Bonding characteristics of Self Compacting Geopolymer Concrete

through Pull Out Test

by

Amatillah Sakinah binti Abd Rahain

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Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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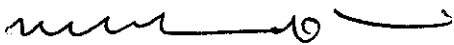
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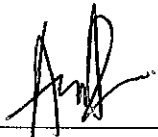(Prof. Ir. Dr. Muhd Fadhil bin Nuruddin)

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This is to certify 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 acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

AMATILLAH SAKINAH BINTI ABD RAHAIN

ABSTRACT

Geopolymer concrete has been recognized as an alternative to replace Ordinary Portland Cement Concrete (OPC) in term of many aspects such as cost saving and environmental friendly material. Fly ash is one of the most utilized waste materials to replace OPC as the binder in the concrete. Fly ash from the combustion of coal in electrical power plant had also been identified as a contributor to the environmental problem if they are not disposed properly. In this research, fly ash was used as the main ingredient to produce geopolymer concrete which obtained from Manjung Power station. Super Plasticizer was added to improve the self-compatibility properties of geopolymer concrete. Thus, this material is called as Self Compacting Geopolymer Concrete (SCGC). This concrete has the ability to be self-compacted without the need of vibration and compaction process. This research is dedicated to investigate the bonding characteristic of Self Compacting Geopolymer Concrete through Pull Out Test. There are two types of steel bars used which are ribbed bars and normal bars. Besides, the molarity of sodium hydroxide in alkaline activating solution also varied. There were four molarity used namely 8M, 10M, 12M and 14M. Besides that, the curing regime that applied was external curing. Each sample was tested at 14 days and 28 days. Pull out test for each sample was done in the laboratory using Universal Testing Machine (UTM). As for the result, it eventually found that out of the molarity used, the highest bond strength occurred when molarity of sodium hydroxide is 12M. On the other hand, between ribbed and round steel bar used, bond strength it at its highest for sample that utilized ribbed bars. Lastly, from the observation comparing curing ages, the highest bond strength happened at samples that have been cured for 28 days compared to 14 days.

ACKNOWLEDGMENT

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CHAPTER 1

INTRODUCTION

1. INTRODUCTION

As time goes by, the development of building and structures in this world have evolved rapidly together with the civilization of mankind. This also includes the technology used as well as type of materials blended in making a great shape in structural history. From the ancient history, magnificent and amazing structures are not new to our world. Pyramid, Coliseum, Aqueduct of Segovia, Pantheon and others are the examples of the great arts left by the gifted and talented architectures and engineers of ancient dynasty. Same goes to the materials used in making these superior structures. In the Roman history, main constituent used in building the structures was Roman Concrete. Roman Concrete, like another typical concrete consists of aggregates and hydraulic mortar- a binder mixed with water that harden with respect to time. The aggregates anyhow varied, which sometimes included pieces of rock, ceramic tile and brick rubber taken from the previous demolished buildings. Gypsum and lime were used as the binder for this concrete.

Dating back to the 4th century BC, lime mortar is widely used in Ancient Rome and Greece as it rapidly replaced the use of clay and gypsum mortar with regards to Ancient Egyptian construction. However, the introduction of ordinary Portland cement during the 19th century has gradually decreased the usage of lime mortars in construction.

Ordinary Portland cement (OPC) was introduced back then from Joseph Aspdin, a British Bricklayer from Leeds. One of his employees (Isaac Johnson) developed the production technique (patented in 1824) which then resulted in more fast-hardening cement with higher compressive strength. In 1843, Aspdin's son William improved

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the version of the cement and named it as "Patent Portland Cement" although he had no patent. Eventually, in 1848, William Aspdin further improved his cement and then he moved to Germany in 1853 where he was involved in cement making.

In making concrete, cement will act as the binder. Mixed with aggregates and water, cement form the ubiquitous concrete which is used in the construction of buildings, roads, bridges, and other structure. In fact, twice as much concrete is used in construction around the world than the total of all other building material [1].

On the other hand, cement consumption is increasing globally by 5% per year [1]. This triggered a warning alarm in the industry as cement production is responsible for 7-10% of total Carbon Dioxide (CO_2) emissions worldwide [1]. In fact, production of 1 ton of OPC will correspondent to the release of 1 ton of CO_2 [2, 3]. In the cement production processes, the CO_2 is emitted during the decomposition of limestone and from kiln fuel combustion. This figure ranked cement as the third biggest contributor to the world's Greenhouse Gas (GHG) [1].

To reduce GHG emissions, many researches have been done to find the most suitable binder to replace cement. Mehta and Monteiro, suggested that the waste product of one industry is recycled as a substitute for virgin raw material of another industry, thereby reducing the environmental impact of both [4]. In concrete industry, the waste products that commonly used are fly ash, silica fume, granulated blast furnace slag, rice hush ash and metakaolin. The usage of these waste material (commonly called as source material), which are rich in silicone and aluminium, provide excellent examples of industrial ecology because they offer a holistic solution to reduce the environmental impact of several industries. In line with that, Davidovits in 1978 has introduced term 'geopolymer' which acts as alternative binder in order to replace cement. Geopolymer is obtained by polymeric reaction of alkaline liquid with silicone and aluminium in source material [5]. The usage of geopolymer will completely replace OPC thus minimize the dependence of on OPC in concrete. It is believed that this will reduce the emissions of GHG up to 80% from this industry [6].

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1.1 Problem Statement

Concrete is an important material in construction world. Concrete is formed from the mixing of binder, water, aggregates and admixtures. Two types of aggregates involved in the concrete formation namely coarse aggregates and fine aggregates. Coarse aggregates normally include gravel, limestone and basalt while fine aggregates normally incorporated sand as its material. Normal concrete will use Ordinary Portland Cement (OPC) as the binder. When water is poured into all these materials, a chemical reaction called hydration will happen where all the materials will bind together thus formed a larger mass.

However, the production of OPC has been proven to show significant effects to the environment. There are lots of effects associated with it but one of the major effects is the emission of CO_2. During the cement production, the CO_2 is emitted during the decomposition of limestone and from kiln fuel combustion which eventually listed cement as the third biggest contributor to the world's Greenhouse Gas (GHG) [1].

Other effects associated with cement production are noise, dust and vibration. Noise and vibration will distract the neighbouring area thus create an uncomfortable environment to them. In addition, dust will harm health as it will affect the respiration system of the consumer.

As there are so many effects from the utilization of OPC, the search for its alternatives is rising day by day. Cement Replacement Material (CRM) has been discovered to be the alternatives as binder. Among them are fly ash, rice husk, ground granulated blast slag (ggbs) and others. For an effective reaction, fly ash (FA) is the most suitable as main material compared to other CRM as it contains high amount of alumina and silica content. Thus, for this research, FA is adopted as the main material.

Difficulty in concrete placement also is being noted while carrying out this research. In construction industry, a sufficient concrete consolidation by using vibrators is essential especially when fresh concrete is poured into formworks for the sake to eliminate stone pockets, honeycomb, and entrapped air that may reduce its strength and durability. Skilled workers will use mechanical vibrators to consolidate concrete properly. However, the usage of mechanical vibrator cause

many harm especially to the surrounding neighbours as it produces loud noise which is categorized as noise pollution.

On the other hand, inadequate compaction also will lead to large numbers of voids and concrete segregation which eventually will affect the performance and durability of the structures especially to slender building parts and area of reinforcing bars. As a result, high cost needed to maintain the defect caused by inadequate compaction. To solve this problem, Self Compacting Concrete (SCC) is employed in this research. Adopting SCC, concrete is compacted into every corner of a formwork, solely using its own weight and without applying vibration and compaction along the process. Self-compacting concrete practices will as well ensure faster construction time and reduced cost for skilled construction workers.

One of the major materials used in construction industry is reinforcement bar. This is to produce reinforced steel. Reinforced steel was designed on the principle that steel and concrete act together in resisting force. Concrete is strong in compression but weak in tension. The tensile strength is generally rated about 10 percent of the compression strength. Thus, concrete performs well for compression members in structure such as columns and posts. However, when it comes to tensile members such as beams, girders, foundation walls and floors, concrete must be reinforced in order to achieve estimated tension strength to sustain the load. So, one of the most important attributes in reinforced concrete is bond strength between the reinforcement bars and the concrete itself. A good bond strength, which result from an optimum combination of several parameters, such as mutual adhesion between concrete and steel interface, pressure of hardened concrete against steel bar or wire due to shrinkage from drying of concrete as well as friction interlock between bar surface deformation or projections and concrete is required so that the two materials are able to act together in a synergistic way.

1.2 Objectives

The objectives of the research are:

1. To evaluate the effect of molarity of Sodium Hydroxide (NaOH) to the performance of bonding between Self Compacting Geopolymer Concrete (SCGC) and steel reinforcement bars

2. To identify the effect of different type of steel reinforcement bars on the bonding properties between Self Compacting Geopolymer Concrete (SCGC) and the bars

3. To establish the bond between Self Compacting Geopolymer Concrete (SCGC) and steel reinforcement bars through pull out test

1.3 Scope of study

Main material used in this research is fly ash which is obtained from Manjung Power Plant. The other materials are alkaline solution which comprises Sodium Hydroxide (NaOH), Sodium Silicate (Na_2SiO_3), super plasticizer, aggregates and extra water. The concentration of NaOH is varied from 8M, 10M, 12M and 14M in order to see its effects on the bonding properties. In addition, the equipment and apparatus used are the same like that are used in producing OPC concrete.

There are two types of rebar which are normal round bar and ribbed rebar. As the objective of this research is to establish the bonding between SCGC and steel reinforcement bar, pull out test is conducted. This test is performed using Universal Testing Machine (UTM) that is available in concrete laboratory. Two testing period of concrete age selected are 14 days and 28 days. In addition, the data for workability is obtained from previous research.

CHAPTER 2

LITERATURE REVIEW

This chapter will briefly explain background of materials and method selected to carry out this research. Several published materials regarding geopolymer concrete, sodium hydroxide (NaOH) and bond test were reviewed throughout this chapter.

2.1 Geopolymer

2.1.1 Definition

1978, Davidovits has discovered a new material to replace cement as an alternative binder for concrete. This binder will be extracted from the polymeric reaction of alkaline liquid with silicone and aluminium in source material [7]. The source material, which acts as the binder is called cement replacement materials (CRM). There are four types of CRM namely natural materials, industrial by-products, natural pozzolan and agricultural wastes. However, the common CRM come from by product type as by product is waste obtained from selected industries which means that it does not cost any cent to produce them.

Examples of by product type are fly ash, ground-granulated blast furnace slag (GGBS) and condensed silica fume. Fly ash is obtained from the combustion of coal at power station, ggbs is the slag from scum formed in iron smelting in a blast furnace, ground to a powder while condensed silica fume is the very fine particles of silica condensed from waste gases given off in production of silicon metal.

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2.1.2 Geopolymerisation

Geopolymerisation is an exothermic process that is carried out through oligomers (dimer, trimer) which provide the actual unit structures for the three dimensional macromolecular edifice .One of several hardening mechanisms involves the chemical reaction of alumino-silicate oxides with alkalis and alkali–polysilicates yielding polymeric Si–O–Al bonds with a $(Si_2O_5, Al_2O_2)_n$ formula. This is accomplished by calcining alumino-silicate hydroxides $(Si_2O_5,Al_2(OH)_4)$ through the reaction $2(Si_2O_5, Al_2(OH)_4) \rightarrow 2(Si_2O_5, Al_2O_2)_n + 4H_2O$ or by condensation of SiO and Al_2O vapours according to reaction $4SiO_{(vapour)} + 2Al_2O_{(vapour)} + 4O_2 \rightarrow (Si_2O_5, Al_2O_2)_n$ which produces also condensed silica fume and corundum $(2SiO + O_2 \rightarrow 2SiO_2$ and $Al_2O + O_2 \rightarrow Al_2O_3)$ [21]. The basic steps of geopolymerisation involve dissolution of solid alumino-silicate oxides in MOH solution (M: alkali metal), diffusion or transportation of dissolved Al and Si complexes from the particle surface to the inter-particle space, formation of a gel phase resulting from the polymerisation between added silicate solution and Al and Si complexes and finally hardening of the gel phase The following reaction scheme is proposed by Xu and Van Deventer [8] for the polycondensation taking place during geopolymerisation of minerals:

$$Al–Si\ material\ (s) + MOH\ (aq) + Na_2SiO_3\ (s\ or\ aq) \tag{1}$$

$$\downarrow$$

$$Al–Si\ material\ (s) + [M_z(AlO_2)_x(SiO_2)_y \cdot nMOH \cdot mH_2O]\ gel \tag{2}$$

$$\downarrow$$

$$Al–Si\ material\ (s)\ [M_a((AlO_2)_a(SiO_2)_b)nMOH \cdot mH_2O] \tag{3}$$
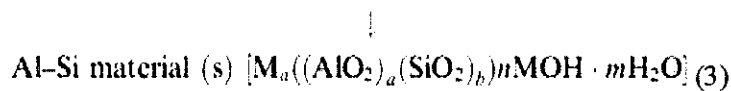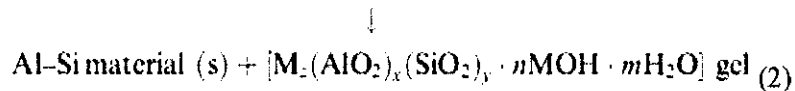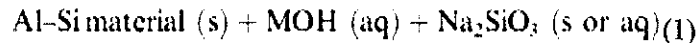
In reactions (1) and (2) the amount of Al–Si material used depends on the particle size, the extent of dissolution of Al–Si materials and the concentration of the alkaline solution. The formation of $[M_z(AlO_2)_x(SiO_2)_y \cdot nMOH \cdot mH_2O]$ gel essentially relies on the extent of dissolution of alumino-silicate materials, while geopolymers with amorphous structure are formed during reaction (3). The time

required for the alumino-silicate solution to form a continuous gel depends on raw material processing conditions.

Dissolution of the starting materials is the major step that has a twofold role. Firstly, polysialate forming species are liberated from the starting materials in a similar way as in the formation of zeolite precursor's .Secondly, dissolution activates the surface and binding reactions take place contributing significantly to the final strength of the structure. The extent of the dissolution step in geopolymerisation is not fully clear while the extent to which other factors complement or not dissolution needs to be further examined.

Under alkaline conditions, alumino-silicates are transformed into extremely reactive materials and it is generally believed that the dissolution process is initiated by the presence of hydroxyl ions. Higher amounts of hydroxyl ions facilitate the dissociation of different silicate and aluminate species, promoting thus further polymerisation However, if a very high alkaline environment (>30 mol% overall Na_2O content) is used, the connectivity of silicate anions may be reduced resulting thus in poor polymerization.

Panagiotopoulou et al. [9] studied the dissolution of different alumino-silicate industrial minerals and by-products and reported that the extent of dissolution is higher when NaOH instead of KOH is used. This is due to the smaller size of Na^+ which can better stabilise the silicate monomers and dimers present in the solution, enhancing thus the minerals dissolution rate .It was also reported that Si and Al seem to have a synchronised leaching behaviour in both alkaline media.

Mikuni et al. [10] studied the dissolution of different types of fly ashes in caustic soda solutions up to 15 N at 25 and 80 °C. It was reported that high dissolution of Al_2O_3 is seen in 80 °C, while increased dissolution of SiO_2 takes place during leaching with increasing NaOH concentrations in 25 °C.

The ability to model the kinetics of a geopolymeric system enables the preparation of mixtures for specific applications and improves quality control during

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production. Provis et al. [11] developed a model describing chemical reaction kinetics, providing thus valuable insights into the reaction processes. This model provides a framework that predicts the behaviour of geopolymer-forming systems. The reaction kinetic framework developed by (Provis and Van Deventer, 2007b) [12] and (Provis and Van Deventer, 2007c)[13], using Energy Dispersive X-ray diffractometry may be used to determine the setting rate of geopolymers. Comparison of model output with experimental data shows that the model is able to provide a plausible description of geopolymerisation [14].

The difference of using geopolymer and OPC concrete is portrayed as in the Figure 2.1 below:
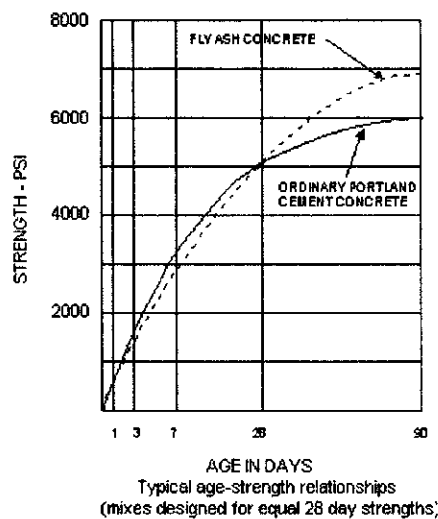
Figure 2.1: Comparison of OPC and geopolymer concrete in term of strength

Instead of that, the usage of this source material will utilize the waste from other industry thus reduce the unwanted material to the environment. For example, fly ash is obtained from the combustion of coal in power station. As the population of the world is increasing, the demand for power supply will also increase. Thus, more fly ash will be produced. So, the issue on the continuity of fly ash supply will not be a big matter to deal of.

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2.1.3 Constituent materials of Geopolymer Concrete

Any material that contains mostly Silicon (Si) and Aluminium (Al) in amorphous form is a possible source material for the manufacture of geopolymer. Several minerals and industrial by-product materials have been investigated in the past. Metakaolin or calcined kaolin ,low-calcium ASTM Class F fly ash [15], natural Al-Si minerals [8], combination of calcined mineral and non-calcined materials [16], combination of fly ash and metakaolin [15], and combination of granulated blast furnace slag and metakaolin have been studied as source materials.

Metakaolin is preferred by the niche geopolymer product developers due to its high rate of dissolution in the reactant solution, easier control on the Si/Al ratio and the white colour. However, for making concrete in a mass production state, metakaolin is expensive.

Low-calcium (ASTM Class F) fly ash is preferred as a source material than high calcium ASTM Class C) fly ash. The presence of calcium in high amount may interfere with the polymerisation process and alter the microstructure.

Davidovits (1999) [17] calcined kaolin clay for 6 hours at 750°C. He termed this metakaolin as KANDOXI (KAolinite, Nacrite, Dickite OXIde), and used it to makegeopolymers. For the purpose of making geopolymer concrete, he suggested that the molar ratio of Si-to-Al of the material should be about 2.0.

On the nature of the source material, it was stated that the calcined source materials, such as fly ash, slag, calcined kaolin, demonstrated a higher final compressive strength when compared to those made using non-calcined materials, for instance kaolin clay, mine tailings, and naturally occurring minerals. However, Xu and van Deventer (2002) [16] found that using a combination of calcined (e.g. fly ash) and non-calcined material (e.g. kaolinite or kaolin clay and albite) resulted in significant improvement in compressive strength and reduction in reaction time.

Natural Al-Si minerals have shown the potential to be the source materials for

geopolymerisation, although quantitative prediction on the suitability of the specific mineral as the source material is still not available, due to the complexity of the reaction mechanisms involved. Among the by-product materials, only fly ash and slag have been proved to be the potential source materials for making geopolymers [18-30].

2.1.3.1 Suitability of Fly Ash as source material in Geopolymer Concrete

Fly ash is considered to be advantageous due to its high reactivity that comes from its finer particle size than slag. Moreover, low-calcium fly ash is more desirable than slag for geopolymer feedstock material.

The suitability of various types of fly ash to be geopolymer source material has been studied by Fernández-Jim nez and Palomo (2003). These researchers claimed that to produce optimal binding properties, the low-calcium fly ash should have the percentage of unburned material (LOI) less than 5%, Fe_2O_3 content should not exceed 10%, and low CaO content, the content of reactive silica should be between 40-50%, and 80-90% of particles should be smaller than 45 μm..

On the contrary, van Jaarsveld et al (2003) found that fly ash with higher amount of CaO produced higher compressive strength, due to the formation of calcium-aluminate-hydrate and other calcium compounds, especially in the early ages. The other characteristics that influenced the suitability of fly ash to be a source material for geopolymers are the particle size, amorphous content, as well as morphology and the origin of fly ash. [18]

2.1.3.2 Alkaline activating solution

Alkali activating solution is important for the dissolving of Si and Al atoms to form geopolymer precursors and finally aluminosilicate material. The most commonly

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used alkaline activators are NaOH and KOH [19,20]. In the synthesis of geopolymers, NaOH was found to significantly affect both the compressive strength and structure of geopolymers. Thus, this project will use the application of NaOH during casting of SCGC.

The NaOH concentration in the aqueous phase of the geopolymeric system acts on the dissolution process, as well as on the bonding of solid particles in the final structure [21]. When fly ash comes into contact with NaOH, leaching of Si, Al and others minor ions begins. The amount of leaching is dependent on NaOH concentration and leaching time [22].

Amongst common material that is used as alkaline solution during production of fly ash-based geopolymer are sodium silicate and potassium hydroxide [23]. Usually either of this material was mixed with sodium hydroxide to produce the alkaline solution. Alkaline solution is important in order to allow the geo polymerization process occurs. Then, the materials are mixed together with fine aggregate and coarse aggregate to form concrete and curing process been done.

Under a strong alkali solution, aluminosilicate-reactive materials dissolve and form free SiO_4 and AlO_4 tetrahedral units [24]. With the progress of the reaction, water is gradually removed, and the SiO_4 and AlO_4 tetrahedral clusters are linked to yield polymeric precursors through the sharing of all oxygen atoms between two tetrahedral units, thereby forming amorphous geopolymers. Three common types of geopolymer are the polysilate Al–O–Si chain, polysialate siloxo Al–O–Si–Si chain and polysialate disiloxo Al–O–Si–Si–Si chain [24].

For NaOH-activated ground fly ash paste that are cured at ambient temperature (25–28 ℃), to obtain relatively high strength, geopolymer pastes, NaOH concentrations of 9.5–14.0 M are recommended. This condition is appropriate for the ground fine fly ash with median particle size of 10.5 lm. For coarser fly ashes, the NaOH concentration needs to be higher in order to obtain a higher rate of strength development of geopolymers. Temperature curing might also be needed [22]. Figure 2.2 compares compressive strength of Original Fly Ash (OFA) and Ground Fly Ash (GFA) geopolymer pastes after 60 days.
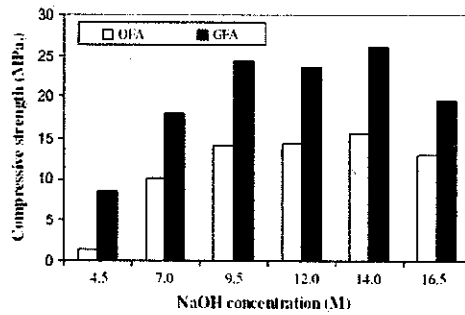
Figure 2.2: Comparison of compressive strengths of geopolymer pastes at age of 60 days.

An increase in NaOH concentration from 4.5 to 14.0 M increased the compressive strength of pastes. The relativelyhigh compressive strengths of 23.0–25.5 MPa were obtained with the NaOH concentrations of 9.5–14.0 M. However, when the concentration of NaOH was 16.5 M, the compressive strength started to decline. When OH⁻ concentration was high enough, dissolution of fly ash was accelerated, but polycondensation was hindered [25-18]. An increase in alkali concentration enhanced strength development of the geopolymers, but excess hydroxide ion concentration caused aluminosilicate gel precipitation at the very early stages, resulting in lower strength geopolymers [26]. Thus, for this research, the concentration of NaOH will vary from 8M to 14M.

2.1.4 Curing of geopolymer concrete

Palomo et al (1999) concluded that the curing temperature was a reaction accelerator in fly ash-based geopolymers, and significantly affected the mechanical strength, together with the curing time and the type of alkaline liquid. Higher curing temperature and longer curing time were proved to result in higher compressive strength [18].

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Heat-curing substantially assists the chemical reaction that occurs in the geopolymer paste. Both curing time and curing temperature influence the compressive strength of geopolymer concrete. Longer curing time improved the polymerization process resulting in higher compressive strength. The rate of increase in strength was rapid up to 24 hours of curing time; beyond 24 hours, the gain in strength is only moderate. Therefore, heat-curing time need not be more than 24 hours in practical applications. [27].

In addition, from a research done [33] which compared curing regime for geopolymer from hot gunny curing, external exposure curing and ambient temperature curing, external exposure curing has found to be the most suitable curing regime. Different from previous curing methods (hot gunny curing), non-blended samples in external exposure curing had higher compressive strength than blended samples. It indicates that modification of Si:Al ratio in source material has significant effect in humid environment but little effect in elevated temperature environment. In conclusion, non-blended samples in external exposure curing had compressive strength of 147% and 92% higher compared to hot gunny and ambient curing respectively. It was also observed that the critical period of geopolymer concrete strength development is within the first week from mixing process. Lack of polymeric reaction during this period reduced the compressive strength.

The compressive strength development of geopolymer concrete was much affected by the curing condition during maturing period. Therefore proper curing method was important to obtain acceptable geopolymer concrete structures. The external exposure curing condition used in this research was an acceptable technique to produce good concrete structures. This led to a conclusion that cast in-situ application (Malaysian climate or equivalent) was a viable alternative and geopolymer concrete is not necessarily limited only to precast industry [33].

2.2 Self Compacting Concrete

2.2.1 Properties of SCC

In 1986, Self-compacting concrete was first invented in Japan. Self-compacting concrete or abbreviated as SCC refers to concrete that settled on its own weight. This means that it will be placed, flow, compacted and fill each and every gaps of reinforcement as well as corner of moulds without any assistance of vibration and compaction procedure. SCC contains superplasticizer as the main ingredient for the self-compaction properties.

The use of very powerful superplasticizers and a high fines content, or of viscosity-enhancing admixtures, makes SCC highly flowable and stable [28], with great passing and filling capacity. This will obviously reduce the attention needed. The selection of SCC is made pertaining to the time allocated for this project. SCC will obviously lessen the time taken to cast the concrete as two main procedures are initially being deducted. Instead of that, SCC also will reduce the rate of repeating mixes as segregation and bleeding can be avoided.

2.2.2 Admixtures used in SCC

In the eleven years of SCC study [18], it is found that all mixes included a superplasticizer by necessity. There was more use of polycarboxylic acid-based materials later in the 11 year period, some of which were described as being developed specifically for use in SCC.

In 30 cases, an air-entraining agent was also used, sometimes as a preblended product with the other admixtures. It was not always clear if this was primarily to provide freeze–thaw resistance or to improve the rheology.

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In 34 cases, a viscosity-modifying agent of some form was also used. The reasons given were to provide stability and/or reduce sensitivity of the mix to variations in materials during production, particularly the aggregate moisture content [29].

On the other side, one of the most important differences between SCC and conventional concrete is the incorporation of a mineral admixture. Thus, many studies about the effects of mineral admixtures on the properties of SCC have been completed. These studies show the advantage of mineral admixture usage in SCC, such as improved workability with reduced cement content. Since cement is the most expensive component of concrete reducing cement content is an economical solution. Additionally, the mineral admixtures can improve particle packing and decrease the permeability of concrete. Therefore, the durability of concrete is also increased. Industrial by-products or waste materials such as limestone powder, fly ash and granulated blast furnace slag are generally used as mineral admixtures in SCC.Thereby, the workability of SCC is improved and the used amount of by-products or waste materials can be increased. Besides the economic benefits, such uses of by-products or waste materials in concrete reduce environmental pollution .

In limestone and basalt quarries, significant amounts of limestone (LP) and basalt (BP) powders are produced as by-products of stone crushers. Large volumes of these powders are accumulated and it is a big problem to propose utilization of these byproducts from the aspects of disposal, environmental pollution and health hazards . Moreover, marble powder (MP) is a waste material with limestone origin and 511,000 tons of MP are produced per year and are deposited as wastes in Turkey. This means that MP is not recycled and used in any areas in Turkey. Thus, it would be profitable if MP could be used in SCC as a mineral admixture and thereby prove valuable for the concrete industry.

In conventional concrete the introduction of high volumes of mineral admixtures to concrete mixtures is limited due to their negative effects on water demand and strength of the hardened concrete. However, these mineral admixtures can be efficiently utilized as viscosity enhancers particularly in powder-type SCC. Thus, the

successful utilization of LP, BP and MP in SCC could turn these materials into a precious resource.

Moreover, these mineral admixtures can significantly improve the workability of Self compacting concrete When used in SCC, these mineral admixtures can reduce the amount of superplasticizer necessary to achieve a given fluidity. It should be noted that the effect of mineral admixtures on admixture requirements is significantly dependent on their particle size distribution as well as particle shape and surface characteristics. From this viewpoint, a cost effective SCC design can be obtained by incorporating reasonable amounts of LP, BP and MP[30].

2.2.3   Used of superplasticizer

There are three main purposes of the usage of plasticizer and superplasticizer namely are to increase workability without changing the mix composition in order to enhance placing characteristics of concrete. Secondly, to reduce the mixing water and the water/cement ratio in order to increase strength and improve durability at a given workability and lastly to reduce both water and cement at a given workability in order to save cement and reduce creep, shrinkage and thermal strains caused by heat of cement hydration.

The usage of plasticizer at higher dosage (as those normally adopted for super-plasticizers), can further reductions in mixing water or higher slump increases but this may result in adverse effects on setting, air volume and strength of concrete [31].

The main ingredients in the superplasticizers are synthetic water-soluble polymers, such as sulfonated melamine formal-dehyde (SMF) condensate or sulfonated naphthalene formaldehyde (SNF) condensate. There are also alternative water soluble synthetic polymers have been recently proposed to reduce the slump-loss drawback, which can partly or completely cancel the initial technical advantage associated with the use of super-plasticizers [31].

The workability of fresh low-calcium fly ash-based geopolymer concrete will be

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enhanced in addition of naphthalene-based super plasticiser , but did not affect the compressive strength of the hardened concrete, except when the content of super plasticiser was 4% a slight reduction in compressive strength occurred. The content of the super plasticiser need not be more than 2% of the mass of fly ash. Beyond this amount, the addition of super plasticiser can cause a slight reduction in the compressive strength of hardened concrete; moreover, amounts greater than 2% may be uneconomical in practice [18].

2.2.4 SCC for reinforced concrete

From experiment carried out by M. Valcuende and C. Parra [6-8], they have found that for moderate load levels, SCC perform a stiffer behaviour than Normally Vibrated Concrete (NVC), probably because of their greater fill capacity and less bleeding.

Secondly, the ultimate bond strength is greater in SCC than in NVC. The differences between the two types of concretes vary with the compressive strength, but are not so great as those recorded for mean stress (less than 7%, 17%, 8% and 1% for mixes 1, 2, 3 and 4, respectively). This can be explained by the fact that bleeding has less negative impact on failure and that the NVC attains greater tensile strength. For concretes of more than 50 MPa, these differences virtually disappear (less than 2%).

Thirdly, a reduction of the anchorage length of reinforcements is proposed for the specific case of high viscosity powder-type SCC. The amount of the reduction depends on the concretes compressive strength.

They also found out that in vertically cast pieces, SCC behaves more homogeneously than NVC, as the top-bar effect is much more pronounced in the latter. Depending on the mix, the loss in mean bond stress between the upper and lower areas of 1.5 m tall columns varies by between 40% and 61% in SCC and between 70% and 86% in NVC. With regard to ultimate stress, the losses vary between 32% and 55% in SCC and between 60% and 74% in NVC.

Lastly, a change to the factor that takes account of top-bar effect for calculating the anchorage length of reinforcements is proposed. The current standards usually put it

at 1.4 for NVC, but 1.25 is proposed for the special case of high viscosity powder-type SCC.

These five (5) observations proved that usage of SCC will establish better bonding between rebar and concrete compared to NVC.

In conclusion, SCC is perfectly suitable as we need to ensure all the gaps between the concrete and the rebar is being filled properly without any flaws or else, bonding between rebar and concrete is questionable which eventually will lead this project to failure. The filling capacity property of SCC will improve the rebar-concrete bond by allowing the mixture to cover the reinforcements more effectively [8]. Blending of SCC and Geopolymer concrete will result in Self Compacting Geopolymer Concrete which is the main attention of this research.

2.3 Bonding of reinforced bar and concrete

The usage of reinforced bar (rebar) in concrete is a common practice throughout the world. This application is called Reinforced Concrete (RC). RC is used as slab, column, beam and wall in construction world. RC is much stronger than concrete itself as it has the rebar to support the load instead of concrete alone. However, the bonding between rebar and concrete must be well established to prevent any failure.

This bond strength will allow RC to act as the structural material. Forces are transferred between the two materials by two kinds of actions, those that are physicochemical (adhesion) and those that are mechanical (friction and bearing action), which are activated by various states of stress. To a large extent, the relative importance of those actions depends on the surface texture and the geometry of the bars [6].

2.3.1 Bond test

Bond between reinforcement and concrete can be analytically described by means of a constitutive bond stress-slip relationship that can be introduced in the solution of problems such as the calculation of the development length .

Generally, the evaluation of such constitutive law is performed with pull out tests, that are normally categorized by short embedment lengths. Moreover, values of bond strength are obtained by assuming a constant distribution of bond stresses along the embedded zone. The procedure has been widely accepted when dealing with steel reinforcement, because slip values at the loaded and unloaded end are very similar and therefore the assumption of a constant distribution can be accepted.

2.3.1.1 Pull out

Figure 2.3 is the simplest model representing the stress transfer between steel and concrete is the so-called "frictional concept", whereby the shear stress that develops along the lateral surface of the bar, (i.e. the bond stress), is a function of the normal confining pressure exerted by the surrounding concrete on the bar surface.
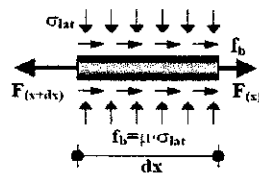
Figure 2.3: Frictional Model for Bond

Although a crude representation of the local stress concentrations around the ribs that engage in concrete, in a smeared sense, the simple frictional model properly identifies the significance of many important design parameters for bond: the higher the normal pressure, the higher the frictional force required for pullout and the higher the strength reserves of the splitting failure mechanism. Confinement may be provided by the cover concrete (supported by hoop tension stresses in the cover), by

transverse reinforcement crossing the splitting crack path, and by transverse compressive stress fields existing in the anchorage region [32].

The bond test is used to conduct a pull-off test in accordance with ASTM C1583, "Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method)." The obtained **pull-off strength** can be used for the following purposes:

- To evaluate the in-place bond strength between a repair overlay and the substrate
- To evaluate the in-place tensile strength of concrete or other materials
- To evaluate the effect of surface preparation procedures on the tensile strength of the substrate

Pull out tests are used to determine whether the in-place strength of concrete has reached a specified level so that, for example: post-tensioning may proceed; forms and shores may be removed; or winter protection and curing may be terminated.

In addition, post-installed pull out tests may be used to estimate the strength of concrete in existing constructions. When planning pullout tests and analyzing test results, consideration should be given to the normally expected decrease of concrete strength with increasing height within a given concrete placement in a structural element. The measured pullout strength is indicative of the strength of concrete within the region represented by the conic frustum defined by the insert head and bearing ring.

For typical surface installations, pull out strengths are indicative of the quality of the outer zone of concrete members and can be of benefit in evaluating the cover zone of reinforced concrete members.

Cast-in-place inserts require that their locations in the structure be planned in advance of concrete placement. Post installed inserts can be placed at any desired location in the structure provided the requirements of pullout test locations shall be

separated so that the clear spacing between inserts is at least eight times the pullout insert head diameter.

Clear spacing between the inserts and the edges of the concrete shall be at least four times the head diameter. Inserts shall be placed so that reinforcement is outside the expected conical failure surface by more than one bar diameter, or the maximum size of aggregate, whichever is greater are satisfied. This test method is not applicable to other types of post-installed tests that, if tested to failure, do not involve the same failure mechanism and do not produce the same conic.

For a given concrete and a given test apparatus, pull out strengths can be related to compressive strength test results. Such strength relationships depend on the configuration of the embedded insert, bearing ring dimensions, depth of embedment, and level of strength development in that concrete. Prior to use, these relationships must be established for each system and each new combination of concreting materials. Such relationships tend to be less variable where both pull out test specimens and compressive strength test specimens are of similar size, compacted to similar density, and cured under similar conditions.

There are three methods to conduct pull out test that are portrayed below in Figure 2.4:
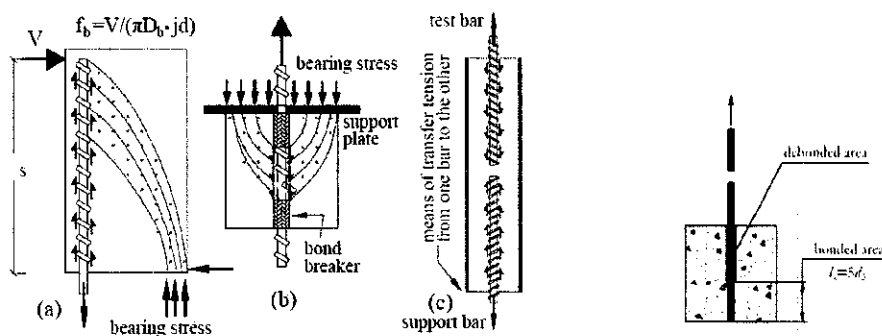
Figure 2.4: Methods to conduct pull out test

For this research, two types of steel rebar that will be used are ribbed bar and normal bar. This is to observe the difference of bonding between these two types of bar and concrete. For testing, with reference to Figure 2.4, method (b) will be selected.

CHAPTER 3

METHODOLOGY

This chapter will explain the materials used in order to carry this research. In addition, several techniques that will be carried out will also be explained.

3.1 Materials

3.1.1 Fly ash

Fly ash is the main ingredient in making geopolymer concrete. In this research, fly ash (FA) that will be used is Low Calcium Fly Ash (ASTM Class F) originated from Manjung Power Station, Perak, Malaysia. This fly ash will act as the binder to glue together all ingredients in producing this geopolymer concrete. The chemical composition of FA as determined by X-Ray Fluorescence (XRF) analysis is shown in Table 3.1

Table 3.1: Chemical composition of fly ash as determined by XRF

CHEMICAL COMPOSITION OF FLY ASH AS DETERMINED BY XRF [24]			
		Requirements as per	
Oxide	(%) by mass	BS EN 450-1:2005	ASTM C 618 Class F
Silicon dioxide (SiO$_2$)	51.19	min. 25%	-
Aluminum oxide (Al$_2$O$_3$)	24.0	-	-
Ferric oxide (Fe$_2$O$_3$)	6.60	-	-
Total SiO$_2$ + Al$_2$O$_3$ + Fe$_2$O$_3$	81.79	min. 70%	min. 70%
Calcium oxide (CaO)	5.57	-	-
Magnesium oxide (MgO)	2.40	max. 4%	max. 5%
Sulphur trioxide (SO$_3$)	0.88	max. 3%	max. 5%
Potassium oxide (K$_2$O)	1.14	-	-
Sodium oxide (Na$_2$O)	2.12	max. 5%	max. 1.5%

3.1.2 Alkaline activating solution

For an effective geopolymerisation, alkaline solution plays an essential role. The most popular alkaline solution used to inhibit geopolymerisation is the combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate (Na_2SiO_3) or potassium silicate (K_2SiO_3).

In this research, a combination of sodium silicate and sodium hydroxide was chosen as the alkaline liquid. Sodium-based solutions were chosen because they are cheaper than Potassium-based solutions. Sodium Silicate (Grade A53 with SiO_2 = 29.43%, Na_2O = 14.26% and water = 56.31%) obtained from Malay-Sino Chemical Industries Sdn Bhd, Malaysia was used in solution form while Sodium hydroxide supplied by QuickLab Sdn Bhd, Malaysia was in pellets form with 99% purity.

Concentration of NaOH was varied from 8M, 10M, 12M and 14M. Thus, to make 1 kg solution of these concentrations, 29.4%, 36.7%, 44.1% and 51.4% of pellets were added to the water respectively. Liquid then was mixed thoroughly and alkaline solution is produced.

For the sake to produce desired workability and required flowability of the fresh concrete, a commercially available superplasticizer namely as Sika Viscocrete-3430, from Sika Kimia Sdn Bhd, Malaysia, and a specified amount of extra water was also used in the mix. The ordinary potable water from concrete laboratory was used for this purpose.

3.1.3 Steel reinforcement bar

Steel reinforcement bar is vital to investigate the bonding between steel reinforcement bars and concrete. For this research, two types of bars selected that were ribbed and round bar with diameter of 12mm respectively. Length of each bar is estimated about 600 mm. The bar length embedded in each cylinders mould was estimated ¾ from the total height of each cylinder which is 200 mm. Thus, for each cylinder, the bar length embedded in the concrete mould was 150 mm. For ribbed bars of diameter 12 mm, they were already available in the concrete laboratory. However, as round bars were not

available, they were obtained from supplier namely JJM Integrated Sdn Bhd located in Ipoh.

3.1.4 Aggregates

For aggregates, both fine aggregates and coarse aggregates were used in this study. For coarse aggregates, crushed granite stone with sieve size maximum 14 mm was selected (BS 812-103.2 1989). The specific gravity of coarse aggregate is 2.66 with SSD condition. For fine aggregates, dry clean natural Malaysian sand was chosen with the fineness modulus of 2.76, maximum size of 5 mm and a specific gravity of 2.61.

3.2 Experimental procedure

In order to cast this SCGC, basically, the steps that will be taken are being explained below.


```
┌─────────────┐  ┌───────────┐  ┌───────────┐  ┌────────┐  ┌───────────┐
│  Materials  │  │ Concrete  │  │ Concrete  │  │ Curing │  │ Concrete  │
│ preparation │  │  mixing   │  │ placement │  │        │  │  testing  │
└─────────────┘  └───────────┘  └───────────┘  └────────┘  └───────────┘
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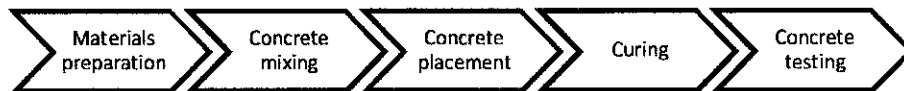
Figure 3.1: Steps taken in making SCGC

In *materials preparation* stage, four main steps that will be done namely composition of concrete with completed concrete mix design form will be calculated. Then, sand is being sieved with sieve size of 5.0 mm and being dried under the sunlight. Next, coarse aggregate that has been sieved initially with the size of 14.0 mm is washed for intending to clean the clay as well as drying and lastly quantities of binder (in this case: fly ash), sand and coarse aggregate is weighed. Alkaline solution is then made by using specified weight of NaOH pellets and water with certain volume. After that, this solution is mixed together with $NaSiO_3$, water and super plasticizer.

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Figure 3.2: Sieving of the aggregate

Figure 3.3: Preparation of the aggregate

Figure 3.3: Preparation of the aggregate

The rest of the procedures will be done as follows: the concrete mixer is wetted until it is clean and moisture. Then, aggregate (coarse and fines) is poured together with the fly ash. This mixture is dry mixed for 2.5 minutes. Next, the mixture of alkaline solution with another three solutions is poured. It is then mixed for another 3 minutes. Lastly, the mixer is stopped and the mixture is hand mixed for another 2 to 3 minutes. Basically, the method above is to cast the concrete which will be used in pull out test. Thus, the apparatus used will also be same such as:

- A non-porous timber or metal platform,

- A pair of shovels,

- A steel hand scoop

- Measuring cylinder

- A concrete mixer

- Cylinder moulds (diameter of 100 mm)

For bar preparation, for each mixture, four normal round bars and four ribbed bars are clipped to the retort stands. Cylinder moulds with dimension (height : 20 cm, diameter : 10 cm) is inserted under the bars. Bars are made sure to penetrate three quarter of the height of the cylinders. So, 15 cm of the bars are being ensured to be in middle inside the cylinders.

Soon after mixing, the concrete mix is poured into cylinder moulds immediately to avoid it settles quickly. After 48 hours, mould is then opened and the samples are brought out.

Figure 3.4: Mould opening

Next, the samples are kept under sun for curing. For this process, external exposure curing is chosen to avoid any unwanted reaction happen between steel rebar and concrete if we choose oven curing due to high temperature (Note: The optimum

curing temperature for geopolymer concrete is oven curing at 70°C). Two period of curing are chosen: 14 days and 28 days.

Figure 3.5: External exposure curing

A sample of four units will be casted for each type of bar (ribbed and normal). These four units will be varied from its NaOH concentration (8M, 10M, 12M, 16M). Thus, eight samples needed for each type of bar if two period of curing is chosen (7 and 28 days). Total samples will be thirty two (32) units.

3.3 Concrete mixture proportion

3.3.1 Mix design

Table 3.2 : Mix design for Self Compacting Geopolymer Concrete

Code	Curing age	Coarse Aggregate	Fine Aggregate	Fly Ash (FA)	NaOH	Na$_2$SIO$_3$	Super Plasticizer	Water	Type of rebar
	Days	Kg/m^3	Kg/m^3	Kg/m^3	Mol (M)	Kg/m^3	% of FA	% of FA	
M81, M82,	14	950	850	400	8	143	6	12	
M85, M86	28								
M101,M102	14	950	850	400	10	143	6	12	
M105,M106	28								Round
M121,M122	14	950	850	400	12	143	6	12	
M125,M126	28								
M141,M142	14	950	850	400	14	143	6	12	
M145,M146	28								
M83, M84,	14	950	850	400	8	143	6	12	
M87, M88	28								
M103,M104	14	950	850	400	10	143	6	12	
M107,M108	28								Ribbed
M123,M124	14	950	850	400	12	143	6	12	
M127,M128	28								
M143,M144	14	950	850	400	14	143	6	12	
M147,M148	28								

3.4 Testing

3.4.1 Pull out test
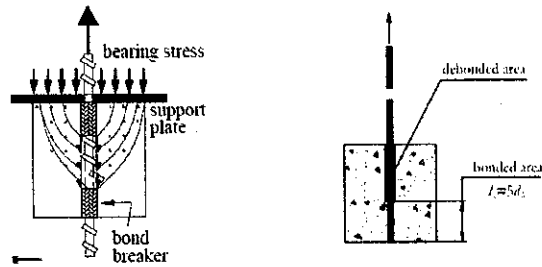
Figure 3.6: Method selected for pull out tests

Selected pull out test is portrayed on the above picture. This test will be carried out using universal testing machine (UTM) in concrete lab. Once the data is obtained, which is ultimate load (kN), formula will be applied to find the result.

The average bond strength value is calculated assuming a uniform distribution along the embedded length L_b (mm) [Equation 3.1]:

$$f_b = P / (\pi \cdot D_b \cdot L_b)$$

where P (Nt) is the applied load and D_b (mm) the diameter of the test bar .

For this test, the pull out rate selected is 0.5 mm/s which are the standard rate for tensile strength test. Test is done for two concrete ages: 14 days and 28 days.

Figure 3.7: Universal Testing Machine (UTM)

Figure 3.8: Sample attached to Universal Testing Machine (UTM)

CHAPTER 4

RESULT AND DISCUSSION

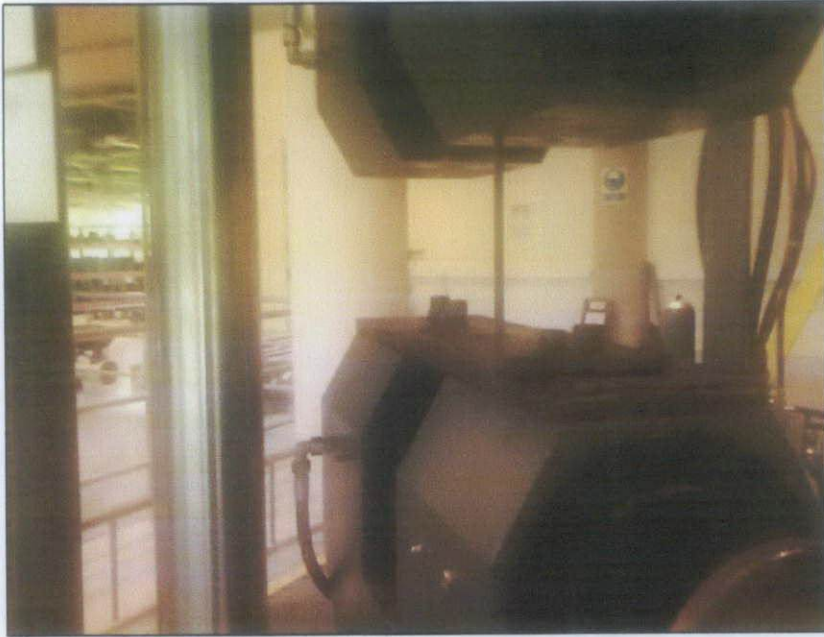In this chapter, the experimental results of Self Compacting Geopolymer concrete (SCGC) will be presented and analysed. Analysis included Pull Out test for both type of steel reinforcement bars: round and ribbed, test results at different concrete age: 14 days and 28 days, and comparison between round and ribbed bars at optimum concrete age. The results also were being synchronized with the performance of SCGC for various molarity of Sodium Hydroxide (NaOH) from the aspect of compressive strength taken from recent study. Lastly, the results were compared to the previous findings on pull out test for Ordinary Portland Cement (OPC) concrete. The outcome of the pull out test is then proved whether it meets the theoretical assumptions   that   have   been   made   initially.

4.1 Pull out test for Self Compacting Geopolymer Concrete

Pull out tests were carried out using Universal Testing Machine (UTM) available in concrete lab. The rate of Pull Out was set to 0.5 mm/s as the standard rate. Pull out test was carried out at 14 and 28 days concrete age. For each molarity of NaOH, 8 samples were prepared in order to obtain the average result. Bond strength is obtained using Equation 3.1.

Table 4.1 summarized all results obtained for pull out test to find bond strength. The interpretation of the results will be explained throughout this chapter.

Table 4.1 :Summary of results for bond strength

Code	NaOH	Type of rebar	Curing age	Load used for pull out	Average bond strength
	Mol (M)		Days	kN	MPa
M81, M82,	8	Round	14	10.16	1.80
M85, M86			28	16.92	2.99
M101,M102	10		14	15.0	2.65
M105,M106			28	20.58	3.64
M121,M122	12		14	37.40	6.61
M125,M126			28	37.80	6.68
M141,M142	14		14	32.80	5.80
M145,M146			28	36.71	6.49
M83, M84,	8	Ribbed	14	21.38	3.78
M87, M88			28	32.97	5.83
M103,M104	10		14	26.29	4.65
M107,M108			28	41.4	7.32
M123,M124	12		14	46.25	8.18
M127,M128			28	59.88	10.59
M143,M144	14		14	37.06	6.55
M147,M148			28	54.43	9.62

4.1.1 Effect of Molarity (M) of NaOH on bond strength of Round Steel Bar sample

Molarity of NaOH was varied from 8M, 10M, 12M and 14M. For round steel bar, 2 samples were prepared for each molarity of NaOH. The average of the results from 2 samples was then calculated.
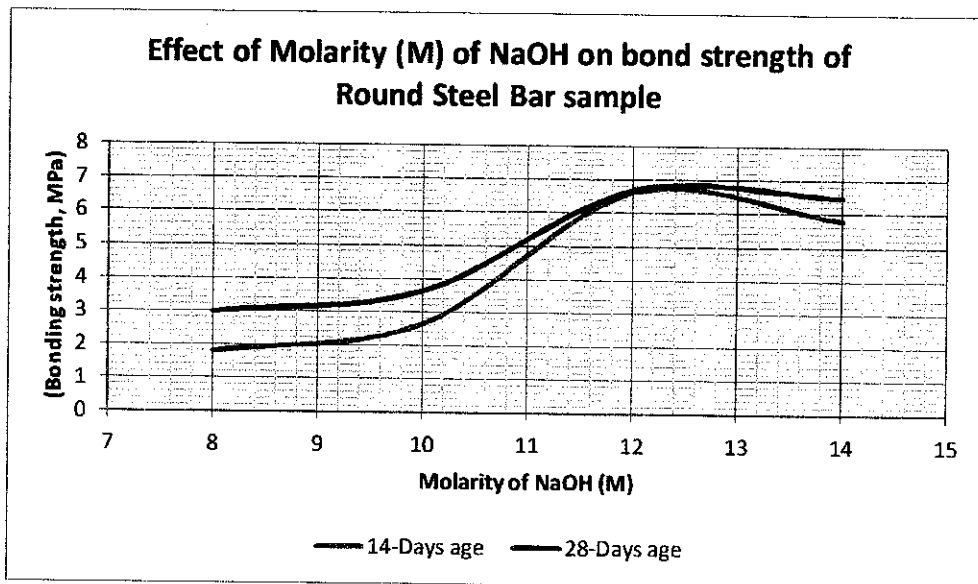
Effect of Molarity (M) of NaOH on bond strength of Round Steel Bar sample

Figure 4.1: Effect of Molarity (M) of NaOH on bond strength of round steel bar sample

Figure 4.1 shows bond strength for round steel bars sample at 14 days and 28 days concrete age with molarity of NaOH as the manipulation variables.

From the result, for each concrete age, the highest bond strength obtained at NaOH molarity of 12M. For SCGC utilizing low calcium fly ash as binder, the optimum alumina and silica reaction is at its optimum when the molarity of NaOH is 12M. Thus, the compressive strength is at the highest in 12M NaOH molarity mixes. That's explained why the highest bond strength also at NaOH molarity of 12M. Here, it is also observed that bond strength is directly proportional to compressive strength.

Comparing between 14 days and 28 days concrete age, there is significant different between bond strength when the molarity of NaOH used were 8M and 10M. Bond strength of 28 days concrete age is higher than 14 days concrete age. However, at 12M of NaOH molarity the bond strength was nearly the same but sample from 28 days still leaded. The bond strength then decreased when the molarity of NaOH is 14M. Returning back to the initial pattern, sample from 28 days concrete age possessed higher bond strength than 14 days age.

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Theoretically, concrete is at its optimum strength when its age is 28 days. Thus, from the result obtained, it is proved that concrete at 28 days age is stronger than 14 days age. Concrete hardens and gains strength as it hydrates. This hydration happens rapidly at first and slows down as time goes by. It is believed, at 28 days, a substantial percentage of the hydration has taken place.

4.1.2 Effect of Molarity (M) of NaOH on bond strength of Round Steel Bar sample

Molarity of NaOH was varied from 8M, 10M, 12M and 14M. Similar to round steel bar, for ribbed bars, 2 samples were prepared for each molarity of NaOH. The average of the results from 2 samples was then calculated.
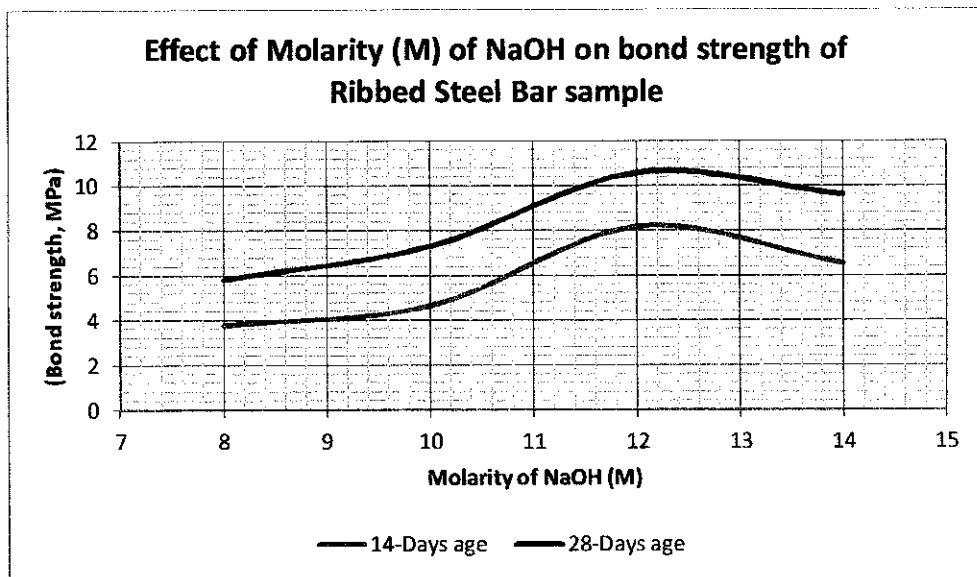

Figure 4.2: Effect of Molarity (M) of NaOH on bond strength of round steel bar sample

Figure 4.2 shows bond strength for ribbed steel bars sample at 14 days and 28 days concrete age with molarity of NaOH as the manipulation variables.

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Starting from 8M, both lines (14 days age and 28 days age) were climbing upward until 12M. The lines then were at their peak when the molarity of NaOH is 12M. Approaching molarity of 14M, the lines were then declining. From the result, for both concrete ages of 14 days and 28 days, the highest bond strength obtained at NaOH molarity of 12M. This is because; silica and alumina reaction as well as geopolymerisation will be at its utmost when the molarity NaOH is 12M. Thus, the compressive strength will possess the highest value in 12M NaOH molarity mixes. From the observation, bond strength will also possess highest performance at the point when compressive strength is at its highest. Thus, bond strength is directly proportional to compressive strength.

In comparing bonding performance between 2 concrete ages, 14 days and 28 days, there is significant different between bond strength beginning the molarity of NaOH from 8M until 14M. Similar to round bars, bond strength of 28 days concrete age is higher than 14 days concrete age. The bonding performance values between these 2 concrete ages are quite obvious.

As explained before in previous graph, concrete will be at its optimum strength when its age is 28 days. Thus, from the result obtained, it is proved that concrete at 28 days age is stronger than 14 days age. This is because, concrete hardens and gains strength as it hydrates. This hydration happens rapidly at first and slows down as time goes by. It is believed, at 28 days, a substantial percentage of the hydration has taken place. Thus, regardless the type of steel bars used, SCGC will possess the highest at 28 days of concrete age.

4.1.3. Effect of Molarity (M) of NaOH on different types of steel bar for 28 days of concrete age

Slightly different from two graphs explained previously which compared bond strength performance between two concrete ages, the graph below emphasized bonding performance difference between different types of steel reinforcement bars.
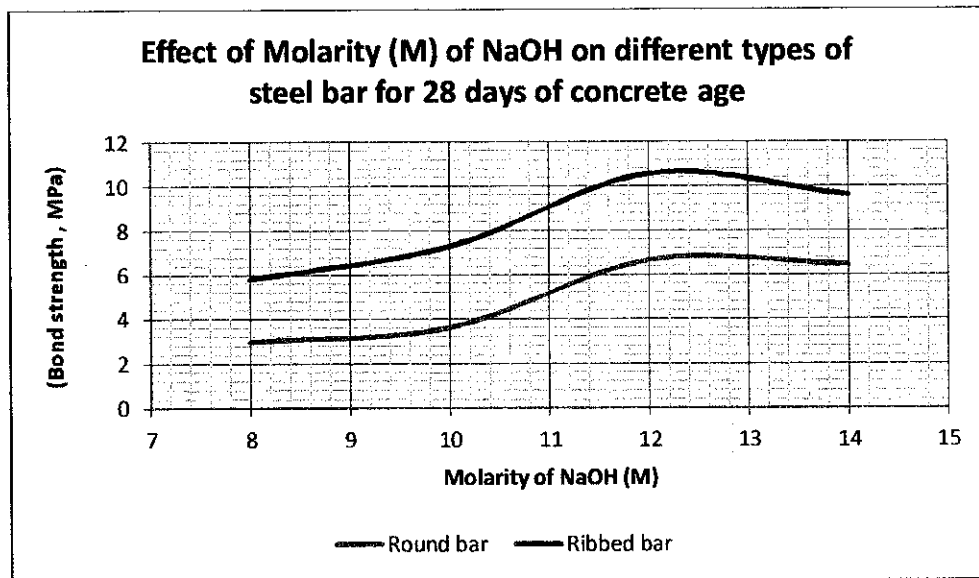
Figure 4.3: Effect of Molarity (M) of NaOH on different types of steel bar for 28 days of concrete age

From the results obtained individually for round and ribbed bars, it showed that for both type of bars, the higher bond strength will take place at concrete age of 28 days. Thus, utilizing the results from 28 days concrete age performance, the difference in performance of two types of steel bars was then compared. From Figure 4.3, starting from NaOH molarity of 8M until 12M, both lines (round bars and ribbed bars) slightly increased until they reached the maximum values at molarity of 12M. The lines then decreased after reaching the peak until NaOH molarity is 14M.

It is also clearly shown that bonding performance of ribbed bars was obviously higher than round bars. This is because, bond response with the properties of the interface of the bars. With reference to these properties, there are three mechanisms that may commence. The first one is adhesion where slipping is relatively minor. Secondly, friction that is prevalent when confinement pressure is present or in the unloading phase and lastly rib action. For round bars, first and second mechanism occurred to influence the bond capacity while for ribbed bars, the third mechanism determines its bond strength. For any circumstance that ribbed bars are used, once the stress exceeds the bond capacity sustained by adhesion and friction which are first and second mechanisms respectively, force is transferred across the ribs [34].

Thus, in line with the theory, it is proved that ribbed bars possess higher bond strength compared to round bars.

Figure 4.4 : Difference in physical appearance between round bar (picture : left) and ribbed bar (picture : right) after pull out test
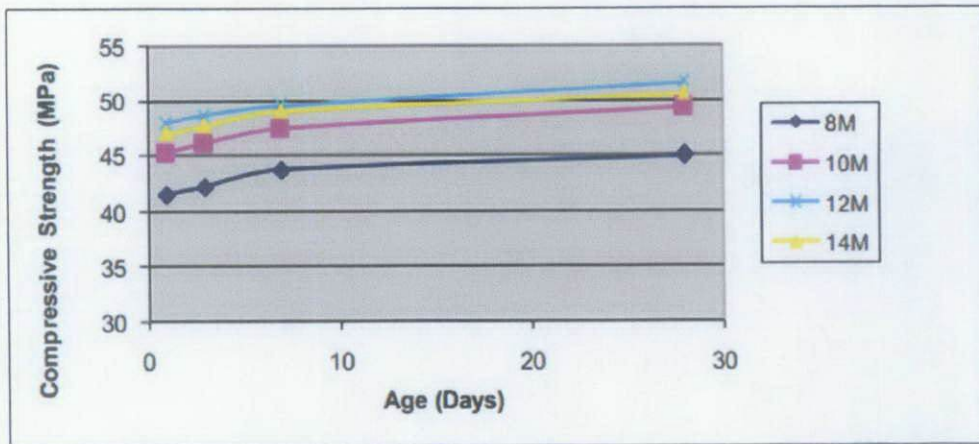
Figure 4.5: Effect of Molarity (M) of NaOH on compressive strength

From previous study [33], it is shown that the highest compressive strength occurred when the molarity of NaOH is 12M and after that, the compressive strength decreased. This is because of the lower rate of polymer formation resulting in the decrease of strength external exposure curing.

For all results obtained in Table 4.1, it showed that the highest bond strength also commenced when the molarity of NaOH is 12M. Thus, it is proved that the bond strength is directly proportional to the compressive strength.

4.2 Difference of bond strength between Ordinary Portland Cement (OPC) concrete and Self Compacting Geopolymer Concrete (SCGC)

Table 4.2 : Difference of ultimate bond stress with variation of water/cement ratio

Concrete	Age (days)	f_c (MPa)	f_t (MPa)	Mean bond stress			Ultimate bond stress			Mode of failure
				τ_b (MPa)	$\tau_b/\sqrt{f_c}$	COV (%)	τ_u (MPa)	$\tau_u/\sqrt{f_c}$	COV (%)	
S-65-32	28	30.21	2.40	11.66	2.12	1.42	18.00	3.27	3.37	Pull-out
	90	37.31	2.82	13.46	2.20	5.28	19.57	3.53	5.57	Pull-out
S-55-32	28	35.77	2.73	13.56	2.27	1.56	21.66	3.62	3.74	Pull-out
	90	44.18	3.20	16.55	2.49	3.69	25.43	3.83	5.23	Pull-out
S-55-42	28	50.18	3.52	17.55	2.48	1.99	27.97	3.95	2.62	Pull-out
	90	59.50	4.14	19.09	2.47	4.41	29.45	3.82	2.36	Pull-out
S-45-42	28	61.15	4.09	20.08	2.64	1.74	39.98	3.83	0.59	Pull-out
	90	69.02	4.80	22.68	2.70	4.65	32.38	3.90	2.65	Splitting

A study done by M. Valcuende, C. Parra [35], which carry the pull out test using round bars for Self Compacting Concrete (SCC) of normal concrete, at two concrete ages that are 28 days and 90 days with mould size of 200mm cube specimen to observe the bond strength. From the result in Table 4.2, the highest bond strength obtained for 28 days concrete age is 39.98 MPa

As for Self Compacting Geopolymer Concrete (SCGC), the highest bond strength for round bars at 28 days concrete age is 6.68 MPa. From this comparison, it showed that there is huge difference between SCC of normal concrete and SCGC which resulted that SCC of normal concrete possessed higher bonding strength rather than SCGC.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This research was conducted to investigate the bonding properties of Self Compacting Geopolymer Concrete (SCGC) through pull out test. Fly ash was selected as the binder for the mixes. In this study, molarity of Sodium Hydroxide was varied from 8M, 10M, 12M and 14M. Sodium Hydroxide is used as alkaline solution to inhibit geopolymerisation in the mixes. The types of steel bars were also varied; round and ribbed steel bars. Last but not least, testing was conducted at two different concrete ages that are 14 days and 28 days to observe the difference in bonding performance. Throughout this research, several conclusions obtained that are:

a) Pull out test is a reliable method to measure bonding strength between SCGC and steel reinforcement bars. In pull out test, load is applied to pull the steel out from the concrete at certain determined rate. Using this load, the result is simply calculated by applying equation and then bonding strength is obtained. Pull out test is done using Universal Testing Machine (UTM) which is easily available at any concrete laboratory. Thus, the equipment itself is easy to find and easy to operate.

b) With reference to NaOH, it is observed that highest bonding strength obtained is when the molarity is 12M. The result produced is 10.59 MPa. It synchronized perfectly with the theory that said geopolymerisation in fly ash is at its utmost rate when NaOH molarity is 12M. From recent study, it is also found that the compressive strength of SCGC is at the highest point when molarity of NaOH is 12M. Thus, bonding strength is directly proportional with compressive strength.

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c) Throughout this study, it was obviously showed that ribbed bars embedded in SCGC will possess higher bonding strength compared to round bars. This happened because in ribbed bars, there was another action that called rib action which would not happen in round bars. Thus, once the stress exceeded capacity taken by adhesion and friction, force is transferred across the ribs. [34].

d) Last but not least, bonding performance also would be higher in the specimens cured after 28 days compared to 14 days. Theoretically, this occurred because concrete hardens and gains strength as it hydrates. This hydration will gradually increase as time goes by until it reaches certain point and eventually it will decrease. Thus, it is believed that at 28 days, the hydration rate is higher than 14 days.

5.2 Recommendations

Further studies regarding Self Compacting Geopolymer Concrete (SCGC) should be done continuously as SCGC has big potential in the industry. With the environmental friendly features and cost saving criteria, SCGC should be developed more for it to attain the characteristics owned by Ordinary Portland Cement (OPC) concrete. One of the criteria owned by OPC concrete is bonding performance between concrete and steel bars and throughout this study, it has proven that SCGC also possess that criteria. More research need to be done to observe the performance of SCGC after the standard period of curing that is 28 days. In addition, as the optimum SCGC curing regime is oven curing at 70°C, thus, the next study may focus on that as additional features to external exposure curing.

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APPENDIX

1) Materials weight calculation

Volume for each cylinder:

$V=\pi r^2 h$

where;

r: 0.05 m, h: 0.2 m

Thus,

$V = \pi(0.05)^2(0.2)$

$=1.571 \times 10^{-3} \text{ m}^3$

As, for each mix, nine cylinders are used. Thus;

$9 \times 1.571 \times 10^{-3} \text{ m}^3$

$= 0.0141 \text{ m}^3$

To obtain the volume for each ingredient, volume of nine cylinders is multiplied to the respective density. Thus;

- Fly ash

: $0.0141 \text{ m}^3 \times 400 \text{ kg/m}^3$

$= 5.64 \text{ kg}$

- Sand

: $0.0141 \text{ m}^3 \times 850 \text{ kg/m}^3$

$= 11.985 \text{ kg}$

- Coarse Aggregate

: $0.0141 \text{ m}^3 \times 950 \text{ kg/m}^3$

$= 13.395 \text{ kg}$

- NaOH

: $0.0141 \text{ m}^3 \times 57 \text{ kg/m}^3$

$= 0.8037 \text{ kg}$

- $NaSiO_3$

: $0.0141 \text{ m}^3 \times 143 \text{ kg/m}^3$

$= 2.0163 \text{ kg}$

- Water

: $12\% \times 5.64 \text{ kg}$

$= 0.6768 \text{ kg}$

- Super plasticizer (SP)

: $6\% \times 5.64 \text{ kg}$

$= 0.3384 \text{ kg}$

For geopolymer SCC, the weight is measured based on the density below

- Fly ash= 400kg/m3
- Sand= 850 kg/m3
- Coarse Aggregate = 950 kg/m3
- NaOH= 57 kg/m3
- NaSiO3= 143 kg/m3
- Water= 12%
- Super plasticizer = 6%

The weight of water and super plasticizer is taken from the percentage stated out of the weight of fly ash.