EFFECT OF ORDINARY PORTLAND CEMENT IN FLY ASH BASED GEOPOLYMER SYSTEM

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CERTIFICATION OF APPROVAL

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CERTIFICATION OF ORIGINALITY

This is to certify that that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgments, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(Michael Terefe Woldemariam)

ABSTRACT

The construction industry in developing countries is growing very fast. And Ordinary Portland cement concrete is one of the most popular materials in demand in this construction industry. Ordinary Portland cement is commonly used as a binding material for the concrete production but the use of this material has brought up some concerning issues of various types. Therefore, scientists in recent years have come up with fly ash based Geopolymer concrete as alternative to replace the Ordinary Portland cement concrete.

The fly ash based geopolymer comes up with some problems of its own. It has a very fast setting time and also it needs considerable amount of energy or heat to attain the desirable strength. These properties of geopolymer concrete are not desirable on the real time construction process. These undesirable properties could be minimized by mixing the fly ash to the Ordinary Portland cement; since the fly ash and the Ordinary Portland cement will complement each other. Therefore, this project aims to identify the optimum fly ash to Ordinary Portland cement ratio for good engineering properties of a concrete and also the specific curing time for each property.

The mix proportioned concrete is to be tested for its compressive strength, tensile strength, fire resistance and for alkali attack resistance. The concrete casted is cured for different periods of time so that the optimum results could be found for each of these properties. And the concrete cubes are going to be tested at the 3rd, 7th and 28th days after they have been casted.

The results of the Ordinary Portland Cement inclusion showed different effects on the different mechanical properties and durability of the concrete. The increase in the percentage inclusion resulted in a lower compression strength and fire resistance but an increase in the tensile strength of the Geopolymer system. The resistance to alkali penetration has also decreased with the increase in the percentage inclusion.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

The construction industry is booming due to the increase in the need for infrastructure especially in developing countries like Malaysia and concrete is one of the most consumed materials. Concrete as a material is the product of fine aggregates, coarse aggregates and binding material in general. Most of the time these constituent materials that make up the concrete are bound together using cement as a binding material.

The ingredients of concrete can be proportioned by weight or volume. The goal is to provide the desired strength and workability at minimum expense. A low water to cement ratio is used to achieve strong concrete. A concrete mix is designed to produce concrete that can be easily placed at the lowest cost. The concrete must be workable and cohesive when plastic, then set and harden to give strong and durable concrete.

There are two basic types of aggregates used in concrete; coarse and fine aggregates. Coarse aggregates may be crushed rock, gravel or screenings. Fine aggregates may also be fine and coarse sand. Sand should be concreting sand and not brickies sand or plasterer’s sand. Aggregates should be both strong and hard. A stronger and harder aggregate will give a stronger and durable final concrete to stand up to wear and tear and weathering. The other important aspect about aggregates is; they should be graded. Graded Aggregates should range in size so that they fit together well. This gives a stronger and denser concrete. They should also be chemically inactive so the aggregates don’t react with the cement.

Binder materials are paste materials that are used to bind all the components or the concrete together and form one solid material. There are several types of binder materials but the most commonly used is; the Ordinary Portland cement. But the Ordinary Portland cement has shortcomings like high emission of carbon dioxide to the environment and high energy demand in the production process, resource depletion and many others. Because of these issues, scientists have been working on to produce alternative materials.

Research studies in the past have shown that geopolymer based concrete has emerged as a promising new alternative to replace cement, as a biding agent, in the field of construction materials. Geopolymer, also known as inorganic polymer, is an Alumino-silicate product obtained from a polymerization process [3]. Though geopolymers can be manufactured from various source materials rich in silica and alumina such as fly ash, silica fume, ground granulated blast furnace slag and metakaolin etc, fly ash based geopolymers have attracted more attention [4].

Geopolymer is such an alternative construction material which can act as a binder replacing cement. It mainly makes use of waste or by-product substances like fly ash which is cheap and will reduce environmental pollution to a large extent. Fly ash based geopolymer concrete is a new product in which no cement is used and geopolymer paste acts as the only binder [1].

Fly ash based geopolymers use fly ash as the material which acts as source of silicon and aluminum for reaction by an alkali to make silicon and aluminum atoms to form geopolymer paste. When fly ash based geopolymer acts as a binder material, fly ash takes part in the reaction to form alumino-silicate binder [1]. It binds components such as aggregate together to form geopolymer concrete.

1.2 PROBLEM STATEMENT

Currently, the common practice in the construction industry is the use of Ordinary Portland cement as a binder material on the production of concrete and mortar. The increase in the infrastructure construction has made an increase in the demand for Portland cement day by day. But this crucial element in the construction industry comes with some ill effects associated with it;like environmental, resource depletion and high energy requirement for production. Therefore, alternative source has been in the search to replace the OPC. In recent years, scientists and researchers came out with the Geopolymer concrete as alternative material. Like any material, Geopolymer also have some disadvantages when using, which are very fast setting and hardening and high energy requirement to attain the desired strength.

The fly-ash based geopolymer has the property of very fast setting and hardening. This property is not favorable in the construction or working site since there will be sometime needed to transport the concrete from the concrete mixing place to the desired construction spot. Even though, this property is also sometimes needed depending up on the temperature of the construction environment and the type of work underway, it has to be properly controlled and moderated.

The fly ash based geopolymer concrete goes under endothermic reaction to set and start attaining its strength. This means it requires heat or energy from the outside environment. This property is not desirable when working at places with a very low and moderate atmospheric temperature. In addition, this endothermic reaction increases the cost of using the material since the external energy source is needed for the setting and attaining strength process.

Studies on both Ordinary Portland cement concrete properties and fly ash based geopolymer concrete properties have been done so far separately. Therefore the Ordinary Portland cement should also be investigated how it acts in a geopolymer system. This project tries to solve the stated problems above by mixing the Ordinary Portland cement with the geopolymer system. The mix proportion between the Rapid hardening Portland cement and the fly ash is assumed to complement each other. The energy released by the ordinary Portland cement when it sets is used by the geopolymer to fulfill its high energy requirement to attain its strength. Therefore, the outcomes of the properties of a concrete with different proportional mixtures of the

Ordinary Portland cement and the fly ash as binding materials has yet to be explored for a better concrete properties.

1.3 OBJECTIVES OF THE STUDY

The main objectives of the proposed final year project are:

- To identify the effect of the Ordinary Portland cement in the Geopolymer system.
- To identify the optimum mixture proportioning of Ordinary Portland cement to fly ash-based geopolymer system to achieve the highest engineering properties at different curing time with an average hardening time and low energy requirement for curing.

1.4 SCOPE OF THE PROJECT

The main focus of this project is to identify the optimum mix proportion of Ordinary Portland cement to fly ash as binding materials for high engineering properties of the concrete formed. The engineering properties that are to be testedare the compressive strength, tensile strength, fire resistance and resistance to chloride attack.

The percentage replacement of the fly ash by the Ordinary Portland cement to be done are; 0%, 5%, 10% and 15%. The curing times that are used for these tests are 24 hours and 48 hours at a temperature of 70^0c inside a curing oven. The casted concrete cubes are going to be tested for their properties at 3,7 and 28 days.

The size of the moulds that are used to shape and size the concrete cubes that are to be tested for their compressive strength, the fire resistance are 100x100x100 (all dimensions in mm). Three concrete cubes are to be tested for each of the above tests based on the each Ordinary Portland concrete cement to fly ash proportioning and for each duration of curing. And the size of the moulds to shape the cylindrical cubes used for the Tensile strength test and the alkali attack resistance test which are200mm in height and 100mm in diameter and 50mm in height and 100mm in diameter respectively.

The estimated time to be taken to complete the work is about 6 months which is about 2 semesters. The projects sets out to conclude whether addition of Ordinary Portland concrete cement in a fly ash based geopolymer system has a positive or negative out come on the final product. Therefore, the Project begins with the mix proportioning and goes further up to identification of the optimum proportion for each individual property.

CHAPTER 2

LITERATURE REVIEW

The construction industry is growing in an exponential rate both in the developed and developing countries. Due to this growth in the construction industry, the issues regarding the environmental effects of the industry have been raised. These concerns especially focus on the cement industry. Therefore the cement replacing technologies have become an area of high interest. It is now believed that new binders are indispensable for enhanced environmental and durability performance. In this aspect, geopolymer technology is one of the revolutionary developments related to novel materials as an alternative to Portland cement.

2.1 ORDINARY PORTLAND CEMENT

Ordinary Portland cement is one of the types of cements in the market. The most important raw materials are Calcium silicates and Calcium oxides. They are bended in a very high temperature in cement rotary kilns. The product of this process is clinker which will be ground to give cement. These Portland cement produced is hydraulic cement. Hydraulic cements are cements which will set and harden when they are mixed with water [36].

There are different properties of Ordinary Portland cement which makes it very important as a material. These properties are fineness, setting time, soundness, specific gravity and compressive strength.

Although aggregates make up the bulk of the mix, it is the hardened cement paste that binds the aggregates together and contributes virtually all of the strength of the concrete, with the aggregates serving largely as low cost fillers. The strengths of the cement paste is determined by both the quality and type of the cement and the water-to cement ratio [36].

When Ordinary Portland cement comes in contact with water, it starts losing its plasticity and it will become hardened. The condition when cement has lost its plasticity and is stiffing, it is called setting. The time corresponding to the paste becoming a hard mass is known as final setting time. It is essential that the initial setting time should not be too less to allow time for mixing, transporting and placing of concrete. Within this time, the cement paste, mortar or concrete should be in plastic condition [37].

The character of concrete is determined by the quality of the cement paste (i.e., the cement and water mixture). The water to cement ratio—the weight of the mixing water divided by the weight of the cement—plus the quality and type of cement determines the strength of the paste, and hence the strength of the concrete. High-quality concrete is produced by lowering the water cement ratio as much as possible without sacrificing the workability of fresh concrete. Generally, using less water produces a higher quality concrete provided the concrete is properly placed, consolidated, and cured [36].

Heat is generated when the Ordinary Portland cement comes in contact with water. The heat is the result of the chemical reaction undergone by the cement ingredients. This heat generated is called heat of hydration [37]. It is usually released to the surrounding environment and it raises the temperature of the concrete mix.

The fineness of the cement plays a much higher role when it comes to the chemical reaction the cement undergoes to form concrete. If the fineness of the cement materials is high there will be a high surface area of the cement particles to come in contact with the water for the reaction which in turn make the reaction very fast and there will be a faster release of the hydration energy. This hydration energy will continue to be released as long as the concrete continues to be cured. The exothermic energy released for 7 days and 28 days is 350 j/g and 400 j/g [35].

2.2 GEOPOLYMER CONCRETE

The cement industry is held responsible for some of the CO_2 emissions. The amount of the carbon dioxide released during the manufacturing of Ordinary Portland Cement due to the calcination of limestone and combustion of fossil fuel is in the order of one ton for every ton of OPC produced. In addition, the extent of energy required to produce OPC is only next to steel and Aluminum [1]. In light of these and other additional facts, there would appear to be little doubt that alternative binders, less aggressive to the environment should replace Portland cement.

In 1978, proposed that binders could be produced by a polymeric reaction of alkaline liquids with the Silicon and the Aluminum in source materials of geological origin or by-product materials such as fly ash and rice husk ash. He termed these binders as geo-polymers [3].

Geopolymers are inorganic polymers that cover a class of synthetic Alumina-silicate materials [1]. Their microstructure is amorphous which refers to the morphology of polymeric materials. In this case, the chains in the structure are long and unorganized and their chemical composition is more or less similar to natural zeolitic materials [2]. The application of these polymers is not only replacing cement but also they can be used for high-tech composites, ceramic applications or as a form of cast stone.

There are two main constituents of geo-polymers, namely the source materials and the alkaline liquids. The first source materials are the materials that are rich in Silicon (Si) and Aluminum (Al) [4]. These materials can be naturally occurring or manufactured industrially. kaolinite, clays, fly ash, silica fume, slag, rice husk ash, red mud could be used as source materials. The choice of the source materials for making geo-polymers depends on factors such as availability, cost, type of application, and specific demand of the end users.

The most common alkaline liquid used in geopolymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate [3]. The use of a single alkaline activator has also been reported and it was concluded that the type of alkaline liquid plays an important role in the polymerization process.

Recent studies have shown that fly ash can be utilised to substitute cement when manufacturing concrete. When used as a partial replacement of Ordinary Portland Cement (OPC), in the presence of water and in ambient temperature, fly ash plays the role of an artificial pozzolan and reacts with the calcium hydroxide during the hydration process of OPC to form the calcium silicate hydrate (CS- H) gel [5]. The spherical shape of fly ash often helps to improve the workability of the fresh concrete, while its small particle size also plays as filler of voids in the concrete, hence to produce dense and durable concrete [6].

Water is added to the freshly prepared geopolymer mix in order to increase the workability of the mix. The water inside these geopolymer mixes is referred as “free water”. These water molecules will also exist inside the structure[10]. However the addition of water beyond a certain limit like the Portland cement system will result in the bleeding or segregation of the fresh mix which will highly decrease the compressive strength of the final concrete. But during the curing process most of the water will be lost due to the high curing temperature and long curing time[13].

There is not much information reported on the behaviour of the freshly mix geopolymer concrete. Palomo [15] concluded that when Metakolin is used as a source material, the fresh geopolymer mortar became very stiff and dry while mixing, and exhibited high viscosity and cohesive nature. They suggested that the gravity type mixer is a better choice for mixing the geopolymer materials when compared to the forced mixer. An increase in the mixing time increased the temperature of the fresh geopolymers, and hence reduced the workability. To improve the workability, they suggested the use of admixtures to reduce the viscosity and cohesion.

Most of the manufacturing process of making geopolymer paste involved dry mixing of the source materials, followed by adding the alkaline solution and then further mixing for another specified period of time [34].

According to Gourley [35] the best choice of fly ash type between the low calcium (ASTM Class F) fly ash and the high calcium (ASTM Class C) fly ash is the low calcium fly ash because the presence of calcium in high amount may interfere with the polymerisation process and alter the microstructure.

Geopolymer concretes are produced by the polymerization process. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si- Al minerals, which results in a three-dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds [1]. This geopolymerization process can be seen in the step by step reaction below.

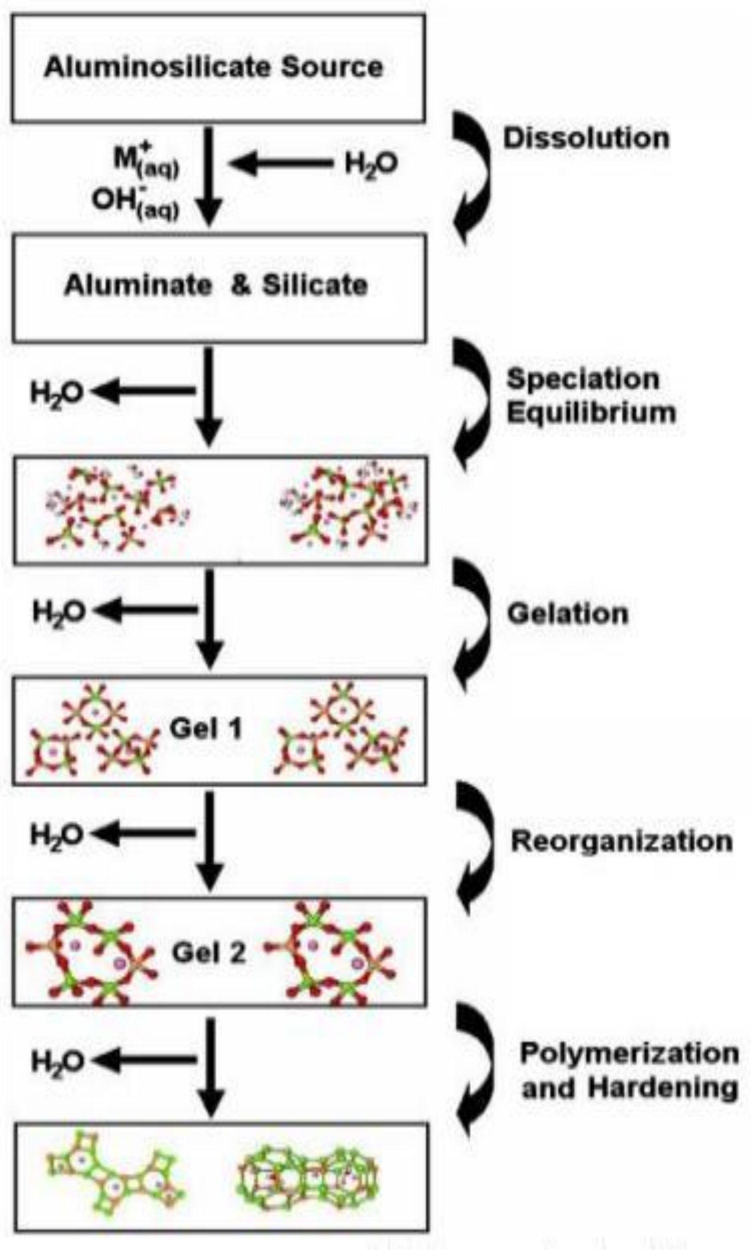


Figure 1: Geopolymerization process

2.2.1 Factors affecting the properties of Geopolymer concrete

There are various factors affecting the mechanical properties and the durability of the geopolymer concrete. Due to these factors the geopolymer concrete have different properties when examined. For the case of this study, the factors to be studied are the period of curing time, the temperature of curing and the molarity of the alkaline solution. These factors are studied by quantifying the mechanical properties and the durability of the geopolymer at different conditions of the factors.

Several factors have been identified as important parameters affecting the properties of geopolymers. Palomo et al [15] concluded that the curing temperature was action accelerator in fly ash-based geopolymers, and significantly affected the mechanical strength, together with the curing time and the type of alkaline activator. Higher curing temperature and longer curing time were proved to result in higher compressive strength.

2.2.1.1 Molarity of the Alkaline Solution

The concentration of the alkaline activator and the mount used also affects the development of the mechanical properties of the geopolymer concrete. Therefore finding the optimum concentration and amount is one of the important activities when doing the preparation for fresh geopolymer mix. Muhd Fadhil et al [12] stated that, the increase from 12M to 14M of a sodium hydroxide solution resulted in slower depolymerisation which subsequently caused a lower compressive strength. sodium hydroxide concentration due to an excess of OH^- concentration in the system involved a strength decrease of the alkali cement.[13] The highest compressive strength was obtained using a solution of sodium hydroxide and sodium silicate as an activator combination of sodium hydroxide and sodium silicate is the most suitable as alkaline activator because sodium silicate contains partially polymerized and dissolved silicon which can react easily, incorporate into the reaction products and significantly contribute to improve the characteristics of mortar and also enhances the process of geopolymerisation process.[13]

Palomo et al [15] concluded that the type of activator plays an important role in the polymerisation process. Reactions occur at a high rate when the alkaline activator contains soluble silicate, either sodium or potassium silicate, compared to the use of only alkaline hydroxides. the addition of sodium silicate solution to the sodium hydroxide solution as the alkaline activator enhanced the reaction between the source material and the solution. Furthermore, after a study of the geopolymerisation of sixteen natural Al-Si minerals, they found that generally the NaOH solution caused a higher extent of dissolution of minerals than the KOH solution [17].

2.2.1.2 Curing time and temperature

Van Jaarsveld et al. [17] studied the interrelationship of certain parameters that affected the properties of fly ash-based geopolymer. And they came up with the parameters; water content, curing time and curing temperature. They stated that the curing temperature and the curing time have the significant influence on the properties of the geopolymer concrete. And they concluded that rapid curing and curing at high temperature reduced the compressive strength and caused a negative effect on the physical properties of the geopolymer.

Some studies have shown that the activation of the alumina-silicate bond requires a generally elevated temperature. Both curing temperature and the period of curing time affect the mechanical properties of fly-ashed based geopolymers. If a geopolymer concrete is set to cure and gain strength at ambient temperature, the reaction of the components materials will be very slow which results in a slower setting and strength development[14]. Palomo et al. generally stated that higher temperature and longer curing time increases the compressive strength of geopolymers. The reason behind is the geopolymerisation process can be improved with a longer period of curing time which in turn increases the compressive strength. The usual optimum curing temperature used is 60^0c but an increase to 70^0c could increase the compressive strength of the geopolymer concrete[15].

According to Xiaolu Guo et al. [16] the relationship between the period of curing time and the compressive strength development in geopolymers is not always directly proportional. The compression strength increases until a specific point depending on the mix proportion and then it begins to decrease after curing for a certain period of time at higher temperature. The reason behind this property is; the granular structure of the geopolymer mixtures breaks down because of the longer period of curing making it vulnerable and weak to compression forces [16].

Curing temperature plays a significant role in the setting and hardening of the geopolymer concrete. Hardjito et al. [5], in their study on low-calcium Fly ash-based geopolymer mortar have reported that curing temperature plays an important role in the geopolymerization process of Fly ash based geopolymer. They have concluded that higher the curing temperature, higher will be the rate of geopolymerization process, which eventually accelerates the hardening of geopolymer mortar.

As stated previously, both curing time and curing temperature significantly influence the compressive strength of geopolymer concrete. Several researchers have investigated the effect of curing time and curing temperature on the properties of geopolymer concrete. They concluded that higher curing temperature and longer curing time proved to result in higher compressive strength but Fareed et al. [11] argued that higher curing temperature does not ensure higher compressive strengths as claimed in their study on Fly ash-based geopolymer concrete.

2.2.2 Mechanical Properties and durability of Geopolymer Concrete

Due to the three-dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds the geopolymer products have shown that they have the properties of high compressive strength, very little drying shrinkage, low creep, good bond with reinforcing steel, good resistance to acid, sulphate and fire attacks. In addition, they also have good sustainability to weathering effects; however, they are not resistant towards high temperature beyond 400^0C [6].

2.2.2.1 Compressive and Tensile strength

The compressive strength is one of the most noteworthy properties of hardened concrete and is considered as the characteristic material value for the classification of concrete. When a material is loaded in such a way that it compresses and shortens; it is said to be in compression. On the other hand if the material is stretched it is said to be in tension.

Concrete in general has a high compressive strength and a lower tensile strength. The tensile strength is usually the fraction of the compressive strength. Because these strength properties, reinforcement bars are added to the concrete so that it will help to increase the tensile strength of the concrete.

According the BS EN 12390-3, 2009 and BS EN 12390-6, 2009 respectively, the compressive and tensile strength of the concrete are tested at 3rd, 7th, 14th, 28th, 56th, 90th days after casting. It is said that for a conventional cement concrete, the samples casted will attain 65% of their compressive strength at the 7th day. The 7th day test is a good way to know that if the concrete at hand can meet the required strength after 28th day. The concrete even after 28th day will continue to gain strength but the strength gain is almost insignificant.

The method of the strength development of the Ordinary Portland cement and strength development of the geopolymer system are assumed different but the strength development curves are more or less similar. The geopolymer system attains its strength as discussed earlier from the geo polymerization process and the Ordinary Portland cement gets its strength from the hydration of the cement material.

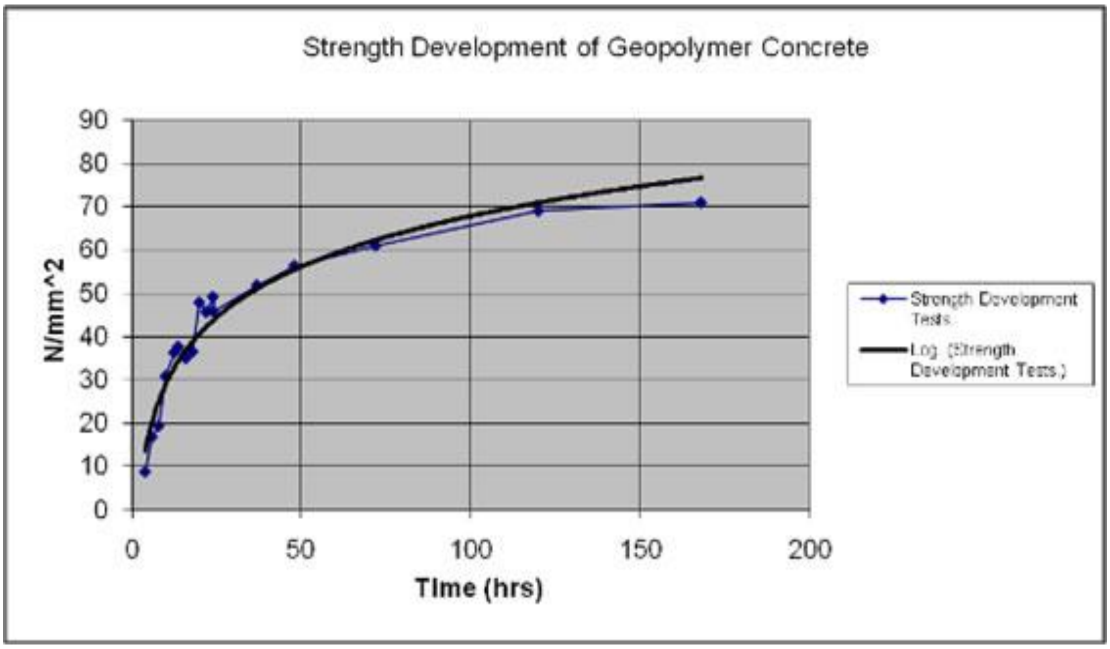


Figure 2: strength development curve

Curing temperature and curing time have been reported to play important roles in determining the properties of the geopolymer materials made from by-product materials such as fly ash. Palomo et al [15] stated that increase in curing temperature accelerated the activation of fly ash, and resulted in higher compressive strength.

Experimental studies have shown that the aggregate-binder interfaces are stronger in geopolymers than in the case of Portland cement [17]. This may lead to superior mechanical properties and long-term durability of geopolymer concretes.

The behavior and failure mode of fly ash-based geopolymer concrete in compression is similar to that of Portland cement concrete. According to the test done by Hardjito and Rangan [5] the strain at peak stress is in the range of 0.0024 to 0.0026.

According to Skvara et al [10] ratio of compressive strength and tensile strength is around 10:5.5 unlike OPC where the ratio is around 10:1. It shows that geopolymer concrete possesses considerable resistance to tensile forces which are responsible for cracking and other issues in concrete structures.

The presence of Ca atoms when the geoplymerisation process takes place creates a different spectrum in the whole process. The available Ca atoms will enter the Si-O-Al-O skeleton and compensate the charge on the Al atoms to give a stronger bond. These stronger bonds result in high overall strength [10].

According to Škvaŕa,F et.al [10], the properties of concrete made by the proportioning of fly-compostion are dependent on the fly ash content in the proportion. In comparison with the fresh cement concretes, the mixtures containing higher percentages of fly ash exhibit a different rheological behaviour. Both the static and dynamic viscosity of the geopolymers concrete is substantially higher.

The development of strength of a fly-ash based geopolymer concrete and inorganic based concrete, Portland cement, is completely different. In general, the development of strength starts with the dissolving of the fly ash particles in alkaline solution and a new geopolymer structure then is formed in the solution. Whereas, the strength development of the Portland cement starts with the hydration of the cement material and then the setting of the hydrated material [10].

In general, geopolymer concrete has a good compressive and tensile strength when compared to the Ordinary Portland cement concrete. The compressive strength should be given a very good attention when investigating the property of concrete because in general concrete has a good tensile strength and comparatively low compressive strength. The compressive and tesile strength of the geopolymers depend on three major factors. These main factors are the curing temperature, the curing time and the molarity of the alkaline solution used.

2.2.2.2 Fire, Freezing and thawing resistance

Temperature resistance are one of the factors accounted for in the construction industry. Concrete when compared to other construction materials has a major advantage when it comes to its fire and frost resistance property. This means it can withstand different stresses and strains created by high magnitudes of loads without failing or collapsing collapse even though the rise in temperature causes a decrease in the strength and modulus of elasticity for concrete. It should also be noted that concrete does not burn or ignite.

The remaining free water in the hardened geopolymer concrete, which was added to increase the workability of the mix, will be transformed from the water to the gaseous state when the concrete is exposed to the high temperature created by the fire. This change of state alters the rate in which heat is transmitted from the surface of the geopolymer concrete into the interior of the concrete components [26].

The property of the geopolymer for a good fire resistance is dependent on the type and quality of aggregates used the modulus of elasticity of the final concrete and the steel reinforcement [29]. The modulus of elasticity is inversely proportional to the increase in the temperature or the fire. At the instant where the modulus of elasticity of these materials is below the required, the geopolymer concrete starts to fail [31].

Geopolymer concrete is highly resistant to freezing and defrosting. Škvaŕa, F et al. [10] reported that as expected the compressive strength results that were obtained after 28 days of samples without any frost resistant tests were higher than the samples that were exposed to freezing cycles. But the exposed samples did not show any disintegration of the structure. From the results fly ash based geopolymer posses and excellent frost resistance compared to the Portland cement concrete.

Non air entrained concrete with low water to binder ratio is durable against freezing and thawing. So it implies that if water-binder ratio is low all water can mix up with binder and other components resulting in low permeability of concrete. It can so hinder the saturation of paste during freezing [31]. If saturation of paste does not take place concrete won’t crack even in absence of any air entraining admixture. Fly ash plays the important role by lowering water-cement ratio and reducing concrete permeability. Experiments conducted by Skvara et al [10] has stated that mass of fly ash geopolymer concrete slightly changes after 150 freezing and defrosting cycles and also there was no deformation and cracking [4]. However concrete with upto 50 % fly ash and 10% silica fume with geopolymer binder has proved most efficient. This hints at the disadvantage of having too much fly ash particles in the mixture. It means that excess or unreacted fly ash will not bind well with geopolymer matrix and will weaken the bonding only.

The American society of testing materials specifies that the best way to test building materials for their fire resistance ability is to structurally load a test assembly and then exposing the underside of the specimen to fire. The assembly is evaluated for its ability to contain the fire by limiting flame spread and heating of the unexposed surface while maintaining the applied load. The assembly is given a rating, expressed in hours, based on these conditions of acceptance.

2.2.2.3 Alkali penetration resistance

Concrete structures are exposed to harsh environments yet are often expected to last with little or no repair or maintenance for long periods of time (often 100 years or more). To do this, a durable structure needs to be produced. In concrete, one of the major forms of environmental attack is chloride ingress, which leads to corrosion of the reinforcing steel and a subsequent reduction in the strength, serviceability, and aesthetics of the structure.

Capillary absorption, hydrostatic pressure, and diffusion are the means by which chloride ions can penetrate concrete. The most familiar method is diffusion, the movement of chloride ions under a concentration gradient. The rate of diffusion is thus controlled not only by the diffusion coefficient through the pore solution but by the physical characteristics of the capillary pore structure [21].

The penetrability of concrete is obviously related to the pore structure of the binding material. This will be influenced by the water-cement ratio of the concrete, the inclusion of supplementary cementing materials which serve to subdivide the pore structure [23], and the degree of hydration of the concrete. The older the concrete, the greater amount of hydration that has occurred and thus the more highly developed will be the pore structure. This is especially true for concrete containing slower reacting supplementary cementing materials such as fly ash that require a longer time to hydrate [20][21]

Another influence on the pore structure is the temperature that is experienced at the time of casting. High-temperature curing accelerates the curing process so that at young concrete ages, a high temperature cured concrete will be more mature and thus have a better resistance to chloride ion penetration than a normally-cured, otherwise identical, concrete at the same at age. However, at later ages when the normally-cured concrete has a chance to hydrate more fully, it will have a lower chloride ion diffusion coefficient than the high-temperature-cured concrete [18].This finding has been attributed to the coarse initial structure that is developed in the high-temperature-cured concrete due to its initial rapid rate of hydration as well as the possible development of initial internal micro-cracking [19].

Geopolymer mortars and concretes kept in the NaCl solution for long periods of time resist to corrosion without showing any signs of sample damage. The exposure of the geopolymers materials to the NaCl solution resulted in the consistent increase in the compressive strength during the whole period of measurement (720 days) and the values were as high as 70 MPa [13]. The penetration of chloride ions into the body of the geopolymers materials (point analyses, the measurement was carried out in the direction perpendicular to the surface in contact with the NaCl solution) shows a decreasing trend and the chloride concentration in the body is low. Almost no corrosion products could be found on the surface of the geopolymer materials while they were kept in the NaCl solution [10].

The incorporation of fly ash increases the porosity of the hardened cement paste at early ages, but the average pore size is reduced, and this often results in a less permeable paste [20]. The dense interfacial zone between aggregate and the matrix is also a result of the use of fly ash [21]. The concrete containing fly ash is, therefore, less susceptible to the ingress of the harmful chloride ions.

CHAPTER 3

METHODOLOGY

This chapter of the thesis presents the methods and the procedures to be undertaken to meet the objectives set at the beginning. It also proposes the scheduling of tasks and the key milestones to direct the progress of the project on the right track. The chapter discusses how the materials are selected for the experiment, the mixing proportions, the mixing procedures, the curing methods and the tests done to accomplish the expected results.

3.1 PROCEDURES FOLLOWED FOR THE EXPERIMENT

The steps or the processes undertaken to do the experiment are shown in the figure below.

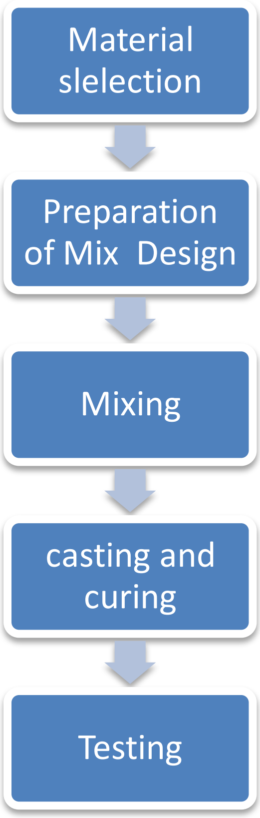


Figure 3: procedures for the experiment

3.1.1 Material Selection and descriptions

For the current experiment, A Low-calcium (ASTM Class F) Fly ash is used as a base material for the geopolymer concrete. This Low-calcium (ASTM Class F) Fly ash has a chemical composition that is shown in the table below and it is obtained from the Manjung power station, Lumut, Perak, Malaysia.

Table 1: composition of fly ash

Oxides	Percent by mass
Silicon dioxide	51.3
Aluminium oxide	30.1
Ferric oxide	4.57
Calcium oxide	8.73
Phosphorus pentoxide	1.6
Sulphur trioxide	1.4
Potassium oxide	1.56
Titanium dioxide	0.698

The alkaline activator that is going to be used is the combination of sodium hydroxide and sodium silicate. The sodium hydroxide comes as pellets and they will be dissolved in water to the required molarity level. The sodium silicate comes as a solution with the following composition shown on the table.

Table 2: Composition of sodium silicate

Components	Percentage(%)
Sodium oxide	14.26
Silicon oxide	29.43
water	56.31

The aggregates used for the concrete are well graded aggregates with coarse aggregates having maximum size of 14mm and 5mm sized fine aggregates with specific gravities of 2.66 and 2.61 respectively. Both of these aggregates are in saturated surface dry condition.

Ordinary Portland cement that is going to be used in the experimental process is the standard in the market. Which has the following components and with their proportion shown in the table below.

Table 3: Composition of OPC

Constituents	% by mass
Calcium oxide	61-67
Silicon oxide	19-23
Aluminium oxide	2.5-6
Ferric oxide	0-6
Sulphate	1.5-4.5

3.1.2 Mix Design and Mix proportion

The mix design for the experiment was taken from previous experiments where trial and error was done to find the optimum mix design for a geopolymer system. Then the proportional mixing is done between the fly ash and the Ordinary Portland concrete cement by mass. The proportioning starts with 100% fly ash to 0% Rapid hardening cement and continues 95% to 5%, 90% to 10% and 85% to 15%.

Table 4: Mix design

Mix Code	Fly Ash (kg/m^3)	OPC (kg/m^3)	Fine Agg. (kg/m^3)	Coarse Agg. (kg/m^3)	Sodium Hydroxide		Sodium silicate	Curing Temp
					(kg/m^3)	Mol.	(kg/m^3)	(^{0}C)
A	400	-	850	950	57	12	143	70
B	380	20	850	950	57	12	143	70
C	360	40	850	950	57	12	143	70
D	340	60	850	950	57	12	143	70

3.1.3 Mixing

The mixing procedure follows after the materials have been selected and the mix design for the specific fly ash to rapid hardening concrete cement proportioning has been done. The procedure for mixing is listed and explained below.

1. The sodium hydroxide pellets are dissolved in water one day before the day of the mixing. The pellets are 99% pure. The solution prepared is 12M by referring to the mix design done.

2. Each of the materials are prepared according to the mix design. The preparation starts with weighing both the coarse and fine aggregates to the calculated weight for the needed volume of the concrete to be prepared.

3. The proportional mix of the fly ash to the rapid hardening concrete cement is prepared for the specific concrete to be mixed.

4. The alkaline activator is then prepared by mixing the stated volume of the required sodium silicate solution on the mix design to the prepared sodium hydroxide solution.

5. Finally, all the materials are added on the concrete mixer shown below. First, the coarse and fine aggregates were mixed in the mixer for about 2.5 minutes and then the alkaline activator was added and it was mixed with the aggregates for 1.5 minutes. Some volume of water is added according to the mix design, to increase the workability of the concrete, and mixed for 1 minute.

Figure 4: Mixer

3.1.4 Casting and Curing

The casting of the concrete cubes is done if the concrete has passed the slump test described above. The concrete is then poured in to the moulds prepared. The moulds are needed to shape and size the concrete to the size and shape for the respective tests to be done. The concrete is left to fill in the moulds by its own weight and then it is vibrated so remove the air bubbles from the moulded concrete.

The dimensions of the concrete moulds are the same for the compression test and the fire resistance. The dimensions are 100x100x100(all dimensions in mm). The dimensions of the moulds for the tensile strength test are 200mm in height and 100mm in diameter and for chloride penetration are 50mm in height and 100mm in diameter.

Three concrete cubes are casted for each specific test at a specific curing temperature. The reason behind the casting of three concrete cubes for each test is to increase the accuracy and the precision of data from the test.

Figure 5: Moulds

Figure 6: Moulds

After the concrete is cast then the moulds are placed inside an oven at a curing temperature of 70^0 c. The experiment is done for curing temperatures of 24 and 48 hours inside an oven. The moulds are taken out of the oven after the specified curing time to be demoulded. Finally, the concrete cubes are left in a dry place so that they could attain their strengths and be tested for the specific date of compression and tensile strength.

3.1.6 Testing

The tests that are done to compare the proportioned rapid hardening cement in geopolymer system to a pure geopolymer are compressive strength test, tensile strength test, fire resistance test and Chloride attack test.

3.1.6.1 Compression strength test

The compressive strength is one of the basic notable properties of concrete. It is the maximum compression force that the concrete can with stand without showing any sign of failure. And the test for this property is performed according to BS EN 12390-3, 2009 using 2000KN capacity digital compressive and flexural testing machine. The compression pace used when doing the test was 3 KN/s.

The compression strength is done at the 3rd, 7th day and 28th day according to the standard testing method. The geopolymer concrete is assumed to attain its optimum strength at the 28th day.

Figure 7: Compressive strength testing machine

3.1.6.2 Tensile strength test

The tensile strength is the ultimate tensile force the material can with stand without showing any sign of failure. From the properties of concrete, it is proved that concrete is good in compression but weak in tension therefore, this test is done if the mix proportioning increases the tensile property of the geopolymer concrete. The test is also done according to the BS EN 12390-6, 2009 on the concrete cylinders. The The compression pace used when doing the test was 0.94 KN/s.

Figure 8: Tensile strength testing machine

3.1.6.3 Fire resistance test

The fire resistance that was done on the casted concrete was done according to American Society of Testing and Materials (ASTM). It is designated as ASTM E 119, Standard Methods of Fire Tests of Building Construction and Materials. The apparatus used for the fire test is a blow torch and an infrared thermometer is used to measure the high temperature.

The concrete samples for this test will be exposed to 800^0c fire for about 1 hour and they are left at ambient temperature for 24 hours before they are tested for their compressive strength.

Figure 9: Blow torch

3.1.6.4 Alkali attack resistance test

The test done to test the alkali resistance test on the concrete samples is the rapid chloride penetration test. (RCPT).The test method involves obtaining a 50 mm diameter core with 200mm diameter. The steps undertaken for the test are shown below.

1. The side of the cylindrical specimen is coated with epoxy
2. After the epoxy is dried, it is put in a vacuum chamber for 3 hours.
3. The specimen is vacuum saturated for 1 hour and allowed to soak for18 hours.
4. It is then placed in the test device (see test method for schematic of device). The left-hand side (–) of the test cell is filled with a 3% NaCl solution. The right-hand side (+) of the test cell is filled with 0.3N NaOH solution. The system is then connected and a 60-voltpotential is applied for 6 hours.
5. Readings are taken every 30 minutes. At the end of 6 hours the sample is removed from the cell and the amount of coulombs passed through the specimen is calculated.

$$Q = 900(I_0+2I_{30}+2I_{60}+\ldots I_t)$$

Where,

Q = current flowing through one cell (coulombs)

I_0 = Current reading in amperes immediately after voltage is applied, and

I_t = Current reading in amperes at t minutes after voltage is applied

The current passed in coulombs that was caluculated from the test results is then compared to the table below to describe the alkali penetration resistance of the concrete. The results range from high permeability to very low permeability based on the amount of the current passed.

Table 5: standard chloride permeability table

Chloride permeability	Charge passing (coulombs)
High	>4000
Moderate	2000 to 4000
Low	1000 to 2000
Very low	100 to 1000

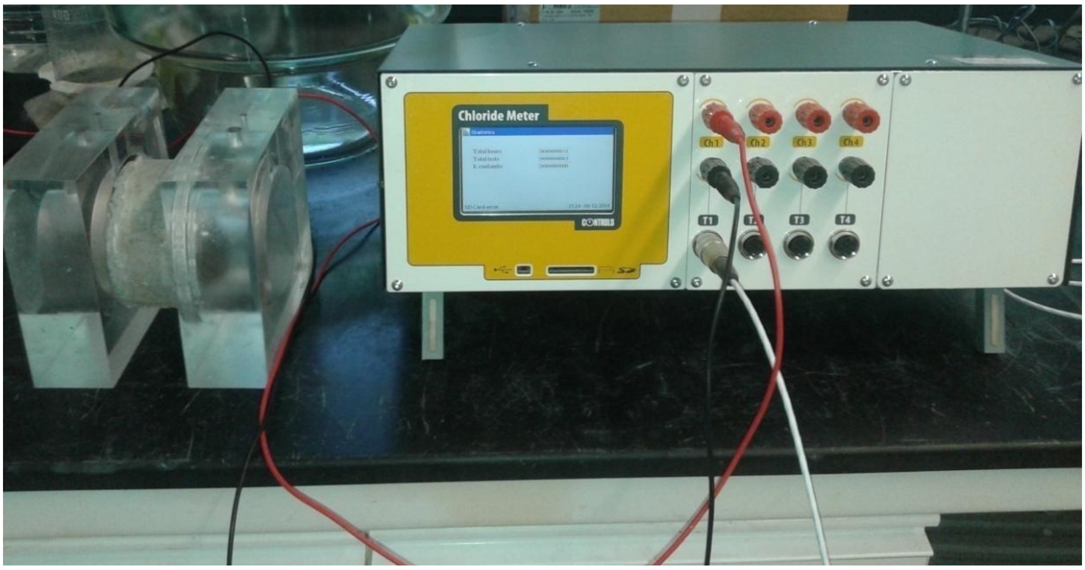


Fig 10: Rapid chloride penetration meter

3.2 Gantt Chart and Key Milestones

The Gantt chart for Final year project 1 is shown on the table below:

Table 6: Gantt chart FYP1

Task ID	Task	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project title	🟨													
2	Meeting with supervisor		🟨												
3	Brainstorming and Literature reading			🟨	🟨	🟨									
4	proposal of problem statement						🟨	🟨							
5	Submission of extended proposal							🟨							
6	Editing the proposal and coming up with sufficient methodology								🟨	🟨					
7	Proposal Defense										🟨				
8	Material order											🟨			
9	Initial experiments								🟨	🟨	🟨	🟨			
10	Writing the Interim report									🟨	🟨	🟨			
11	Submission of Interim report												🟨		

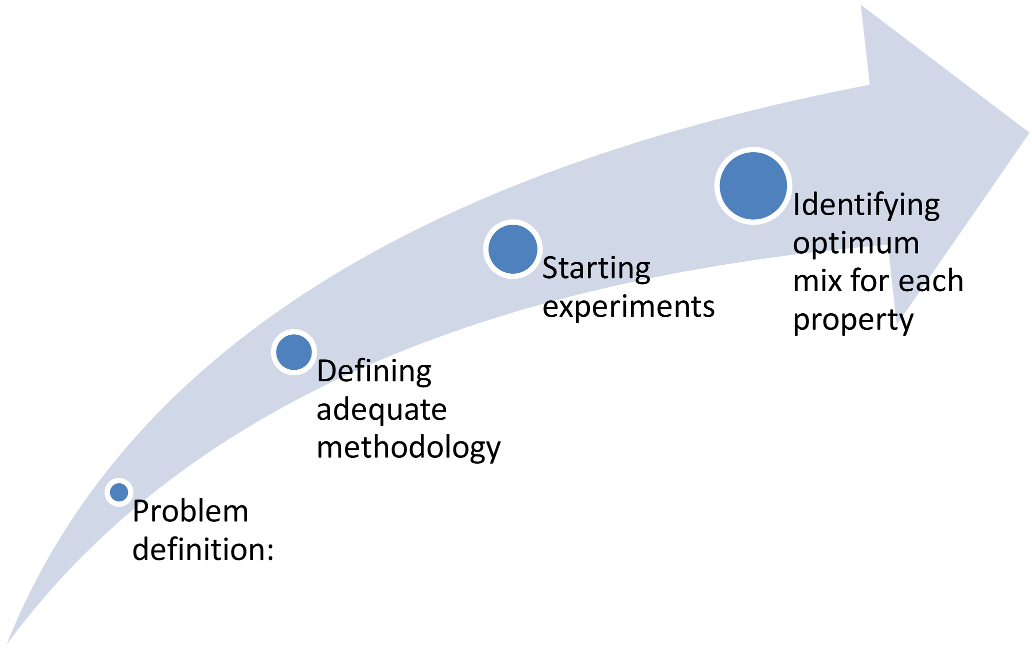
The Gantt chart for Final year project 2 is shown on the table below:

Table 7: Gantt chart FYP2

Task ID	Task	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Conducting Experiment	■	■	■	■	■	■	■							
2	Submission of progress report							■							
3	Analyzing the results							■	■						
4	Identifying the optimum mixes for each property							■	■	■					
5	Pre- SEDEX										■				
6	Submission of Draft Final report										■				
7	Submission of Dissertation											■			
8	Submission of Technical paper												■		
9	Viva														■
10	Submission of Dissertation hard bound														■

Key Milestones for Final year project

Problem definition:	Week 2(fyp 1)
Defining adequate methodology:	Week 7 (fyp 1)
Starting experiments :	Week 10(fyp 1)
Identifying optimum mix for each property :	Week 14(fyp 2)



CHAPTER 4

RESULTS AND DISCUSSION

This chapter presents the results obtained from the experiments done by following the procedures on the methodology proposed. The results obtained are the compressive strength, the tensile strength, the fire resistance and the chloride penetration resistance of the samples. The results stated are presented in tables and graphs and also analyzed and compared to the properties of the materials in the - current industry.

4.1 COMPRESSION AND TENSILE STRENGTH

The following table presents the results of the compression and tensile strengths of the individual samples according to their respective cement inclusion and curing period. The first table presents the obtained properties of the samples after 24 hours of curing and the second table shows the characteristic values of the samples after 48 hours of curing.

Table 8: Strength data for 24 hours curing

Property	Percentage inclusion											
	0%			5%			10%			15%		
	3 days	7 days	28 days	3 days	7 days	28 days	3 days	7 days	28 days	3 days	7 days	28 days
Compressive strength	100.1	103.9	109.8	93.1	95.5	104.1	88.1	90.8	100.6	89.5	87.3	96.2
	95.5	103.5	107.6	96.4	100.3	117.2	84.2	86.5	97.2	83.2	90.9	95.1
	93.7	105.6	116.2	90	93.7	109.06	87.4	93.4	91.9	84.1	89.9	91.8
Tensile Strength	3.532	3.761	6.039	4.213	4.259	4.24	5.103	5.435	5.568	4.254	6.028	6.152
	4.268	3.927	5.536	4.362	5.348	5.779	4.649	4.832	5.167	4.157	5.414	5.881
	3.757	5.353	4.19	3.597	4.661	5.468	3.969	4.997	4.859	4.366	5.505	5.429

Table 9: Strength data for 48 hours

Property	Percentage inclusion											
	0%			5%			10%			15%		
	3 days	7 days	28 days	3 days	7 days	28 days	3 days	7 days	28 days	3 days	7 days	28 days
Compressive strength	105.3	120.1	123.8	101.7	112.4	115.3	98.1	102.7	108.6	90.2	99.44	101.9
	101.7	116.9	119.6	103.6	107.4	109.2	100.5	99.2	107.1	92.5	94.67	100.6
	109.4	118.2	117.1	100	106.5	110	100.1	97.8	103.6	94.7	88.97	102.8
Tensile Strength	6	5.786	5.652	4.752	5.249	5.771	4.828	5.831	6.152	5.016	5.983	6.234
	4.78	4.463	5.429	4.473	4.986	5.683	4.98	6.053	5.823	5.124	5.821	5.847
	4.02	4.825	5.416	5.147	4.883	4.975	4.871	4.862	5.467	5.368	5.637	6.119

The difference between the maximum and the minuimum of the results of the samples for a specific cement inclusion is taken for each property and the following graphs are drawn for the compressive strength of the samples. The first graph is done for samples cured for 24 hours and the second one for 48 hours.

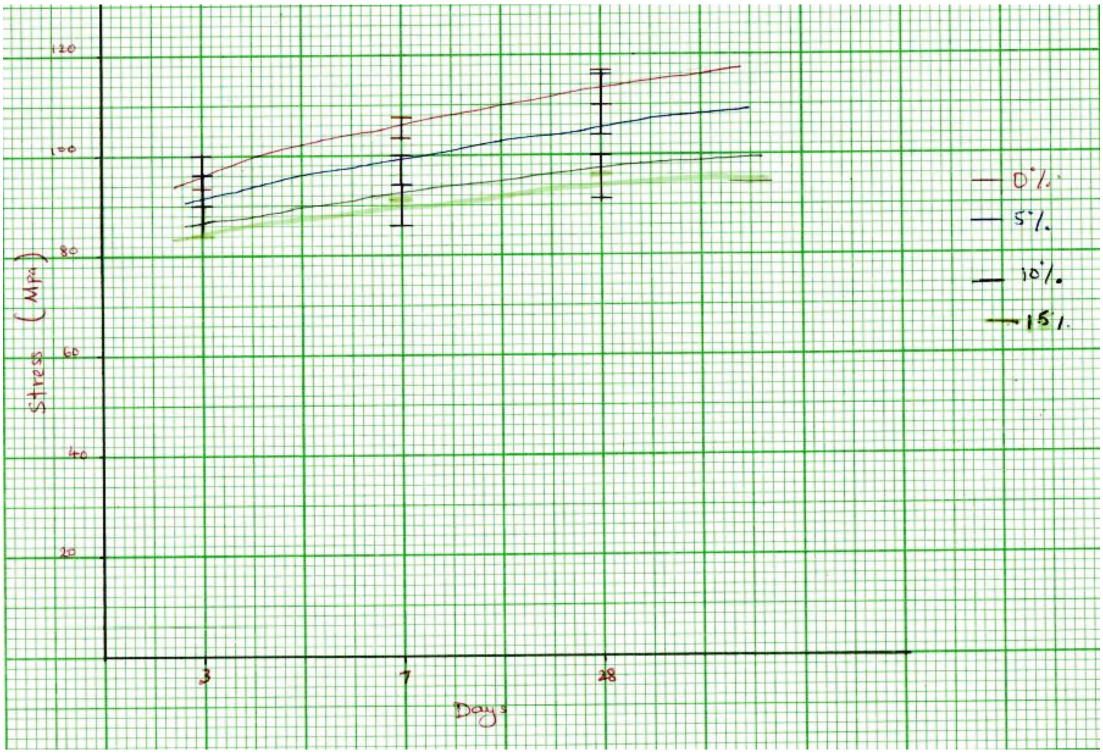


Figure 11: compressive strength for 24 hour curing

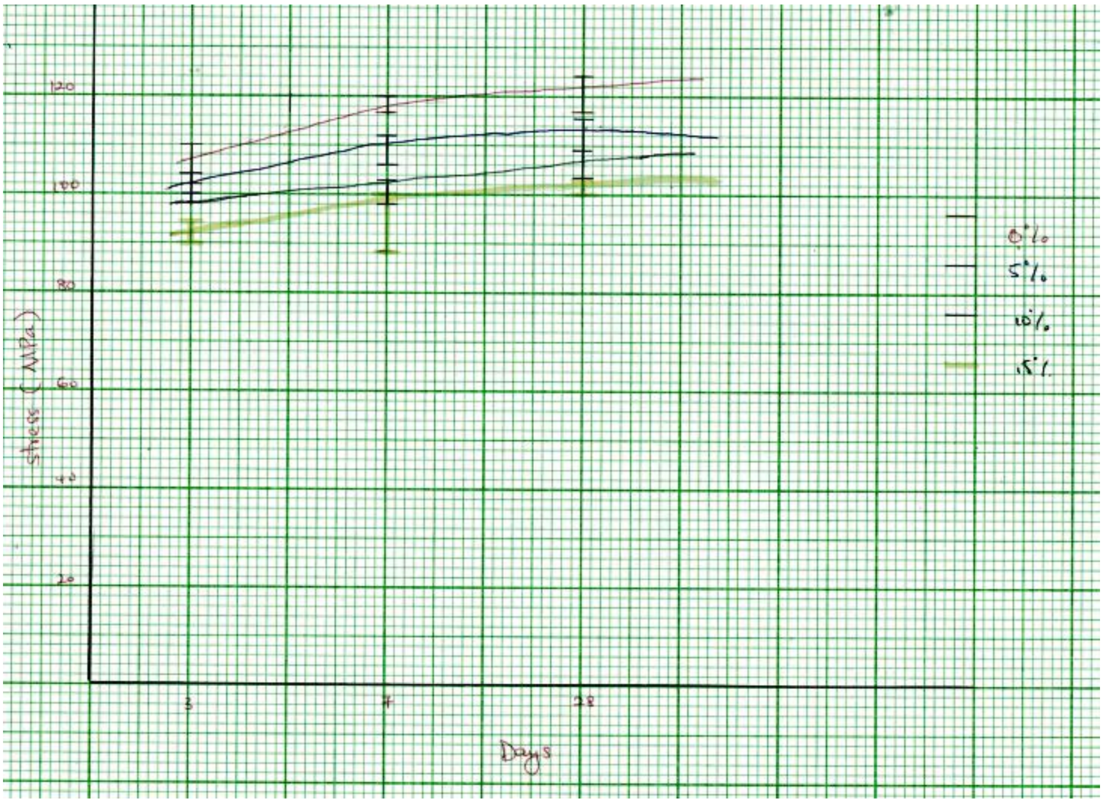


Figure 12: compressive strength for 48 hours curing

The above graphs show the general compressive strength development of the geopolymer concrete. As it can be seen, the compressive strength development is not much different from the strength development of the conventional concrete as stated by Palomo et al [15], It gains most of the strength before the 28th day after casting and it continues to gain some more steadily. From the figures on the table, it can be said that the compressive strength of the geopolymer concrete with or without the inclusion of cement is always higher than the conventional cement concrete at all the testing dates.

The compressive strength of the geopolymer as it can be seen from the graphs decreases with the increase in the cement inclusion. The geopolymer concrete samples have the highest compressive strengths at the 3rd, 7th and 28th day testing with the 0% cement inclusion to the mix and the second highest compressive strengths can be seen with the 5% cement inclusion. And the samples with 15% cement inclusion have the lowest compressive strengths. This phenomenon is true for both 24 and 48 hours curing.

The graphs of the compressive strength development of the 24 hours and the 48 hours cured samples show that the samples at each of the different inclusion ratios after 48 hours curing developed more strength than their 24 hours counterparts. This early and continuous strength development is because of the sufficient energy provided for the formation of the bond. In the literatures, it was discussed that the increase in the curing periods increases the compressive strength of the geopolymer concrete and the graphs also show the same thing. Therefore, the inclusion of cement in the geopolymer system does not affect the required curing period to attain the highest compressive strength.

Van Jaarsveld et al [17] suggested using different types of alkaline solution namely sodium hydroxide and potassium hydroxide with sodium silicate for better strength outcomes and the experiment followed this procedure and the results for all the days for compression tests are very high.

The graphs show that the additional energy coming from the cement inclusion in the mix ratio does not release enough energy that is sufficient to increase the compressive strength of the concrete samples. Which means the deducted fly ash could have made a better adhesion between the ingredients of the geopolymer.

Like the compressive strength, the values of the tensile strength were measure and put in the tables 9 and table 10 for the respective curing periods of the concrete samples and the following graphs were drawn based on these data.

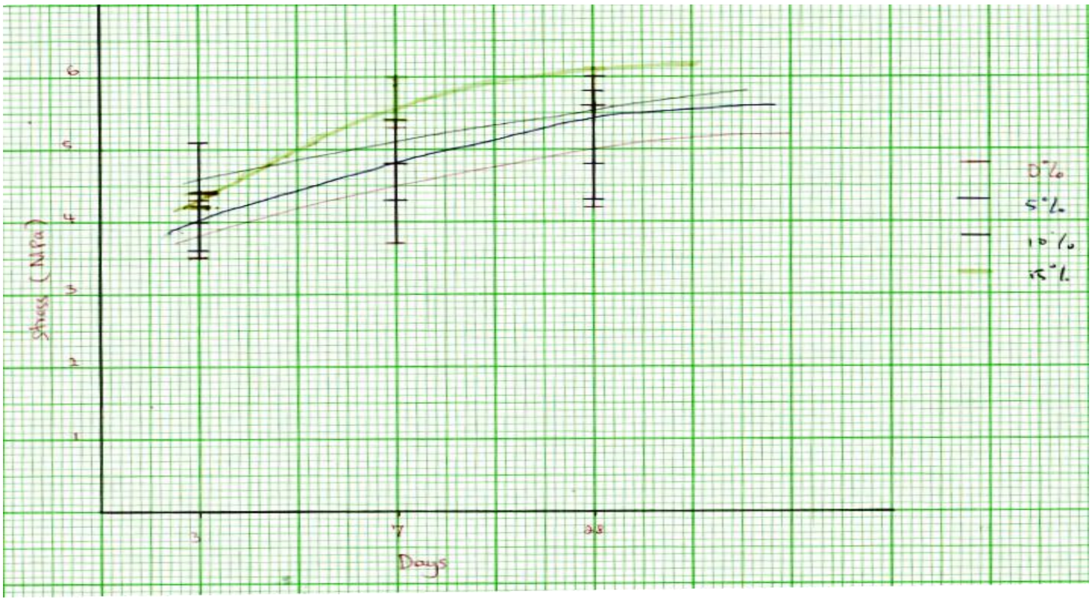


Figure 13: Tensile strength for 24 hour curing

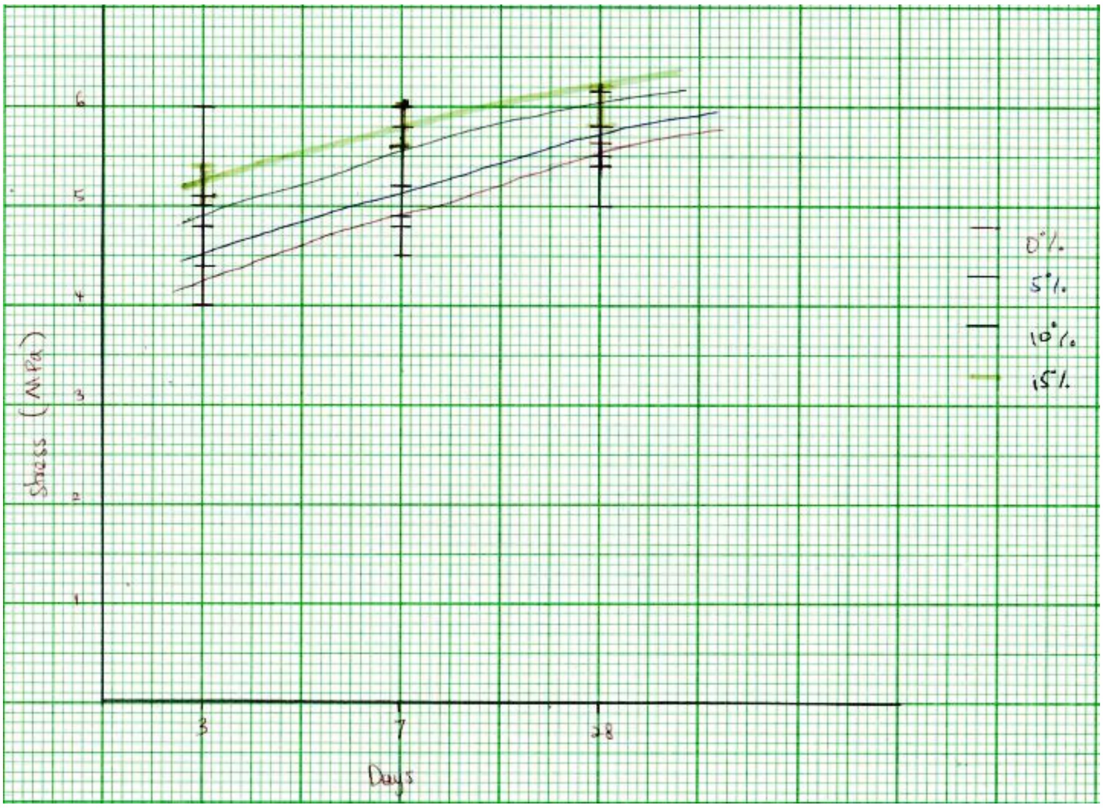


Figure 12: Tensile strength for 48 hours curing

The graphs of the tensile strength development show that the tensile strength of the geopolymer is the similar to the tensile strength development of the conventional cement concrete. from the figures on tables 7 and 8, the tensile strength of the geopolymer samples with the inclusion of the cement is higher at each of the test dates when compared with the cement based concrete for both 24 and 48 hours curing.

It can be seen from the graph above that the tensile strength of the samples for each of the respective inclusion of cement are higher when cured for 48 hours than 24 hours. This property happens because of the increase in curing time which gives the binder paste to bond the components of the concrete to give a higher tensile strength.

The tensile strength of the samples varies according to the ratio of the cement inclusion. From the graphs above, the increase in the inclusion of cement directly increases the tensile strength of the concrete samples regardless of the curing periods. It can be seen that the highest tensile strength recorded was at the inclusion of 15% cement to the mix ratio. The tensile strength is more or less gained almost at the 7th day and it increases steadily in very small amounts for both 24 and 48 hours curing period.

4.2 FIRE RESISTANCE

The table below show the raw data collected from the fire resistance test for both 24 and 48 hours cured samples. The test is done after 28 days based on the ASTM E 119, Standard Methods of Fire Tests of Building Construction and Materials.

Table 10: compressive strength after fire attack

	0%		5%		10%		15%	
Compressive strength (N/mm^2)	24 hours	48 hours	24 hours	48 hours	24 hours	48 hours	24 hours	48 hours
	92.7	101.6	85.4	92.8	83.62	93.1	76.84	85
	96.1	109.4	92	106.3	82.74	102.2	75.3	88.3
	94.76	102.6	100.1	108.1	74.09	97.6	80	86.2

From the table above, the averages of each mix proportions are taken to draw the graphs below.

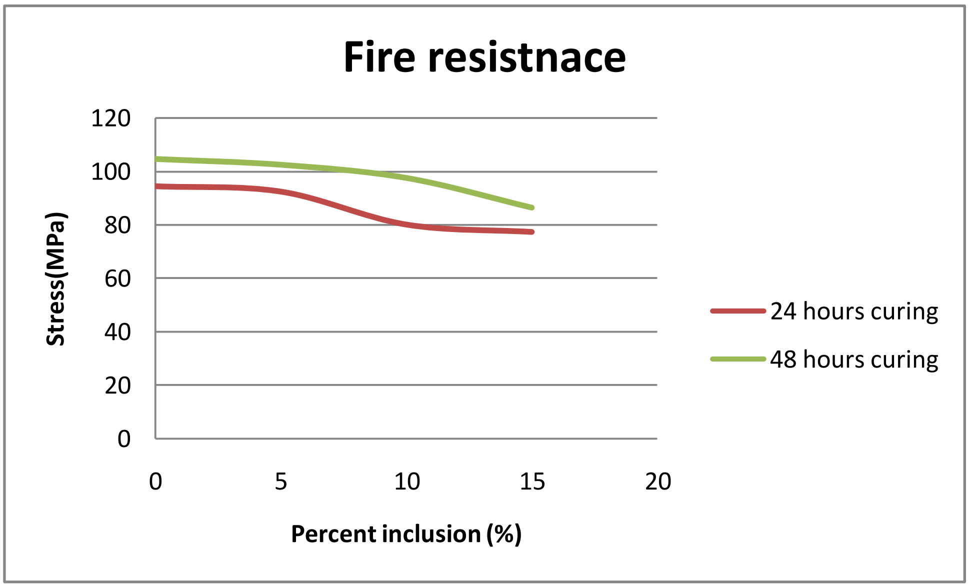


Figure 15: fire resistance

From the graphs above it can be said that the fire resistance of the samples decreases with the increase in the cement content of the mix proportion. This decrease in fire resistance is for both of the curing periods. The highest resistance can be seen at 0% OPC inclusion and the lowest is at 15% OPC inclusion.

The graphs show that the samples cured for 48 hours have a much better resistance than the samples cured for 24 hours at all of the fly ash-cement mix proportions. This means that much more stronger bonds were formed by the 48 hours that made the samples stay more intact during the fire attack and the compression test afterwards.

The graphs above show that there is a decrease of 15-17% in compression strength after the fire resistance testing for the 24 hours cured samples and a decrease of 10-13% for the 48 hours cured samples. According to American standard for testing materials, if the decrease in the strength of the samples is less than 20%, then the samples have a good fire resistance and the results are acceptable. Since the decrease in fire resistance results for both of the curing periods are less than 20%, inclusion of the cement is acceptable.

This high fire resistance has resulted from the strong Aluminium-silica bond attaching the ingredients of the geopolymer concrete. The selection of a good aggregate type has also a big factor when it comes to the fire resistance of the concrete samples.

The decrease in fire resistance with the increase in the cement inclusion happened because of the insufficient energy that was provided from the exothermic reaction of the Ordinary cement setting. The experiment tried to replace some of the fly-ash by the Ordinary Portland cement to add in more energy for the endothermic geopolymerisation process to boost the strength of the concrete samples but this replacement did not even cover the strength provided by the replaced fly ash.

4.3 ALKALINE PENETRATION RESISTANCE

The Alkaline penetration resistance of the concrete samples was done by the rapid chloride penetration test. The test was conducted 28 days after casting the concrete. The following table is prepared after the raw data obtained was calculated using the formula provided in the methodology part.

Table 11: Current that passed through the concrete samples (Coulombs)

	0%		5%		10%		15%	
Chloride penetration (coulombs)	24 hours	48 hours	24 hours	48 hours	24 hours	48 hours	24 hours	48 hours
	3182	2799	3132	2678	3245	3267	3196	3100
	2752	2749	3085	3261	3447	3023	3929	3811
	2641	2918	3113	3334	3072	3201	3142	3047

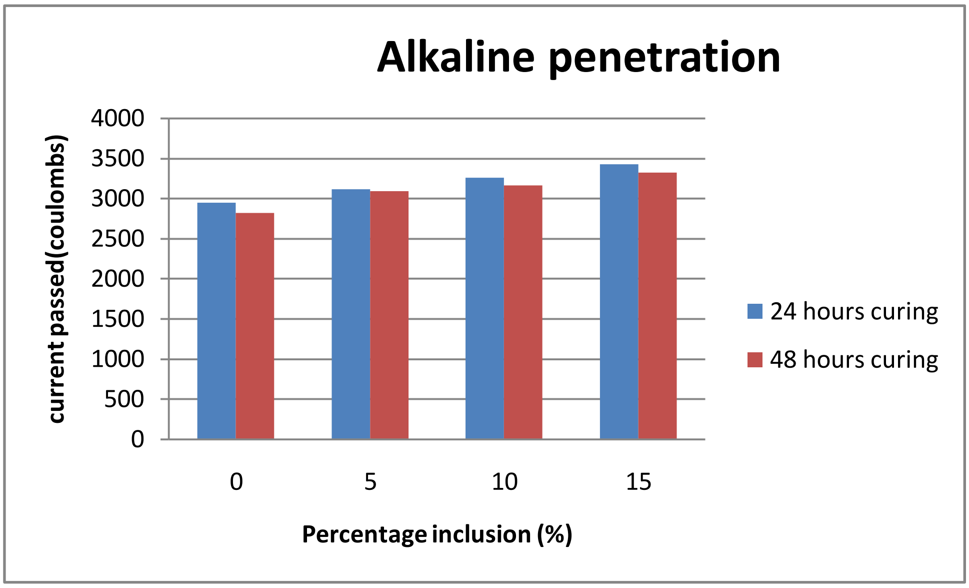


Fig 16: Alkaline penetration

The graph above shows that the penetration of the chloride ions increases with the increase in Ordinary Portland cement inclusion in the mix. The increase in the chloride ions penetration is increase with the cement inclusion regardless of the period of curing.

From the table 5, the standard current penetration of samples, for 24 hours penetration; at 0% cement inclusion the average current passed through the sample when compared to the table 5 is between 2000 and 4000 coulombs which means it has a medium chloride ion penetration. At 5% and 10% the average current that passed through the samples is between 2000 and 4000 coulombs which means it has also a medium chloride penetration. At 15% chloride penetration the average current that passed is 3422 coulombs Which means the samples with that inclusion are have a medium chloride penetration.

For 48 hours cured concrete samples the average current passed in the 0% cement inclusion samples is 2000 and 4000 coulombs for the 5% cement inclusion samples. The average current in coulombs that passed through the 10% cement inclusion samples is 2000 and 4000 coulombs for the samples with 15% cement inclusion.

It was mentioned in the literature review that the permeability of concrete to alkaline ions depends on the porosity of the structure or molecules of the binding material [23]. Therefore, the increase in the chloride penetration can be attributed to the porosity to chloride ions of the Ordinary Portland cement as compared to the fly ash it replaced.

The chloride penetration is highest for 24 hours of curing and it decrease for the 48 hours cured concrete samples. The reason behind this phenomenon is described by Detwiler et al [18], the pore structure of the concrete samples is also affected by the temperature and the period of curing, since the 48 hours cured samples will be more matured and well structured than the 24 hours cured samples, the chloride penetration is lower.

4.4 WORKABILITY

The workability of the mix decreases with the increase in the inclusion percentage of the cement. The 0% and the 5% inclusion mixes have a good workability and a good setting time. These mixes have enough time to be transported from the mixing area to the casting and placement area. But at the 10% and the 15% cement have a very low workability and they also have a very fast setting time which makes them very difficult to work with. The reason behind this variation of workability and setting time is because of the amount of heat released when the cement reacts and starts setting. As the amount of the cement is increased in the mix proportion¸ the amount of heat also increases. Therefore it could be said that the percentage of the cement in the mix proportion is inversely related to the workability of the mix and the setting time of the mix.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSION

As it was thoroughly discussed in the literature review, the fly ash based geopolymer has superior compressive strength, tensile strength, fire resistance and alkali attack resistance over the Ordinary Portland cement. These desirable properties are in general the result of the Aluminium silica bond. And the main objective of this project is to identify an optimum percentage mixture of these two cementious materials to form a concrete that has the high mechanical and durability properties of the fly ash based geopolymer concrete with a good setting time and less energy requirement of the Ordinary Portland cement. In addition, it also tries to identify the optimum curing period for each of the properties.

From the results and discussion chapter, it can be seen that the addition of cement has different effects on the compressive strength and the tensile strength of the geopolymer concrete. Regardless of the curing periods involved, the compressive strength has substantially decreased with the increase in the percentage of Ordinary Portland cement inclusion, where the compressive strength is the highest with no cement inclusion. But for the tensile strength of the samples, the tensile strength increased with the increase in Ordinary Portland cement inclusion in the mix for both 24 and 48 hours curing. Like the compressive strength, the fire resistance of the concrete samples casted decrease with the increase in the percentage inclusion of the Ordinary Portland cement inclusion, where the 0% cement inclusion having the highest fire resistance. When it comes to alkali penetration resistance, it could be concluded that the increase in the Ordinary Portland cement inclusion has increased the porosity of the concrete samples to the chloride ions, which means decrease in the alkali penetration resistance. In general, from the results obtained, the inclusion of Ordinary Portland cement has different effects on the mechanical and durability of the geopolymer system.

5.2 RECOMMENDATION

The results obtained from the experiment are lower than expected for the percentages of the Ordinary Portland cement inclusion for some of the properties. It can be suggested that this low results could be corrected by the addition of water in the mix design. Therefore, future investigations should be done on these properties by adding water in the system.

This project has been done to indentify the effects of the inclusion of the Ordinary Portland cement in the geopolymer system in the mechanical properties and durability of the geopolymer concrete. This work studied very few properties of the system due to time constraint; therefore additional research should be done deeply to study the effects more deeply.

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