STUDY OF FLY ASH WASTE STYROFOAM CONCRETE UNDER TROPICAL ENVIRONMENT

LEE YEE LOON
KOH HENG BOON
MOHD HILTON BIN AHMAD
NURAZUWA BTE MD NOOR
AHMAD SHAKRI BIN MAT SEMAN

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UNIVERSITI TUN HUSSEIN ONN MALAYSIA
ABSTRACT

Geopolymer concrete (Geocrete, GPC) is a recently developed material to address the global issue of climate change. GPC does not require Portland cement as binder. Instead fly ash, sodium silicate and sodium hydroxide are used. This study focused on Grade 35 concrete mix design with workability of 500 mm in slump flow. The effects of glass fiber, biomass aggregate and treated expanded polystyrene (EPS) were determined in GPC mixtures. GPC specimens were cast into cubes and prisms. There were 36 prisms of GPC as control and 36 prisms were added glass fiber for flexural strength test at 7 days, 14 days and 28 days. 108 cubes of size 100 mm were cast to determine compressive strength at 7 days, 14 days, 28 days and 56 days. There were 54 cubes of size 100mm for water penetration test and sulphuric acid test conducted at 7 days, 14 days and 28 days. GPC was exposed to ambient temperature of around 33°C and heat cured at 60°C for 24 hours. Experimental results showed that the workability of GPC achieved 250 mm slump and flow diameter of 530 mm. Compressive strength and flexural strength of GPC were 75.8 MPa and 6.01 MPa respectively. Water penetration of GPC achieved 7.3 mm at the age of 28 days. Weight loss and compressive strength change of GPC in 10 % concentration sulphuric acid tests were 2.34 % and 46.38 MPa reductions at the age of 28 days. These results showed that GPC has high compressive and flexural strengths, low water penetration and better sulphuric acid resistance compared to conventional concrete. This study is to be extended to cover other aspects related to strength, durability and dimensional stability under sustained load in order to increase the body of knowledge of geopolymer concrete for sustainable construction.
CHAPTER I

INTRODUCTION

1.0 Background of study

Concrete is the most widely used construction material due to its availability and versatility. Concrete structures can have any conceivable shapes. The applications of concrete have greatly prompted the development of civilization, economic progress, stability and quality of life (Metha, P.K, 1999).

However, cement industry produces carbon dioxide (CO$_2$) which causes global issue on climate change. With every ton of cement produced, almost a ton of CO$_2$ is emitted (Klein, 1998). In terms of conventional concrete mixtures (i.e. not using fly ash, slag or silica fume), about 480 kg of CO$_2$ is emitted per cubic meter of concrete produced. All of these contribute about 7% of the total CO$_2$ generated worldwide (Malhotra, V.M, 1999).

Geopolymer concrete is a recently developed material to address these global issues. It is different from normal concrete. It is made of naturally occurring or man-made alumina-silicates (kaolin or fly ash) as geopolymeric raw material. The wider use of these geopolymeric materials will lead to reduction of the energy consumption and the CO$_2$ emission.
Davidovits (1994), reported less than 3/5 energy is required and 80%-90% less CO₂ is generated for the production of geopolymeric material than Portland cement. Thus, the development and application of geopolymer concrete has great significance in environmental protection.

1.1 Objective of research

The objectives of this research are outlined as follows:

i. To determine mechanical properties namely compressive strength, flexural strength and physical properties such as water penetration and sulphuric acid resistance of geopolymer concrete (GPC).

ii. To investigate the effect of glass fibre, biomass aggregate, and treated expanded polystyrene in GPC mixtures.

1.2 Scope of research

Literature review on some of the properties, advantages, and applications of geopolymer concrete were carried out throughout the study. This research focused on the development of GPC. Grade 35 concrete mix was designed with high workability (slump flow of 500 mm range). The effects of glass fibre, biomass aggregate and treated expanded polystyrene (EPS) was determined in GPC mixtures. GPC specimens were cast into cube and prisms. There are 36 prisms used to cast GPC as control and 36 prisms were added glass fiber for flexural strength test at 7 days, 14 days and 28 days. 108 pieces of 100 mm cube were cast to determine compressive strength test carried out at 7 days, 14 days, 28 days and 56 days. The compressive strength test was conducted at the Material Laboratory of Universiti Tun Hussein Onn Malaysia (UTHM) using
Universal Testing Machine. There were 54 cube 100 mm for water penetration test and sulphuric acid test conducted at 7 days, 14 days and 28 days. GPC was exposed to ambient temperature ranging from 30°C and was being heat cured at 60°C for 24 hours. Analytical study was carried out to develop a new correlation between compressive strength and flexural strength of GPC compared to correlation was established by ACI.

1.2 Problem statement

Cement is most important building materials around the world. It is mainly used for the production of concrete. Concrete is a mixture of inert minerals aggregate, e.g. sand, gravel, crushed stone and cement. Cement consumption and production is closely related to the construction industry. Cement production is a highly energy intensive production process. The energy consumption by the cement industry is estimated at about 2% of the global primary energy consumption or most 5% of total global industrial energy consumption (WEC, 1995). Due to the dominant use of carbon intensive fuels, e.g. coal, in clinker making, the cement industry is a major source of carbon dioxide (CO₂) emissions.

In point of view of environmental concern, geopolymer concrete (GPC) is introduced because it has potential to minimize the carbon dioxide emission to provide sustainable construction. This is because geopolymer concrete does not required Portland cement as binder. Instead of fly ash, sodium silicate and sodium hydroxide are used. Fly ash is an abundant waste material in electrical plant. It is economical and environmental friendly due to its low cement requirement and pozzolana characteristic of fly ash that is easily mixed.

Geopolymer concrete was applied in precast concrete product such as railway sleepers, electric power poles, precast box culvert, precast wall in several countries. Geopolymer concrete is well known in foreign country due to its properties such as high fire resistance, high compressive strength, and good resistance towards sulphate attack. In Malaysia, geopolymer concrete is not popular. There are a few main reasons why
Malaysia’s construction sector does not apply the geopolymer concrete. It may due to the material preparation, cost production, method preparation, and mix proportion as well as the test method on geopolymer concrete. Unique characteristics of geopolymer concrete due to its required heat to polymerization process at certain temperature compared to conventional concrete is also one of the factor why geopolymer concrete is unpopular in Malaysia.

Thus, this study has been conducted to develop a general guidance on the preparation of geopolymer concrete. Besides that, this research will compare between the mechanical and physical properties of OPC concrete with geopolymer concrete (GPC).

1.4 Contribution of study

This research involves an experimental study to compare the compressive strength, flexural strength, water penetration test as well as sulphuric acid test between OPC concrete and GPC. Moreover, the effects of glass fibre, biomass aggregate and treated expanded polystyrene on the mechanical and physical properties of OPC and GPC will be investigated.
CHAPTER II

LITERATURE REVIEW

2.0 Introduction

Concrete is the most widely used construction materials in the world. However, production of Portland cement will release carbon dioxide into environment. In fact, about 1.5 tons of raw materials is needed in the production of every ton of Portland cement, at the same time, about one ton of carbon dioxide (CO₂) is released into the environment in the production process (Mehta, P.K., 1999). Besides that, production of Portland cement is extremely resource and energy intensive process. Thus, geopolymer concrete is introduced to address such global issue on climate change. Davidovits reported that about less 3/5 energy was required and 80% - 90% less CO₂ is generated for the production of geopolymer than that of Portland cement. Hence, it is a great significance to environmental protection for the development and application of geopolymer concrete (Davidovits, J., 1994).

2.1 Geopolymer concrete

Geopolymer is an aluminosilicate binder material which was first introduced by Joseph Davidovits in year of 1978. Geopolymer may be synthesized at high temperature by alkaline activator of aluminosilicates obtained from industrial waste, calcined clays and natural minerals. In alkaline liquid, aluminosilicate reactive materials are rapidly
dissolved into solution to form free SiO$_4$ and AlO$_4$ tetrahedral units (H.Xu, 2001). During the polycondensation process, the tetrahedral units are linked in an alternate manner to yield amorphous geopolymer. Geopolymer concrete is generally produced from one or more solid component (binder) and one or more liquid component (activator) which reacts to form strong and durable materials.

Figure 2.1: Character of geopolymer concrete.

2.2 Composition of geopolymer concrete

These are the main materials used to produce geopolymer concrete mixes:

i. Fly ash
ii. Rice husk ash
iii. Silica fume
iv. Fine aggregate
v. Alkaline liquid
vi. Coarse aggregate
2.2.1 Fly ash

Many previous studies show that fly ash as pozzolana material is effective for improving the various properties of concrete. It has also been reported that damage due to autogenously shrinkage is significantly reduced in concrete or cement paste when fly ash is added (Pipat Termkhajornkit, 2004). It provided good properties of concrete as it improved the strength and durability of the concrete. Very fine fly ash is an excellent pozzolanic material. It was found that high fineness of fly ash (mean diameter, d50 about 3.8 microns) can be used to produced high strength concrete 70 MPa at the age of 7 days (Jaturapitakkul et al. 2004). The detail composition of fly ash can be determined by XRF was shown in Table 2.1.

High calcium (class C) fly ashes have more a glassy structure (calcium aluminate) and minor constituents of crystalline compounds which are highly reactive. Besides that, low calcium (class F) fly ashes contain a large portion of silicate glass of high silica content and crystalline phases of low reactivity. Therefore, class F fly ashes are less reactive than class C fly ashes (Babu & Venkatachalam, 2001). Furthermore, fly ash are also used in mixtures with industrial by products such as kiln dust in Aerated Autocalved Concrete(AAC) and it to be used in producing zeolite like structures in blends containing them. However, the physical contribution of fly ash to concrete is much documented; but the chemical contribution to the overall structure development has not been fully understood.

<table>
<thead>
<tr>
<th>Oxides</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>CaO</th>
<th>Na₂O</th>
<th>MgO</th>
<th>K₂O</th>
<th>SO₃</th>
<th>LOI</th>
</tr>
</thead>
<tbody>
<tr>
<td>% by mass</td>
<td>61.16</td>
<td>30.08</td>
<td>4.62</td>
<td>1.75</td>
<td>0.76</td>
<td>0.18</td>
<td>0.36</td>
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<td>0.18</td>
<td>0.36</td>
<td>0.19</td>
<td>0.6</td>
</tr>
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</table>

2.2.2 Rice husk ash

Rice husk ash (RHA) is known to possess high potential of being utilized as a cementitious material for concrete because 85% to 97% of the ash weight is consists of amorphous silica. RHA is an economical cement material to replace and available in many parts of the world. In order to have an effective uses of RHA, it is essential to make it on a mass scale and economically. The simplest and economical way to mass produce RHA is to burn rice husk in the open air. A good quality RHA was obtained by burning conically shaped piles of husks in opening air; although the test result showed that the ashes were not good as done by Mehta (Cady and Groney, 1976). However, another test result was done and showed that a good quality was prepared by burning rice husks under a free air supply condition at 400°C for 4 hours, cooling the ash instantly and grinding it for about 100 minutes (Yamamoto and Lakho, 1982).

2.2.3 Silica fume

Silica fume is a by-product which can be obtained from manufacture of metal alloys such as silicon and ferrosilicon. Silicon fume is a fine particle and very effective pozzolana material. It is one of the mineral admixtures to add in Portland cement concrete to enhance the mechanism properties such as compressive strength. The concrete consists of silica fume will increase the strength and improve the modulus of elasticity as well as concrete flexural strength. Besides that, concrete mixed with silica fume will give a greater resistance to various chemical attacks due to the reduced permeability of the concrete. Hence, using silica fume as admixtures in concrete will produce a low permeability and high compressive strength concrete.
2.2.4 Fine aggregate

The aggregate which passes through a 4.75 mm sieve is permitted by the specifications. Sand is generally considered to have a lower size limit of about 0.07 mm. Material between 0.06 mm and 0.002 mm is classified as silt, and smaller particle are called clay. The soft deposit consisting of sand, clay in about equal properties is termed loam. The fine aggregate may be of the following types.

i. natural sand, i.e. the fine aggregate resulting from natural disintegration of rock and/or that which has been deposited by stream and glacial agencies.

ii. crushed stone sand, i.e. the fine aggregate producing by crushing hard stone,

iii. crushed gravel sand, i.e. the fine aggregate produced by crushing natural gravel.

Table 2.2: BS and ASTM grading requirement for fine aggregate

<table>
<thead>
<tr>
<th>BS sieve</th>
<th>Percentage by weight passing sieve</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grading zone 1</td>
</tr>
<tr>
<td>9.5 mm</td>
<td>100</td>
</tr>
<tr>
<td>4.75 mm</td>
<td>90-100</td>
</tr>
<tr>
<td>2.36 mm</td>
<td>60-95</td>
</tr>
<tr>
<td>1.18 mm</td>
<td>30-70</td>
</tr>
<tr>
<td>600 μm</td>
<td>15-34</td>
</tr>
<tr>
<td>300 μm</td>
<td>5-20</td>
</tr>
<tr>
<td>150 μm</td>
<td>0-10</td>
</tr>
</tbody>
</table>

A good concrete can be obtained with sand of zone 4, particularly using vibration. Work at the Building Research Establishment (D.C. Teychenne, 1978) has shown that increasing the content of particles smaller than 150 μm (No 100) in crushed
rock fine aggregate from 10 to 25 percent result in only a small decrease compressive strength of concrete, typically by 10 percent.

2.2.5 Alkaline liquid

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 (Davidovits et al., 1999).

Palomo et al (1999) concluded that the type of alkaline liquid plays an important role in the polymerization process. Reactions occur at a high rate when the alkaline liquid contains soluble silicate, either sodium or potassium silicate compared to the use of only alkaline hydroxides (Xu and van Deventer, 2000) confirmed that the addition of sodium silicate solution to the sodium hydroxide solution as the alkaline liquid enhanced the reaction between the source material and the solution. Furthermore, after a study of the geopolymerisation of sixteen natural Al-Si minerals, it is found that generally the NaOH solution caused a higher extent of dissolution of minerals than the KOH solution. The chemical composition of activators are shown in Table 2.3.

Table 2.3: Composition of activator solution (Fernandez et al, 2006)

<table>
<thead>
<tr>
<th></th>
<th>SiO₂</th>
<th>Na₂O</th>
<th>SiO₂/Na₂O</th>
<th>Specific gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium Silicate</td>
<td>28%</td>
<td>8%</td>
<td>3.5</td>
<td>1.48 g/cm³</td>
</tr>
<tr>
<td>Sodium Hydroxide</td>
<td>Molarity</td>
<td>Solids %</td>
<td>Liquid %</td>
<td>Specific gravity</td>
</tr>
<tr>
<td></td>
<td>16M</td>
<td>44.4</td>
<td>55.6</td>
<td>1.34 g/cm³</td>
</tr>
</tbody>
</table>
2.2.6 Coarse aggregate

The aggregate which are retained on the 4.75 mm sieve are termed as coarse aggregate. The graded coarse aggregate is described by its nominal size, i.e. 40 mm, 20 mm, 16mm and 12.5mm. The coarse aggregate may be one of the following types:

i. crushed gravel or stone obtained by the crushing of gravel or hard stone,
ii. uncrushed gravel or stone resulting from the nature disintegration of rock , or
iii. partially crushed gravel or stone obtained as a product of the blending of the above two types.

Table 2.4: Grading requirement for coarse aggregate according to BS 882: 1973

<table>
<thead>
<tr>
<th>BS sieve</th>
<th>40 - 5</th>
<th>20 - 5</th>
<th>14 - 5</th>
<th>63</th>
<th>40</th>
<th>20</th>
<th>14</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm in</td>
<td>1½- 3/16</td>
<td>3/4 -3/16</td>
<td>½-3/16</td>
<td>2 ½</td>
<td>1½</td>
<td>⅞</td>
<td>½</td>
<td>3/8</td>
</tr>
<tr>
<td>75 3</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>63 2 ½</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>85-100</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37.5 1 ½</td>
<td>95-100</td>
<td>100</td>
<td>-</td>
<td>0-30</td>
<td>85-100</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 3/4</td>
<td>35-70</td>
<td>95-100</td>
<td>100</td>
<td>0-5</td>
<td>0-25</td>
<td>85-100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>14 ½</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>90-100</td>
<td>-</td>
<td>85</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>10 3/8</td>
<td>10-40</td>
<td>30-60</td>
<td>50-85</td>
<td>-</td>
<td>0-25</td>
<td>50</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>5 3/16</td>
<td>0-5</td>
<td>0-10</td>
<td>0-10</td>
<td>0-5</td>
<td>10</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.36 No 8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0-5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The actual grading requirement depends to some extent on the shape and surface characteristic of the particles. For instance, sharp, angular, particles with rough surfaces
will have a slightly finer grading in order to reduce the possibility of interlocking and compensate for high friction between the particles.

2.3 Glass fibre

Glass fibres are fabricated by extruding molten glass and are the most common reinforcing fibre for FRP. Low cost, high tensile strength, high corrosion resistance and excellent insulating properties are the advantages of glass fiber (Vijay, 1999). There are four types of glass fiber which are E-glass fiber; S-glass fiber, C-glass fiber and alkaline resistance fiber (AR). E-glass and S-glass are two types of glass fiber most commonly used in the composite industry (Bemokrane, et al, 1995). S-glass fiber is more expensive than E-glass and it has high strength, stiffness and excellent strain.

However, types of S-glass fiber susceptible to degradation in marine environments (Shahidi, 2003). Typically, types of E-glass fiber have well properties because it good in electrical resistance, acidic resistance, and high strength as well as low cost (Bemokrane, et al, 1995). Types of C-glass fiber is applies in acidic environment due to its chemical stability (Shahidi, 2003). Alkaline resistance fiber has used in alkaline environment such as marine to minimize the concrete weight and strength loss (Bemokrane, et al, 1995).

2.4 Expanded polystyrene

Expanded polystyrene is commonly used in packaging. Polystyrene is an aromatic polymer made from the aromatic monomer styrene. Polystyrene is well known as thermoplastic substances which it is solid state in room temperature and flows when subjected to heat and becomes solid state when it cooled. The force of attraction in polystyrene is mainly due to short range of van der Waals attraction between chains.
Molecules of polystyrene are long hydrocarbon chains that consists of many atoms that attracts force between molecule is large. Polystyrene can be recycle used because it takes a long period to biodegradation and usually as a form of pollution in the outdoor environment (Bandypadhyay, 2007).

Expanded polystyrene is rigid and well closed cell foam. It usually is white and made of pre-expanded beads. Expanded polystyrene widely used in moulded sheets for building insulation. Expanded polystyrene sheet usually are packages as rigid panels known as bead board. The density of expanded polystyrene is range of 16 kg/m³ to 640 kg/m³ (Goodier, K., 1961). Expanded polystyrene is well in thermal resistivity which is about 28m.K/W and it slightly little has flame spread less than 25 minutes.

2.5 Chemistry of geopolymer concrete

The chemical composition of geopolymer is similar to zeolite but it shows an amorphous microstructure. According to Joseph Davidovits in year of 2002 state that, the first chemical element in the geopolymer founded in 1970 is the aluminosilicate kaolinite reacts with NaOH at 100°C-150°C and undergoes polycondenses into hydrated sodalite (a tecto- aluminosilicate) or hydrosodalite.

\[ \text{Si}_2\text{O}_5, \text{Al}_2(\text{OH})_4 + \text{NaOH} = \text{Na}(-\text{Si-O-Al-O})_n \]

kaolinite  \hspace{1cm} \text{hydrosodalite}

The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al mineral, those results in a three dimensional polymeric chain and ring structure consists of Si-O-Al-O bonds as follow

\[ \text{Mn}[-(\text{SiO}_2)z-\text{Al}_2\text{O}_3] \text{n.wH}_2\text{O} \]
Since n is the degree of polycondensation, M is predominantly a monovalent cation (K⁺, Na⁺), although Ca²⁺ may replace two monovalent cations in the structure (Davidovits, J., 1999). In the same result, Davidovits pointed out that although the SiO₂ / Al₂O₃ ratio given by z is 1, 2 or 3 for the sialate-siloxo and sialate-disiloxo chains even z can be higher than 3 (up to 32). A geopolymer can take one of the basic forms which is the cross linking of poly-silicate chains with a silicate link (-Si-O-Al-O-) bonds is shown in Figure 3. Therefore, the geopolymer material diagram can be shown as described by equation below.

\[
\begin{align*}
\eta(SiO_2 + Al_2O_3 + \eta SiO_2 + 4\eta H_2O + NaOH & \rightarrow Na^+, K^+ + \eta OH_2 + SiO_2 + Al_2O_3 + Si-(OH)\_n \quad (Si-Al \text{ materials}) \\
(\text{geopolymer precursor})
\end{align*}
\]

\[
\begin{align*}
\eta(\text{OH})_2 + Si-O-Al-O-Si-(OH)\_n + NaOH & \rightarrow (Na^+, K^+)-(Si-O-Al-O-Si-O-)+(4\eta H_2O) \\
(\text{geopolymer backbone})
\end{align*}
\]

Figure 2.2: Geopolymer backbone and geopolymer precursor (Edward G. Nawy, 2008)

Figure 2.3: Geopolymer molecular networks (Davidovits, J., 1999)

The formation of geopolymer materials is shown by Edward in Figure 2.2, it is not clear since setting and hardening of geopolymer precursor. Therefore, in terms of
the second equation (geopolymer backbone) shown in Figure 2.3, water is released during the chemical bonds. The water removed from the geopolymer matrix during the hydration process. Hence, there are two main constituents of geopolymer which are the source materials and the alkaline liquids. 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.

2.6 Corrosion resistance of geopolymer concrete

Geopolymer concrete is well known as a better corrosion resistance in both acid and salt environment. It is because limestone has not used as a material in formation of geopolymer concrete. Therefore, it is especially suitable for tough environmental conditions compared to Portland cement concrete which could undergo sulphate attack and acid attack. Additional, geopolymer concrete can become bending when it is in sea water environment. In contrast, Portland cement concrete is impossible in sea water compared to geopolymer concrete which useful in marine environment and on islands short of fresh water (X.J.Song, 2005) was shown in Figure 2.4 and 2.5.

Figure 2.4: Weight loss of specimens put into 5% HCL (X.J.Song, 2005)
Figure 2.5: Change in compressive strength after put 5% HCL (X.J. Song, 2005)

2.7 Thermal resistances of geopolymer concrete

Geopolymer concrete has excellent thermal stability. Thermal stability of geopolymer concrete depends on the chemistry composition of geopolymeric binder itself such as alkali ion and temperature regime. However, conversion reaction at high temperature will be affected by reaction additives and filler materials. Regarding this point, aggregate with small grain size and a certain amount of reactive phases can react with the binder material during the alkaline solution or thermal treatment in investigation on geopolymer stabilized clays (A. Buchward, 2004). Therefore, thermal stability of geopolymer binder is strongly correlated to its real composition. Additional, a certain thermal resistance depends on the specific application of geopolymer material.

There are three main group of application which can be divided according to the frequency and duration of thermal load:

i. Building materials which resist fire disaster should be designed for a long life property at normal climate temperatures. For instance, the massive construction
such as wall and column should be designed as fire resistant in order to protect the construction behind from high temperature.

ii. The geopolymer material has to pass a high temperature production step quite similar to the production of special ceramics and glass ceramics can undergo geopolymer route.

iii. High temperature application materials like refractory materials and adhesive as well as filter materials should be able to withstand permanent temperature load under certain condition.

The material profile may be different in all three groups of application but quite similar in terms of thermal properties.

2.8 Compressive strength

The compressive strength of concrete is one of the most important properties. In most of the structural applications, concrete is employed primarily to resist compressive stresses. There are other measure of concrete strength such as flexural strength and tensile strength, the compressive strength still frequently being used as a measure of the resistance because it is the most convenient to measure. For this reason, the compressive strength is generally used to determine the overall quality of a concrete. There are a lot of factors contribute to the strength of concrete. The primary factor influencing strength is porosity but this property is difficult to measure. Similarly, the influence of aggregate on micro cracking is not easily quantified. Hence in practical, the main influencing factors on strength taken in consideration are water/geopolymer by mass ratio, degree of compaction, age, and temperature. Other influencing factors like fineness of modulus of combine aggregate, the maximum size of the aggregate, and quality of the aggregate such as grading, surface texture, shape, strength, and stiffness are regarded as of secondary importance.
2.9 Flexural strength

Flexural tensile strength is to estimate the load at which the concrete member may crack. The flexural tensile strength at failure or the modulus of rupture is consequently determined and used when necessary. Additional, the modulus of rupture is determined by testing standard test specimens of 150 mm x 150 mm x 700 mm over a span of 600 mm or 100 mm x 100 mm x 500 mm over a span of 400 mm under symmetrical two point load. Hence, the strength estimated by flexural test is higher than tensile strength of concrete because of the assumption of the linear behaviour of material up to failure in the computation.

3.0 Durability and water permeability

According to ACI Committee 201, durability is defined as its ability to resist weathering action, chemical attack, abrasion or any other form of deterioration. A durable concrete should maintain its original form, quality and its serviceability when exposed to surrounding environment for a long service life. The design life of concrete varies between 50 and 120 years. In order to be durable, concrete must be relatively impervious. The deterioration can be due either to physical factors or chemical causes as listed in Table 2.5.

Water permeability is defined as the properties that govern the rate of flow fluid into a porous solid. Permeability is the ease with which liquids or gases can travel through concrete. It is related to water tightness of liquid retaining structures and to chemical attack. There is a test are now prescribed by BS 1881: Part 5 : 1970 for the determination of the initial surface absorption which is defined as the rate of flow of water into concrete per unit area after a given time, under a constant head of 200 mm of water and at a given temperature. The typical water permeability values associated with
concrete quality are stated in the Technical Report No 31 of the Concrete Society, which is listed in Table 2.6.

Table 2.5: Physical and chemical causes of concrete deterioration (Kenneth N. Derucher, 1998).

<table>
<thead>
<tr>
<th>Physical Factors</th>
<th>Chemical Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Mechanical damage is caused by impact abrasion, erosion and cavitations</td>
<td>- Sulphate attack</td>
</tr>
<tr>
<td>- Freezing and thawing</td>
<td>- Acid attack</td>
</tr>
<tr>
<td></td>
<td>- Carbonation</td>
</tr>
<tr>
<td></td>
<td>- Aggregate chemical reactions</td>
</tr>
<tr>
<td></td>
<td>- Alkali silica reactions</td>
</tr>
<tr>
<td></td>
<td>- Alkali carbonate reactions</td>
</tr>
</tbody>
</table>

Table 2.6: Quality of water permeability concrete (Concrete Society- Technical Report No 3).

<table>
<thead>
<tr>
<th>Water permeability</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt; 10^{-12}$</td>
<td>Good</td>
</tr>
<tr>
<td>$10^{-12} - 10^{-10}$</td>
<td>Average</td>
</tr>
<tr>
<td>$&gt; 10^{-10}$</td>
<td>Poor</td>
</tr>
</tbody>
</table>
3.1 Parameters effects on geopolymer concrete

3.1.1 Material

The strength of geopolymer depends on natural sources of material. The basic material of geopolymer include of fly ash, fine aggregate, coarse aggregate, alkaline liquid, water, superplasticizer. Besides that, the details of chemical composition of fly ash can be determined by X-Ray Fluorescence (XRF). In the batches of fly ash, the molar Si to Al ratio is about 1-3. Sodium silicate solution and sodium hydroxide solution are known as alkaline activator. The sodium hydroxide (NaOH) was prepared by dissolving either the flakes or the pellets in water. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molar, M, sand is small aggregate in geopolymer concrete (Nguyen and Bui and Dang, 2008). In order to improve the workability of geopolymer concrete, we can add some chemical admixtures such as superplasticizer in the mixtures. Hence, the fresh geopolymer will gain strength. Figure 2.6 show that geopolymer phases development on the surface of fly ash particles.

![Geopolymer image](image)

Figure 2.6: Geopolymer phase’s development on the surface of the fly ash particle (Nguyen and Bui and Dang, 2008).
3.1.2 Superplasticizer

In fresh geopolymer state, the geopolymer concrete has a stiff consistency. Therefore, workability of geopolymer paste can be improved by added chemical admixtures such as superplasticizer. The quantity of superplasticizer used is according to proportion of fly ash. However, there is a little effect on the compressive strength up to about two percent of the admixture to the mass of fly ash.

Superplasticizer is linear polymers containing sulfonic acid group attached to the polymer backbone at regular intervals (Verbeck, 1968). Most of the commercial formulations belong to one of four families:

i. Sulfonated melamine-formaldehyde condensates (SMF)
ii. Sulfonated naphthalene - formaldehyde condensates (SNF)
iii. Modified lignosulfonates (MLS)
iv. Polycarboxylate derivatives

The sulfonica acid groups are responsible for neutralizing the surface charges on the cement particles and causing dispersion, thus releasing the water tied up in the cement particle agglomerations and thereafter reducing the viscosity of the paste and concrete (Mindess and Young, 1981).

In this research, superplasticizer Darex 20 with high range water reducer will be used during this experiment. Darex 20 high range water reducers maintain a low water cement ratio for high strength, with plasticity for easy placement. Superplasticizer admixtures improve the performance of concrete in both its plastic and hardened states.

3.1.3 Water content

Water content in the mixtures plays an important role in the strength achievement of geopolymer concrete (Barbosa et al, 2000). The reaction occurring in the case of geopolymer concrete is different from that of Portland cement concrete. In geopolymer
concrete, water is required to improve workability but is expelled during curing at high temperature. Therefore, it will increase the porosity of concrete. The results indicate that as the H₂O to Na₂O ratio of the mix increases the compressive strength decreases. The water will evaporate at high temperature causing the porosity of the concrete to increase. As a result, the compressive strength of geopolymer concrete will decrease. According to Neville (1995), H₂O to Na₂O ratio of 10 to 14 could be used only for the concrete designed with a fly ash content of 408 Kg/m³ and the ratios will change on variation of fly ash content.

3.1.4 Molar ratio NaOH, Na₂O and H₂O

![Graph showing the effect of Na₂O/SiO₂ molar ratio on compressive strength](image)

Figure 2.7: Effect of Na₂O/ SiO₂ molar ratio on compressive strength (Hadjito, D. and Rangan, 2005).
Figure 2.8: Effect of H₂O/ NaO₂ molar ratio on compressive strength (Hardjito, D. and Rangan, 2005).

Geopolymer concrete is much different compared to Portland cement concrete due to the binder (Edward G. Nawy, 2008). The basic material sources used to form geopolymer paste is fly ash which will react with alkaline solution that binds the fine aggregate and coarse aggregate. However, the compressive strength of geopolymer concrete will be influenced by molar ratio of H₂O, Na₂O and SiO₂. To maintain the molar ratio of H₂O to Na₂O, increasing the concentration of sodium hydroxide (NaOH) could be done during geopolymer mixtures added with water.

Obviously, higher water content of the mixtures will result in higher Na₂O to SiO₂ molar ratio. Therefore, increasing the Na₂O to SiO₂ molar ratio does not have much effect on the compressive strength of geopolymer concrete, which is shown in Figure 2.7. Meanwhile, Figure 2.8 shows that increasing the molar ratio of H₂O to Na₂O will cause the compressive strength of geopolymer concrete to decrease.
3.1.5 Water to geopolymer solid ratio

Compressive strength of geopolymer concrete will decrease as the water to geopolymer solids ratio by mass increases as shown in Figure 2.9. The water to geopolymer solid ratio by mass increase means that the workability in the geopolymer mixtures contains more water. The workability of geopolymer paste is determined by slump test. Therefore, higher workability of geopolymer mixtures will reduce the compressive strength. Hence, a good workability control is needed to produce a better compressive strength of geopolymer concrete.

![Figure 2.9: Effect of water to geopolymer solid ratio on compressive strength (Hardjito, D. and Rangan, 2005).](image)

3.1.6 Curing time and curing temperature

Heat is a reaction accelerator for fresh geopolymer paste curing and carried out mostly at high temperature. There are two primary factors influencing the compressive strength of