solid ratio and by giving sufficient durability as well as minimum strength for the conditions of the particular site.

The geopolymer concrete that has a compressive strength of are found up to 70 MPa. Its compressive strength is rapidly gaining by the concrete as well as it can be faster than the concrete of ordinary Portland cement. After 24 hour, the concrete strength was found to be more than 25 MPa.

4.4 Factors affecting compressive strength of GPC

4.4.1 Fineness and content of fly ash

It is known that in the activation of geopolymer concrete, the fineness of fly ash plays a significant role. Increase in the fineness means increases the compressive strength as well as the workability. By raising the reaction rate demanding less heating time due to attains a given strength, that finer particles were observed and resulted in (Jamkar et al., 2013).

The compressive strength of geopolymer concrete increases with an increase in the percentage of replacement of fly ash with GGBS. Flyash can be replaced by GGBS up to 28.57 %, beyond that fast setting is observed (Ganapati et al., 2012).

Previous studies showed that the current range of Fly ash content for making geopolymer concrete is between 320 to more than 400 kg/m^3. In the present work fly, ash type F with fineness – and amount 400 kg/m^3 is fixed for all the mixtures.

4.4.2 Alkaline solution to fly ash ratio

Increase in the ratio of alkaline liquid to fly ash increase the strength of concrete up to a certain limit. Beyond the limit of increasing the alkaline fluid to fly ash ratio, the compressive strength would be decreased. Decreasing in it, the geopolymer concrete is due to increase in water in a substantial increase in the number of pores due to heat curing as well as the preparation of alkaline liquid.

To normal concrete, this behaviour can be similar besides, as water in the ratio of cement increases it and decreases (Tennakoon, 2016). Usually, alkaline activator to fly ash ratio ranges between 0.30 - 0.50. It is noticed that the rate of alkaline liquid to fly ash, by mass, is not much effective in varying the compressive strength of the geopolymer concrete (Vora and Dave, 2013).

Results from the literature, it was revealed by Mohd et al. (2012) that in the optimum amount of alkaline liquid, the alkaline activator/fly ash ratio of 0.4 was on it. This can be clear that the highest rate of polymerisation will be compared to the different ratio. It was shown by “effect of alkaline solution to fly ash ratio on geopolymer mortar properties“ that the solution of the higher alkaline towards the ratio of fly ash can bring a longer setting time as well as develop the workability.

Higher solution-to-fly ash ratio shows higher strength at the same concentration of sodium hydroxide solution. But higher solution-to-fly ash ratio gives the more viscous mix and creates difficulties in compaction which ultimately reduce the strength (Patankar et al., 2014).

In the present research alkaline solution to fly ash ratio was fixed equal to 0.45.

4.4.3 Water to geopolymer solid ratio

In the sodium silicate solution, it, entire water mass, is determined by the sum of the mass of water contained. For the making of the sodium hydroxide solution and the mass of extra water are used by the mass of the water which is put to improve the workability. It is known that they determined the mass of geopolymer solids when they added up the mass of sodium hydroxide as well as fly ash and by, in the sodium silicate solution, making the mass of solids as well as the solution of the sodium hydroxide, i.e. the mass of Na_2O flakes and Na_2SiO_3 solids. Inversely it, the compressive strength of geopolymer concrete, is proportional to the water-to geopolymer solid ratio and in cement concrete is similar to water-to-cement ratio.

The ratio of the suitable range of water-to-geopolymer solid can be in the range of 0.25 to 0.35. The segregated mix was given by a higher ratio on the other hand, viscous and dry mixes were given by lower ratio (Patankar et al., 2013).

In the present research water to geopolymer, solid ratio ranged between 0.24-0.33.

The increase in water to geopolymer solids ratio results into an increase of the workability of mixes but the compressive strength of geopolymer concrete reduces (Vora and Dave, 2013).

4.4.4 Molarity of NaOH

Sodium hydroxide molarity solution plays an important role in the strength of geopolymer concrete. In general, with higher concentration of sodium hydroxide solution, higher compressive strength can be achieved. The concrete specimens with molarity vary from 8 to 18 M, and curing at temperature for 80^{o}C after testing shows that the 16M gives better strength than another molarity (Sharma and Ahmad, 2016, Madheswaran et al., 2013). We have to notice that the leaching of alumina and silica, as well as sodium hydroxide concentrations at the high level was enhanced. This, in increased polymerization, resulted, and because of that, the strength will be increased. In a reduction of strength, on the other hand, the sodium hydroxide concentration of 20 M resulted.

The reason is that the reduction of strength, as well as the high concentration of hydroxide ions OH^-, sodium hydroxide concentration at high level, was available as a result it can, at the early stage of development, cause aluminosilicate gel precipitation, (Topark et al., 2014). According to previous studies (Rajesh et al., 2014) it was found that 12 M, sodium hydroxide solution gives strength 1.25 times more than that of geopolymer concrete with other molarities after 28 day of hot curing.

Patankar et al. (2014) showed that there is no significant variation in compressive strength of geopolymer mortar above 13 M concentration of sodium hydroxide solution. This could be because of the high viscous mixture form at greater concentration. Presently the effect of various concentrations of sodium hydroxide solution on the compressive strength has considered, Molarity varied between 8 to 16 M. Results indicate that 12 M of sodium hydroxide has given the highest compressive strength of geopolymer concrete as shown in Figure 4.1. There was a reduction in compressive strength by nearly 8 % and 15 % when the molarity increased to 16 M and decreased to 8 M respectively.

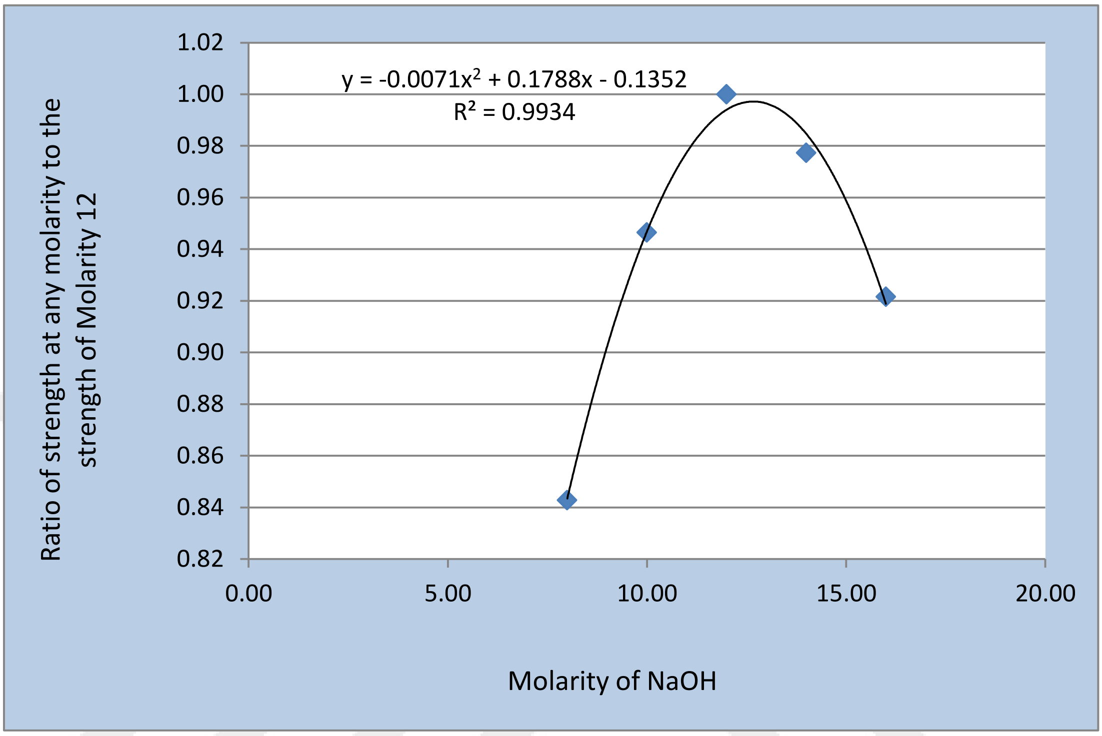


Figure 4.1 Effect of molarity of NaOH on the compressive strength of GPC expressed by the ratio of strength at other molarities to the strength at molarity 12 M

4.4.5 Ratio of sodium silicate to sodium hydroxide

Varying the ratio of sodium hydroxide to sodium silicate solution from 1 to 3.5 by mass on the compressive strength of geopolymer concrete was studied. The average maximum strength was obtained when the ratio was 2.5.

It has been concluded that the cost of alkaline liquid is economical when and the test results remarkably more consistent when the ratio of sodium silicate solution-to-sodium hydroxide solution is 2.5 (Sanni et al., 2013). In the research the ratio fixed equal to 2.5 for all the mixtures.

4.4.6 Addition of super plasticiser

Superplasticiser was used for all the mixtures to improve the workability of fresh low-calcium fly ash based geopolymer concrete. According to (Hardjito and Rangan, 2005). Do the content of the superplasticiser need not be more than 2% of the mass of fly ash. Adding super plasticizer, beyond this amount, a slight reduction in the compressive strength of hardened concrete can be can caused ; additionally , the amounts can be greater than 2% and may be ,in practice , uneconomical (Hardjito and Rangan, 2005).

4.4.7 Rest period

At an elevated temperature as well as by the time taken from the completion of casting of concrete specimens to the beginning of curing, the term 'Rest Period' is known, in context to various practical applications. For instance, we used the fly ash based geopolymer concrete in precast concrete industry, a sufficient time among casting of products must be given and to send to the curing chamber. It has been observed that one-day rest period has resulted into higher gain in compressive strength as compared to that for without rest period. In this investigation three rest periods were considered 0, 24 and 48 hours. After casting the specimen, and before applying heat curing. The results indicated that increasing rest period to 48 hrs. Increased the compressive strength by about 5 % in contrast, specimens without resting period; i.e., immediately cured after casting, showed lower compressive strength by about 10 %. These ratios must be considered for proper proportioning of Geopolymer concrete.

4.4.8 Curing hour and curing temperature

Cuing hour and curing temperature is very significant parameter of geopolymer concrete because it is very important for polymerization process. Longer curing time and curing hour is improved the polymerisation process resulting in development of higher compressive strength. Temperature for making geopolymer concrete is in between 60 to 90^{o}C. Similarly, duration of heating in the range of 6 to 24 hours produces higher compressive strength. However, the increase in strength beyond 12 hour is not very significant (Nagral et al., 2014).In this investigation, all specimens are cured under the temperature of 70^{o}C and curing time was 24 hour.

4.5 Models for the compressive strength of ordinary concrete

Commonly the concrete strength can be its most valuable property an overall picture of the quality of concrete is given due to the strength has a direct manner to the hydrated cement paste structure. Besides, the concrete strength has significant factors of structural design. For compliance purposes are specified.

In engineering practice, at any time and cured in water are the strength of concrete that for and depends primarily on the ratio of cement/ water and the compacting degree. For mix proportioning purposes and hardened concrete are contained about 1% of air voids. As a result, for fully compacting concrete, we took strength for proportional in an inverse manner to the ratio of water/cement. Duff Abrams in (1919) has established the rule to find the strength of concrete.

$$\mathbf{f_c = \frac{A}{B^{\frac{w}{c}}}} \qquad \textbf{Eq (1)}$$

Where; the W/C represents the water/cement ratio of the mix originally taken by volume, and A, B, are empirical constants.

Feret was the first to propose a model for predicting concrete compressive strength. The basic parameter in Féret’s equation is the cement concentration in the fresh paste. It postulates that strength is a function of the ratio of cement to paste and air Feret at 1892 and De Larrard (2014a) as given in the following equation.

$$\mathbf{f_c = A\left(\frac{V_c}{V_c+V_w+V_a}\right)^{B}} \qquad \textbf{Eq (2)}$$

Where; V_c, V_w and $V_a$are the volumes of cement, water and air and A, B are empirical constants.

It is known that the strengths postulated that what so called ‘the compressive strength of cement paste’ in direct manner has a relation to the gel to space ratio, X, that stands for the ratio of the gel volume towards the capillary porosity volume .

$$\mathbf{f_c = A(X)^B} \qquad \textbf{Eq (3)}$$

Bolomey proposed a linearized form of Féret’s formula. The following equation has given to fit his experimental data.

$$\mathbf{f_c = 24.6\left(\frac{c}{w} - 0.5\right)} \qquad \textbf{Eq (4)}$$

Where:

C and w are the masses of cement and water per unit volume of concrete

Finally, Abrams proposed an exponential equation with two adjustable parameters, which is still popular

In North America, such a formula used to estimate the compressive strength of concrete Popovics (1998).

$$\mathbf{f_c = 147 * 0.0779^{\frac{w}{c}}} \qquad \textbf{Eq (5)}$$

Acceptable predictions were given by majority of models due to the strength that can be in most often influenced by the ratio of water-to-cement W/C in comparison to the properties and gradation of aggregates’.

The mean error made by Féret’s formula in predicting the compressive strength of concrete is halved by the introduction of maximum paste thickness term.

The MPT concept incorporates the effects of both aggregate volume and maximum size of aggregate. An intermediate form of a general model for the compressive strength of mature concrete is then the following De Larrard (2014b).

$$\mathbf{f_c \propto A\left(\frac{V_c}{V_c+V_w+V_a}\right)^{B}.MPT^{-r}} \qquad \textbf{Eq (6)}$$

Where:

MPT: Maximum paste thickness

A = kg. Rc28

Kg: Constant that must be calibrated on some available results dealing with the aggregate used.

Rc28: The ISO strength of the cement at 28 day

B: The exponent, initially was found equal to 2 for cement paste in the classical Feret equation later for the plate structure theoretically calculated was equal to 3, and from the regression of experimental results the value has been modified became 2.85 (De Larrard, 2014a).

4.5.1 Compressive strength of GPC

It was shown by Vora and Dave (2013) that compressive strength of geopolymer concrete can be increased by increasing in the curing time rest period concentration of sodium hydroxide solution, curing temperature and decreasing with increasing in the water ratio towards the geopolymer solids by admixture dosage as well as mass . It was concluded by him that the alkaline liquid ratio towards fly ash cannot be affected by the compressive strength of the geopolymer concrete and mass. By mass, the ratio of the effect of water geopolymer solids on the illustrated compressive strength, the sum of the mass of water is the entire mass of water that existed in the solution of sodium silicate, in the solution of sodium hydroxide, in the mass of extra water as well as in the mass of water, to the mixture will be added.

The sum of the mass of fly ash is the mass of geopolymer solids, the mass of solids in the solution of the sodium silicate and the mass of sodium hydroxide solids. It was shown in the results that the compressive strength of geopolymer concrete decreased as the water-to-geopolymer solids ratio by mass increased. It is analogous, namely the test trend, to the effect of water-to-cement ratio that is well-known for the compressive strength of portland cement concrete.

4.5.2 Modified feret model

The experimental results and the previous data from the literature indicated that there is a strong relationship between the compressive strength of geopolymer concrete and the geopolymer binder concentration. Presently, this relation expressed using modified Feret's model as follows:

$$\mathbf{fc}(\mathbf{t}) = \mathbf{a} * \left[\mathbf{d}(\mathbf{t}) + \left(\frac{\mathbf{V_{gs}}}{\mathbf{V_{gs}} + \mathbf{V_{tw}}}\right)^{\mathbf{b}}\right] * \mathbf{MPT^{d}} \qquad \textbf{Eq (7)}$$

Where:

fc : Cube compressive Strength of GP concrete at any age.

$\mathrm{d(t)}$: Is the kinetics parameter at age t. It is supposed to be a characteristic of the geopolymer binder. This can be determined from the following equation.

$$\mathbf{d}(\mathbf{t}) = \mathbf{c} * \mathbf{Log}\ (\mathbf{t}) \qquad \textbf{Eq (8)}$$

$\mathbf{t}$: The age of geopolymer concrete, age would be considered at the time after placing the geopolymer concrete in the molds.

$\mathbf{V_{gs}}$: Volume of geopolymer solid (the sum of volume of fly ash, volume of sodium silicate solid and volume of sodium hydroxide flakes)

$\mathbf{V_{tw}}$: Total Volume of water (volume of water used for NaOH solution, volume of water in sodium silicate solution and volume of extra water)

Volume of water in Super plasticizer SP has not been considered, because the doss up to 2% has no effect on the strength of concrete, beyond this limit the effect must be considered by taking the water included in SP. ($\mathbf{a}, \mathbf{b}, \mathbf{c}$ and $\mathbf{d}$) are empirical constants from the regression analysis of the experimental results, their values are estimated statistically using nonlinear curve estimation from the software package SPSS-version-22. The program used quasai-Newton method for the best fit equation with the highest coefficient of determination $R^2 = 0.943$ and lowest loss function expressed by the residual mean squares = 3.712. Table (4.1 and 4.2) showing statistical analysis taken as the output of the program, lower and upper bound values of the estimated parameters and ANOVA table are shown.

$$\mathbf{a = 545.698}\ ,\ \ \mathbf{b = 6.089}\ ,\qquad \mathbf{c = 0.003}\ ,\qquad \mathbf{d = -0.145}$$

MPT: The distance between aggregates this is called maximum paste thickness this can be determined by the following equation.

$$\mathbf{MPT^d = D * \left(\sqrt[3]{\frac{g*}{g}} - 1\right)} \qquad \textbf{Eq (9)}$$

Where:
D: Maximum size of aggregate (mm).

g*: Equal to the packing density of the aggregate, considered as a granular mix.

g : The aggregate volume in a unit volume of concrete. Aggregate volume determined by the following equation.

$$g = V_{CA} + V_{FA} = \frac{1230}{2700} + \frac{660}{2650} = 0.704$$

g*: packing density determined practically = 0.78 by the following method

$$\boldsymbol{Packing\ density} = \frac{\boldsymbol{Bulk\ density\ of\ combined\ aggregate * Weight\ fraction}}{\boldsymbol{Specific\ gravity}} \ \textbf{..}\ \text{Eq (10)}$$

Bulk density of combined (Coarse & Fine) experimentally measured= 2.087 g/cm^3 or 2087 kg/m^3

$$\text{Packing density of coarse} = \frac{2.087 * 0.65}{2.70} = 0.502$$

$$\text{Packing density of fine} = \frac{2.087 * 0.35}{2.65} = 0.275$$

$$\text{Total Packing density } (g *) = 0.502 + 0.275 = 0.78$$

Substituted to determine maximum paste thickness; as for maximum size =9.5

$$\mathbf{MPT = 9.5 * \left(\sqrt[3]{\frac{0.78}{0.704}} - 1\right) = 0.323}$$

4.5.3 Regression analysis by SPSS

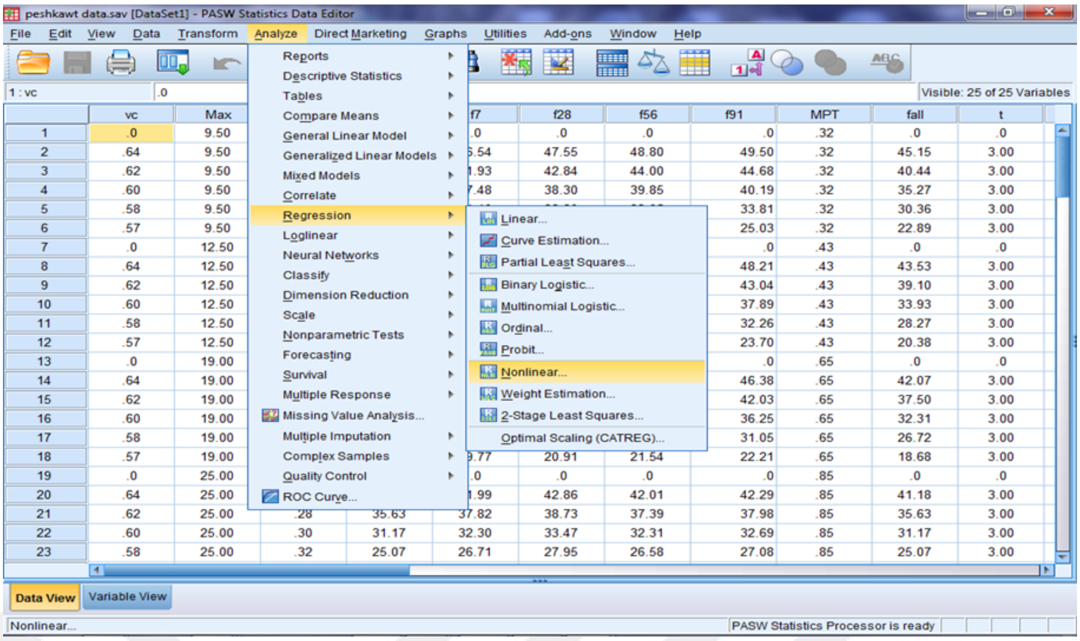
SPSS stands for statistical Package for the social sciences, this program used to analyze data collected from the experimental works carried out on the geopolymer concrete.

The steps are indicated in the points below:

- Open the program
- PASW statistic data editor
- Click on analyze
- Click on regression
- Select nonlinear
- From the list of variables select fall to represent the strength of concrete. At any time as a dependent variable.
- Select parameters, with their names a, b, c and d
- Give starting value to each parameter and continue
- From the model expression , write the model including all independent variables and parameters
- From the button Loss , select " sum of residual function"
- Click on ok
- The program will run to determine the best fit values for the parameters numerically by many numbers of iterations, for each iteration residual sum of squares will be decreased
- Derivatives will be calculated numerically. The program will stop after a number of iterations

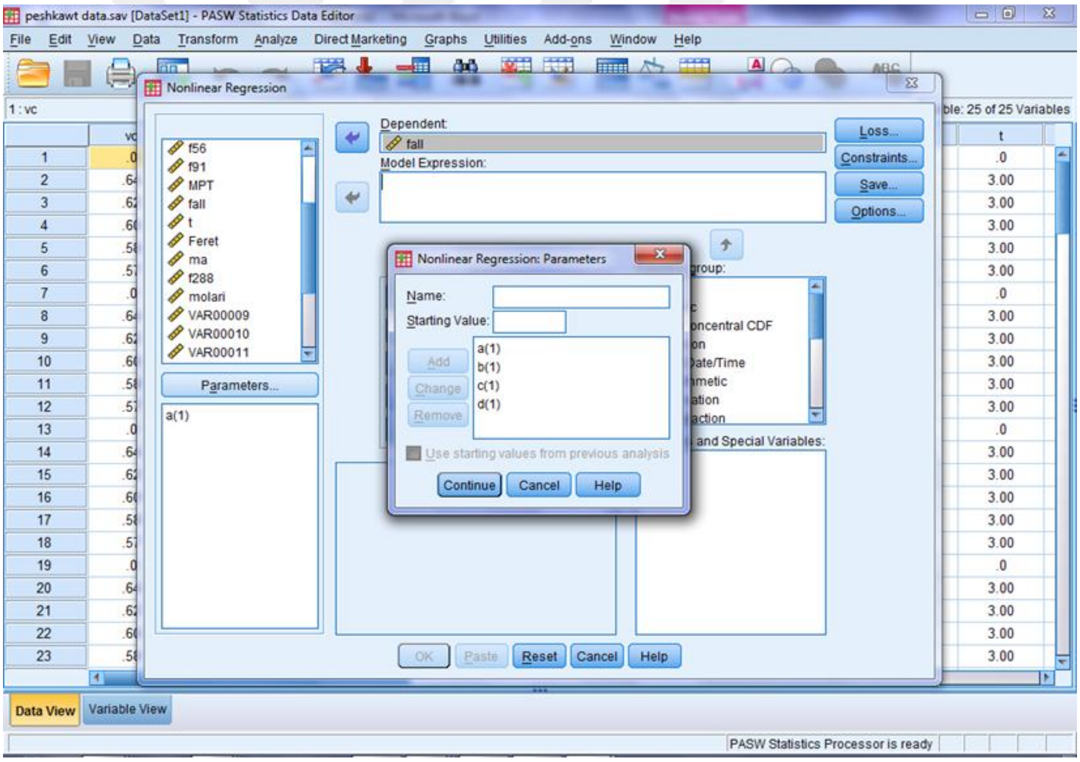
- The program will show the best value for the parameters with ANOVA table

Figure 4.2 the steps of proceure analysis in SPSS program:



	vc	Max	f91	MPT	fall	t
1	.0	9.50	.0	.32	.0	.0
2	.64	9.50	49.50	.32	45.15	3.00
3	.62	9.50	44.68	.32	40.44	3.00
4	.60	9.50	40.19	.32	35.27	3.00
5	.58	9.50	33.81	.32	30.36	3.00
6	.57	9.50	25.03	.32	22.89	3.00
7	.0	12.50	.0	.43	.0	.0
8	.64	12.50	48.21	.43	43.53	3.00
9	.62	12.50	43.04	.43	39.10	3.00
10	.60	12.50	37.89	.43	33.93	3.00
11	.58	12.50	32.26	.43	28.27	3.00
12	.57	12.50	23.70	.43	20.38	3.00
13	.0	19.00	.0	.65	.0	.0
14	.64	19.00	46.38	.65	42.07	3.00
15	.62	19.00	42.03	.65	37.50	3.00
16	.60	19.00	36.25	.65	32.31	3.00
17	.58	19.00	31.05	.65	26.72	3.00
18	.57	19.00	22.21	.65	18.68	3.00
19	.0	25.00	.0	.85	.0	.0
20	.64	25.00	42.29	.85	41.18	3.00
21	.62	25.00	37.98	.85	35.63	3.00
22	.60	25.00	32.69	.85	31.17	3.00
23	.58	25.00	27.08	.85	25.07	3.00

(a)

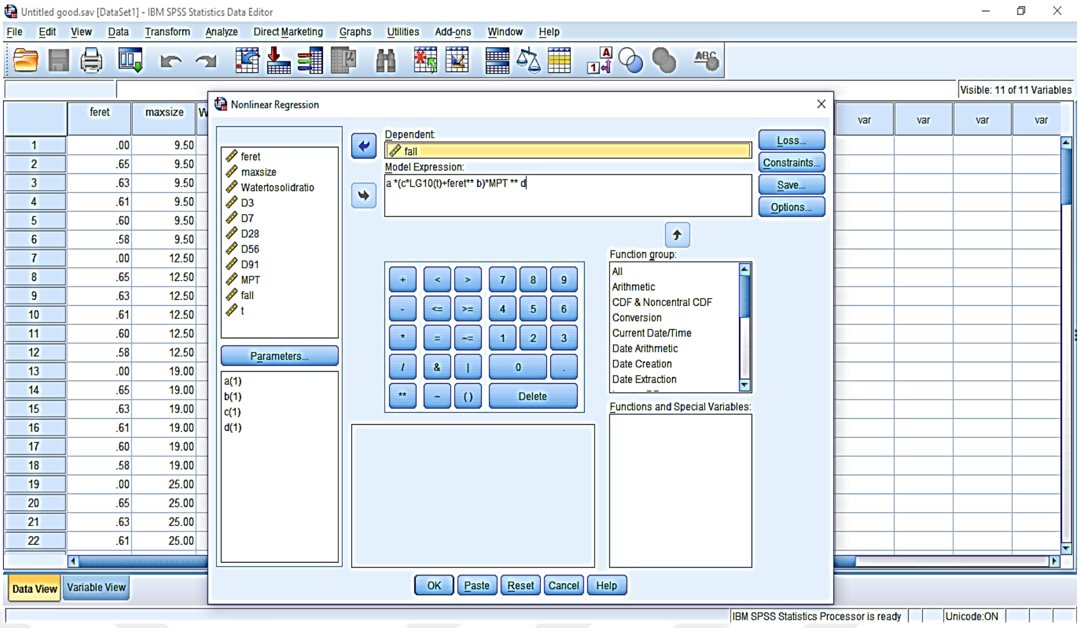


Dependent: fall

Model Expression:

Parameters: a(1) b(1) c(1) d(1)

(b)



	feret	maxsize
1	.00	9.50
2	.65	9.50
3	.63	9.50
4	.61	9.50
5	.60	9.50
6	.58	9.50
7	.00	12.50
8	.65	12.50
9	.63	12.50
10	.61	12.50
11	.60	12.50
12	.58	12.50
13	.00	19.00
14	.65	19.00
15	.63	19.00
16	.61	19.00
17	.60	19.00
18	.58	19.00
19	.00	25.00
20	.65	25.00
21	.63	25.00
22	.61	25.00

Dependent: fall

Model Expression: a *(c*LG10(t)+feret** b)*MPT ** d

Parameters:
a(1)
b(1)
c(1)
d(1)

(c)

Figure 4.2 The steps of proceure analysis in SPSS program

Figure 4.3 shows predicted versus measured values of the compressive strength. This is a graph of measured compressive strength in the data and the strength as predicted by the modified feret model. Ideally, all the points fall on the diagonal line, which indicates highly correlated.

Table 4.1 Iteration History

Iteration History[b]

Iteration Number[a]	Residual Sum of Squares	Parameter			
		a	b	c	d
1.0	118116.358	1.000	1.000	1.000	1.000
1.1	2.605E+44	106.021	94.775	-114.563-	-35.199-
1.2	1.435E+43	5.754	-45.664-	5.356	-19.695-
1.3	38300.817	1.660	-3.503-	1.889	-.413-
2.0	38300.817	1.660	-3.503-	1.889	-.413-
2.1	23001.682	1.823	-3.751-	2.438	-.498-
3.0	23001.682	1.823	-3.751-	2.438	-.498-
3.1	15992.681	2.159	-3.829-	3.496	-.399-
4.0	15992.681	2.159	-3.829-	3.496	-.399-
4.1	14698.610	2.871	-3.214-	3.345	-.240-

5.0	14698.610	2.871	-3.214-	3.345	-.240-
5.1	16999.556	4.411	-2.381-	1.554	-.209-
5.2	14205.314	3.241	-3.107-	3.022	-.219-
6.0	14205.314	3.241	-3.107-	3.022	-.219-
6.1	13732.666	3.894	-2.788-	2.365	-.213-
7.0	13732.666	3.894	-2.788-	2.365	-.213-
7.1	13458.604	5.245	-2.246-	1.475	-.217-
8.0	13458.604	5.245	-2.246-	1.475	-.217-
8.1	12249.797	5.964	-2.185-	1.347	-.231-
9.0	12249.797	5.964	-2.185-	1.347	-.231-
9.1	11699.159	7.282	-1.799-	1.015	-.228-
10.0	11699.159	7.282	-1.799-	1.015	-.228-
10.1	11319.142	9.956	-1.224-	.599	-.229-
11.0	11319.142	9.956	-1.224-	.599	-.229-
11.1	9714.724	12.667	-.917-	.456	-.235-
12.0	9714.724	12.667	-.917-	.456	-.235-
12.1	9563.240	18.080	-.208-	.238	-.231-
13.0	9563.240	18.080	-.208-	.238	-.231-
13.1	7715.976	20.808	-.173-	.218	-.237-
14.0	7715.976	20.808	-.173-	.218	-.237-
14.1	7067.196	25.845	.284	.158	-.232-
15.0	7067.196	25.845	.284	.158	-.232-
15.1	6301.173	31.296	.577	.113	-.229-
16.0	6301.173	31.296	.577	.113	-.229-
16.1	5674.666	42.197	1.184	.067	-.223-
17.0	5674.666	42.197	1.184	.067	-.223-
17.1	4525.453	53.109	1.521	.046	-.219-
18.0	4525.453	53.109	1.521	.046	-.219-
18.1	4113.816	74.931	2.254	.024	-.209-
19.0	4113.816	74.931	2.254	.024	-.209-
19.1	2806.495	96.763	2.635	.016	-.202-
20.0	2806.495	96.763	2.635	.016	-.202-
20.1	2662.956	140.424	3.465	.009	-.189-
21.0	2662.956	140.424	3.465	.009	-.189-
21.1	1507.950	162.260	3.566	.007	-.185-
22.0	1507.950	162.260	3.566	.007	-.185-
22.1	1235.565	205.927	4.113	.006	-.177-
23.0	1235.565	205.927	4.113	.006	-.177-
23.1	918.559	249.597	4.471	.005	-.170-
24.0	918.559	249.597	4.471	.005	-.170-
24.1	879.808	336.937	5.166	.004	-.160-
25.0	879.808	336.937	5.166	.004	-.160-
25.1	524.620	380.608	5.322	.004	-.156-

26.0	524.620	380.608	5.322	.004	-.156-
26.1	504.260	467.950	5.806	.003	-.150-
27.0	504.260	467.950	5.806	.003	-.150-
27.1	435.296	511.621	5.956	.003	-.147-
28.0	435.296	511.621	5.956	.003	-.147-
28.1	431.197	546.422	6.097	.003	-.145-
29.0	431.197	546.422	6.097	.003	-.145-
29.1	430.635	545.565	6.088	.003	-.145-
30.0	430.635	545.565	6.088	.003	-.145-
30.1	430.635	545.707	6.089	.003	-.145-
31.0	430.635	545.707	6.089	.003	-.145-
31.1	430.635	545.698	6.089	.003	-.145-

Derivatives are calculated numerically.

a. Major iteration number is displayed to the left of the decimal, and minor iteration number is to the right of the decimal.

b. Run stopped after 65 model evaluations and 31 derivative evaluations because the relative reduction between successive residual sums of squares is at most SSCON = 1.00E-008.

Table 4.2 Parameter estimates

Parameter	Estimate	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
a	545.698	42.554	461.414	629.983
b	6.089	.177	5.739	6.438
c	.003	.001	.002	.004
d	-.145-	.015	-.174-	-.116-

Table 4.3 ANOVA^{a} result

Source	Sum of Squares	df	Mean Squares
Regression	124839.106	4	31209.776
Residual	430.635	116	3.712
Uncorrected Total	125269.740	120	
Corrected Total	7426.644	119	

Dependent variable: fall^{a}

a: R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = 942.

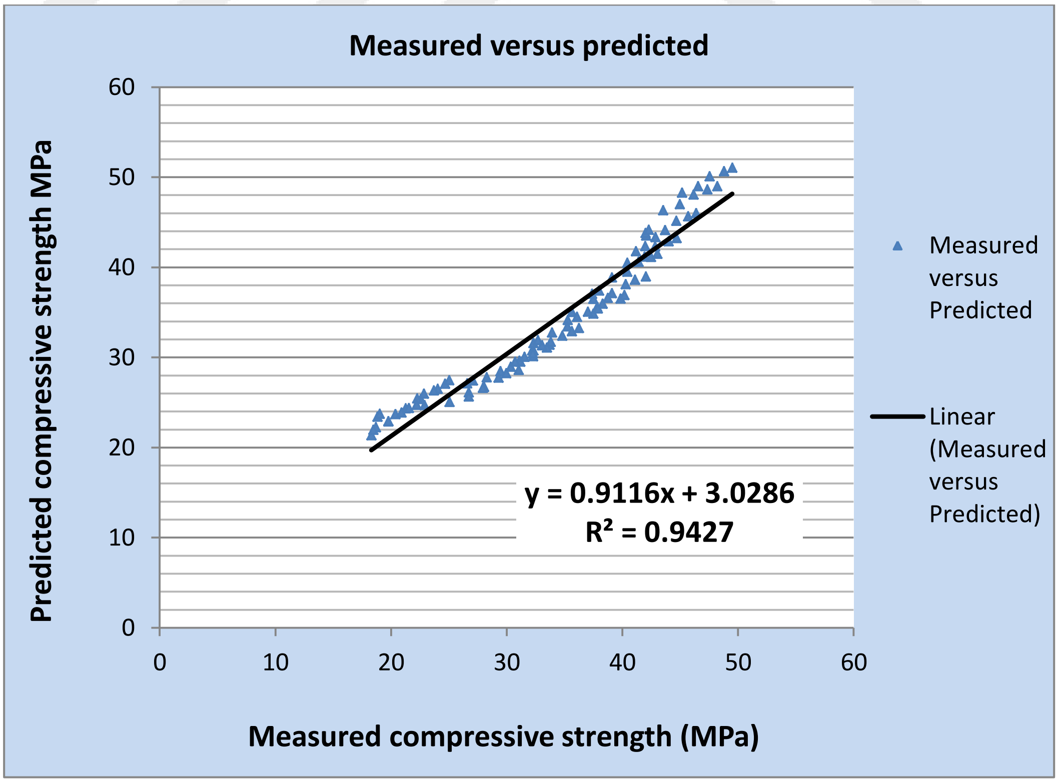


Figure 4.3 Predicted versus measured compressive strength of GPC

4.5.4 Application example

Suppose age of GPC = 7 days

Total amount of aggregate = 1230 + 660 = 1890 kg/m^3

Maximum size of aggregate =19.0 mm

Fly Ash content = 400 kg/m^3

Volume of fly ash = 400 / 2.2 = 181.81 L

Alkaline liquid to fly ash ratio = 0.45

Alkaline liquid = 0.45*400 = 180 kg/m^3

Na_2SiO_3/ NaOH = 2.5

Na_2SiO_3 Solution = 128.5 kg

NaOH Solution = 51.5 kg

Molarity NaOH = 12

The water utilized for making NaOH Solution = 0.639 * 51.5 = 32.91 kg

Solid weight of NaOH flakes = 0.361 * 51.5 = 18.59 kg

Solid Volume of NaOH = 18.59 / 2.13 = 8.73 L

The water utilized for making Na_2SiO_3 Solution = 0.559 * 128.5 = 71.83 kg

Solid weight of Na_2SiO_3 = 0.441* 128.5 = 56.67 kg

Solid Volume of Na_2SiO_3 = 56.67 / 2.4 = 23.61 L

Total volume of solids = Volume of fly ash + Volume of NaOH flakes + Volume of solid Na_2SiO_3

Total volume of solids = 181.81 + 8.73 + 23.61 = 214.15 L

Total volume of water = Volume of water in NaOH + Volume of water in Na_2SiO_3 + Volume of extra water added

Consider volume of extra water added = 30 kg/m^3

Total volume of water V_{tw} = 32.91 + 71.83 + 30 = 134.74 kg

Total volume of Solids $V_{gs} = 214.15$

D (t) = 0.003* Log (7) = 0.0025

$$MPT^{d} = 19 * \left(\sqrt[3]{\frac{0.78}{0.704}} - 1\right) = 0.65$$

Substitute in the modified Ferret equation

$$\boldsymbol{fc(7) = 545.698 * \left[0.0025 + \left(\frac{214.15}{214.15 + 134.74}\right)^{6.089}\right] * 0.65^{-0.145}}$$

$fc(7) = 31.2\ MPa$ Compared to actual strength 33.71 MPa

4.5.5 Procedure for the mix design of GPC

Suppose the strength of geopolymer concrete required at age of 28 day =40 MPa, and suppose that the molarity of NaOH =14.Then the percentage of water and solids for making NaOH solution can be determined from the following (Table 4.4).

Table 4.4 Percentage of water and solids for making NaOH solution

Molarity	8	10	12	14	16
% (NaOH) Flakes	26.2	31.4	36.1	40.4	44.4
% Water	73.8	68.6	63.9	59.6	55.6

Strength ratio= 0.92

Strength ratio at any M16/M12 = 0.92

Strength required at M16 = M12 * 0.92

Strength required at M16 = 40 MPa

Then characteristic strength required at M12= 40 / 0.92

= 43.47

From Figure (4.6) , determine $\frac{\boldsymbol{water}}{\boldsymbol{Geopolymer\ Solid}}$ required for making GPC.

At the specified age and for the available maximum size of aggregate suppose maximum size of aggregate=19.0 mm

Water / Solid ratio = 0.25

Consider Alkaline to fly ash ratio = 0.45

$$\frac{(\boldsymbol{W_{NaOH}} + \boldsymbol{W_{Na2SiO3}} + \boldsymbol{Extra\ W})}{(\boldsymbol{S_{FA}} + \boldsymbol{S_{NaOH}} + \boldsymbol{S_{Na2SiO3}})} = \mathbf{0.25}$$

$0.25{*}(S_{FA} + S_{NaOH} + S_{Na2SiO3}) = (W_{NaOH} + W_{Na2SiO3} + Extra\ W)$

$0.25{*}(FA + 44.4 + 44.1) = (55.6\ + 55.9 + Extra\ W)$

If we consider FA= 400 kg/m^3

Then extra water = 10.62 ≅11 kg /m^3

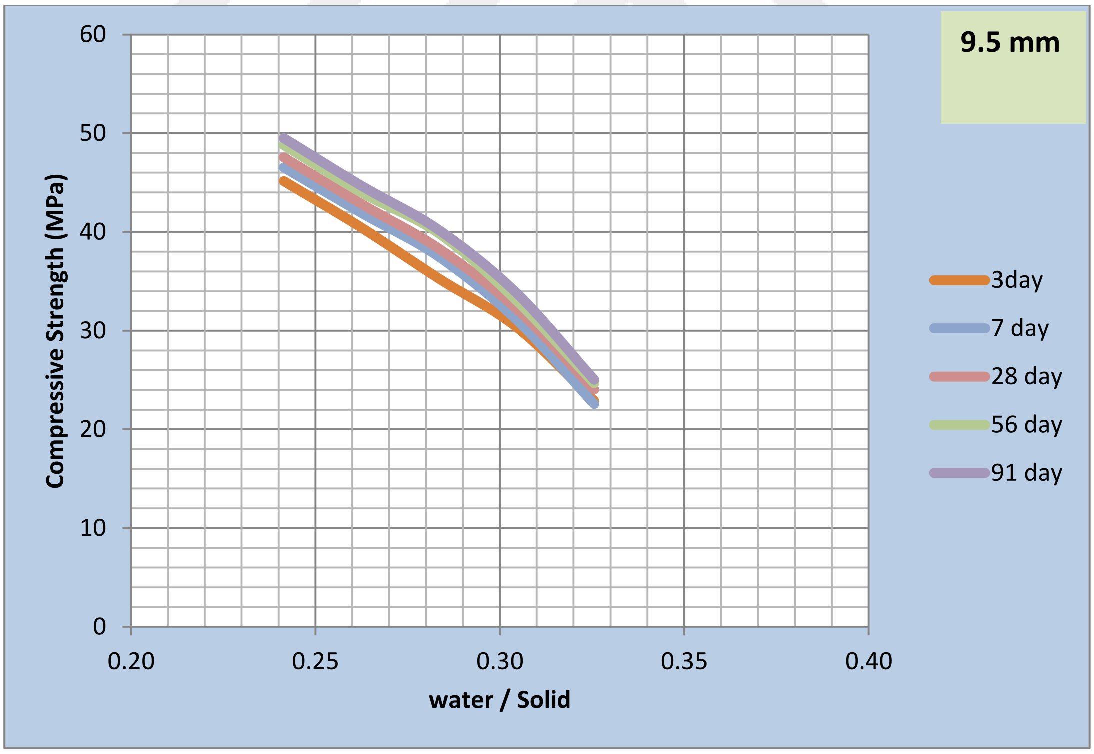


Figure 4.4 Effect of water to solid ratio on the compressive strength of geopolymer concrete at different ages and different maximum sizes of aggregate

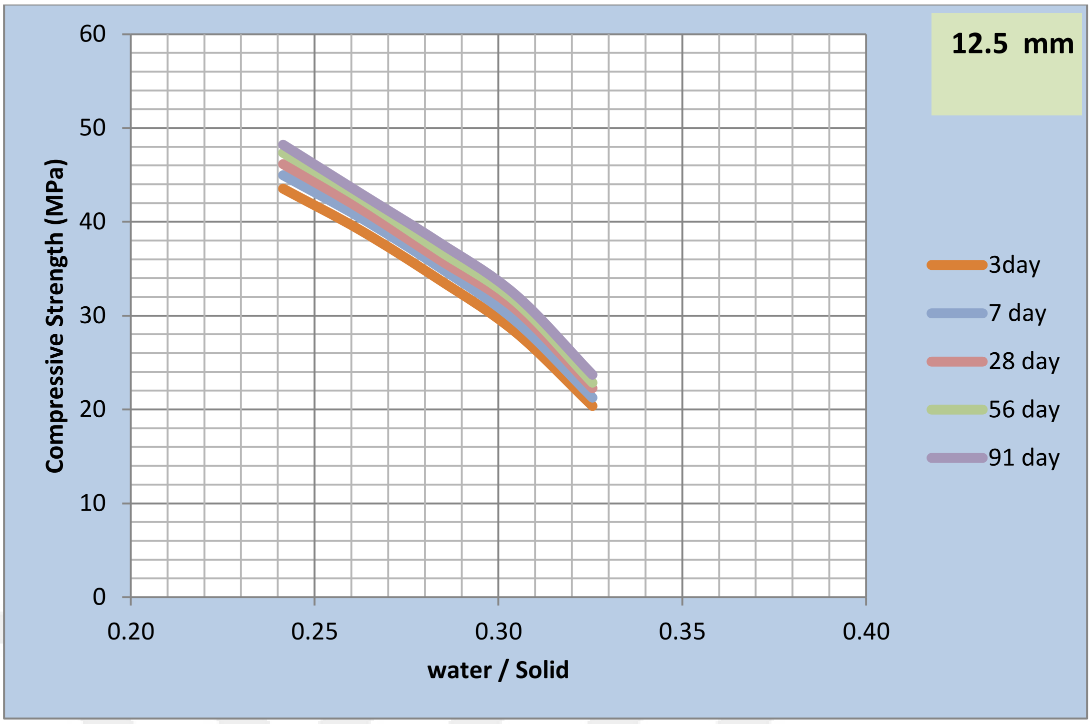


Figure 4.5 Effect of water to solid ratio on the compressive strength of geopolymer concrete at different ages and different maximum sizes of aggregate

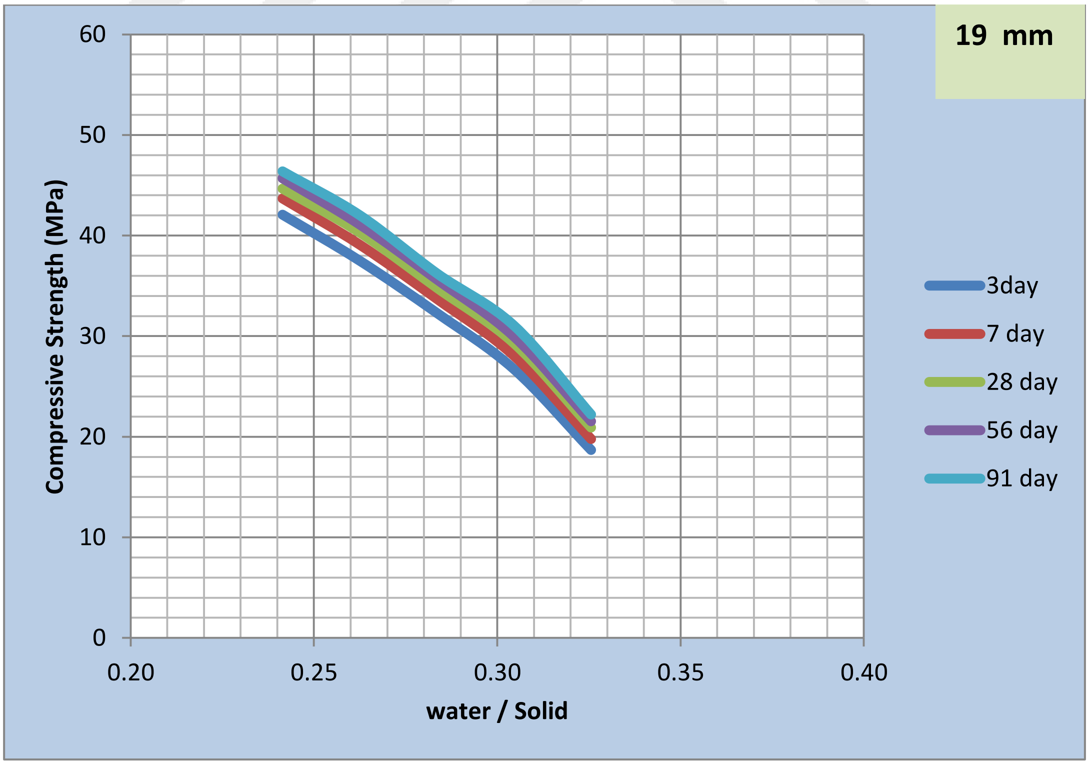


Figure 4.6 Effect of water to solid ratio on the compressive strength of geopolymer concrete at different ages and different maximum sizes of aggregate

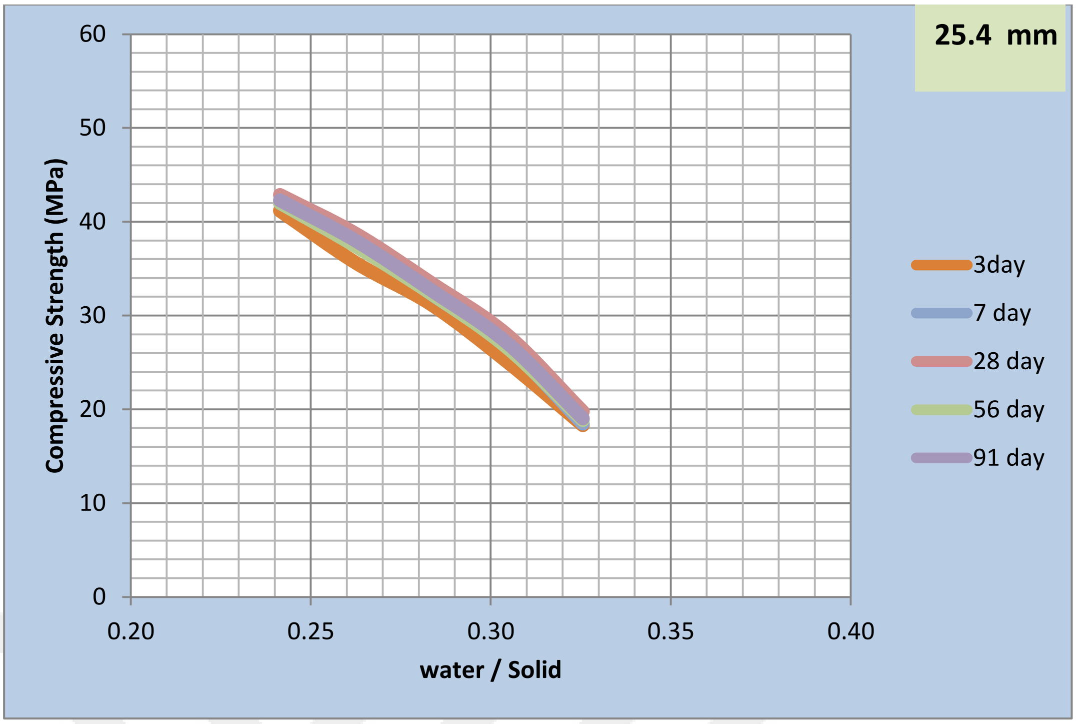


Figure 4.7 Effect of water to solid ratio on the compressive strength of geopolymer concrete at different ages and different maximum sizes of aggregate

4.5.6 Estimate density of GPC

As the age of concrete increases, there is a slight increase in the average density. The density of geopolymer concrete composites was found approximately equivalent to that of conventional concrete. The weight of fresh and hardened geopolymer concrete measured see Table 4.5. The density varied with Fneness of Fly ash we can find density by chart or type of aggregate see Figure 4.8.

The difference between take compressive strength in laboratory with using equation 7 is small, the Feret equation is modified to new equation so after used new equation Equation 7 then compared to laboratory compressive strength result, the equation have good result.

After pass equation in stastitcl analysis, we used to all mix in the experimental study. For checked and compared tow type results we created tow below table. Table 4.6 is the result in the laboratory and Table (4.7) is the predicted result from used new modified equation equation 7.

Table 4.5 Density of geopolymer concrete

$\frac{Water}{Geopolymer\ Solid}$	Density of Geopolymer Concrete Kg/m^3	
	Fresh	**Hardened**
0.2404	2480	2448
0.2676	2490	2458
0.2959	2500	2467
0.3255	2510	2476
0.3565	2520	2484

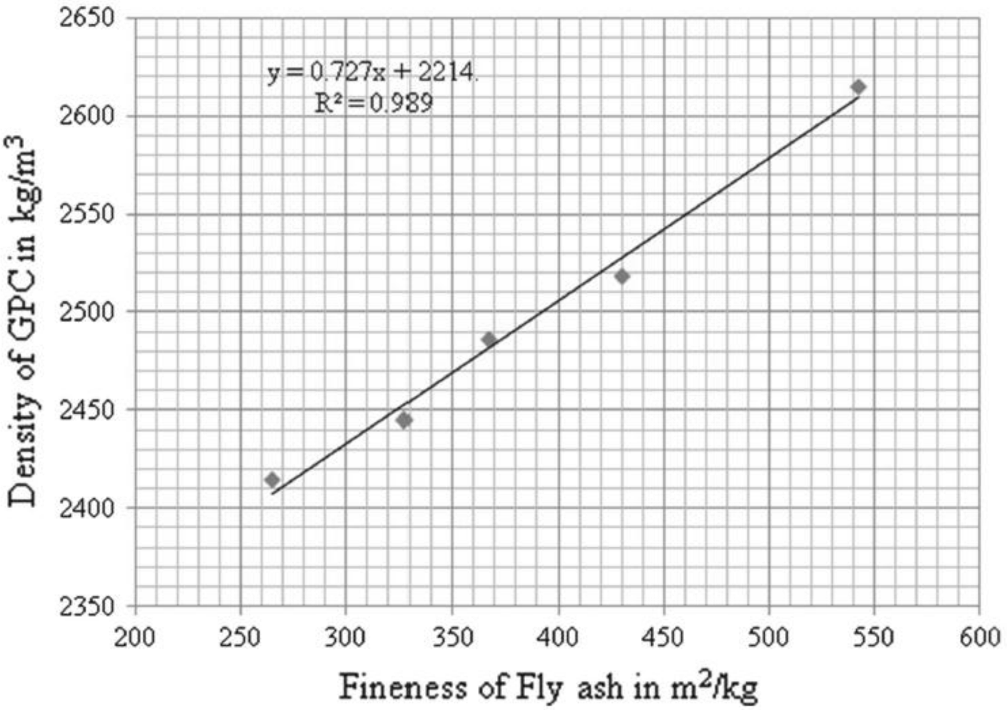


Figure 4.8 Relation between fineness of fly ash and density of geopolymer concrete

Table (4.6) Experimental result in laboratory

group	Mix	Compressive strength (Mpa)				
		3 Day	7 Day	28 Day	56 Day	91 Day
1	1	45.15	46.54	47.55	48.81	49.5
	2	40.72	41.93	42.85	44	44.69
	3	35.55	37.48	38.83	39.86	40.19
	4	29.89	31.1	32.2	33.06	33.81
	5	22	22.57	24.04	24.67	25.04
2	6	43.53	44.96	46.15	47.35	48.21
	7	39.1	40.43	41.4	42.47	43.04
	8	33.93	35.26	36.07	37.03	37.89
	9	28.27	29.47	30.73	31.54	32.26
	10	20.38	21.26	22.27	22.85	23.7
3	11	42.07	43.69	44.66	45.69	46.38
	12	37.5	39.09	40.3	41.1	42.03
	13	32.31	33.71	34.81	35.64	36.25
	14	26.72	28.05	29.29	29.97	31.05
	15	18.68	19.77	20.91	21.54	22.21
4	16	40.63	41.99	42.86	44.02	45.06
	17	35.95	37.82	38.73	39.6	40.89
	18	30.73	32.3	33.47	34.36	35.09
	19	25.38	26.71	27.95	28.69	29.58
	20	17.23	18.47	19.76	20.3	21.04

Ttable (4.7) Predicted result by new modified equation

group	Mix	Compressive strength (Mpa)				
		3 Day	7 Day	28 Day	56 Day	91 Day
1	**1**	48.29	48.98	50.10	50.67	51.05
	2	40.50	41.18	42.31	42.87	43.25
	3	34.16	34.84	35.97	36.53	36.91
	4	28.97	29.65	30.78	31.34	31.72
	5	24.70	25.39	26.51	27.07	27.46
2	**6**	46.35	47.01	48.08	48.62	48.99
	7	38.86	39.52	40.60	41.14	41.51
	8	32.78	33.44	34.52	35.05	35.42
	9	27.80	28.46	29.54	30.08	30.44
	10	23.70	24.36	25.44	25.98	26.35
3	**11**	43.53	44.14	45.16	45.66	46.01
	12	36.50	37.12	38.13	38.64	38.98
	13	30.78	31.40	32.41	32.92	33.27
	14	26.11	26.73	27.74	28.24	28.59
	15	22.26	22.88	23.89	24.40	24.74
4	**16**	41.77	42.36	43.34	43.82	44.15
	17	35.03	35.62	36.59	37.08	37.41
	18	29.54	30.14	31.11	31.59	31.93
	19	25.05	25.65	26.62	27.11	27.44
	20	21.36	21.96	22.93	23.41	23.75

The Figuers (4.9 to 4.13) shows the results of predicted and laboratoray compressive strength at different ages of conceret.

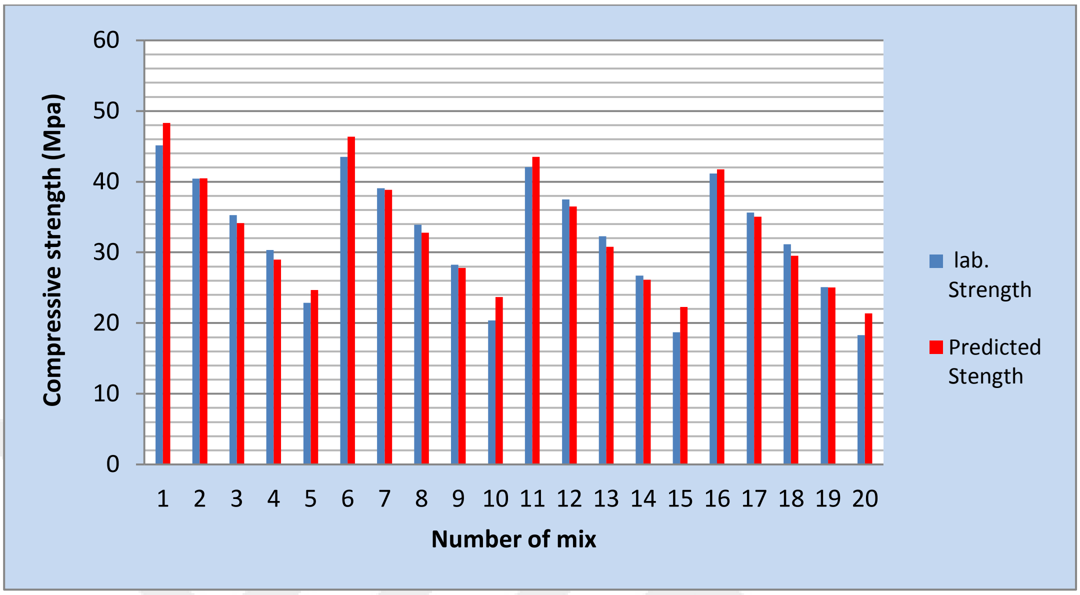


Figure 4.9 The results of predicted and laboratoray compressive strength at 3 day

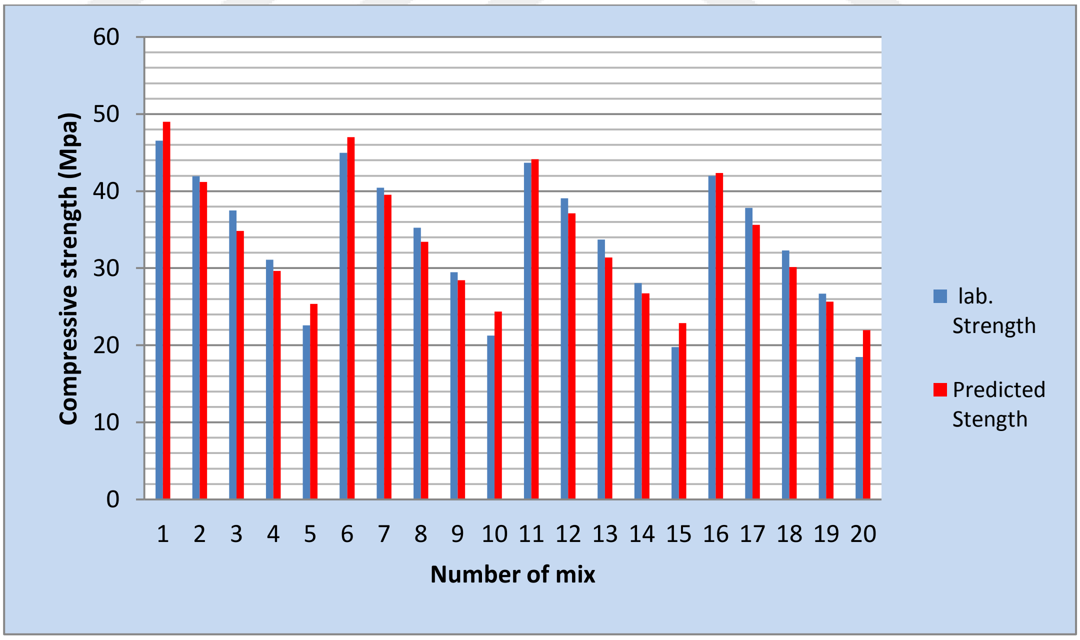


Figure 4.10 The results of predicted and laboratoray compressive strength at 7 day

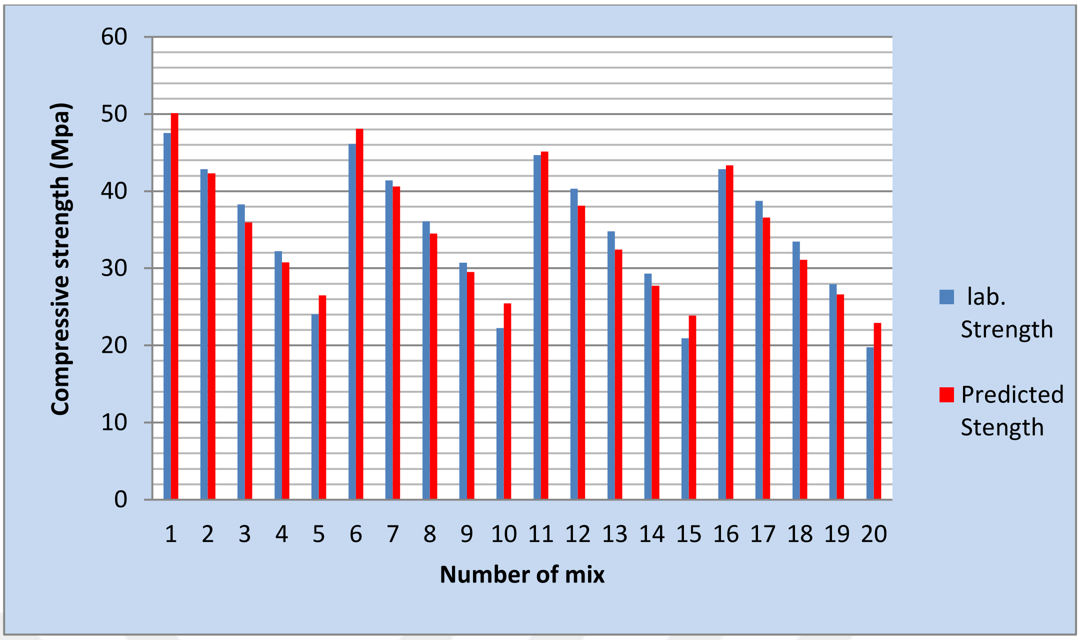


Figure 4.11 The results of predicted and laboratoray compressive strength at 28 day

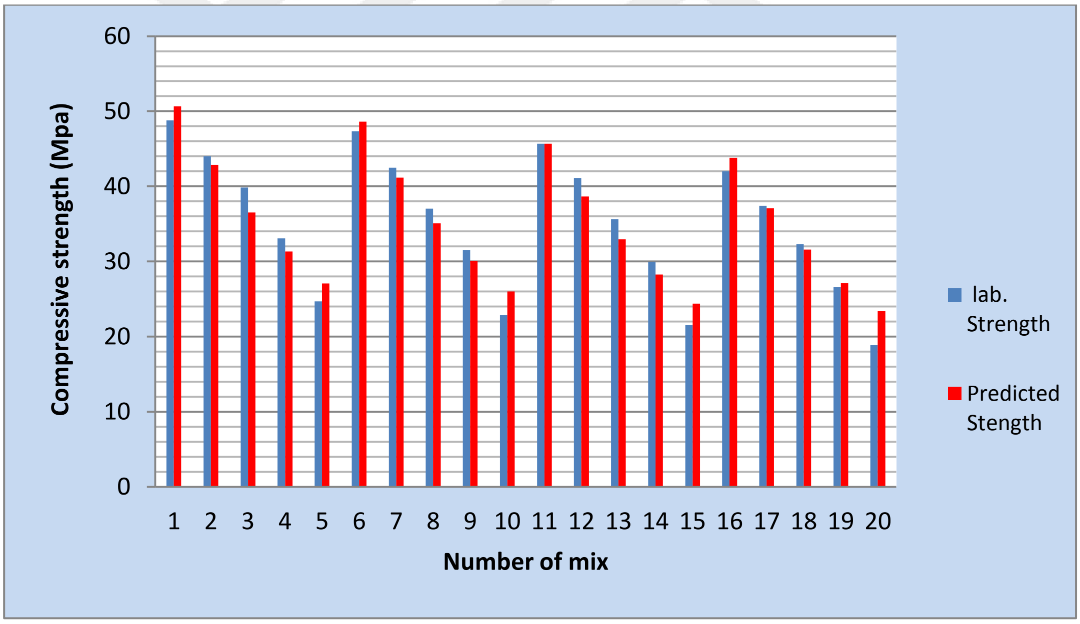


Figure 4.12 The results of predicted and laboratoray compressive strength at 56 day

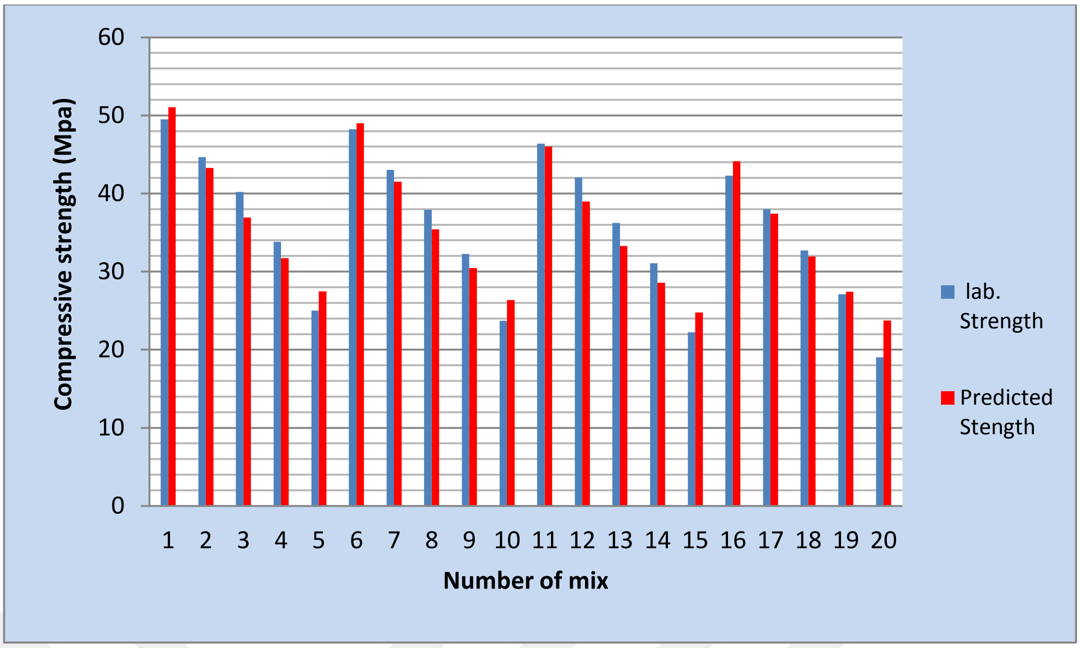
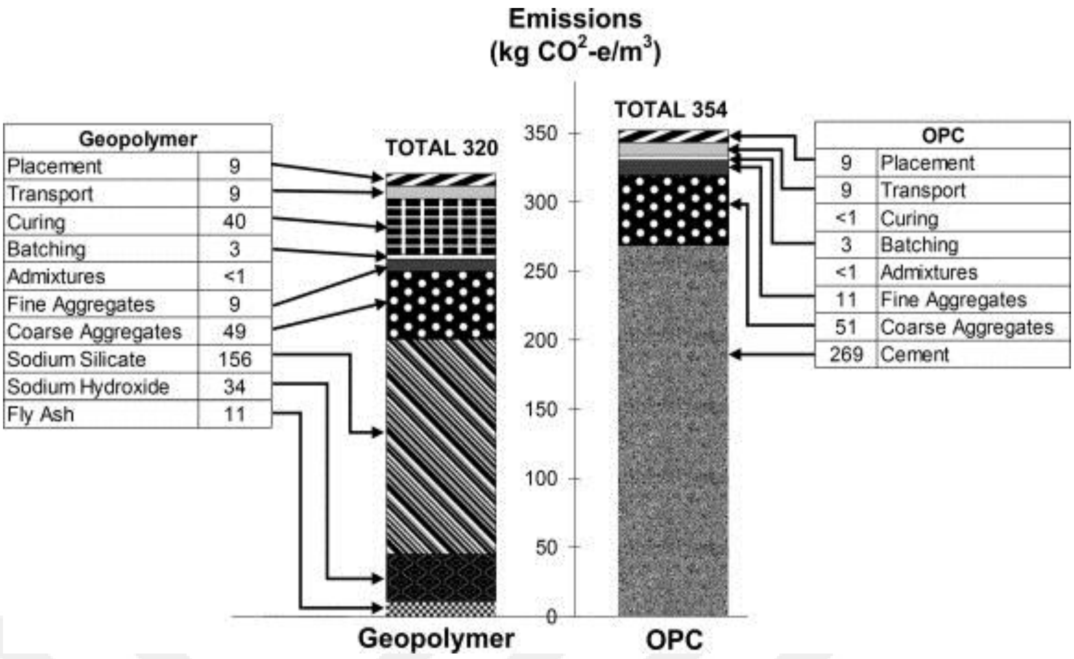


Figure 4.13 The results of predicted and laboratoray compressive strength at 91 day

4.6 Comparison between GPC with OPC about CO_2

The greenhouse gases emissions during the life cycle of geopolymer concrete are approximately 62 to 66 % lower than emissions from the reference concrete (Fawer et al., 1999). The geopolymer cement has calicum 80% lower embodied greenhouse gas intensity than an equivalent amount of ordinary Portland cement binder used in reference concrete of a similar strength, confirming the data published by the Geopolymer Institute, where the reductions are in the range of 70 to 90 % (Habert et al.,2011).

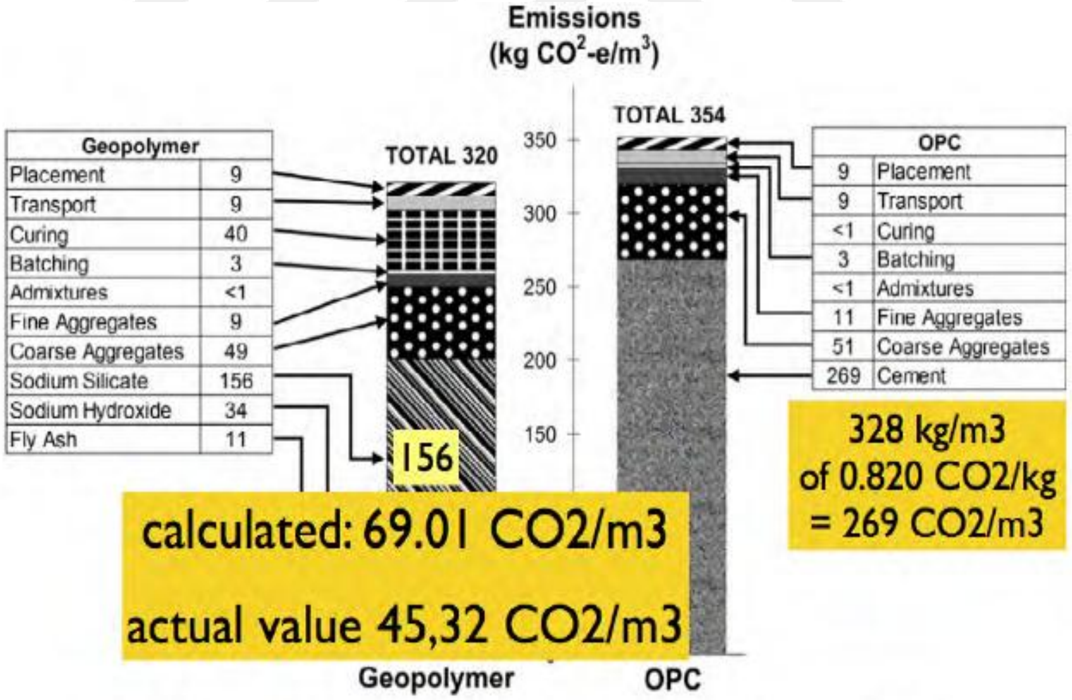
We hope this selection will inspire additional, and much-needed, research on the environmental implications of genuine geopolymer cement mix designs, bearing in mind that industrialization and commercialization already started with the production of structural geopolymer concretes for public buildings and infrastructure airport see Figure 4.14 and 4.15.



Geopolymer	
Placement	9
Transport	9
Curing	40
Batching	3
Admixtures	<1
Fine Aggregates	9
Coarse Aggregates	49
Sodium Silicate	156
Sodium Hydroxide	34
Fly Ash	11

OPC	
9	Placement
9	Transport
<1	Curing
3	Batching
<1	Admixtures
11	Fine Aggregates
51	Coarse Aggregates
269	Cement

Figure 4.14 Comparison between GPC with OPC



Geopolymer	
Placement	9
Transport	9
Curing	40
Batching	3
Admixtures	<1
Fine Aggregates	9
Coarse Aggregates	49
Sodium Silicate	156
Sodium Hydroxide	34
Fly Ash	11

OPC	
9	Placement
9	Transport
<1	Curing
3	Batching
<1	Admixtures
11	Fine Aggregates
51	Coarse Aggregates
269	Cement

156

calculated: 69.01 CO2/m3

actual value 45,32 CO2/m3

328 kg/m3
of 0.820 CO2/kg
= 269 CO2/m3

Figure 4.15 Comparison between GPC with OPC about CO_2

4.7 Summary

This chapter dealt with the statistical analysis to find the best fit equation predicts compressive strength of geopolymer concrete from its mixture proportion, where the compressive strength is one of the desired and required properties of hardened concrete. The main concept of finding the equation is derived from the feret model. It can be summarized as follows.

- The main ingredients of geopolymer concrete are listed, then necessary requirements for the mixture proportion has placed, which are interconnected with the requirements of conventional concrete.
- All the factors that effects on the compressive strength of geopolymer concrete and related to the ingredient materials are listed.
- Some of the most important previous models that predicts compressive strength of conventional concrete are mentioned, one of these models found out by feret in 1897 predicts compressive strength of conventional concrete from the concentration of cement in cement paste, the model developed by de Larrard in the nineteenth of the last century to include maximum paste thickness around aggregate particles and the effect of age of conventional concrete. This is the most important model for the mixture proportion of concrete.
- New model derived from Feret model to predict compressive strength of Geopolymer concrete from the concentration of solid material in the binder paste material, Solid material includes, fly ash and other solids coming from the alkaline solution, while total water in the binder paste materials includes, water from alkaline solution plus extra water if added.
- A regression analysis has been done to new model to find the empirical constant of the best fit equation with a highest coefficient of determination $R^2 = 0.943$ and lowest loss function expressed by residual mean squares. Statistical analysis showed that new model is applicable to geopolymer concrete.

- A new procedure is proposed for the mixture proportion to determine the quantities of ingredients required to produce gepolymer concrete from the minimum compressive strength specified by structural engineer.
- The greenhouse gases emissions during the life cycle of geopolymer concrete are approximately 62%-66% lower than emissions from the ordinary portland cement concrete.

CHAPTER 5
RESULTS AND DISCUSSION

5.1 Introduction

This Chapter discusses the investigative results. The compressive quality test results presented in various figures or tables are all related to the average evaluation of the compressive attributes of three test concrete solid shapes within a configuration. The values of standard deviations are plotted on the test information points in the form of mistake bar. Section (5.4) of this chapter discusses the effect of various essential factors on the compressive strength of geopolymer concrete based on fly fiery remains.

The following parameters are taken into account:

- Concrete age.
- Activator liquid-to-fly ash ratio, by mass.
- The concentration of sodium hydroxide solution, in molar.
- The inclusion of superplasticiser.
- Sodium silicate solution-to-sodium hydroxide solution ratio, by mass.
- Handling time.
- Curing time.
- Extra water to mixture.
- Different aggregate size.

5.2 Workability

To examine workability of geopolymer concrete, slump test has been used successfully. The outcomes showed that there are low levels of alkali-soluble calcium. The slump loss of geopolymer concrete having low calcium fly cinder seems to be the same or less than that of Ordinary portland concrete.

It has also been found that the seeping of geopolymer concrete is less than that of Ordinary portland concrete. It is observed that there is sufficient workability when the water-to-geopolymer solids proportion by mass is higher than 0.22, and low water retention values are used. The blends for this examination are all in the range of 0.24 to 0.36. The workability can be expanded with the utilization of a superplasticiser. The superplasticiser rate is utilized 2% of the mass of fly ash.

5.3 Compressive strength results

The compressive quality of concrete is one of the significant criteria received to assess the nature of concrete for various applications, and auxiliary outline of concrete is generally in light of its esteem. Quality of concrete, as of now examined in part 6 is its protection from stress and it might be estimated in various routes, among which, uniaxial compressive quality is presumably the most essential. The mechanics of disappointment is a perplexing wonder. See Table 5.1. The results to all blend it can be accepted that the solid in opposing disappointment produces both union and interior grinding.

The attachment and inside erosion created by concrete in opposing disappointment are connected for the most part to the water to folio proportion and curing temperature. As it, depended on the first water to cover proportion administer, for a given fastener and adequate totals, the quality that might be created by workable blend of folio, total and water.

5.4 Test procedure

The compressive strength of geopolymer concrete was determined by preparing each mixture as 150xl50xl50 mm. UNI (2003) (BS EN 12390-3:2000). Was used to determine the compressive strength of these samples. Chapter three explains the methods of casting and curing. For every mixture, three samples were tested at 3, 7, 28, 56, and 90 days and the results were obtained by calculating the average compressive strength from these values.

The following formula was used to determine the compressive strength:

Fcu =P/A Eq (5.1)

Where:

Fcu: Signifies the cube compressive strength in N/mm^2

P: Signifies the highest applied to the cube in N

A: Refers to the area of the concrete surface in mm^2

A: Constant rate of load increase of 2 KN/S was used by the crushing machine to determine the compressive strength.

5.4.1 Relationship between compressive strength and density

Compressive strength also increased when there was an increase in density, similar to normal concrete, which showed that compressive strength and density of geopolymer concrete were directly proportional.

5.4.2 Effect of age on compressive strength of geopolymer concrete

On the compressive strength of fly ash-based geopolymer concrete, many tests done to explore the influence of age. To examine the impact of age, another arrangement of experiments was performed as well as on the compressive quality of fly fiery was the same to be concrete of based geopolymer.

Due to the substantially fast polymerisation process, the chemical reaction of the heat-cured geopolymer concrete can be the compressive strength that is impossible to vary by the age of concrete. Contrary to the conventional characteristic of Ordinary portland concrete, this observation was, besides, to gain the strength over time as well as to undergo the process of hydration.

However, to contrast age and compressive quality we take Group two; this gathering has five mixture M6, M7, M8, M9, and M10, See Table 5.1. Demonstrates the impact of age on the compressive quality for these examples. The test 3D shapes were monitored 24 hour rest period and addressed for 24 hour in the furnace at 70^{o}C.

Since the compound response of the warmth utilised cured geopolymer concrete is because of the considerably quick polymerisation process, the compressive quality does not fluctuate with the time of cement.

This perception is as opposed to the outstanding conduct of Ordinary portland solid, which experiences hydration process and henceforth picks up quality after some time.

Table 5.1 Effect of age on the compressive strength

Group 2	**Compressive strength (MPa) with Age (days)**				
	3	**7**	**28**	**56**	**90**
Mix 6	43.53	44.96	46.15	47.35	48.21
Mix 7	39.10	40.43	41.40	42.47	43.04
Mix 8	33.93	35.26	36.07	37.03	37.89
Mix 9	28.27	29.47	30.73	31.54	32.26
Mix 10	20.38	21.26	22.27	22.85	23.70

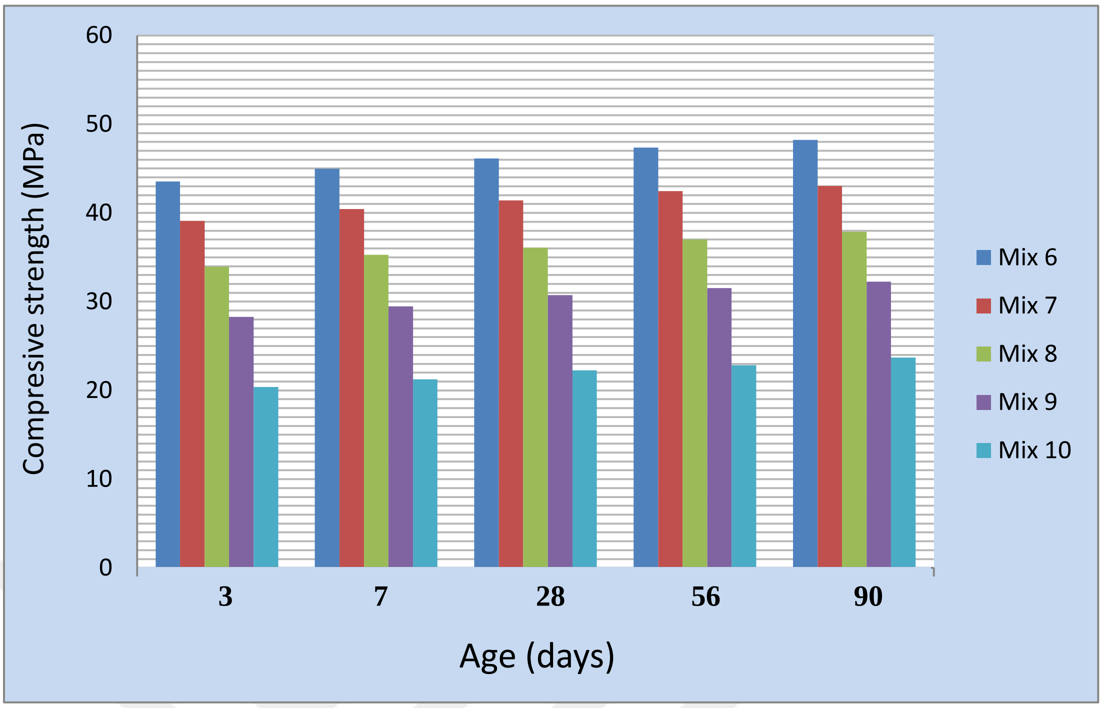


Figure 5.1 Effect of age on the compressive strength

Figure 5.1 demonstrates the impact of age on the compressive quality for these examples. This Figure affirms that the compressive quality of warmth cured fly fiery debris based geopolymer concrete does not shift with time of cement.

The geopolymer concrete does not require a long time to take high quality, it is not same customary Portland bond concrete, however for thought about between geopolymer concrete and typical solid we threw two blends for everyone. See Table 5.2 the outcome of both kind of concrete at a similar age. In this investigation is clear for both kind of solid what age is sufficient to great quality, see Figure 5.2 to the contrasted diverse quality and same age.

Table 5.2 The result for both type of concrete

Type	**Group 9**	**Compressive strength (MPa) with Age (days)**				
		3	**7**	**28**	**56**	**90**
OPC	**Mix 37**	15.39	28.57	39.63	41.82	43.56
GPC	**Mix 38**	45.78	47.14	48.25	49.31	50.42

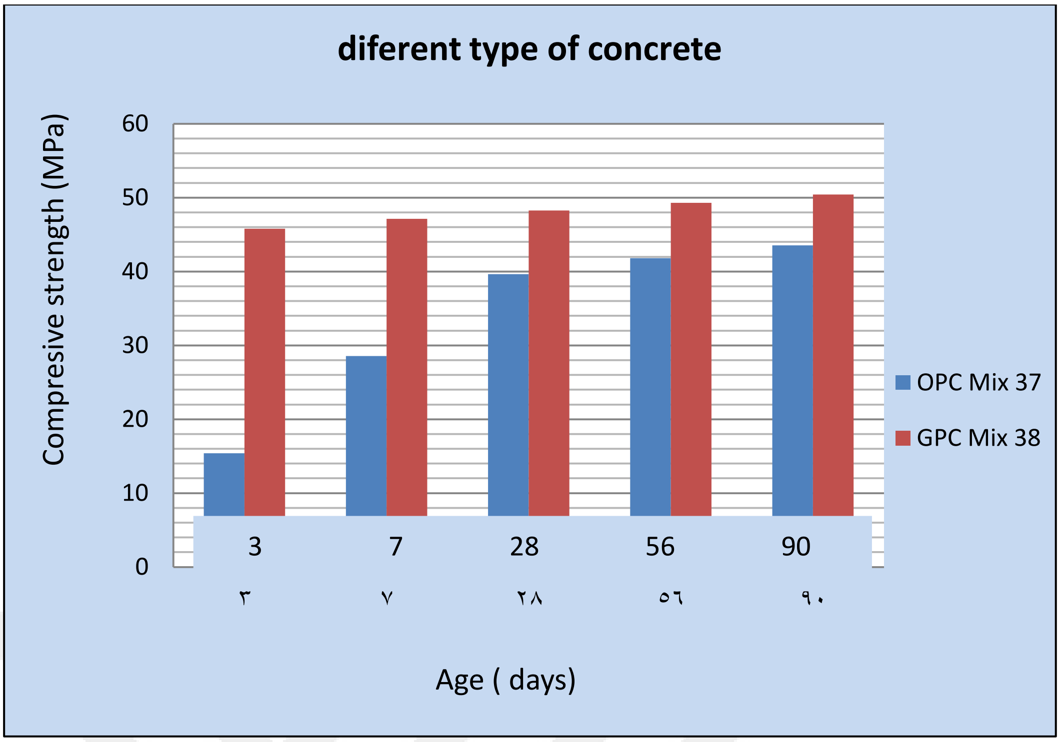


Figure 5.2 The compared different strength with same age

For geopolymer concrete at seven day age was accomplished 85-90 % rate from compressive quality yet for ordinary cement at 28 day was performed 90% rate from compressive quality.

However, for geopolymer solid age isn't fluctuating, seven day is sufficient to take great quality this property is essential at work in the site and a terrible climate.

5.4.3 Effect of extra water on compressive strength of GPC

Water has a significant influence on the characteristic of geopolymer. In standard Ordinary portland concrete, water in the blend synthetically responds with the cement to deliver glue that ties the totals. In the fly fiery debris based geopolymer solid, water in the blend does not cause a substance response because the synthetic procedure that jumps out at delivering the cover is because of polymerisation. With a particular purpose to set up the impact of water content in the blend, tests were performed. Nonetheless, lab encounter demonstrated that water content in the geopolymer solid blend influenced the properties of cement in the new state and additionally in the solidified state.

The blend extents for these arrangements of tests were gotten from many trial blends. The impact of water content in the group one, five arrangements of mixtures 1, 2, 3, 4, and 5 were made. In the main set to five-set Mixtures, include 10, 20, 30, 40, and 50 kg per meter cube separately was produced.The test factors were (H_2O-to-Na_2O and Na2O-to-SiO_2). Concerning H_2O-to-Na_2O molar proportion, just the range from (8 to 16) was observed to be plausible. For H_2O-to-Na_2O molar proportion under 8 the solid blends were not effectively workable; then again, for estimations of this proportion more noteworthy than around 16 extensive isolation of blend fixings happened due to the nearness of abundance water.

The test 3D shapes were cured for 24 hour. At before diagram shows the impact of extra water proportion on the compressive quality of geopolymer concrete for different curing temperatures. However, it would be appropriate to test the behaviour of fly ash based mixtures blended with additives and containing additional water as it improves the workability which may be necessary for some applications. The subtle elements of these mixtures are given in Table 5.3 and Figure 5.3.

The motivation behind this set was to explore the impact of Extra water proportion on the compressive qualities of cement, while the molar proportions of different oxides in the blends are steady is 12 M, and all other variables are consistent.Expansion in this proportion diminished the compressive quality of cement. As the Extra water proportion expanded, the blends contained more water and turned out to be more workable. In Table 5.3 shows the impact of water to geopolymer bainder ratio proportion on the compressive quality of fly fiery debris based geopolymer concrete. It should be observed that the compressive quality diminished just imperceptibly when the Extra water proportion expanded from 20 to 30.

Table 5.3 Result effective different extra water

Group 1	**Compressive strength (MPa) with Age (days)**				
	3	**7**	**28**	**56**	**90**
Mix 1	45.15	46.54	47.55	48.81	49.50
Mix 2	40.72	41.93	42.85	44.00	44.69
Mix 3	35.55	37.48	38.83	39.86	40.19
Mix 4	29.89	31.10	32.20	33.06	33.81
Mix 5	22.00	22.57	24.04	24.67	25.04

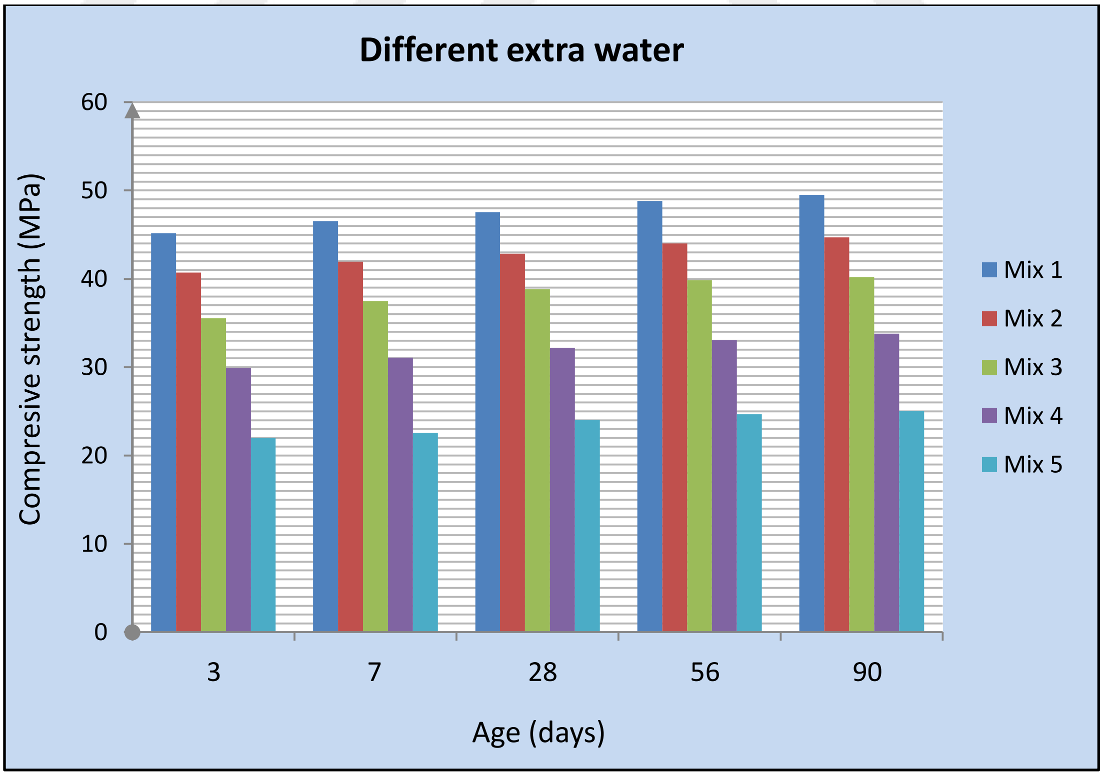


Figure 5.3 Effective different of extra water

In these test, information demonstrates that any adjustment in the water content alone does not influence the sodium hydroxide arrangement fixation since all response completed following 24 hour amongst water and sodium hydroxide powder. The test information was exhibited in Table 5.8. Shows that the compressive quality of geopolymer concrete diminished as the proportion of water to-geopolymer solids by mass expanded. This test drift closely resembles the notable impact of water-to-bond proportion on the compressive quality of Portland bond concrete. In any case, the nearness of additional water in the blend enhanced the workability new concrete, as delineated by the droop test information of these Mixtures plotted in another segment.

5.4.4 Effect of curing temperature on compressive strength of GPC

This research showed that the curing of geopolymer concrete at higher temperatures, up to 60°C, would yield a higher compressive strength than at a lower temperature, yet any increase in curing temperature over this threshold made no substantial difference to its strength. About curing the rate temperature is very important and Excessive evaporation may change the mixture and would cause a less dense concrete with a weaker compressive strength. It is recommended during the curing of geopolymer concretes at temperatures up to 100°C; samples should be wrapped and then sealed to prevent excessive evaporation of the samples during curing, investigated the effects of conditions of curing on the properties of geopolymer concrete. It was found that strength properties of geopolymer significantly increase with the increase in the temperature rate of curing; the setting of geopolymer is measured among a few minute and a few hours at ambient temperature. The material then continues to evolve fast and reaches about 80 – 90% of its final compressive strength in a few hour or day, on geopolymer concrete showed that the curing temperature has an essential effect on setting and hardening. Higher temperatures increase the early age development of compressive strengths. See Table 5.4 about rate temperature.

Table 5.4 Effective of rate temperature on compressive

Group 8	**Compressive strength (MPa) with Age (days)**				
	3	**7**	**28**	**56**	**90**
Mix 35	0.00	6.15	16.37	20.77	30.27
Mix 36	36.05	38.98	41.11	42.32	42.99

In this research showed found that the curing of geopolymer concrete at higher temperatures, up to 60°C, would yield a higher compressive strength than at a lower temperature, yet any increase in curing temperature over this threshold made no substantial difference to its strength. About curing the rate temperature is very important and excessive evaporation may change the mixture and would cause a less dense concrete with a weaker compressive strength. It is recommended during the curing of geopolymer concretes at temperatures up to 100°C; samples should be wrapped and then sealed to prevent excessive evaporation of the samples during curing, investigated the effects of conditions of curing on the properties of geopolymer concrete. It was found that strength properties of geopolymer significantly increase with the increase in the temperature rate of curing; the setting of geopolymer is measured between a few minute and a few hours at ambient temperature. See Figure 5.4. The material then continues to evolve fast and reaches about 80 to 90 % of its final compressive strength in a few hours or day, on geopolymer concrete showed that the curing temperature has an essential effect on setting and hardening. Higher temperatures increase the early age development of compressive strengths.

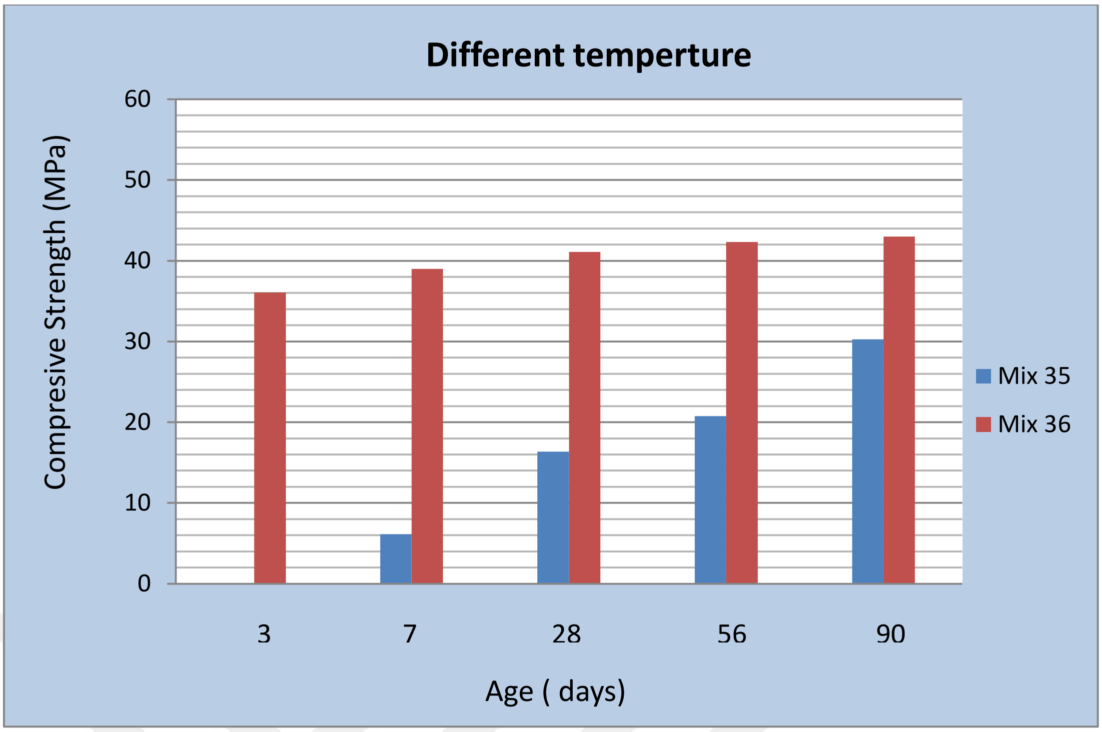


Figure 5.4 Effective of rate temperature on compressive

5.4.5 Effect of change molarity on compressive strength of GPC

The impact of sodium hydroxide focus on the compressive quality of geopolymer concrete.in this examination has five diverse molarity at group five register mixtures Mix21, Mix22, Mix23, Mix24,and Mix25 The test outcomes appeared in Table 5.5 exhibit that the compressive quality of geopolymer solid increments with the expansion in the convergence of sodium hydroxide.

Compressive quality of solid examples increments as sodium hydroxide fixation in the fluid stage increments from 8 M to 12 M in any case, it marginally increments with the further increment in sodium hydroxide focus from 12 M at that point diminish from 14 M to 16 M.

In any case, there is variety in the quality amongst 8 M and 16 M. It is acknowledged that an expansion in soluble base focus upgraded geopolymerization process coming about to an increment in the compressive quality of geopolymer concrete.

Their examination demonstrated that when activator fixation expanded above 16 M, a lower rate of polymer development was created bringing about the marginally lessening of mechanical quality.

Table 5.5 Result to different molarity

Molarity	Group 5	Compressive strength (MPa) with Age (days)				
		3	7	28	56	90
8	**Mix 21**	32.21	33.63	34.87	35.66	36.86
10	**Mix 22**	36.05	37.31	39.27	40.40	41.56
12	**Mix 23**	38.59	39.50	41.52	42.56	43.36
14	**Mix 24**	37.67	38.98	40.46	41.52	42.21
16	**Mix 25**	35.57	36.79	38.59	38.59	39.83

The contrast between instances of mixes of gathering xix as far as variety in compressive quality is the molar convergence of sodium hydroxide arrangement. Mix 23 with 12 M centralization of sodium hydroxide arrangement has possessed the capacity to increase substantially higher compressive quality when contrasted with different cases.

The after effects of compressive quality showed in Figure 5.5. Demonstrates expanding design as the NaOH fixation used in geopolymer union increments from 8 to 12. Nonetheless, higher grouping of 14 and 16 showed is no workabilty

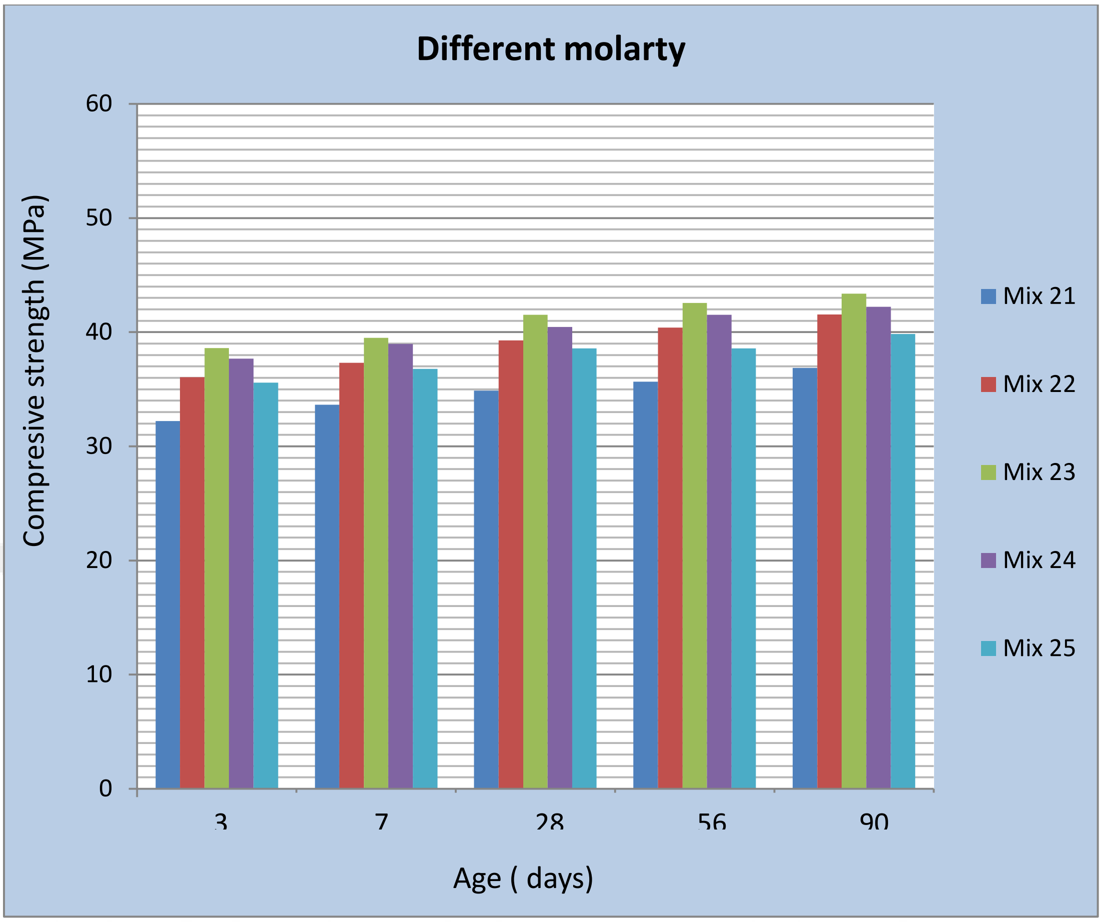


Figure 5.5 Different concentration of NaOH

Geopolymer arranged from the mix 21 showed least compressive qualities 34.87 MPa though Sodium hydroxide grouping of mix23 gave high compressive quality of 41.52 MPa at that 28 day see Figure 5.5.

Disintegration of silica and alumina from fly fiery remains were enormously impacted by Sodium hydroxide fixation where it has been demonstrated that expanding molarity will build the separation of the dynamic types of crude material and yielding development of more geopolymer gel organize. Be that as it may, too high NaOH fixation may upset the geopolymerization procedure because of the unreasonable amount OH-particles which prompt wasteful response.

Figure 5.6 Compare between high and low molarity

5.4.6 Effect of rest period on compressive strength of GPC

The term 'Rest Period' was begat to demonstrate the time taken from the fulfillment of throwing of test examples to the beginning of curing at a hoisted temperature. This may be essential in certain down to earth applications. For example, when fly fiery remains based geopolymer concrete is utilized as a part of precast solid industry, there must be adequate time accessible between throwing of items and sending them to the curing chamber. Keeping in mind the end goal to think about the impact of rest period, group 7, mixtures 32, 33 and 34 were made.

The points of interest of these mixtures are given in Table 5.6. Amid this period, the test blocks were secured to stay away from the loss of dampness, the test 3D squares from mixture 32 without the rest period. The broiler temperature on the main day to definite day was 70^{o}C. This variety in the temperature reenacted the sweltering climate condition amid the rest period.

Table 5.6 Result to different rest period

Group 7	Compressive strength (MPa) with Age (days)				
	3	7	28	56	90
Mix 32	37.96	39.07	41.89	42.84	43.36
Mix 33	43.50	44.87	46.76	47.66	48.13
Mix 34	45.66	46.96	48.74	49.87	51.27

The test outcomes are plotted in Figure 5.7. It can be seen that every one of the examples from mixtures 32, 33, and 34 picked up quality after the rest period.

The quality picks up was most extreme when the rest period was three day; past that almost no further quality pick up was achieved. The degree of quality picks up was noteworthy, in the scope of 15 to 30 percent (Figure 5.7).

Of the compressive quality of examples with no rest period. On account of examples from mixture 34, the greatest quality picks up was in excess of 30 percent. The correct explanation behind this quality pick up isn't clear. Be that as it may, the advantages appeared by the rest period might be abused practically speaking.

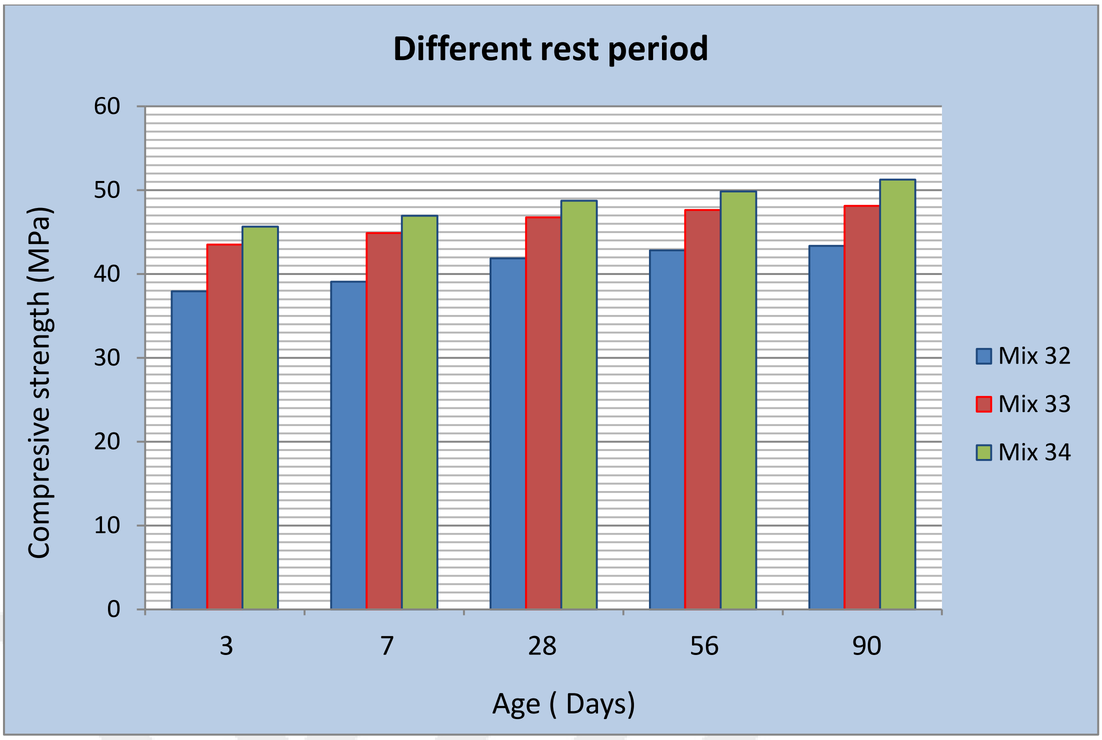


Figure 5.7 Compresive strength compare with different rest period

5.4.7 Effect of size aggregate on compressive strength of GPC

Concrete is a composite material made of aggregate bonded together by alkaline solution which hardens over time. The major components of concrete are alkaline solution, aggregates fines and coarse aggregate same time with extra water.

The aggregates taking about 70 to 85 % of the total volume, depending on the mix proportion. Concrete is used in large quantities almost everywhere mankind has a need for infrastructure because of its high compressive strength and durability aggregate grading is an important element in concrete mixing and the resultant compression strength. In concrete structures, the mix proportion of the different components together with the aggregate type and size determine the compressive strength of hard concrete. The compressive strength of concrete is one of its major properties that structural engineers take into consideration before erecting any structure. An experiment was conducted to determine the effect of aggregate size on the compressive strength of concrete. The experiment had four treatments, which were the aggregate sizes 9.5, 12.5, 19.0 and 25.4 mm and the control. A constant mix for all groups with a water/GPB ratio of 0.24, 0.27, 0.3, 0.33, and 0.36 was used throughout the experiment. For all groups we used five types rate of Extra water 10, 20, 30, 40, and 50 Kg per cube meter. After casted we have rest period to 24 hour after than we have curing for 24 hour in the oven at temperature 70°C. See Table 5.7. We take these results if extra water equaled to 10 Kg per meter cube. Research today shows that a combined gradation where there is not a lot of voids seems to provide a stronger stone matrix. These, in combination with having a good percentage of fractured faces on the rock, tend to mechanically strengthen the concrete. The coarse aggregate size is not as much of a factor as the gradation of sizes of aggregate, the shape of the aggregate, and the strength of the aggregate. The size of the aggregate is very important when you have reinforcement. If the aggregate cannot get around the reinforcement, you will have segregation with just mortar and no aggregate in spots where the aggregate can not get through. The aggregates are responsible for the unit weight, elastic modulus and dimensional stability of concrete because these properties depend on the physical characteristics strength and bulk density of the aggregate. This is not beneficial at all. The goal is for the concrete mixture to be homogeneous throughout the structure see Figure 5.8. In this Research today shows the mean concrete compressive strength increased with decreased aggregates size.

Table 5.7 Compare between different grade sizes of aggregate with compressive strength

W / GPB	**Group (1, 2, 3 and 4)**	**Compressive strength (MPa) with Age (days)**				
		3	**7**	**28**	**56**	**90**
0.24	**Mix 1 (9.5 mm)**	45.15	46.54	47.54	48.8	49.49
	Mix 6 (12.5 mm)	43.53	44.96	46.14	47.35	48.21
	Mix 11 (19 mm)	42.07	43.69	44.66	45.69	46.38
	Mix 16 (25.4 mm)	40.63	41.99	42.86	44.02	45.05

To investigate the effects of aggregate size on the compressive strength of concrete, with particular reference:

- To assess the compressive strength of different coarse aggregate sizes on concrete.
- To determine the workability of concrete made from different sized coarse aggregates.

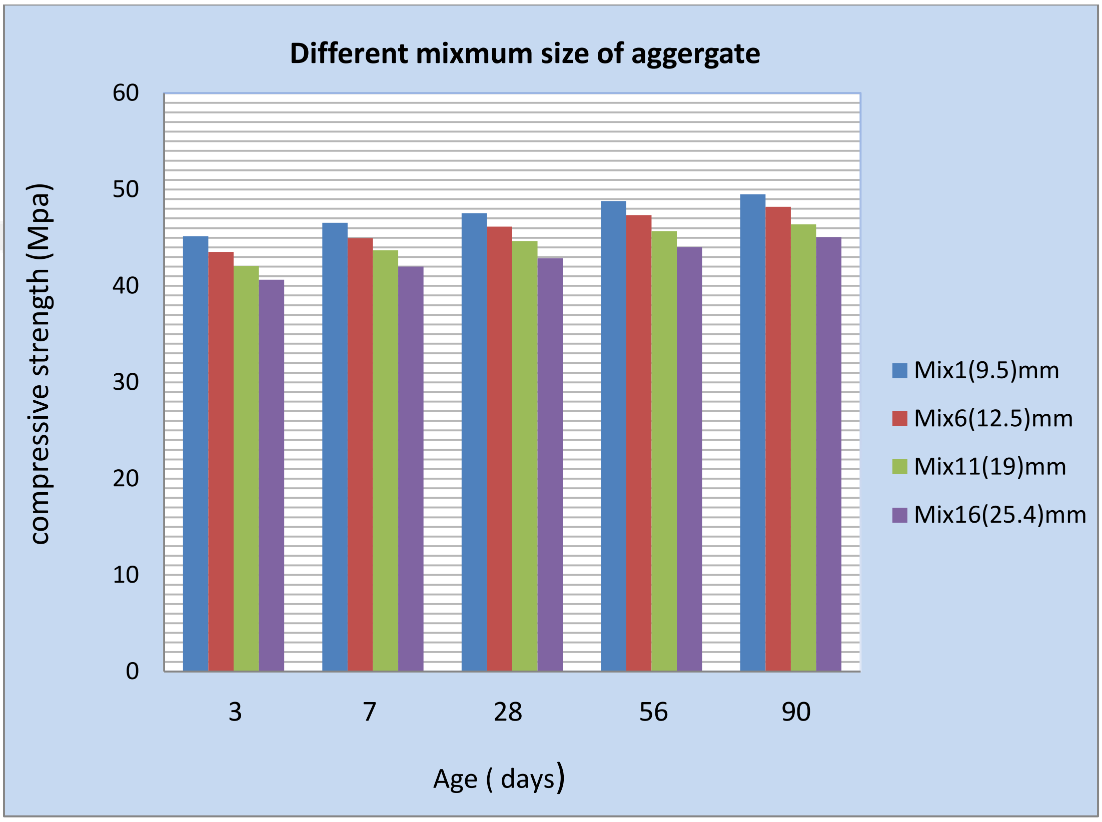


Figure 5.8 Compare between different grade sizes of aggregate with compressive strength

5.4.8 Effect of water to binder ratio on compressive strength of geopolymer

The impact of water-to-geopolymer ratio on the development of fly-ash based geopolymer concrete was discussed in this section. The compressive strength of geopolymer concrete was found to be inversely related to the water-to-geopolymer binder ratio, just like the water-to-cement ratio in cement concrete.

Water-to-geopolymer binder ratio refers to the ratio of the overall quantity of water the amount of water present in the solution as well as the water added to the mix to the geopolymer binder quantities of sodium hydroxide, fly ash and sodium silicate solutions. It is noted in fresh geopolymer concrete that when other parameters are kept the same, there is an increase in the flow with an increase in the water-to-geopolymer binder ratio. When the quantity of water is changed, it is observed that the compressive strength of geopolymer concrete decreases when the water-to-geopolymer binder ratio increases Table (5.8). A change in water quantity also causes an increase in the flow of geopolymer binder when the geopolymer binder ratio increases.

Table 5.8 Effect of water to binder ratio on compressive strength

Group 2	**Compressive strength (MPa) with Age (days)**				
	3	**7**	**28**	**56**	**90**
Mix 6	43.53	44.96	46.15	47.35	48.21
Mix 7	39.10	40.43	41.40	42.47	43.04
Mix 8	33.93	35.26	36.07	37.03	37.89
Mix 9	28.27	29.47	30.73	31.54	32.26
Mix 10	20.38	21.26	22.27	22.85	23.70

The mixture was very dry and could not be used when the water-to-geopolymer binder ratio was between 0.16 and 0.24. When the value of water-to-geopolymer binder ratio was between 0.24 and 0.27 the mixture was quite viscous and the mixing process took a long time.

When the value of water-to-geopolymer binder ratio was between 0.27 and 0.33 the mixture was cohesive and viscous, but its flow was slow for a long duration. When the water-to-geopolymer binder ratio was between 0.33 and 0.40 the geopolymer concrete was distributed in the same way as a self-compacting concrete. The geopolymer concrete becomes more viscous as the water-to-geopolymer binder ratio decreases. The reason for this is that there is a decrease in the amount of water present in the mixtures.

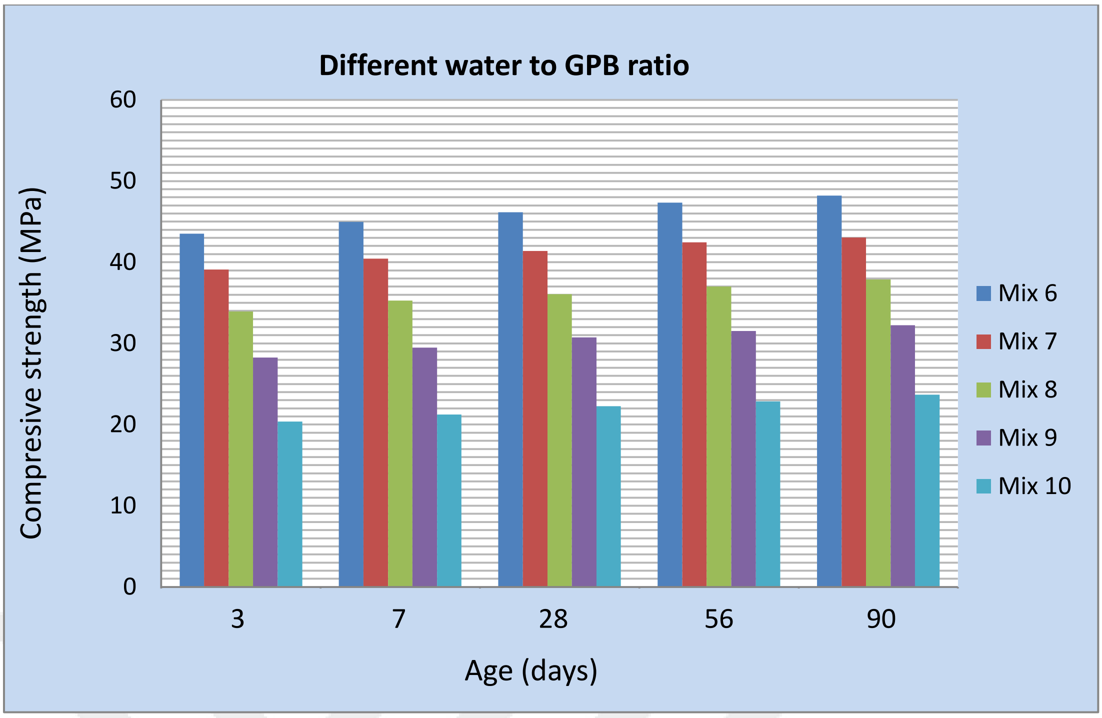


Figure 5.9 Effect of water to binder ratio on compressive strength

The most appropriate range for water-to-geopolymer binder ratio is between 0.25 and 0.35. When the ratio is higher than this, a segregated mix is obtained, and when it is lower, the mixture obtained is dry and viscous.

However, when the water-to-geopolymer binder ratio increases, the workability of the mixtures increases; however, there is a decrease in the compressive strength of the geopolymer concrete.

5.4.9 Effect of curing time on compressive strength of GPC

The compressive strength of the geopolymer concrete is affected by curing time. When the curing time is long, the polymerisation process improves and leads to higher compressive strength. The compressive strength increases at a rapid rate in the initial 24 hour of curing time, and after 24 hour, the increase in quality becomes constant. Warm curing is suggested for low-calcium fly fiery remains based geopolymer concrete. To examine the effect of curing time, studies were carried out on bunch 6, mixes 26 to 31 tested at 3, 7, 28, 56 and 90 days of age to determine compressive strength. The 3D shapes being tested were cured for various curing periods, ranging from 0 to 120 hour 5 day.

The results of the tests cured at a temperature of 70^{o}C are shown in Table 5.9 and Figure 5.10. The polymerisation process improved when the curing time was longer, leading to an increase in compressive quality. When curing time increased, there was an increase in the rate of strength improvement.

Table 5.9 Show curing time from zero to 5 day

Curing time(hr)	**Group 6**	**Compressive strength (MPa) with Age (days)**				
		3	**7**	**28**	**56**	**90**
0	**Mix 26**	0.00	5.09	13.05	19.44	28.65
24	**Mix 27**	38.28	40.84	43.51	44.71	45.50
48	**Mix 28**	42.02	43.23	44.46	45.21	46.05
72	**Mix 29**	43.76	44.78	46.10	46.44	46.95
96	**Mix 30**	44.91	45.95	46.89	47.45	47.89
120	**Mix 31**	45.23	46.27	47.69	48.11	48.54

But at mix 27, for curing time 24 hour at 70^{o}C we used oven dry. The compressive strength is more than 35 MPa. In a predictable manner, the strength will be raised by increasing the curing time in all of the mixture, but it is not more than 24 hours because more than 24 hour is not significant. We can take 80-90 % of the compressive strength if we have 24 hour curing time.

The rate of increment in quality was fast up to 24 hour of curing time. It was demonstrated by the outcomes that much drawn out curing time had not delivered material that is weaker. It is clearly that by curing time it influenced in a significant manner the strength development.

In gradual manner, the compressive Strength can be increased by the age based on the strength development that is initial, in the period of the oven curing time. In this research the compressive strength development was clearly shown because of the curing time variation.

From Figure (5.10) although the 24 hour of curing time, the strength can be varied in a significant manner because of the curing temperature that described as initial, in a small range, the strength varied after a full curing time day. The curing time differences can affect compressive strength minor differences. Gradually, it increases by increasing the curing time during the curing temperature is 70°C.

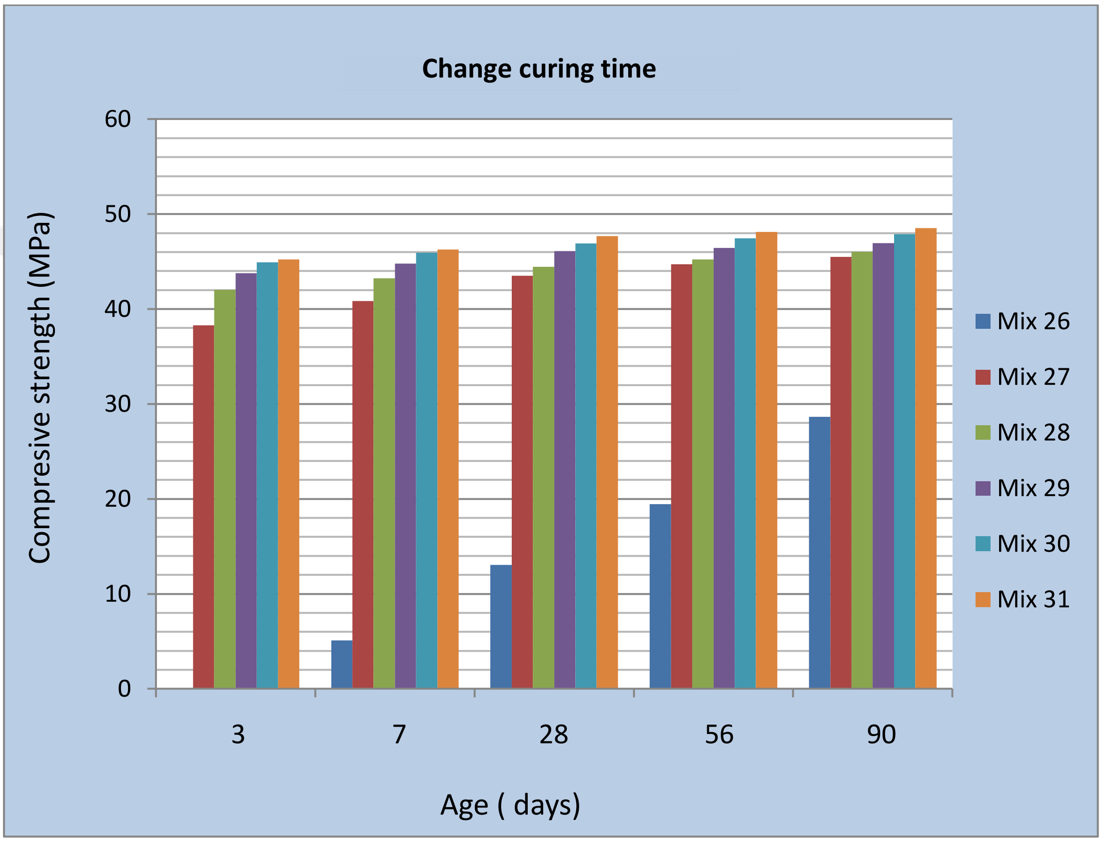


Figure 5.10 Show curing time from zero to 5 day

CHAPTER 6
CONCLUSIONS

- Geopolymers concrete show to give the better compressive strength compared to the portland cement concrete.
- The increase of compressive strength of geopolymer concrete relates to the increase in the proportion of surrogate of fly ash.
- The strength of concrete increases up to a certain limit with thw increase in the rate of alkaline liquid to fly ash. Beyond the limit of increasing the alkaline liquid to fly ash ratio, the compressive strength would be decreased. Decreasing in it, the geopolymer concrete is due to increase in water in a substantial increase in the number of pores due to heat curing as well as the preparation of alkaline liquid.
- The increase in water to geopolymer solids ratio results in the increase of the workability of mixes but the compressive strength of geopolymer concrete reduces.
- The molarity of Sodium hydroxide solution can control the strength of geopolymer concrete. The achievement of higher compressive strength has a direct relationship with higher rates of Sodium hydroxide solution. The concrete specimens with molarity vary from 8 to 16 M and curing at temperature for 70^{o}C after testing shows that the 12 M gives better strength than another molar.
- Varying the ratio of sodium hydroxide to sodium silicate solution from 1 to 3.5 by mass on the compressive strength of geopolymer concrete was studied. The average maximum strength was obtained when the ratio was 2.5. It has been concluded that the cost of alkaline liquid is economical when and the test results remarkably more consistent when the ratio of the sodium silicate solution-to-sodium hydroxide solution is 2.5.
- Adding superplasticiser, beyond 2 % of the mass of fly ash, an inconsiderable decrease in the compressive strength of hardened concrete can be can cause.
- The results indicated that increasing the rest period to 0, 24 and 48 hours. Increased the compressive strength by about 5 %, in contrast, specimens without resting period

immediately cured after casting, showed lower compressive strength by about 10 %. These ratios must be considered for proper proportioning of geopolymer concrete.

- Cuing hour and curing temperature is a very significant parameter of geopolymer concrete because it is essential for the polymerisation process. Longer curing time and curing hour are improved the polymerisation process resulting in the development of higher compressive strength.
- The experimental results and the previous data from the literature indicated that there is a strong relationship between the compressive strength of geopolymer concrete and the geopolymer binder concentration. Presently, this relation expressed using modified Feret's model.
- The new model derived from Feret model to predict compressive strength of Geopolymer concrete from the concentration of solid material in the binder paste material, Solid material includes, fly ash and other solids coming from the alkaline solution, while total water in the binder paste materials includes, water from alkaline solution plus extra water if added.
- Regression analysis has been done to the new model to find the empirical constant of the best-fit equation with the highest coefficient of determination $R^2 = 0.943$ and lowest loss function expressed by residual mean squares. Statistical analysis showed that the new model applies to geopolymer concrete.
- A new procedure is proposed for the mixture proportion to determine the amounts of components needed to produce geopolymer concrete from the minimum compressive strength specified by the structural engineer.
- The greenhouse gases emissions during the life cycle of Geopolymer concrete are approximately 62% to 66% lower than emissions from the ordinary portland cement concrete.

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APPENDIX A. FLY ASH BASED GEOPOLYMER CONCRETE PRODUCTION

Figure A-1 Washed gravel befor used

Figure A-2 Ready materials for two different mixes

Figure A-3 Using the electric mixture

Figure A-4 Pan mixer without alkaline solution

Figure A-5 The alkaline liquid was mixed with dry mixture

Figure A-6 Super plasticizer mixed with remaining extra water

Figure A-7 Final steps to mixture

Figure A-8 Putting PVC cover to cubes

Figure A-9 Casting cubs on the vibretor

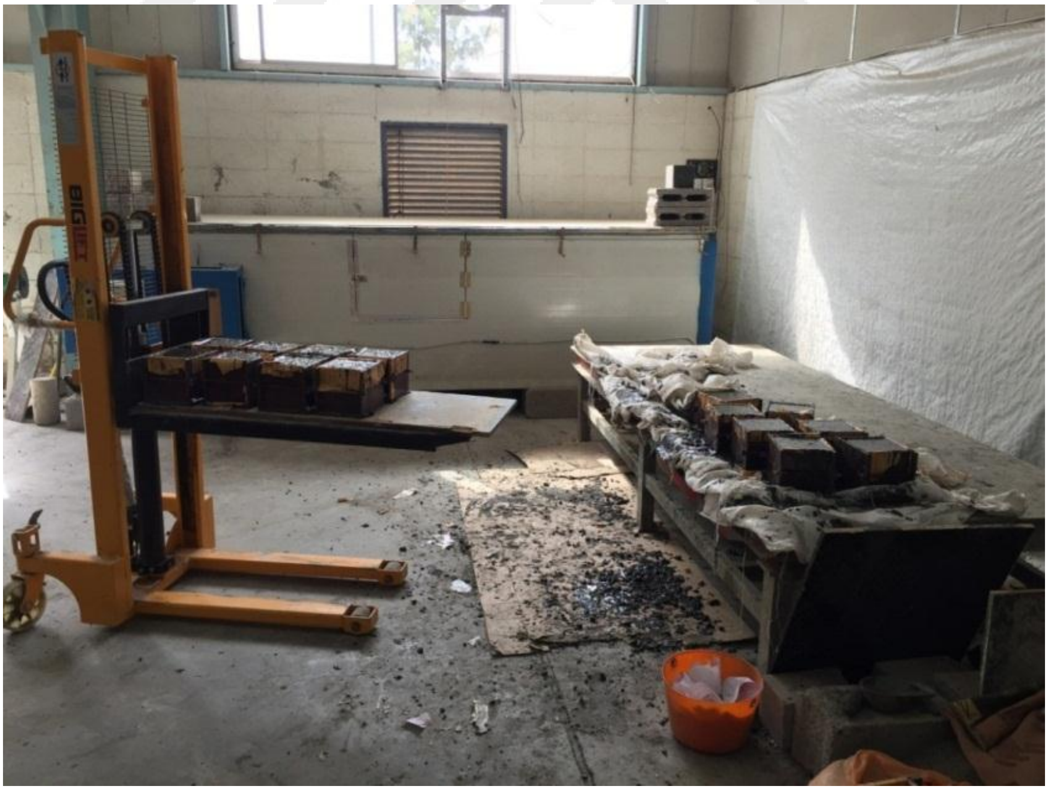

Figure A-10 Trinsportation cubs to another loucation

Figure A-11 Putting in the laboratory

Figure A-12 Rest period after casting to (24) hour

Figure A-13 Dry oven (1*1*4) meter

Figure A-14 Putting cubes in the oven

Figure A-15 After cured for any group puted in the dry space in laboratory

APPENDIX B. COMPRESIVE STRENGTH TEST PROCEDURE

Figure B-1 Compressive strength test machine

Figure B-2 Compressive Strength test for geopolymer concrete cubes

Figure B-3 Some samples after failure

APPENDIX C. MIX DESIGN FOR EXPERIMENTAL STUDY

Table C Mix design for all groups

Group	Mix	Course Agg. (kg/m3)	Fine Agg. (kg/m3)	Fly Ash (kg/m3)	NaOH Molarity	Extra Water (kg/m3)	W/GPB	Mix. size agg.(mm)	Rest Period (hr)	Temperature (C)	Curing Time (hr)
1	1	1230	660	400	12	10	0.24	9.5	24	70	24
	2	1230	660	400	12	20	0.27				24
	3	1230	660	400	12	30	0.30				24
	4	1230	660	400	12	40	0.33				24
	5	1230	660	400	12	50	0.36				24
2	6	1230	660	400	12	10	0.24	12.5	24	70	24
	7	1230	660	400	12	20	0.27				24
	8	1230	660	400	12	30	0.30				24
	9	1230	660	400	12	40	0.33				24
	10	1230	660	400	12	50	0.36				24
3	11	1230	660	400	12	10	0.24	19	24	70	24
	12	1230	660	400	12	20	0.27				24
	13	1230	660	400	12	30	0.30				24
	14	1230	660	400	12	40	0.33				24
	15	1230	660	400	12	50	0.36				24
4	16	1230	660	400	12	10	0.24	25.4	24	70	24
	17	1230	660	400	12	20	0.27				24
	18	1230	660	400	12	30	0.30				24
	19	1230	660	400	12	40	0.33				24
	20	1230	660	400	12	50	0.36				24

5	21	1230	660	400	8	26.4	0.30	9.5	0	70	24
	22	1230	660	400	10	29.1	0.30				24
	23	1230	660	400	12	31.5	0.30				24
	24	1230	660	400	14	33.7	0.30				24
	25	1230	660	400	16	35.8	0.30				24
6	26	1230	660	400	12	10	0.24	12.5	0	70	0
	27	1230	660	400	12	10	0.24				24
	28	1230	660	400	12	10	0.24				48
	29	1230	660	400	12	10	0.24				72
	30	1230	660	400	12	10	0.24				96
	31	1230	660	400	12	10	0.24				120
7	32	1230	660	400	12	10	0.24	12.5	0	70	24
	33	1230	660	400	12	10	0.24		24		
	34	1230	660	400	12	10	0.24		48		
8	35	1230	660	400	12	10	0.24	9.5	0	30	24
	36	1230	660	400	12	10	0.24			70	
9	37	1150	720	400	……	163	………	12.5	…..	……	……
	38	1230	660	400	12	10	0.24		24	70	24

APPENDIX D. COMPRESIVE STRENGTH TEST RESULT IN LABORATORY

Table D Compresive strength result for all groups

Group	Mixture	Compressive strength (MPa) with Age (Days)				
		3	7	28	56	90
1	Mix 1	45.15	46.54	47.55	48.81	49.50
	Mix 2	40.72	41.93	42.85	44.00	44.69
	Mix 3	35.55	37.48	38.83	39.86	40.19
	Mix 4	29.89	31.10	32.20	33.06	33.81
	Mix 5	22.00	22.57	24.04	24.67	25.04
2	Mix 6	43.53	44.96	46.15	47.35	48.21
	Mix 7	39.10	40.43	41.40	42.47	43.04
	Mix 8	33.93	35.26	36.07	37.03	37.89
	Mix 9	28.27	29.47	30.73	31.54	32.26
	Mix 10	20.38	21.26	22.27	22.85	23.70
3	Mix 11	42.07	43.69	44.66	45.69	46.38
	Mix 12	37.50	39.09	40.30	41.10	42.03
	Mix 13	32.31	33.71	34.81	35.64	36.25
	Mix 14	26.72	28.05	29.29	29.97	31.05
	Mix 15	18.68	19.77	20.91	21.54	22.21
4	Mix 16	40.63	41.99	42.86	44.02	45.06
	Mix 17	35.95	37.82	38.73	39.60	40.89
	Mix 18	30.73	32.30	33.47	34.36	35.09
	Mix 19	25.38	26.71	27.95	28.69	29.58
	Mix 20	17.23	18.47	19.76	20.30	21.04

5	**Mix 21**	32.21	33.63	34.87	35.66	36.86
	Mix 22	36.05	37.31	39.27	40.40	41.56
	Mix 23	38.59	39.50	41.52	42.56	43.36
	Mix 24	37.67	38.98	40.46	41.52	42.21
	Mix 25	35.57	36.79	38.59	38.59	39.83
6	**Mix 26**	0.00	5.09	13.05	19.44	28.65
	Mix 27	38.28	40.84	43.51	44.71	45.50
	Mix 28	42.02	43.23	44.46	45.21	46.05
	Mix 29	43.76	44.78	46.10	46.44	46.95
	Mix 30	44.91	45.95	46.89	47.45	47.89
	Mix 31	45.23	46.27	47.69	48.11	48.54
7	**Mix 32**	37.96	39.07	41.89	42.84	43.36
	Mix 33	43.50	44.87	46.76	47.66	48.13
	Mix 34	45.66	46.96	48.74	49.87	51.27
8	**Mix 35**	0.00	6.15	16.37	20.77	30.27
	Mix 36	36.05	38.98	41.11	42.32	42.99
9	**Mix 37**	15.39	28.57	39.63	41.82	43.56
	Mix 38	45.78	47.14	48.25	49.31	50.42

APPENDIX E. SAMPLE SPSS STATISTICS VERSION 22 PROGRAM

Nonlinear Regression Analysis

```
GET

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* NonLinear Regression.



MODEL PROGRAM  a=1 b=1 c=1 d=1.




COMPUTE  PRED_=a * (c * LG1(t) + feret ** b) * MPT ** d.




NLR c.s
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LR.TMP'
  /PRED PRED_
  /CRITERIA SSCONVERGENCE 1E-8 PCON 1E-8.
```

APPENDIX F. ARTIFICIAL NEURAL NETWORK DATA

Table F Geopolymer concrete artificial neural network inputs, targets and predicted outputs

Lab Strength	Time	Feret	MPT	Predicted Strength	Residual
45.15	3	0.651	0.323	48.29	3.14
40.44	3	0.632	0.323	40.50	0.06
35.27	3	0.614	0.323	34.16	-1.11
30.36	3	0.597	0.323	28.97	-1.39
22.89	3	0.581	0.323	24.70	1.81
43.53	3	0.651	0.425	46.35	2.82
39.10	3	0.632	0.425	38.86	-0.23
33.93	3	0.614	0.425	32.78	-1.15
28.27	3	0.597	0.425	27.80	-0.47
20.38	3	0.581	0.425	23.70	3.33
42.07	3	0.651	0.646	43.53	1.45
37.50	3	0.632	0.646	36.50	-1.00
32.31	3	0.614	0.646	30.78	-1.52
26.72	3	0.597	0.646	26.11	-0.61
18.68	3	0.581	0.646	22.26	3.58
41.18	3	0.651	0.85	41.77	0.59
35.63	3	0.632	0.85	35.03	-0.60
31.17	3	0.614	0.85	29.54	-1.63
25.07	3	0.597	0.85	25.05	-0.02
18.3	3	0.581	0.85	21.36	3.06
46.54	7	0.651	0.323	48.98	2.44
41.93	7	0.632	0.323	41.18	-0.75
37.48	7	0.614	0.323	34.84	-2.64
31.1	7	0.597	0.323	29.65	-1.45
22.57	7	0.581	0.323	25.39	2.82
44.96	7	0.651	0.425	47.01	2.04
40.43	7	0.632	0.425	39.52	-0.91
35.26	7	0.614	0.425	33.44	-1.83
29.47	7	0.597	0.425	28.46	-1.01
21.26	7	0.581	0.425	24.36	3.11
43.69	7	0.651	0.646	44.14	0.45
39.09	7	0.632	0.646	37.12	-1.98
33.71	7	0.614	0.646	31.40	-2.30
28.05	7	0.597	0.646	26.73	-1.32
19.77	7	0.581	0.646	22.88	3.11
41.99	7	0.651	0.85	42.36	0.37
37.82	7	0.632	0.85	35.62	-2.20
32.30	7	0.614	0.85	30.14	-2.16
26.71	7	0.597	0.85	25.65	-1.06
18.47	7	0.581	0.85	21.96	3.48
47.55	28	0.651	0.323	50.10	2.55

42.84	28	0.632	0.323	42.31	-0.53
38.30	28	0.614	0.323	35.97	-2.33
32.20	28	0.597	0.323	30.78	-1.42
24.04	28	0.581	0.323	26.51	2.47
46.15	28	0.651	0.425	48.08	1.94
41.40	28	0.632	0.425	40.60	-0.80
36.07	28	0.614	0.425	34.52	-1.56
30.73	28	0.597	0.425	29.54	-1.20
22.27	28	0.581	0.425	25.44	3.17
44.66	28	0.651	0.646	45.16	0.49
40.30	28	0.632	0.646	38.13	-2.17
34.81	28	0.614	0.646	32.41	-2.40
29.29	28	0.597	0.646	27.74	-1.55
20.91	28	0.581	0.646	23.89	2.98
42.86	28	0.651	0.85	43.34	0.48
38.73	28	0.632	0.85	36.59	-2.14
33.47	28	0.614	0.85	31.11	-2.36
27.95	28	0.597	0.85	26.62	-1.33
19.76	28	0.581	0.85	22.93	3.17
48.80	56	0.651	0.323	50.67	1.87
44.00	56	0.632	0.323	42.87	-1.13
39.85	56	0.614	0.323	36.53	-3.32
33.05	56	0.597	0.323	31.34	-1.71
24.67	56	0.581	0.323	27.07	2.40
47.35	56	0.651	0.425	48.62	1.27
42.47	56	0.632	0.425	41.14	-1.33
37.03	56	0.614	0.425	35.05	-1.97
31.54	56	0.597	0.425	30.08	-1.46
22.85	56	0.581	0.425	25.98	3.13
45.69	56	0.651	0.646	45.66	-0.03
41.10	56	0.632	0.646	38.64	-2.46
35.64	56	0.614	0.646	32.92	-2.72
29.97	56	0.597	0.646	28.24	-1.72
21.54	56	0.581	0.646	24.40	2.86
42.01	56	0.651	0.85	43.82	1.81
37.39	56	0.632	0.85	37.08	-0.32
32.31	56	0.614	0.85	31.59	-0.72
26.58	56	0.597	0.85	27.11	0.53
18.84	56	0.581	0.85	23.41	4.57
49.50	90	0.651	0.323	51.05	1.55
44.68	90	0.632	0.323	43.25	-1.43
40.19	90	0.614	0.323	36.91	-3.28
33.81	90	0.597	0.323	31.72	-2.09
25.03	90	0.581	0.323	27.46	2.43
48.21	90	0.651	0.425	48.99	0.78
43.04	90	0.632	0.425	41.51	-1.53
37.89	90	0.614	0.425	35.42	-2.47

32.26	90	0.597	0.425	30.44	-1.82
23.70	90	0.581	0.425	26.35	2.65
46.38	90	0.651	0.646	46.01	-0.37
42.03	90	0.632	0.646	38.98	-3.04
36.25	90	0.614	0.646	33.27	-2.98
31.05	90	0.597	0.646	28.59	-2.46
22.21	90	0.581	0.646	24.74	2.54
42.29	90	0.651	0.85	44.15	1.87
37.98	90	0.632	0.85	37.41	-0.57
32.69	90	0.614	0.85	31.93	-0.77
27.08	90	0.597	0.85	27.44	0.36
19.03	90	0.581	0.85	23.75	4.72

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FOREIGN LANGUAGE

- English
- Kurdish
- Arabic

Work experience

	Place	Enrollment
2013-Present	Ministry of Defense	Civil Engineer