PRODUCTION OF LIGHTWEIGHT GEOPOLYMER MATERIAL FOR STRUCTURE APPLICATION

By

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Dissertation Submitted In Partial Fulfilment of the Requirements for the

Bachelor of Engineering (Hons)

(Chemical Engineering)

SEPTEMBER 2012

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Chemical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CHEMICAL ENGINEERING)

Approved by,

____

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September 2012

CERTIFICATION OF ORIGINALITY

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.

(FATINAH BINTI MANGSOR)

ACKNOWLEDGEMENT

First and foremost, I would like to express my gratitude to the Almighty for making the Final Year Project II (FYP II) a successful and useful one. A token of appreciation also goes to AP Dr Zakaria Man, my supervisor for his guidance and advises throughout the progress of this project. To all lecturers involved in FYP II, I would like to express my gratitude in hearing and solving any doubts and problems throughout the course this semester. Lastly, special thanks to our family and fellow colleagues for their support and company in making this FYP II something to be proud of.

Thank you.

ABSTRACT

The problem is to replace the normal cement with the lightweight of geopolymer material for structure application. This is because building material like roof, tiles, panelling are made from ceramic or cement which is heavy and cause difficulty in handling also if to be transport to the construction site. Therefore, the geopolymer products offer an alternative to recover those problems. In this case, the lightweight geopolymer are very desirable for the building construction as they can reduce their capital in transportation and gain more profit. The aim of this project is to form geopolymer composite incorporate with untreated rice husk into the formation of the geopolymer in order to reduce the weight of the geopolymer. Therefore, an alternative has been applied for this project; the rice husk as a filler will be added into the production of the lightweight geopolymer. The lightweight geopolymer have been created by mixing of fly ash with sodium hydroxide (NaOH) with the addition of untreated rice husk. This research been done by varies the concentration of the NaOH in range of 10-14M and also the particle size of the untreated rice husk between coarse and fine size and been cured at room temperature and at 60oC for about 7 days. There are four testing have been done for this project. First is density test where both type of sample (coarse and fine R.H) shown that when the concentration of NaOH increasing, the density of the sample is decreasing which meets our target to produce lightweight geopolymer. Then, for compressive strength, the results shown that lightweight geopolymer are less strength than pure geopolymer however it’s still have strength which can be apply for indoor structure material such as wall panels. For water absorption test and setting time test results showed some variation of the lightweight geopolymer. Thus, this project have to do further development and study for findings such as by using much finer untreated rice husk and so on.

TABLE OF CONTENTS

CERTIFICATION OF APPROVAL i

CERTIFICATION OF ORIGINALITY i

ACKNOWLEDGMENT iii

ABSTRACT. iv

TABLE OF CONTENTS v

LIST OF TABLE, FIGURE AND GRAPH. viii

CHAPTER 1: INTRODUCTION 1

1.1 Background of Study 1

1.2 Problem Statement 3

1.3 Scope of Study 4

1.4 Objectives. 4

CHAPTER 2: LITERATURE REVIEW 5

2.1 Concrete and Environment. 5

2.2 Fly Ash 6

2.3 Geopolymer. 6

2.4 Wall panels. 7

2.5 Concrete Roof Tile. 8

2.6 Sources of material. 9

2.7 Alkaline Liquids. 9

2.8 Preparations of Geopolymer. 10

2.9 Setting Time Measurement. 12

2.10 Compressive Strength Test. 13
2.11 Water Absorption and Density. 14
2.12 Scanning Electron Microscopy (SEM. 15
CHAPTER 3: METHODOLOGY 17
3.1 Research Method. 17
3.2 Table of Workflow. 21
3.3 Tools, Equipments and Materials. 22
CHAPTER 4: RESULTS AND DISCUSSION 23
4.1 Density of Coarse Untreated R.H Lightweight Geopolymer. . . 23
4.2 Compressive Strength of Coarse Untreated R.H Lightweight Geopolymer. . 25
4.3 Water Absorption % of Coarse Untreated R.H Lightweight Geopolymer. . 27
4.4 Setting Time of Coarse Untreated R.H Lightweight Geopolymer. . . 30
4.5 Density of Fine Untreated Rice Husk Lightweight Geopolymer. . . 31
4.6 Compressive Strength of Fine Untreated R.H Lightweight Geopolymer. . 34
4.7 Water Absorption Percentage of Fine Untreated R.H Lightweight Geopolymer. 36
4.8 Setting Time of Fine Untreated Rice Husk Lightweight Geopolymer. . . 38
CHAPTER 5: CONCLUSION AND RECOMMENDATIONS . . . 39
5.1 Conclusion. 39
5.2 Recommendations 39
REFERENCES 40
APPENDICES 42

LIST OF TABLE

Table 1.0: The comparison of quantities of CO2 produced from the conversion of raw materials to OPC and to alternative cement compounds.

Table 2.0: Chemical compositions (mass %) of Class F fly ash

Table 3.0: The mixture for production of geopolymer

Table 4.0: Research Result at Room Temperature

Table 5.0: Research Result at 60^0C

Table 6.0: FYP I Gantt Chart and Milestone

Table 7.0: FYP II Gantt Chart and Milestone

Table 8.0: Particle size of fine rice husk distributions

LIST OF GRAPH

Graph 1.0: Average density of the lightweight geopolymer (coarse R.H) at room temperature

Graph 2.0: Average density of the lightweight geopolymer (coarse R.H) at 60^oC

Graph 3.0: Average compressive strength of lightweight geopolymer (coarse R.H) at room temperature

Graph 4.0: Average compressive strength of lightweight geopolymer (coarse R.H) at 60^oC

Graph 5.0: Water absorption percentage of pure geopolymer (coarse R.H) at room temperature

Graph 6.0: Water absorption percentage of pure geopolymer (coarse R.H) at room temperature

Graph 7.0: Water absorption percentage of 15% coarse R.H at room temp. and 60^oC

Graph 8.0: Water absorption percentage of 10% coarse R.H at room temp. and 60^oC

Graph 9.0: Water absorption percentage of 5% coarse R.H at room temp. and 60^oC

Graph 10.0: Setting time of lightweight geopolymer (coarse R.H) at room temp.

Graph 11.0: Average density of the lightweight geopolymer (fine R.H) at room temperature

Graph 12.0: Average density of the lightweight geopolymer (fine R.H) at 60^{o}C

Graph 13.0: Average compressive strength of lightweight geopolymer (fine R.H) at room temperature

Graph 14.0: Average compressive strength of lightweight geopolymer (fine R.H) at 60^{o}C

Graph 15.0: Water absorption percentage of 15% fine R.H at room temp. and 60^{o}C

Graph 16.0: Water absorption percentage of 10% fine R.H at room temp. and 60^{o}C

Graph 17.0: Water absorption percentage of 5% fine R.H at room temp. and 60^{o}C

Graph 18.0: Setting time of fine R.H lightweight geopolymer at room temp.

LIST OF FIGURE

Figure 1.0: Overview of Project Aim

Figure 2.0: Example of wall panels

Figure 3.0: Example of concrete roof tiles

Figure 4.0: Geopolymers reaction in two steps

Figure 5.0: The effect of temperature on setting time

Figure 6.0: Research Compressive Strength Result

Figure 7.0: Microstructure of Geopolymer (SEM)

Figure 8.0: Microstructure of Geopolymer (SEM)

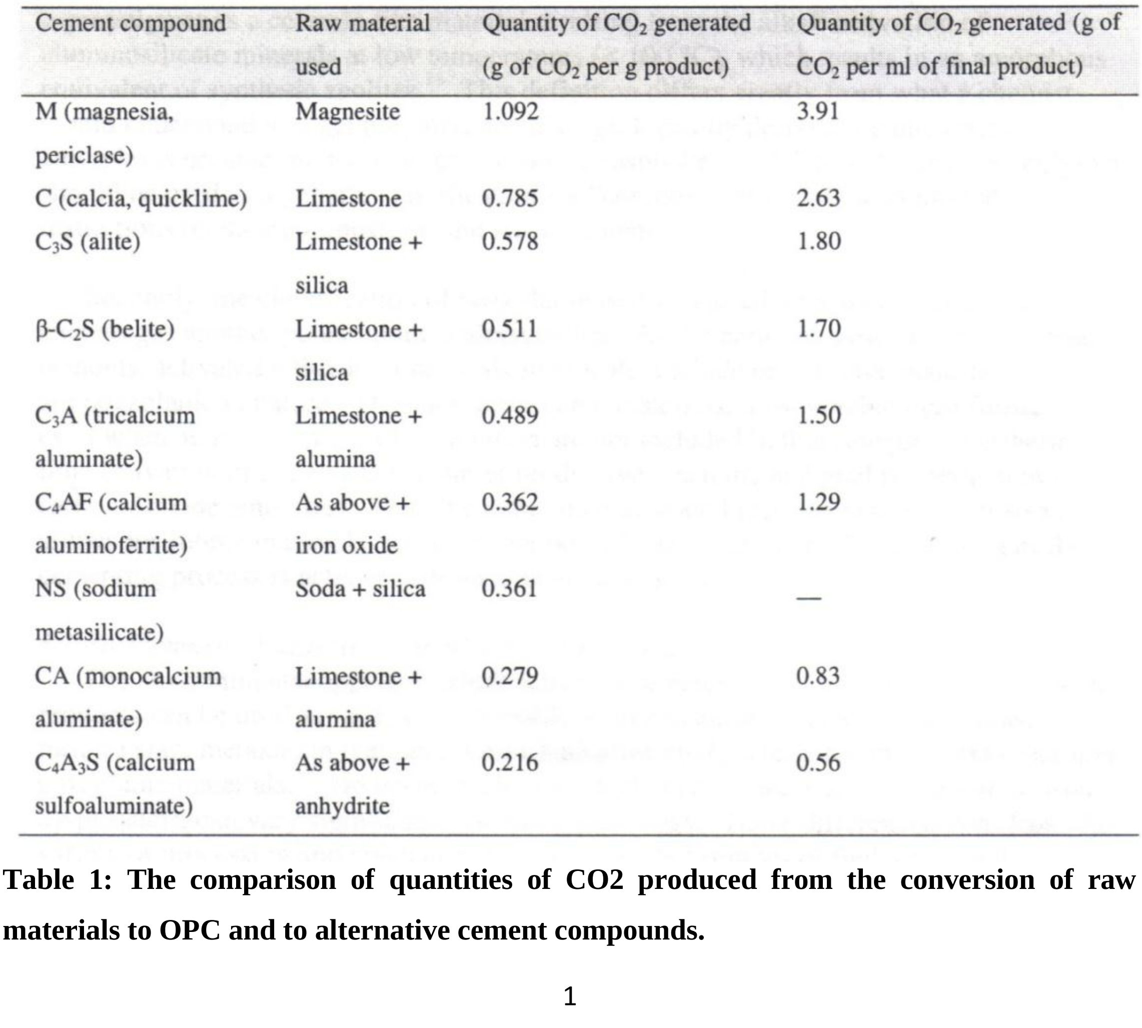
Figure 9.0: Porous nature of geopolymer material (SEM)

Figure 10.0: Research method flowchart

CHAPTER 1: INTRODUCTION

1.1 Background of Study

Presently, the most used cement for structure is using the Portland cement. Literally, the production of the Portland cement is intensive energy and emits around 7% of carbon dioxide (CO_2) to the total global emission. They state that the production of one kilogram of Portland cement produces approximately one kilogram of carbon dioxide (CO_2). The table below shown the four major types of cement that have lower CO2 emissions. These types include calcium (sulfo) aluminate cements, calcium sulfate-based cements, magnesia cements, and alkali activated cements. This last type that is alkali activated cements shows increased demand because of its consumption of industrial by-products like fly ash and blast furnace slag and also because its emits smaller carbon footprint.



Cement compound	Raw material used	Quantity of CO_2 generated (g of CO_2 per g product)	Quantity of CO_2 generated (g of CO_2 per ml of final product)
M (magnesia, periclase)	Magnesite	1.092	3.91
C (calcia, quicklime)	Limestone	0.785	2.63
C_3S (alite)	Limestone + silica	0.578	1.80
β-C_2S (belite)	Limestone + silica	0.511	1.70
C_3A (tricalcium aluminate)	Limestone + alumina	0.489	1.50
C_4AF (calcium aluminoferrite)	As above + iron oxide	0.362	1.29
NS (sodium metasilicate)	Soda + silica	0.361	—
CA (monocalcium aluminate)	Limestone + alumina	0.279	0.83
C_4A_3S (calcium sulfoaluminate)	As above + anhydrite	0.216	0.56

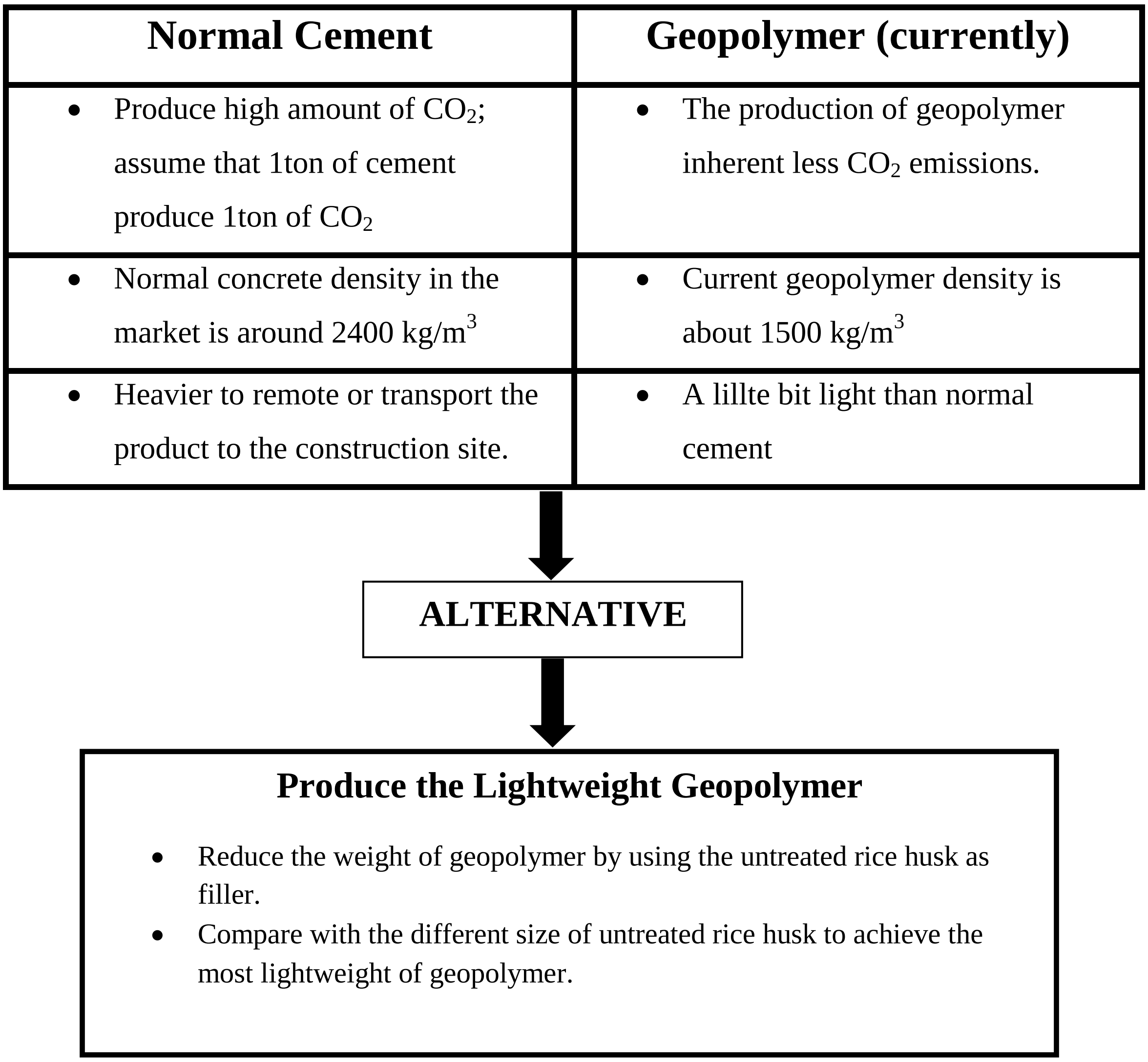
Table 1: The comparison of quantities of CO2 produced from the conversion of raw materials to OPC and to alternative cement compounds.

The current production process is based on the following chemical reaction from limestone and silica into the calcium silicates and carbon dioxide products.

$$5CaCO_3 + 2SiO_2 \rightarrow Ca_3SiO_5 + Ca_2SiO_4 + 5CO_2$$

The alternative that has been researched to replace the Portland cement is by using the geopolymer materials for structure. Geopolymer is inorganic polymer that was developed by Joseph Davidovits in 1978 (Comrie and Davidovit, 1988; *Davidovits et al.,* 1990). The bond of geopolymer is chemical bonding the mechanism is different to cement hydration. The production of geopolymer structure required low energy and its inherent low CO_2 emission. The reaction process of geopolymer binder system is characterized by dissolution of alumino-silicate oxides and followed by the polymerization reaction of those dissolved species, in the presence of alkali ions for charge balancing in framework cavities nearby AlO_4 constituents. That reaction will produce the SiO_4 and AlO_4, based on the depending on the SiO_2/Al_2O_3 ratio in the system. Most of the constructions now are focused on the lightweight materials used in order to reduce the weight of the building and improve the efficiency of thermal insulation of the building. Therefore, they are more focused on the synthesis of the lightweight geopolymer materials. The raw material using to produce the geopolymer material are **Si-Al material** such as **fly ash, rice husk ash (RHA), diatomaceous earth (DE), furnace slag, cenospheres, kaoline** and many more as long as the substance contain high the material contain high silica oxide (SiO_2) and alumina oxide (Al_2O_3). The fly ash is used as the addition of cement.

The current density of the **normal concrete** and **geopolymer** in the market are **2400 kg/m^3** and **1500 kg/m^3** respectively. These shown that the weight of geopolymer still not light enough. As such, the density of geopolymer can be further reducing if suitable lightweight fillers can be added to form geopolymer composites. Which lightweight of geopolymer can make transportation for this product much easier and easy to handle.



Normal Cement	Geopolymer (currently)
• Produce high amount of CO_2; assume that 1ton of cement produce 1ton of CO_2	• The production of geopolymer inherent less CO_2 emissions.
• Normal concrete density in the market is around 2400 kg/m^3	• Current geopolymer density is about 1500 kg/m^3
• Heavier to remote or transport the product to the construction site.	• A lillte bit light than normal cement

ALTERNATIVE

Produce the Lightweight Geopolymer

- Reduce the weight of geopolymer by using the untreated rice husk as filler.
- Compare with the different size of untreated rice husk to achieve the most lightweight of geopolymer.

Figure 1 : Overview of Project Aim

1.2 Problem Statement

1.2.1. Producing the lightweight Geopolymer

The problem is **to replace the normal cement with the lightweight of geopolymer material for structure application**. This is because geopolymer products are such as roof, floor, wall panels and many more are produced at one production plant and it will be deliver to the customer or construction site at different place a very remote and need to be transported at very far away construction site. In this case, the lightweight geopolymer are very desirable for the building construction as they can reduce their capital in transportation but gain more profit. In fact, observer plays a key role during researching the cement production, and there are shown an essential component in many structure developments such as Portland cement.

The aim of this project is **to form geopolymer composite incorporate with untreated rice husk into the formation of the geopolymer in order to reduce the weight of the geopolymer.** Therefore, an alternative has been applied for this project; the rice husk as a filler will be added into the production of the lightweight geopolymer. There will be four different percentage of rice husk for the samples that will be prepared that are 5%, 10% and 15%. Those four different percentages samples will be produced at two different temperatures that is at room temperature and at 60^0C temperature in order to makes the comparison for the best lightweight geopolymer.

Composite materials are widely used in all types industries based on the types of applications. The most popular composites are ceramic composites where materials are expected to encounter high temperatures such as engine components, exhaust systems and fire barriers. Researched have reported that typical geopolymer can sustain temperatures up to 800°C. This composition was evaluated for a number of applications that require fire-resistance. This inorganic polymer is derived from naturally occurring geological materials, namely silica and alumina, hence the name geopolymer which it is also consume low cost. Geopolymer is a two-part system consisting of a silicate liquid and a silica powder and cures at a reasonably low temperature of 150ºC. Hardener can be added to achieve a cure room temperature (22 º C).

1.3 Scope of Study

Deal with the production of lightweight geopolymer material for structure.

1.4 Objectives

1. To **prepared lightweight geopolymer using the untreated rice husk** with different particle size as filler.
2. **Characterization of geopolymer composites**
3. To **conduct the mechanical test** such as compressive test, setting time test, water absorption test and density to be compare with the standard geopolymer.

CHAPTER 2: LITERATURE REVIEW

2.1 Concrete and Environment

In cement industries, the trading of carbon dioxide (CO_2) emissions is the most critical issue. This is because the emission of CO_2 lead to the greenhouse effect as CO_2 is one of the greenhouse gases. These causes might be able to give the effect of the rises of global temperature which will lead to climate changes. Based on the targets for emission reduction that been established by the 1997 Kyoto Protocol, every industries need to apply the ‘tradeable emissions’ refers to the economic mechanisms that are expected to help the countries worldwide to meet that expectations. Speculation has arisen that one ton of emissions can have a trading value about US$10 (Malhotra 1999; Malhotra 2004).

The contribution of Portland cement production worldwide to the greenhouse gas emission is estimated to be about 1.35 billion tons annually or about 7% of the total greenhouse gas emissions to the earth’s atmosphere (Malhotra 2002). Furthermore, it has been issued that the durability of ordinary Portland cement (OPC) concrete is under consideration, especially those built in corrosive environments as many concrete structures, start to decline after 20 to 30 years, eventhough they have been designed for more than 50 years of service life (Mehta and Burrows 2001).

The Portland cement has a few disadvantages for example:

1. Produces nearly one ton of CO_2 in every one ton of cement’s produce.
2. Heavy to transport from one place to another.
3. Poor performance in salty environments.

For that, geopolymer material is one of the solutions in order to produce the environmental friendly concrete as its production release less amount of the carbon dioxide (CO_2) emissions to the surrounding and others advantages.

2.2 Fly Ash

According to the American Concrete Institute (ACI) Committee 116R, fly ash is defined as ‘the finely divided residue that results from the combustion of ground or powdered coal and that is transported by flue gasses from the combustion zone to the particle removal system’ (ACI Committee 232 2004). Fly ash is the important material in production of normal concrete and also geopolymer.

There are a few type of class for fly ash which every type have different compositions and give different advantages. The stronger fly ash material is usually is Class F. Which is this type of fly ash can produce high strength of geopolymer. The chemical composition is generally composed of the oxides of silicon (SiO2), aluminium (Al2O3), iron (Fe2O3), and calcium (CaO), and with the present of lesser amount of magnesium, potassium, sodium, titanium, and sulphur. Below is the example of the compositons in the fly ash of Class F (Hwai-Chung Wu, Peijiang Sun (2005)).

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	P_2O_5	SO_3	TiO	Carbon	Other	Total
57.8	29.5	2.9	0.7	0.7	0.2	2.3	0.1	0.3	1.5	3.3	0.4	99.7

Table 2: Chemical compositions (mass %) of Class F fly ash

2.3 Geopolymer

Geopolymers are members of the family of inorganic polymers. In 1978, Davidovits proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminium (Al) in a source material of geological origin or in byproduct materials such as fly ash and rice husk ash to produce binders. Because the chemical reaction that takes place in this case is a polymerisation process, Davidovits (1994, 1999)) coined the term ‘Geopolymer’ to represent these binders.

Although the theories and applications for Portland cement/normal cement are well used for construction of the structure, development of geopolymer concrete material still provides an open area for research. The main idea of this production is to produce the lightweight of geopolymer material for structure compared to the Portland cement/normal cement which also produces less pollutant to the environment. The main drawback of this strategy is the difficulty to provide the appropriate material which match with the market demand.

Eventhough geopolymer product has been produces, the focus of the different between geopolymer and Portland cement is regarding their weight or density. It shown that, the geopolymer product in the market now are a little bit lighter than Portland cement but it still only slightly different. Therefore, the alternative now is to produce the lightweight geopolymer by adding the rice husk into the formula (Figure 4).

There are a few advantages of the geopolymer materials such as:

a) Stronger and lighter
b) Better resistance to acid, base and salt
c) 60% less greenhouse gas (CO_2) emission from normal cement
d) More durable

There are a few structure applications that can use geopolymer as it material such as:

a) Tiles
b) Wall panels
c) Ceiling/Roof
d) Storage Tank

Therefore, the application mention above is currently in high demand. So that, the production of lightweight and strong geopolymer material are expected to replace the current material for those application such as tiles, floor, ceiling and many more.

2.4 Wall panels

For this application, I take a look at the Foam Fly-ash Concrete Panel. This type is considered as the lightweight of concrete. The Foam Fly-ash Concrete Panel usually used as Partition wall, EPS sandwiched external wall panel and many more. However, this type of panel does not support high compressive strength which is only around 33Mpa due to its lightweight of material. Therefore, lightweight geopolymer seems can be great substitute to this material as it has much more high compressive strength that is around 55Mpa.

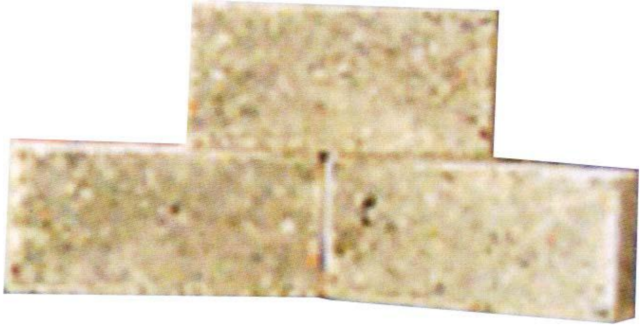


Figure 2 : Example of wall panels

2.5 Concrete Roof Tile

This type of concrete roof tile is made from sand, cement and water. The raw materials basically contain of Portland cement, blended hydraulic cement and fly ash, sand and others aggregates. However, the problem of concrete roof tile is that it is heavy which can cause difficulty for instalment and it is also fragile which is easily to break. By of that problem faced, geopolymer is the alternative that can be use as it is much stronger and lighter.

Figure 3: Example of concrete roof tiles

2.6 Sources of material

The production of geopolymer source of material contains mainly Silicon (Si) and Aluminium (Al) in amorphous form. Several minerals and industrial by-product materials have been researched in the past. Metakaolin or calcined kaolin, low-calcium ASTM Class F fly ash, natural Al-Si minerals, combination of calcined mineral and non-calcined materials, combination of fly ash and metakaolin, and combination of granulated blast furnace slag and metakaolin have been considered as source materials.

Production of geopolymer preferred metakaolin is due to its high rate of dissolution in the reactant solution, easier control on the Si/Al ratio and the white colour (Gourley 2003). However, metakaolin is quite expensive. Therefore, using of metakaolin required high cost of capital is it is used for making concrete in a mass production state.

The Class F fly ash is also known as low-calcium fly ash is ideal as a source material than high calcium (ASTM Class C) fly ash. This is because the occurrence of calcium in high amount may interfere with the polymerisation process and alter the microstructure (Gourley 2003). Fly ash is considered to be advantageous due to its particle size is finer than slag with cause high reactivity. Moreover, low-calcium fly ash is more desirable than slag for geopolymer feedstock material.

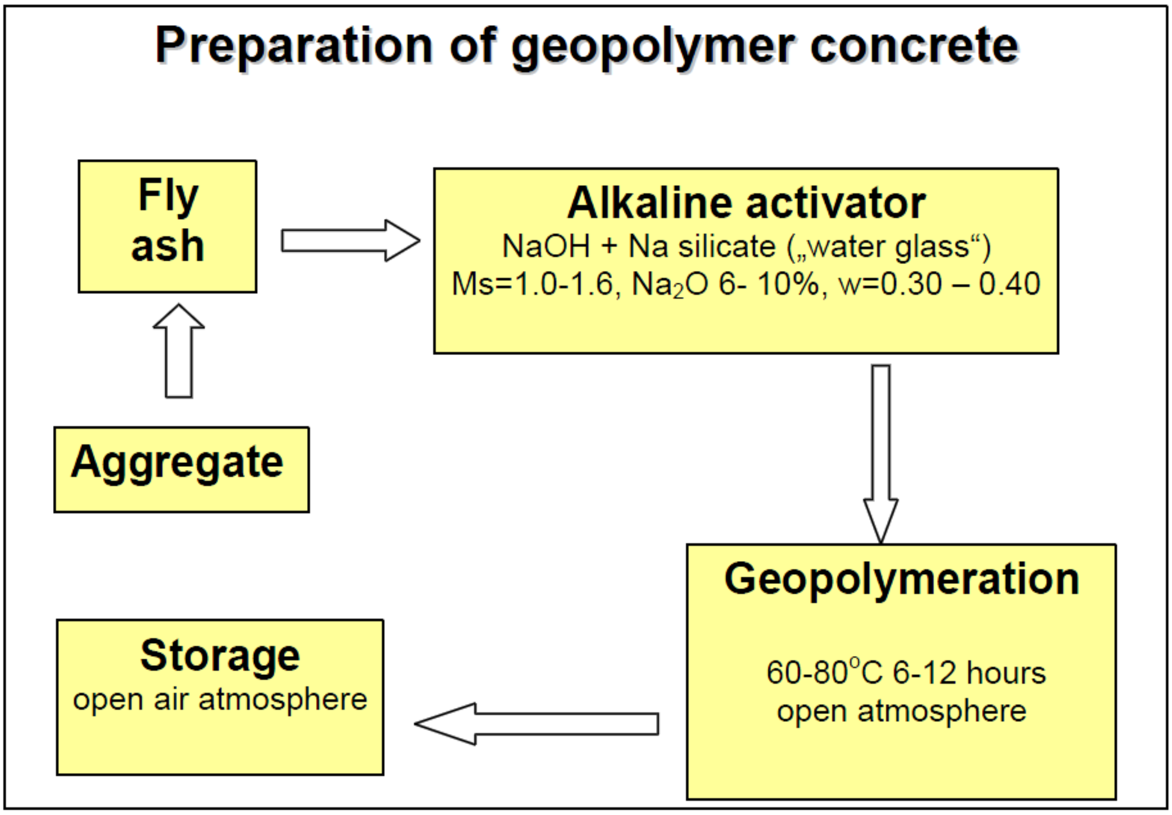
2.7 Alkaline Liquids

The most common alkaline liquid used in geopolymerisation is a mixture of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate (Davidovits 1999; Palomo et al. 1999; Barbosa et al. 2000; Xu and van Deventer 2000; Swanepoel and Strydom 2002; Xu and van Deventer 2002).

Palomo et al (1999) concluded that in the polymerisation process, type of alkaline liquids used plays an important role. Reactions take place 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) shown that the addition of sodium silicate solution to the sodium hydroxide solution as the alkaline liquid improved the reaction between the source material and the solution. Generally the NaOH solution caused a higher degree of dissolution of minerals than the KOH solution.

2.8 Preparations of Geopolymer

Firstly, NaOH and metakaolinite are missed at certain ratio for 10minutes by using a mechanical mixer. After the sodium silicate was added, the fly ash was then mixed. Then, further up 10 minutes of mixing process, the samples were cast in 25mm cube molds and vibrated for 5 minutes in order to release the bubbles inside the samples. The molds are sealed at set into two different temperatures that is at room temperature and another one at 60^0C for 1 to 7 days. The samples then were kept at room temperature for another 24-156hours after it have been removed from the moulds. Then, the sample can begin the physical and mechanical property measurements. Based on Skvara (Skvara. 2005), figure below show the overview of the process making.



The formation of the geopolymer is as the reaction below:

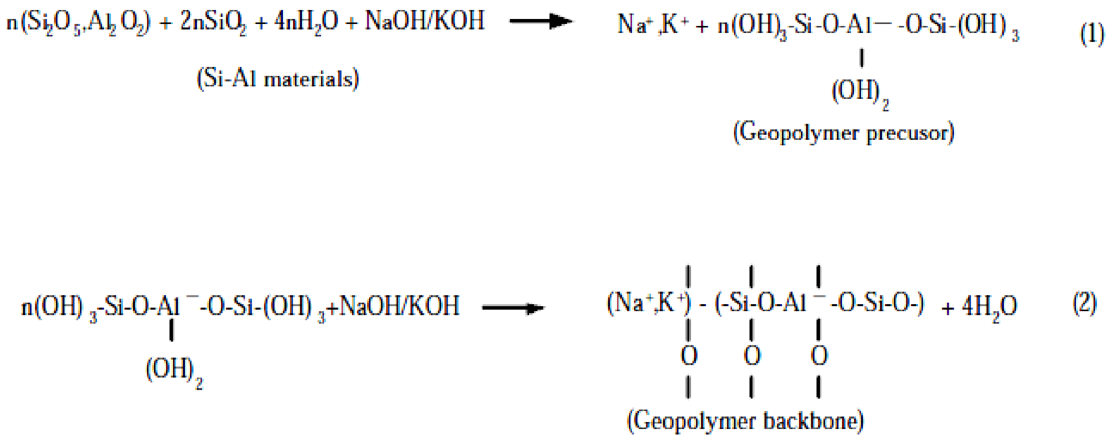
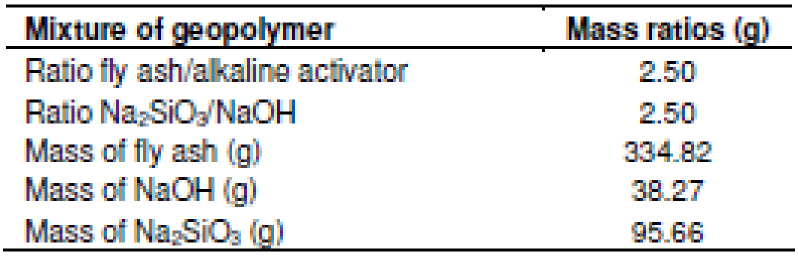


Figure 4 : Geopolymers reaction in two steps



Mixture of geopolymer	Mass ratios (g)
Ratio fly ash/alkaline activator	2.50
Ratio Na_2SiO_3/NaOH	2.50
Mass of fly ash (g)	334.82
Mass of NaOH (g)	38.27
Mass of Na_2SiO_3 (g)	95.66

Table 3: The mixture for production of geopolymer

The chemical reaction may comprise the following steps (Davidovits 1999; Xu and van Deventer 2000):

- Dissolution of Si and Al atoms from the source material through the action of hydroxide ions.
- Transportation or orientation or condensation of precursor ions into monomers.
- Setting or polycondensation/polymerisation of monomers into polymeric structures.

There are a few tests that will be complying for this project in order to get the best result for this project. The tests are the geopolymer setting time measurements that conducted by Vicat needle. The Archimedes method are been using as the testing methods and formulas for physical property. After 7 days, the compressive strength tests for all samples can been carrying out by using the compressive strength analysis apparatus. Then, the test that been done is for the water absorption test. Which is the test conducted is where the geopolymer will be weight than it will be immersed about a few days then weight the mass after the immersion to get the quantity of the water that have been absorb. Lastly, density test which it is mass over volume (m/v), where every geopolymer that have been produced then will be calculated its density to ensure we achieve the target to produce lightweight geopolymer.

2.9 Setting Time Measurement

According to Wang J. W. And Cheng T. W. (2003), A Vicat needle was used to measurement the geopolymer setting time. By recording the time of a 1 mm needle penetration in the softening specimen of 25 mm was determined; it is the initial setting time. The final setting time is when the needle does not sink visibly into the paste. Figure below shows the effect of temperature on the setting time. It is can be seen that the initial setting time and final setting time at room temperature and 60℃ are 531, 60 and 566, 65 min, separately.

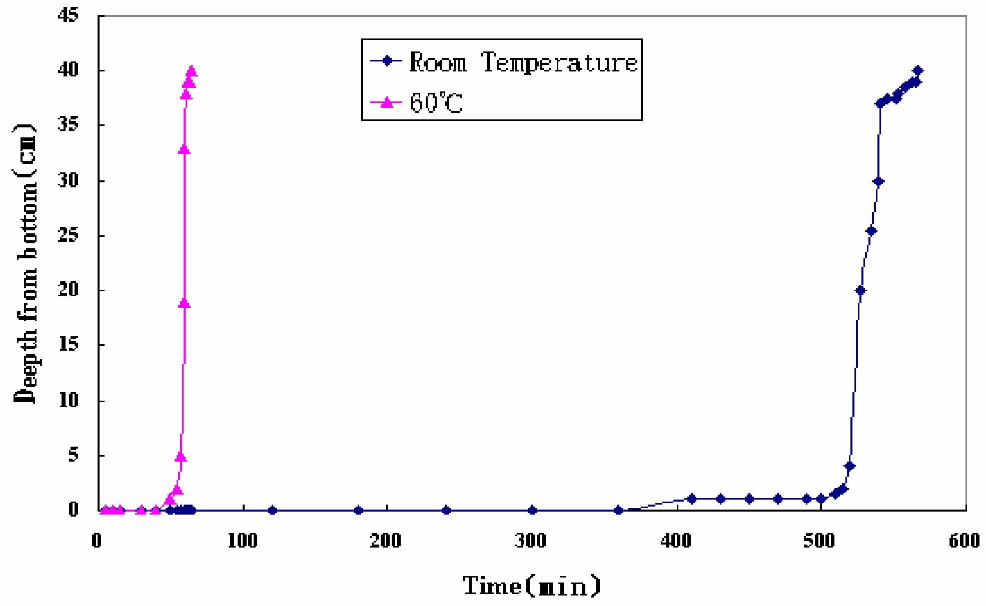


Figure 5 : The effect of temperature on setting time

Based on that research, the setting time of geopolymer at 60^0C is faster than at the room temperature because of the water loss increasing the setting rate. This certified of the higher temperature to speed up the geopolymerization taking place.

2.10 Compressive Strength Test

Tony Song from Building Construction & Research Consultancy (BCRC) described that geopolymer concrete set at room temperature (23˚C) within 24 hours and achieved compressive strengths of at least 35MPa and 55Mpa at cured for 7days and 28days respectively. Hence, it is suitable for insitu applications such as linings and repairs. Geopolymer concrete can be quickly set at high temperature (60˚C ~70˚C). It developed at least 50MPa and 70MPa at ages of 1d and 28d respectively and hence it is suitable for prefabricated product manufacture.

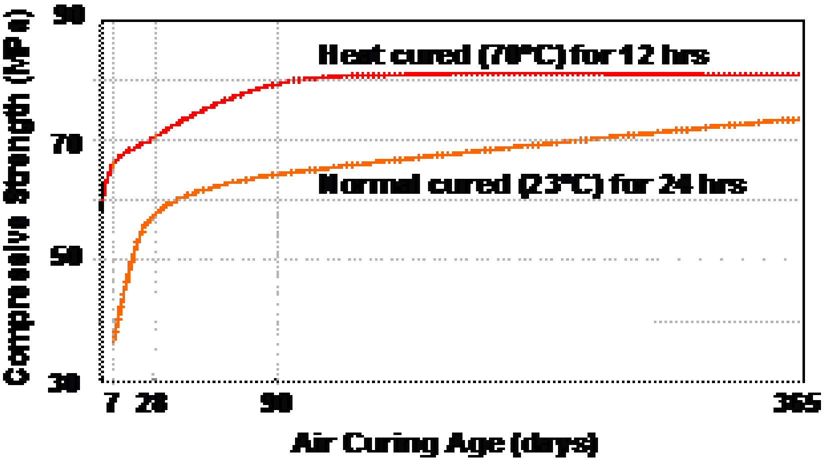
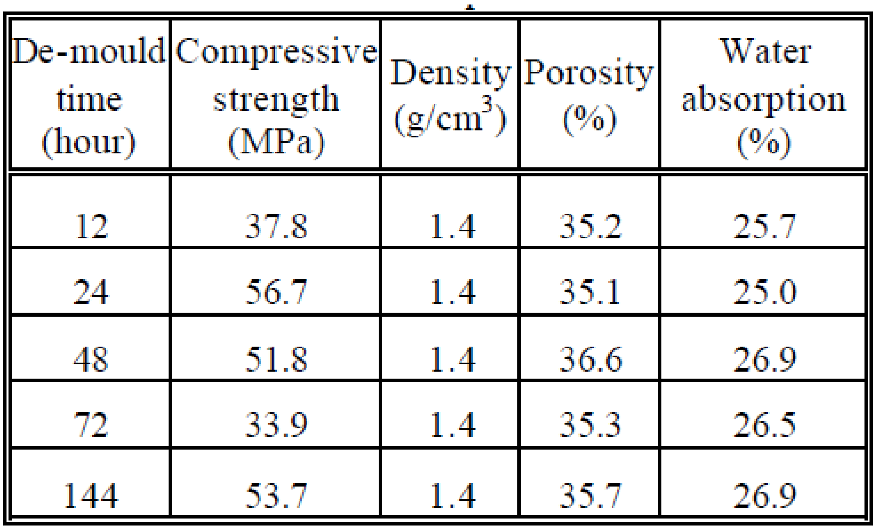


Figure 6 : Research Compressive Strength Result

From the research, it shown that the compressive strength of geopolymer at 60^0C is higher than that setting at room temperature. This situation could because of the higher temperature advocate geopolymerization process occurring.

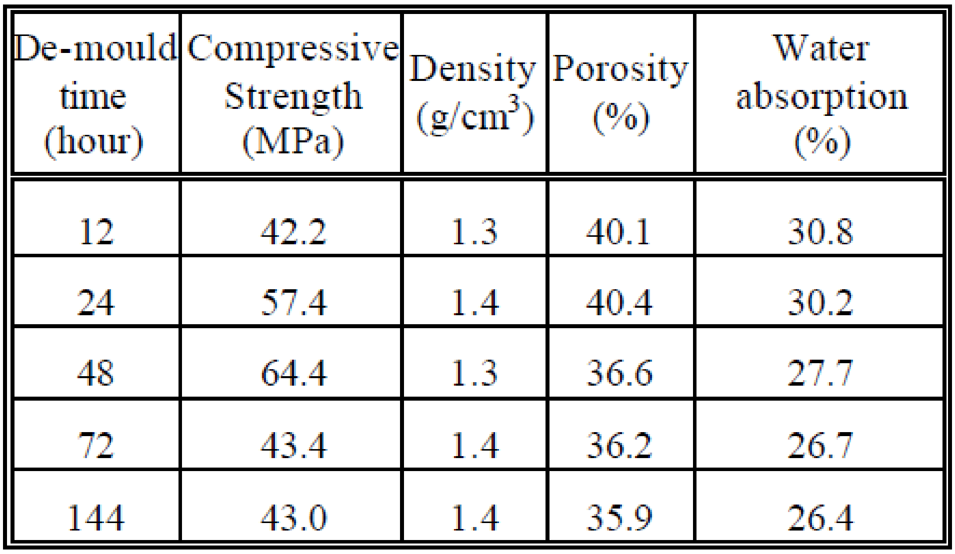
2.11 Water Absorption and Density

According to Wang J. W. And Cheng T. W. (2003), researched have shown the differences between the geopolymer at room temperature and geopolymer at 60^{0}C. The result is as shown below:



De-mould time (hour)	Compressive strength (MPa)	Density (g/cm^3)	Porosity (%)	Water absorption (%)
12	37.8	1.4	35.2	25.7
24	56.7	1.4	35.1	25.0
48	51.8	1.4	36.6	26.9
72	33.9	1.4	35.3	26.5
144	53.7	1.4	35.7	26.9

Table 4: Research Result at Room Temperature



De-mould time (hour)	Compressive Strength (MPa)	Density (g/cm^3)	Porosity (%)	Water absorption (%)
12	42.2	1.3	40.1	30.8
24	57.4	1.4	40.4	30.2
48	64.4	1.3	36.6	27.7
72	43.4	1.4	36.2	26.7
144	43.0	1.4	35.9	26.4

Table 5: Research Result at 60^{0}C

From the researcher result above, it shown that the density of geopolymer at 60^{0}C is lesser a little bit than at room temperature. This situation might be because of the higher temperature being able to cause of less moisture of the geopolymer which can affect its mass.

2.12 Scanning Electron Microscopy (SEM)

The scanning electron microscope (SEM) uses a focused beam of high-energy electrons to generate a multiplicity of signals at the surface of solid specimens. From this equipment, we can verify the external morphology (texture), chemical composition, and crystalline structure and orientation of materials making up the sample because of the signals that have been derive the electron-sample interactions. For this project, SEM is used to study the microstructure of the base material (fly ash) and the resulting geopolymer samples. The test was carried out using secondary and backscattered electron detectors. To prepare for this test, the SEM samples must be prepared in powder form. The samples were cut into 0.5 mm thick slices and then grinded into powder form.

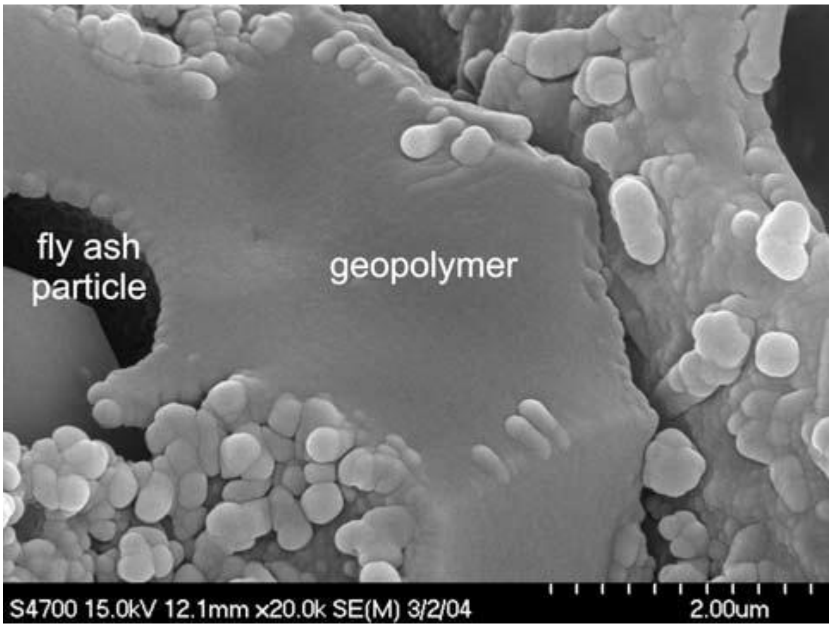


Figure 7 : Microstructure of Geopolymer (SEM)

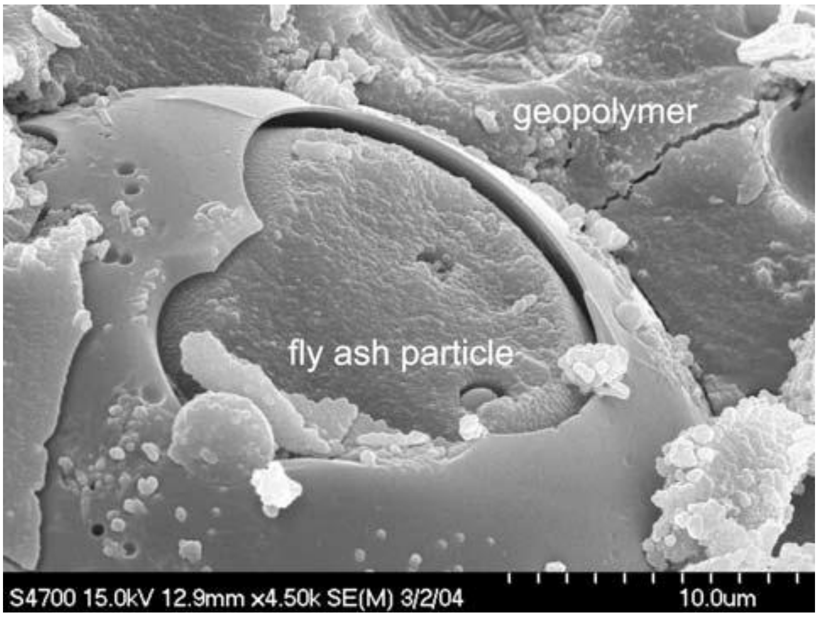


Figure 8 : Microstructure of Geopolymer (SEM)

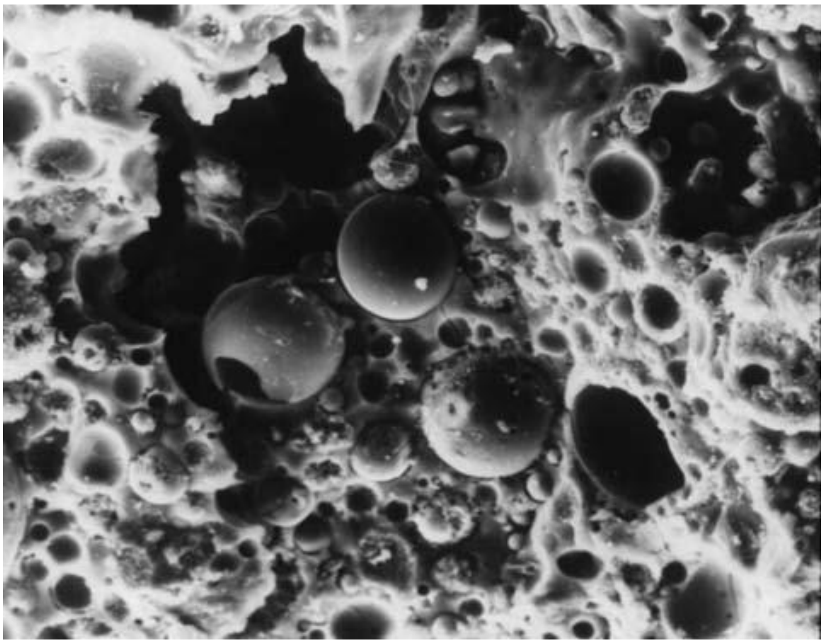


Figure 9 : Porous nature of geopolymer material (SEM)

CHAPTER 3: METHODOLOGY

3.1 Research Method

Method to be implementing:

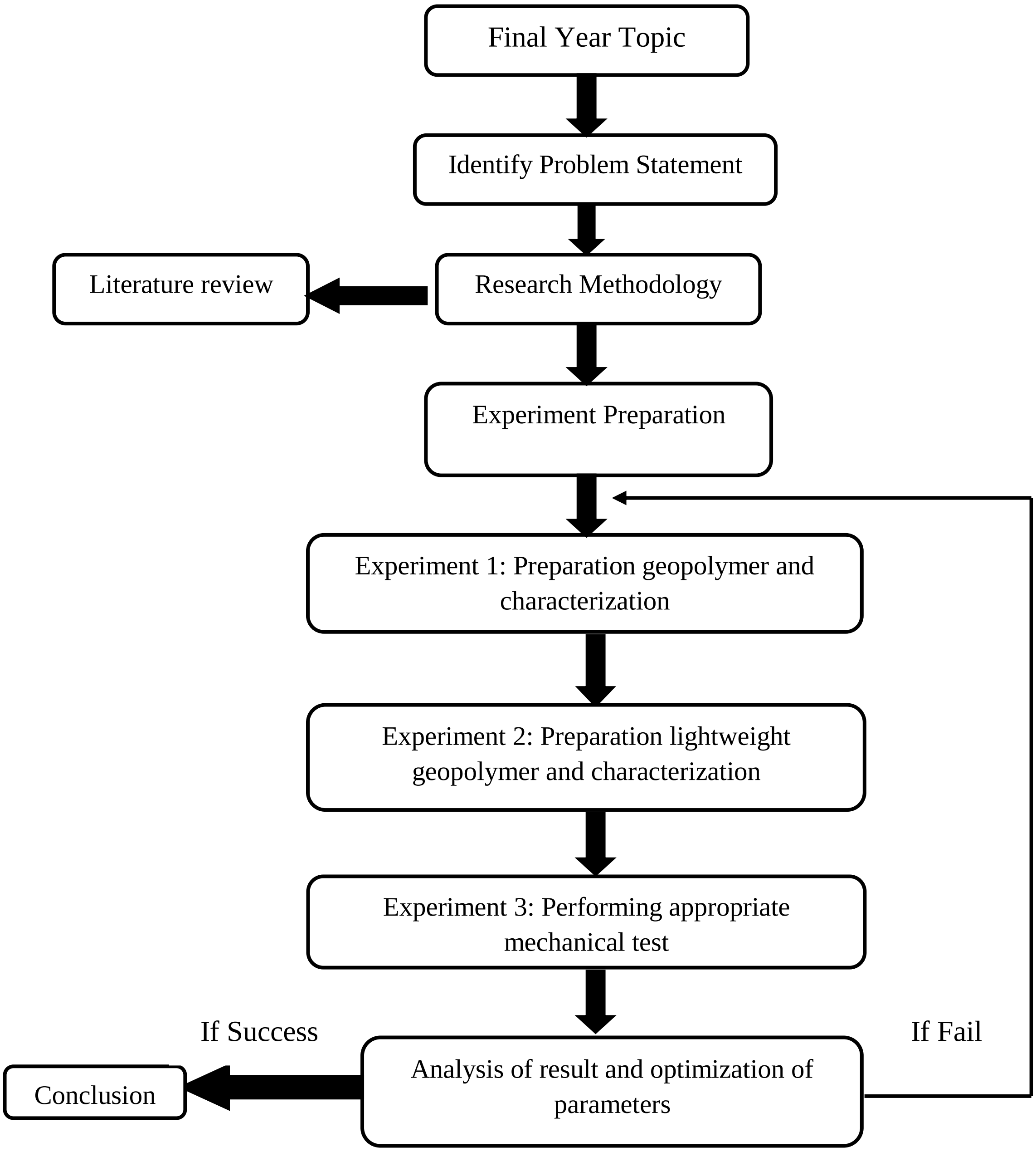


Figure 10 : Research method flowchart

3.1.1 Research Study

As these project is relating with the geopolymer material. So, the basic about geopolymer should be understood first. Other than that, the reason of the improvement from Portland cement which is formal material used for structured to using the geopolymer for structure.

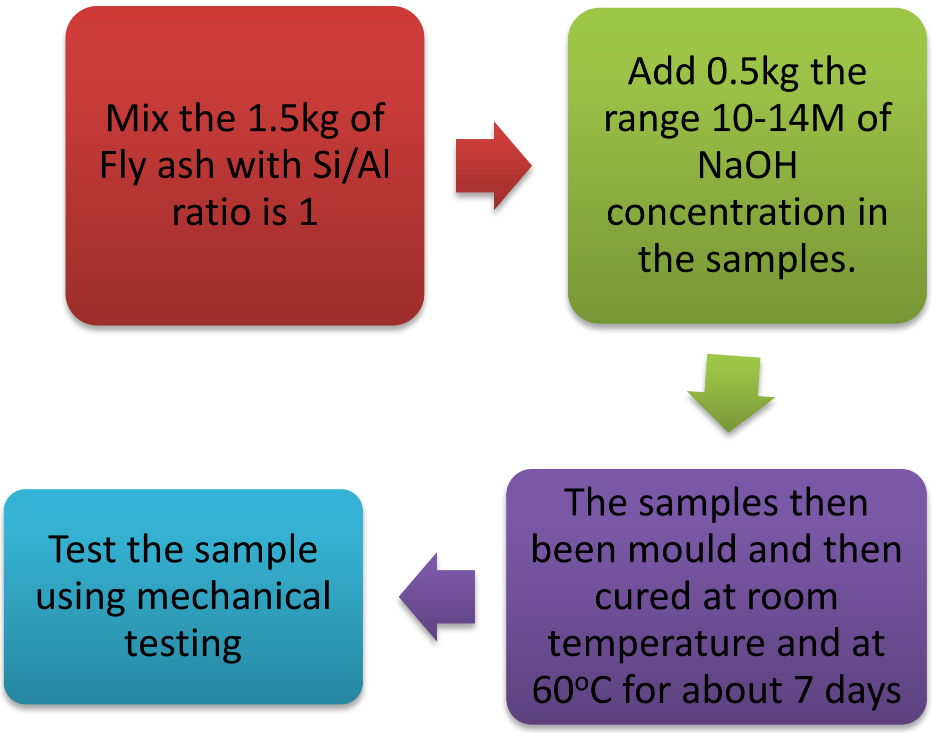
3.1.2 Problem Statement and Objective

The problem is to replace the normal cement with the lightweight of geopolymer material for structure, by fabricate the rice husk as the addition of the reaction.

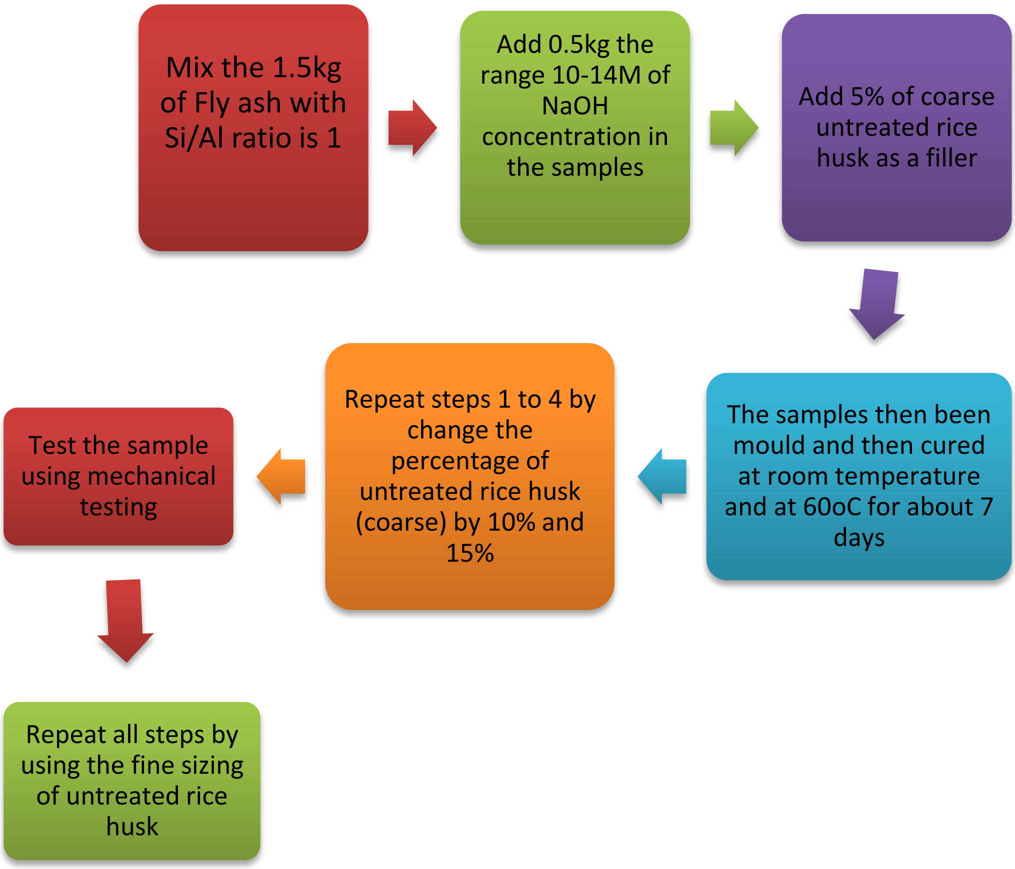
3.1.3 Experiment Preparation

We will proceed with the product making processes by apply based on the study researches that have been done. The aim of this project is to try to fabricate a rice husk into the formation of the geopolymer in order to reduce the weight of the geopolymer.

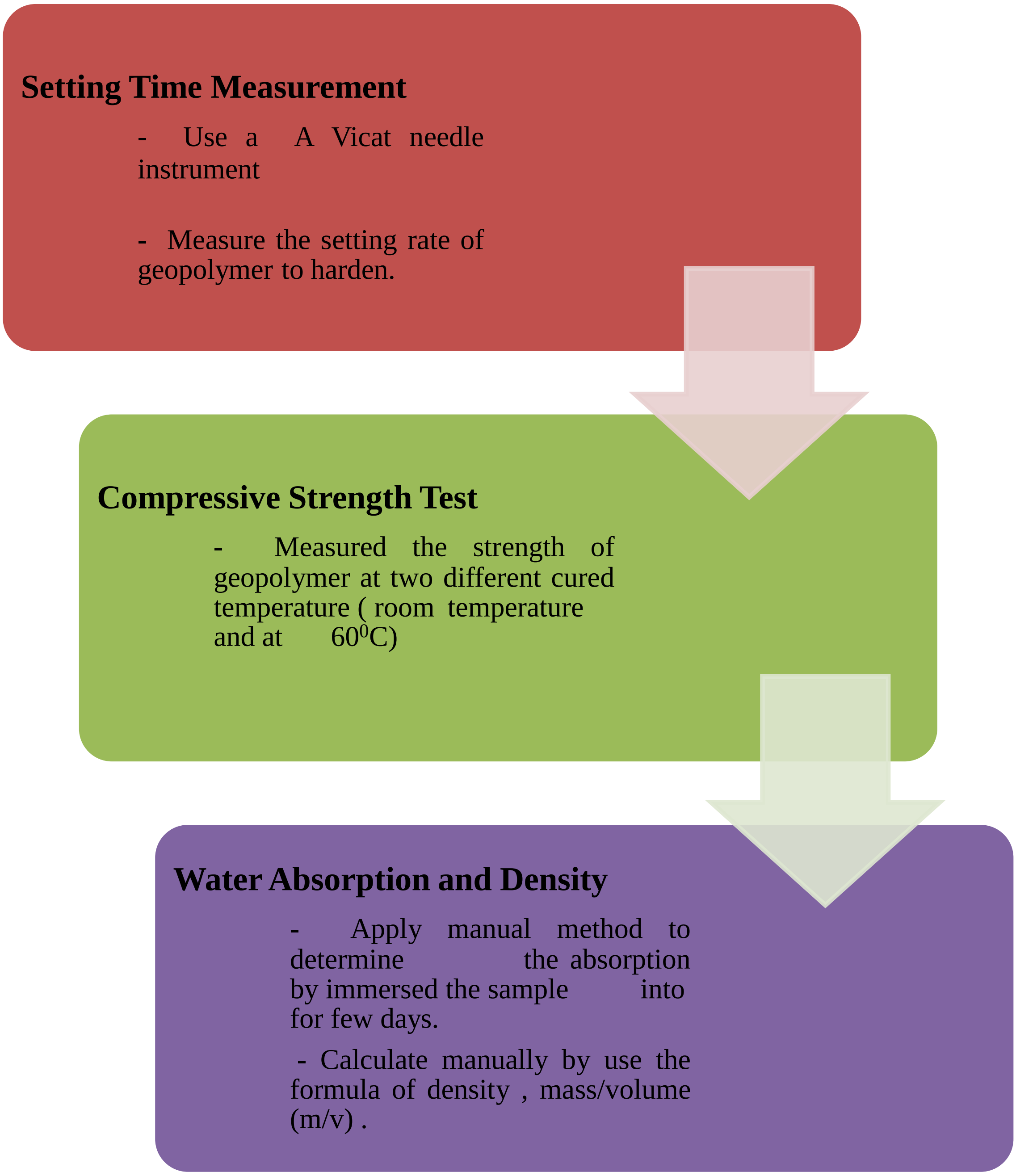
3.1.4 Experiment 1: Preparation pure geopolymer



3.1.5 Experiment 2: Preparation lightweight geopolymer (coarse and fine R.H)



3.1.6 Experiment 3: Performing appropriate mechanical test



Setting Time Measurement

- Use a A Vicat needle instrument
- Measure the setting rate of geopolymer to harden.

Compressive Strength Test

- Measured the strength of geopolymer at two different cured temperature (room temperature and at 60^0C)

Water Absorption and Density

- Apply manual method to determine the absorption by immersed the sample into for few days.
- Calculate manually by use the formula of density , mass/volume (m/v) .

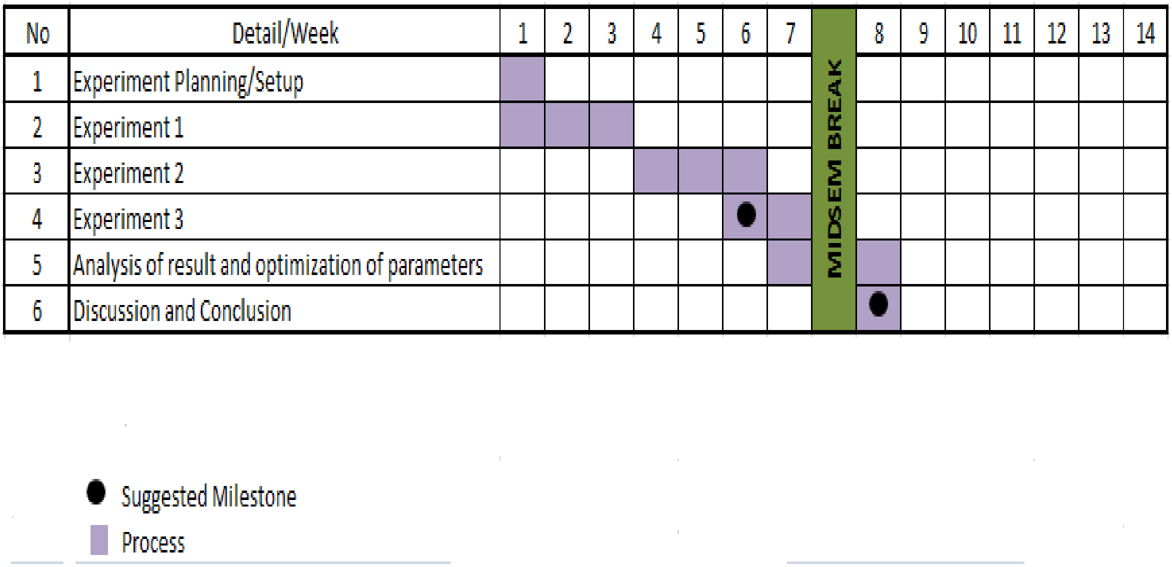
3.2 Table of Workflow

The flow of the work is presented in the table below:

No	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic	▨	▨						Mid-semester Break							
2	Preliminary Research Work		▨	▨	▨	▨										
3	Submission of Extended Proposal Defence						●									
4	Proposal Defence									▨	▨					
5	Project work continues											▨	▨	▨		
6	Submission of Interim Draft Report														●	
7	Submission of Interim Report															●

● Suggested Milestone
▨ Process

Table 6: FYP I Gantt Chart and Milestone



No	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Experiment Planning/Setup	▨							MIDSEM BREAK							
2	Experiment 1	▨	▨	▨												
3	Experiment 2				▨	▨	▨									
4	Experiment 3						●	▨								
5	Analysis of result and optimization of parameters							▨		▨						
6	Discussion and Conclusion									●						

● Suggested Milestone
▨ Process

Table 7: FYP II Gantt Chart and Milestone

3.3 Tools, Equipments and Materials

Here are some of the chemicals and equipment that will be used for this project.

Chemicals/Materials:

i) Fly ash
ii) Sodium Hydroxide
iii) Untreated rice husk

Tools/Equipment:

i) Beakers
ii) Stirrer
iii) Measuring Cylinders
iv) Brush
v) Water bath
vi) Oven
vii) Compressive strength machine
viii) Vicat needle equipment
ix) Mixer machine
x) 50mm*50mm*50mm mould

However, there might be other materials or equipments will be added along the accomplishment of this project.

CHAPTER 4: RESULTS and DISCUSSIONS

For this project, the simplify mixture of geopolymer production as shown below:

Fly Ash + NaOH → Geopolymer + H_2O

To produce good geopolymer, we need to use the high silicon (Si) and the aluminium (Al) in a source of material. For that, fly ash is one of the example materials that have high Si/Al contained. For formation of geopolymer, an alkaline solution is needed to perform the reaction with the fly ash. For this project, the alkaline solution or also said as the activator that been used is NaOH only but varies its concentrations. Other than that the next step is varies the size particle of untreated rice husk. This project have tested in two condition of geopolymer curing which are at room temperature and at 60^oC which is the average temperature for geopolymer cured.

Shown below are the results of pure geopolymer which means that 0% of untreated rice husk (coarse and fine sizes) contained and then the quantity of the untreated rice husk are varies from 5%, 10% and 15% for the formation of lightweight geopolymer. The formation of lightweight geopolymer is as follow the formula below:

Fly Ash + NaOH + Untreated Rice Husk → Geopolymer + H_2O

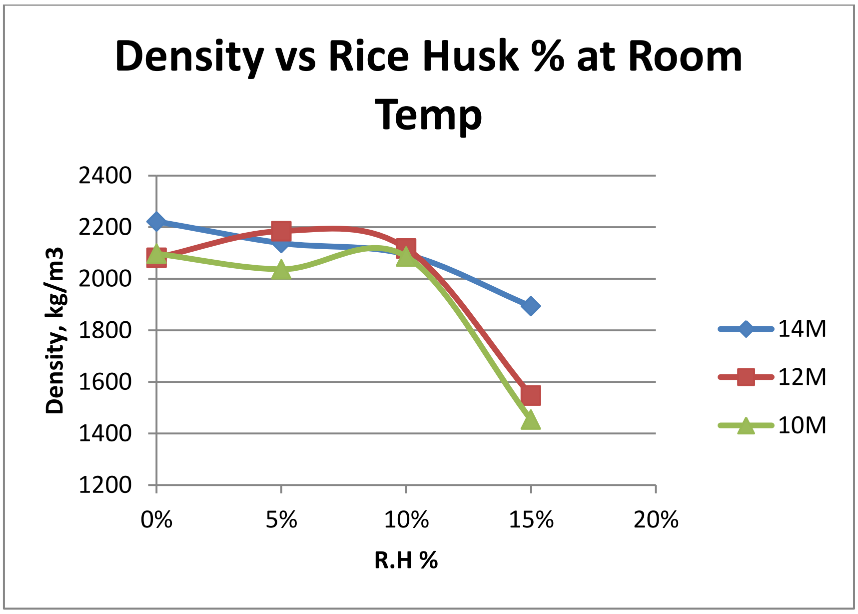
There are four type of testing that has been done which the results are shown by the graphic below.

4.1 Density of Coarse Untreated Rice Husk Lightweight Geopolymer

Effect of Fly Ash + NaOH + Untreated Rice Husk (coarse) → Geopolymer

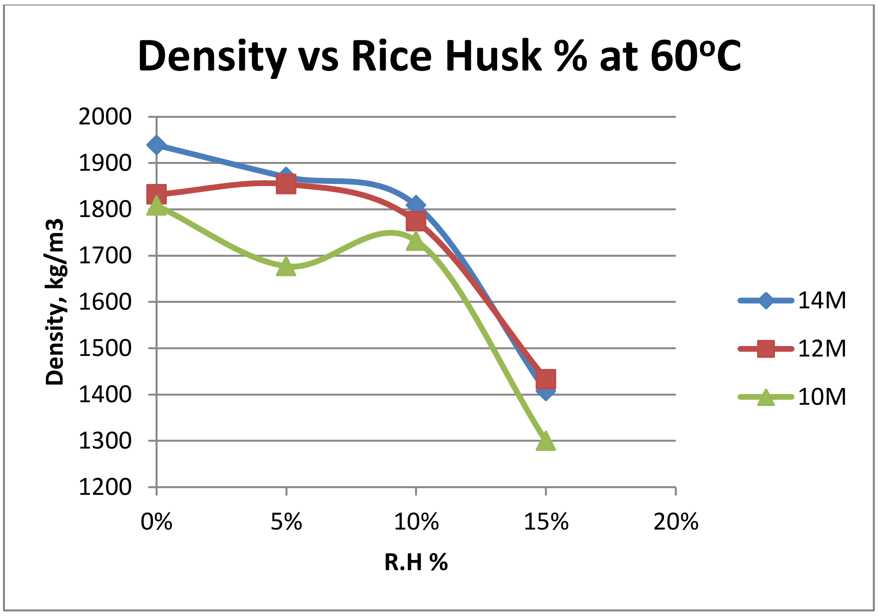
Volume = 0.05m* 0.05m*0.05m

= 0.000125 m^3



Graph 1 : Average density of the lightweight geopolymer (coarse R.H) at room temperature

Based on graph 1, the results shown that the density of lightweight geopolymer that cured at room temperature for 7days are decreasing with increasing of the R.H contained compared to the pure geopolymer (0% R.H).



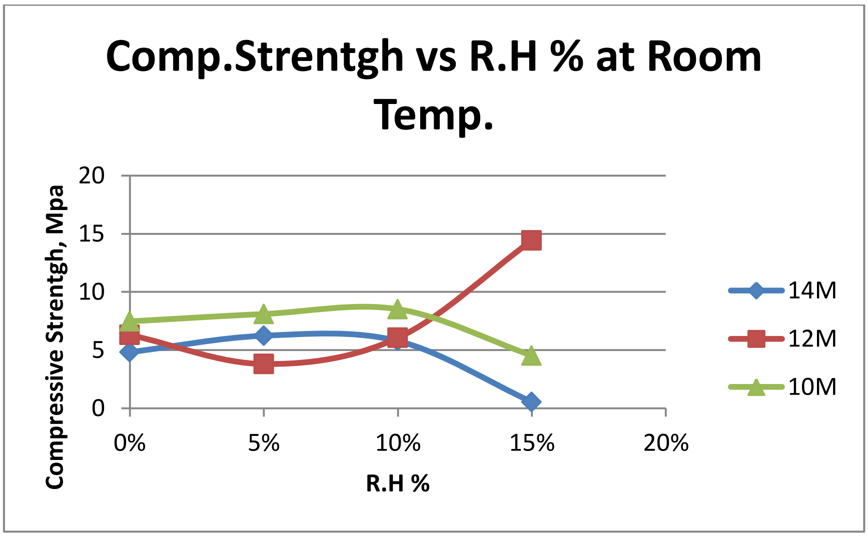
Graph 2 : Average density of the lightweight geopolymer (coarse R.H) at 60^{o}C

Based on graph 2, showed that the density of lightweight geopolymer that cured at 60°C for 7days are decreasing with increasing of the R.H contained compared to the pure geopolymer (0% R.H).

From the both graphs obtained above, it shown that from the both cured conditions that been experimented which are at room temperature and at 60°C; the densities of lightweight geopolymer at 60°C are much more lesser densities at room temperature as the untreated rice husk contained increased. The 0% of untreated rice husk contained indicates that it is pure geopolymer. **The lowest density at room temperature and at 60°C is at 10M NaOH with 15% R.H**. This phenomenon might be cause by the amount of water in the geopolymer because if we refer the formula of the geopolymer production, the product show that the formation of geopolymer and water. When the geopolymer that cured at 60oC, it is probably cause by the amount of water inside it been vaporised or absorbed. While compared by the increasing of NaOH concentrations; shown that high concentrations (14M) give high densities compared to the lowest NaOH concentration (10M). This is because that NaOH have quite a high density, thus high concentrations give high density theoretically.

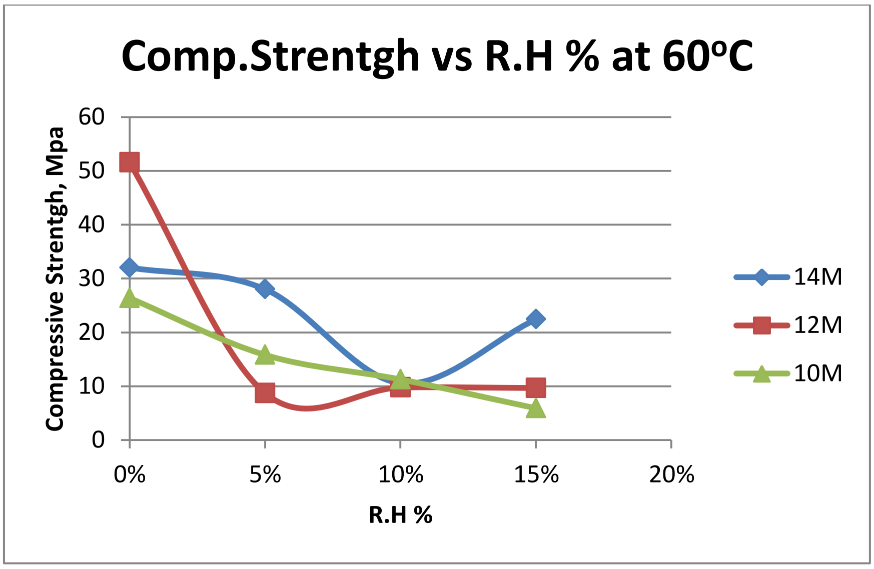
4.2 Compressive Strength of Coarse Untreated Rice Husk Lightweight Geopolymer

Pace Rate = 0.9kN/s



Graph 3 : Average compressive strength of lightweight geopolymer (coarse R.H) at room temperature

From graph 3, the compressive strength for 10M and 14M are decreasing with the increasing of R.H. While for 12M NaOH the compressive strength is increasing.



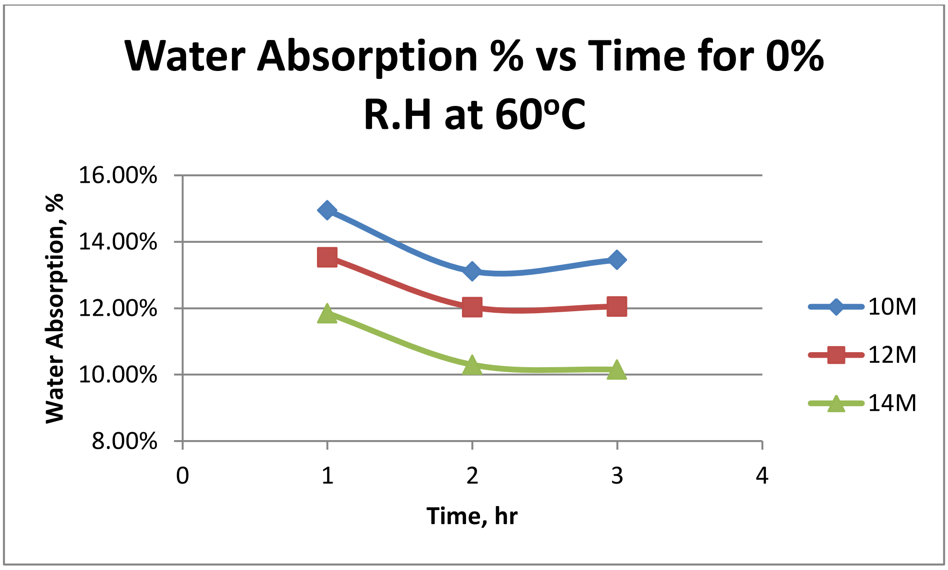
Graph 4 : Average compressive strength of lightweight geopolymer (coarse R.H) at 60°C

From graph 4, the compressive strength for 12M and 14M are not uniform might because of the errors from the machine. While for 10M the strength are decreasing with increasing of R.H.

Based on the graph 3 and 4, it shown that from the both cured conditions that been experimented which are at room temperature and at 60°C; the compressive strength of lightweight geopolymer at 60°C are higher compared to at room temperature as the untreated rice husk contained decreased. The 0% of untreated rice husk contained indicates that it is pure geopolymer. However, as the rice husk contained increased, the strength are decreased if compared with the pure geopolymer for both conditions. This cause by the mixture of the rice husk increased affect the binding formation of the geopolymer and might be cause by the sizing of the coarse rice husk that will make the geopolymer have the porous parts. However, these lightweights do have a strength which based on the result show; this lightweight geopolymer are more suitable for indoor construction such as wall panels compared to be used as main structure.

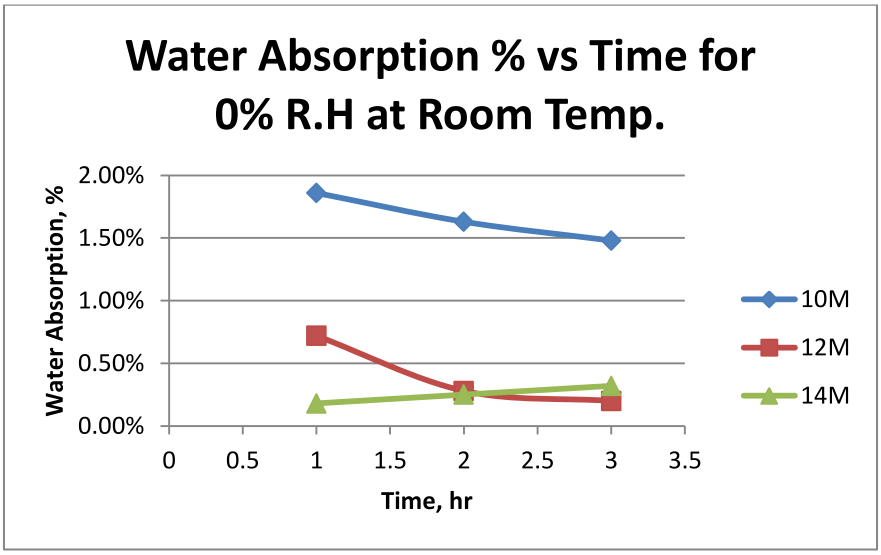
4.3 Water Absorption Percentage of Coarse Untreated Rice Husk Lightweight Geopolymer

For water absorption test, this test have been done by immersed the samples into the tap water. The results taken are at every one hour and last until three hours for every samples.



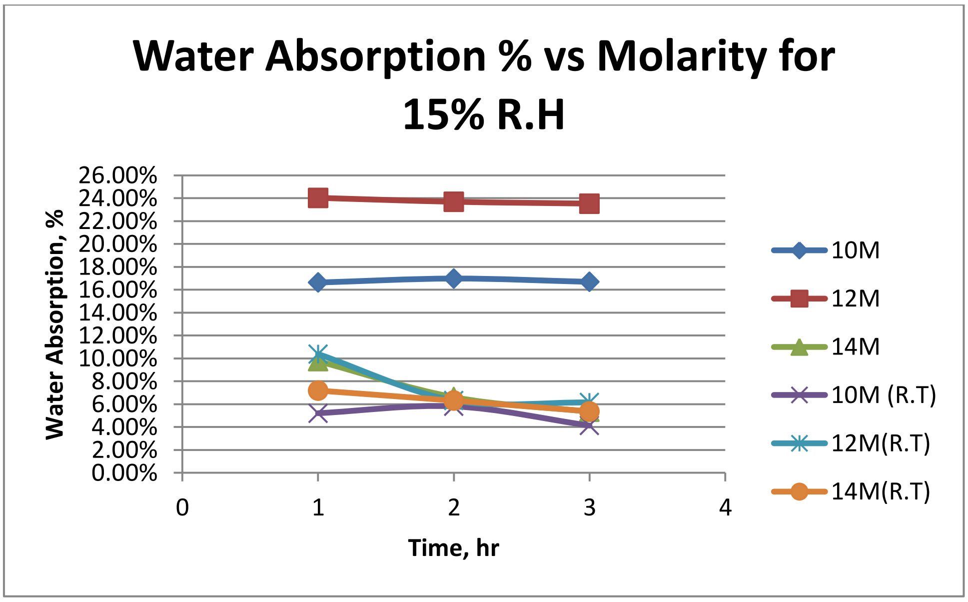
Graph 5 : Water absorption percentage of pure geopolymer (coarse R.H) at room temperature

Graph 5 shown that the water absorption percentage for pure geopolymer at 60°C decreased by time for every concentrations of NaOH.



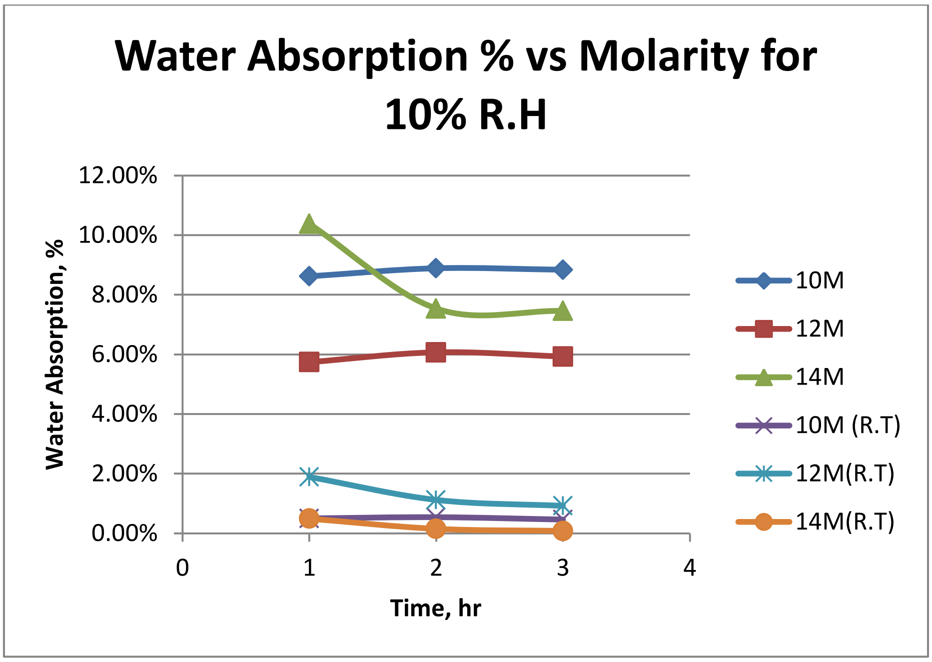
Graph 6 : Water absorption percentage of pure geopolymer (coarse R.H) at room temperature

While for graph 6, the water absorption percentages for room temperature samples showed that at 14M NaOH are increased by time while for 10M and 12M NaOH the percentages are decreased.



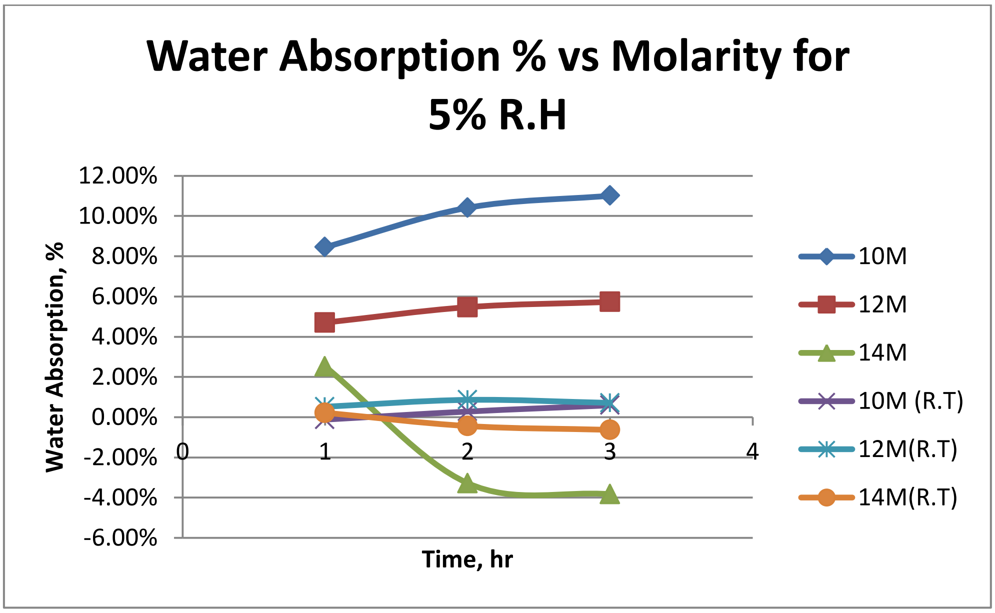
Graph 7 : Water absorption percentage of 15% coarse R.H at room temp. and 60°C

From the graph 7, at 15% of R.H contained the water absorption percentages are decreased for every NaOH concentrations for both cured conditions.



Graph 8 : Water absorption percentage of 10% coarse R.H at room temp. and 60°C

As for graph 8, the result shown that at 10% of R.H contained the water absorption percentages are decreased for 14M concentrations for both cured conditions and 10-12M at room temperature while 10-12M at 60°C is increased.

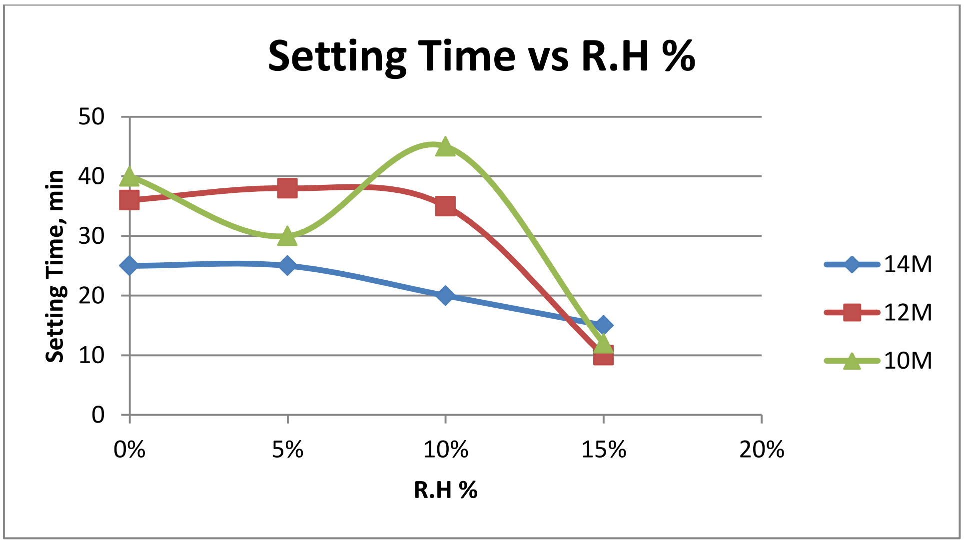


Graph 9 : Water absorption percentage of 5% coarse R.H at room temp. and 60°C

While at 5% R.H, the result shown that for NaOH 10-12M cured at 60^{o}C; the water absorption percentages are increased, but for 14M it is decreased. At room temperature, the result obtained show that for NaOH 12-14M water absorption decreased while for 10M it is increased.

From both graphs above, based on all the results which are for pure geopolymer (0% R.H) or with the mixture of R.H; it's shown that the water absorption percentage are decreasing because of the weight of samples decreased. This mainly because of the sample dis-attach throughout the testing process while immersed in the water

4.4 Setting Time of Coarse Untreated Rice Husk Lightweight Geopolymer



Graph 10 : Setting time of lightweight geopolymer (coarse R.H) at room temp.

From the graph 10, we can see that when the concentration of the NaOH is higher, the time taken for the sample to become harden is faster. This because of when the concentration is higher, the process of geopolymerisation perform much faster to form the geopolymer. For the setting time testing, the test is done at room temperature because mainly the processes for structure application are usually based on the surrounding temperature.

4.5 Density of Fine Untreated Rice Husk Lightweight Geopolymer

For the fine untreated fine rice husk, the project had been done by grinding the untreated rice husk into fine size. By doing the sieve process, I can assume the size distributions in the fine rice husk. The distributions percentage can be seen based on the calculation below:

These distributions had been done for 10g of sample been sieved about 10 minutes.

Calculation:

Sieve Sizing, microns	Mass of Tare Sieve, g	Mass after sievering, g	Mass of size distributions, g	Size distributions percentage, %
600	330.0	330.3	0.3	3%
425	269.4	271.4	2.0	20%
300	285.4	287.9	2.5	25%
212	275.8	278.2	2.4	24%
150	269.0	270.2	1.2	12%
> 150	387.7	389.3	1.6	16%

Table 8 : Particle size of fine rice husk distributions

Mass of size distributions, g = Mass after sievering, g - Mass of Tare Siever, g

Mass of size distributions, g = 330.3g – 330.0g

= 0.3g

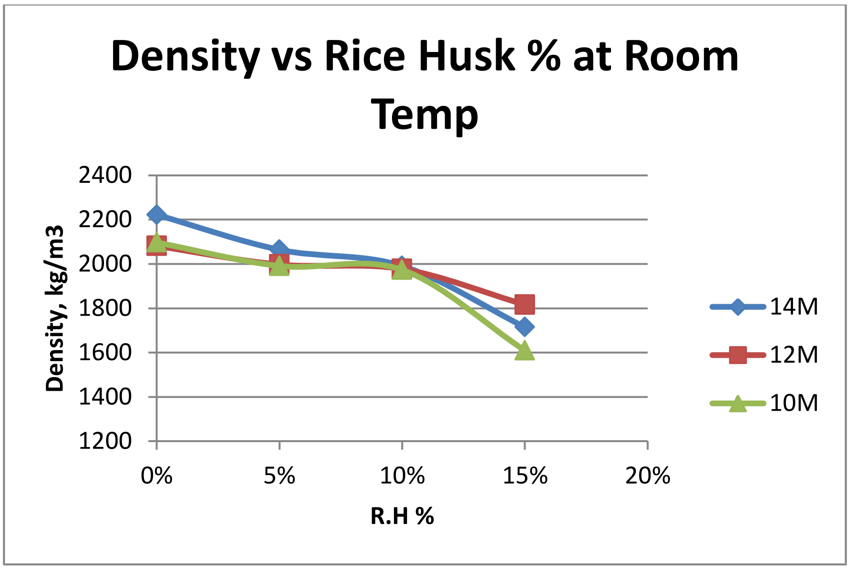
Size distributions percentage,% = (Mass of size distributions, g / Mass of sample, g) * 100%

= (0.3/10)*100% = 3%

Effect of Fly Ash + NaOH + Untreated Rice Husk (fine) → Geopolymer

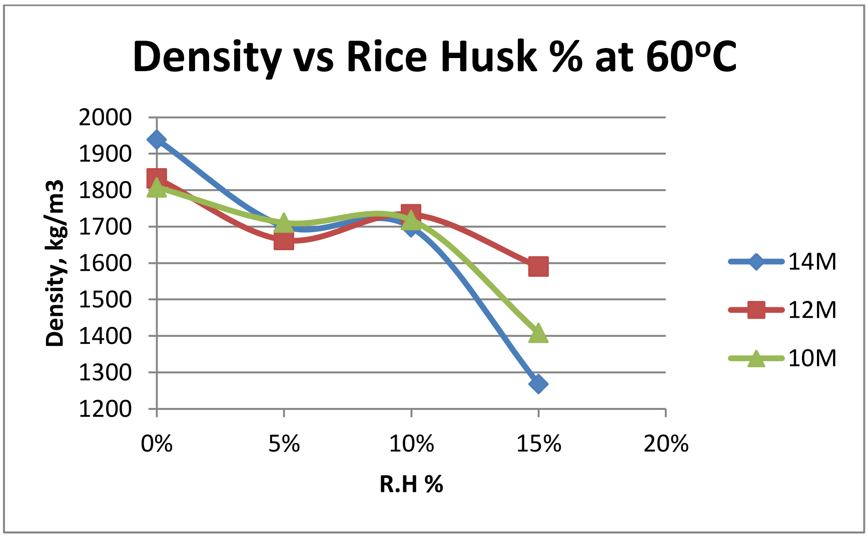
Volume = 0.05m* 0.05m*0.05m

$$= 0.000125\ m^3$$



Graph 11 : Average density of the lightweight geopolymer (fine R.H) at room temperature

Same as the coarse rice husk, graph 11 shown that the density of lightweight geopolymer that cured at room temperature for 7days are decreasing with increasing of the R.H contained compared to the pure geopolymer (0% R.H) for all NaOH concentrations.



Graph 12 : Average density of the lightweight geopolymer (fine R.H) at 60°C

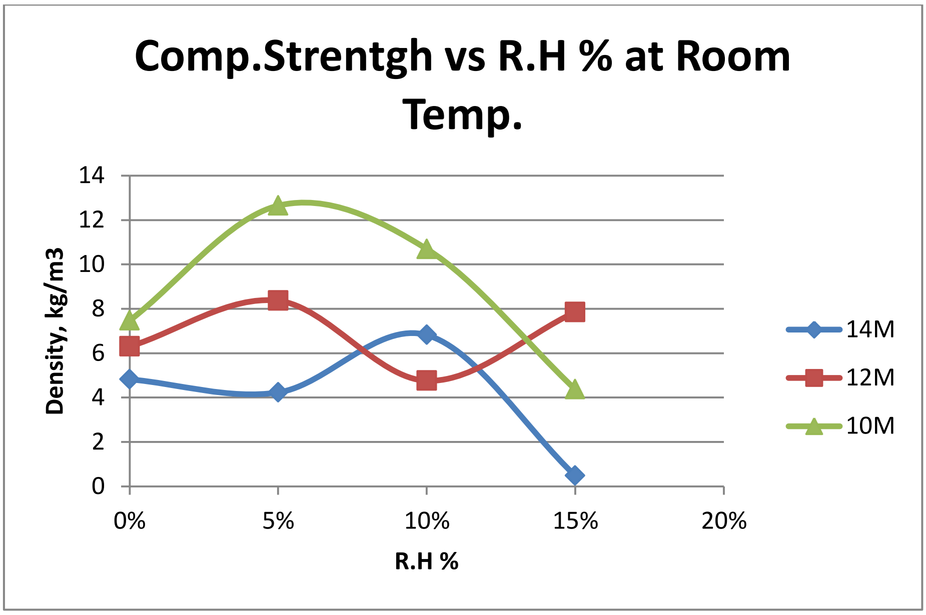
Based on graph 12, showed that the density of lightweight geopolymer that cured at 60oC for 7days are decreasing with increasing of the R.H contained compared to the pure geopolymer (0% R.H).

Graph 11 and 12 shown that from the both cured conditions that been experimented which are at room temperature and at 60^{o}C; the densities of lightweight geopolymer for fine R.H at 60^{o}C are much more lesser densities at room temperature as the untreated rice husk contained increased. **The lowest density at room temperature is at 10M NaOH with 15% R.H while at 60^{o}C the lowest density is at 15M NaOH with 15% R.H**.

This phenomenon might be cause by the amount of water in the geopolymer because if we refer the formula of the geopolymer production, the product show that the formation of geopolymer and water. When the geopolymer that cured at 60^{o}C, it is probably cause by the amount of water inside it been vaporised or absorbed. While compared by the increasing of NaOH concentrations; shown that high concentrations (14M) give high densities compared to the lowest NaOH concentration (10M). This is because that NaOH have quite a high density, thus high concentrations give high density theoretically.

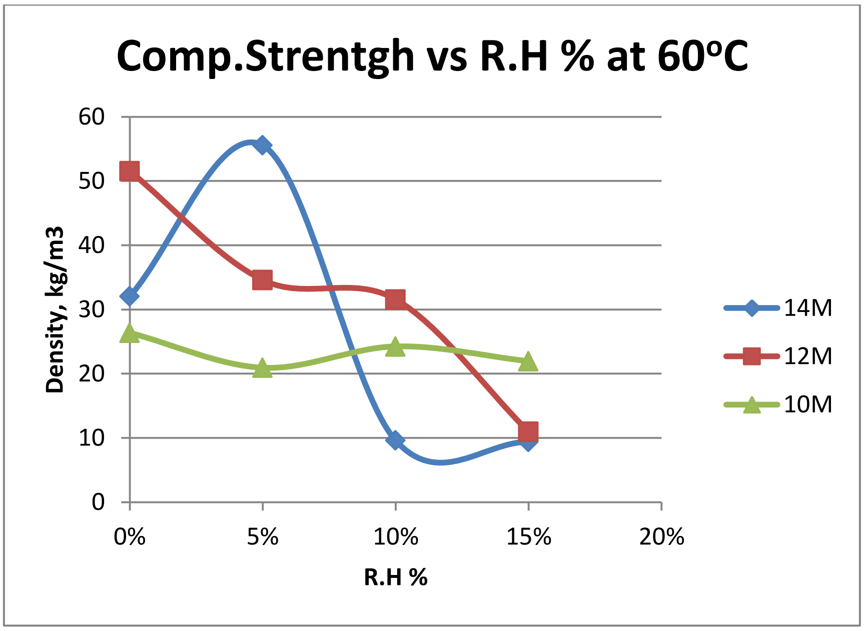
4.6 Compressive Strength of Fine Untreated Rice Husk Lightweight Geopolymer

Pace rate = 0.9kN/s



Graph 13 : Average compressive strength of lightweight geopolymer (fine R.H) at room temperature

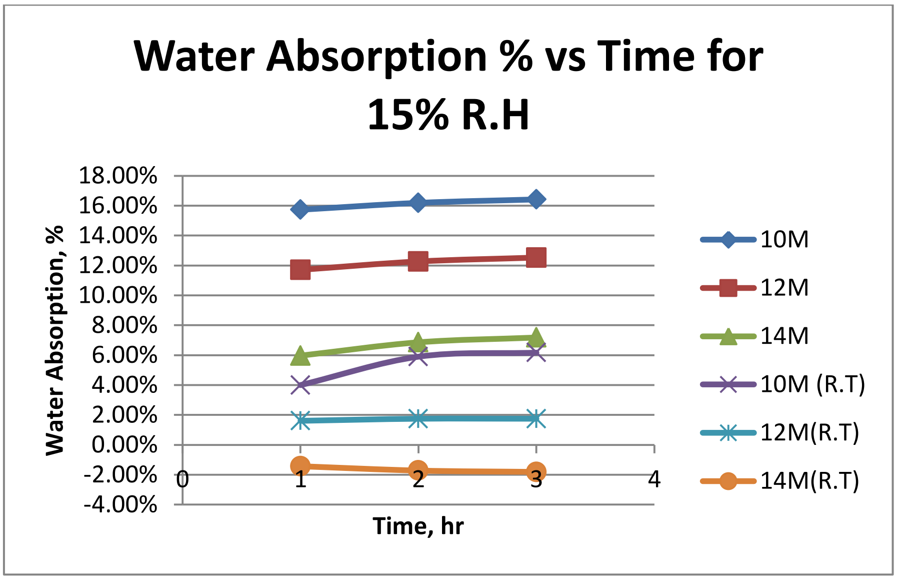
From graph 13, the compressive strength results are not uniform because there are some increasing and decreasing in their strength. These most probably happen because of some error. Where we can see that are some increased and decreased variations for every concentrations.



Graph 14 : Average compressive strength of lightweight geopolymer (fine R.H) at 60^{o}C

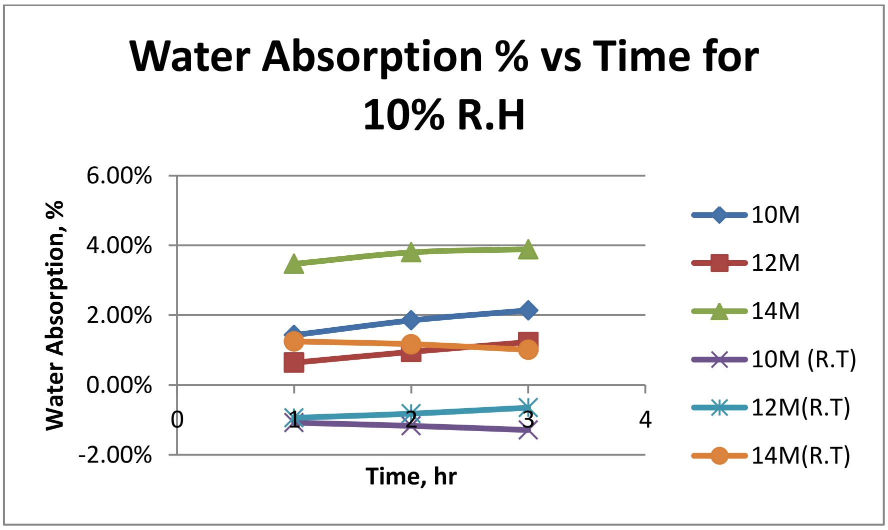
Based on the both graph above, it shown that from the both cured conditions that been experimented which are at room temperature and at 60^{o}C; the compressive strength of lightweight geopolymer at 60^{o}C are higher compared to at room temperature as the untreated rice husk contained decreased. The 0% of untreated rice husk contained indicates that it is pure geopolymer. However, from the graph shown; the results are not uniform which might because of the errors from the compressive machine.

4.7 Water Absorption Percentage of Fine Untreated Rice Husk Lightweight Geopolymer



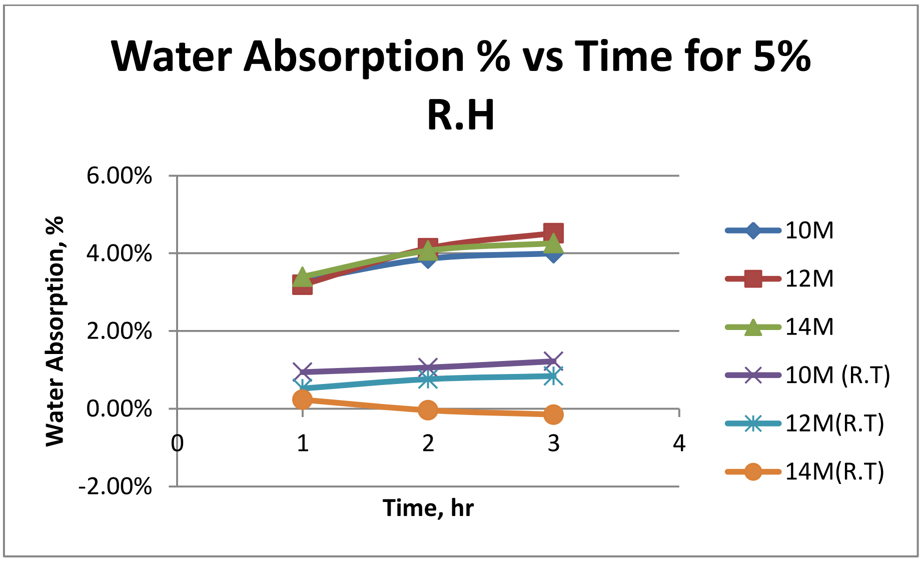
Graph 15 : Water absorption percentage of 15% fine R.H at room temp. and 60°C

From the graph 15, at 15% of R.H contained the water absorption percentages are increased for 10-14M NaOH concentrations at 60°C and for 10-12M NaOH at room temperature and only for 14M at room temperature the percentage is decreased.



Graph 16 : Water absorption percentage of 10% fine R.H at room temp. and 60°C

As for graph 16, the result shown that at 10% of R.H contained the water absorption percentages are increased for 10-14M NaOH concentrations at 60oC and for 12M NaOH at room temperature and for 10M and 14M NaOH at room temperature the percentages are decreased.

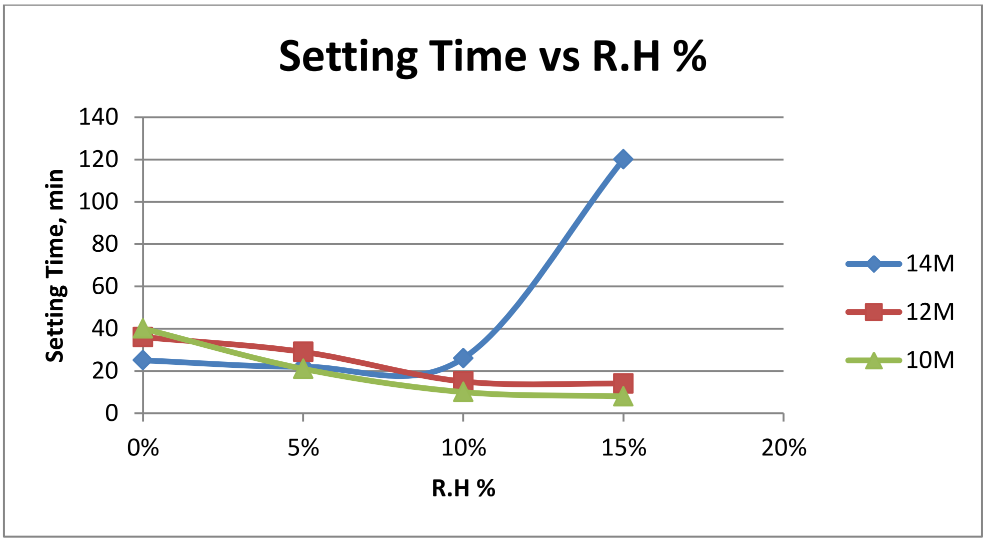


Graph 17 : Water absorption percentage of 5% fine R.H at room temp. and 60^{o}C

As for graph 17, the result shown that at 5% of R.H contained the water absorption percentages are increased for 10-14M NaOH concentrations at 60^{o}C for 10-12M NaOH at room temperature and only for 14M at room temperature the percentage is decreased.

From all the water absorption testing result obtained for fine rice husk experiment, it showed that at 12M NaOH concentration for 10% R.H has the least water absorptions for cured at 60^{o}C while 12M NaOH concentration for 15% R.H has the good result in water absorption for room temperature condition.

4.8 Setting Time of Fine Untreated Rice Husk Lightweight Geopolymer



Graph 18 : Setting time of fine R.H lightweight geopolymer at room temp.

Graph 18 shows that, when the concentration of the NaOH is higher, the time taken for the sample to become harden is faster. This because of when the concentration is higher, the process of geopolymerisation perform much faster to form the geopolymer. Same with the previous experiment, the setting time test is done by using a Vicat needle equipment at room temperature because mainly the processes for structure application are usually based on the surrounding temperature.

From overall test results obtained, it shown that the results of lightweight geopolymer by using fine untreated rice husk are much better that using the coarse untreated rice husk especially for density test which will aligned with the objective the project for the development of lightweight geopolymer by using untreated rice husk as a filler.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Therefore, the objectives of this project which are to prepared lightweight geopolymer using the untreated rice husk with different particle size as filler, to characterize of geopolymer composites and to conduct the mechanical test such as compressive test, setting time test, water absorption test and density to be compare with the standard geopolymer will successfully achieved with the structured and planned experimental work, the availability of tools required and with the adequate time given for project completion. From the all test result, the aim to produce lightweight geopolymer is identified. This is because all the densities of the sample are lighter than the pure geopolymer. Conclude that, on average results that at **12M** NaOH concentration shown a good result among all.

5.2 Recommendation for Future Work

However, further study and development regarding this project need to be done in order to produce good lightweight geopolymer with maximum strength and less water absorption capability. Next project can be observing by varies:

1. The size of rice husk. Use finer sizing of rice husk.
2. Cured the samples for more than 7 days for both conditions (room temperature and at $60^{o}C$).
3. Use other substances as a filler to produce lightweight geopolymer.

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APPENDICES

Appendix A - Calculation:

Calculation to find Si/Al ratio in pure fly ash:

$$SiO_2 = \frac{(\ 43.34 + 42.69 + 43.73\ )\%}{3}$$

$$= 43\%$$

$$Al_2O_3 = \frac{(\ 20.77 + 20.81 + 20.81\ )\%}{3}$$

$$= 21\%$$

Assume:

100g of FA = 43g of SiO_2 + 21g of AL_2O_3

1 mol SiO_2 = 28.0855g + 32g = 60g

Thus, in 60g of SiO_2 has 28.0855g of Si

60g of SiO_2 = 28.0855g of Si

$$43g\ of\ SiO_2 = \frac{(43g\ \times 28.0855g)}{60} = 20.13g\ of\ Si$$

1 mol of Al_2O_3 = (26.98 * 2)g + 48 = 101.96g

Therefore, in 101.96g of Al_2O_3 has 54g of Al

101.96g of Al_2O_3 = 54g of Al

21g of Al_2O_3 = 54g of Al

$$21g\ of\ Al_2O_3\ \equiv \frac{(21 \times 54)g}{101.96g} = 11.12g\ of\ Al$$

Therefore, 100g of FA = 20.13g of Si + 11.12g of Al

100g of FA = 20.13g of Si

$$1155g\ of\ FA\ \equiv \frac{(20.13\ \times 1155)g}{100g} = 232.5g\ of\ Si$$

100g of FA = 11.12g of Al

$$1155g\ of\ FA\ \equiv \frac{(11.12\ \times 1155)g}{100g} = 128.44g\ of\ Al$$

$$\frac{Si}{Al} = \frac{232.5g}{128.44g} = 1.81$$

It shows that Si/Al = 1.81 : 1

Calculation to find mass of NaOH pellets needed for different concentrations:

MW of NaOH = 40 g/mol

Volume of Volumetric flask = 0.5L

Number of mol = MV

Therefore, 10M = mol/0.5L

= 5 mols

Mass of NaOH = 5 moles * 40g/mol

= 200g of NaOH

Thus, for 12M and 14M NaOH as below:

12M = mol/0.5L

= 6 mols

Mass of NaOH = 6 moles * 40g/mol

= 240g of NaOH

14M = mol/0.5L

= 7 mols

Mass of NaOH = 7 moles * 40g/mol

= 280g of NaOH

Appendix B – Table of data collected:

- Pure geopolymer

Effect of NaOH

Density

Volume (m3) 0.000125

Num	Molarity	Mass (g)		Average Mass		Avg Mass (kg)		Density = mass/volume (kg/m3)	
		60^{O}C	Room.Temp	60^{O}C	Room.Temp	60^{O}C	Room.Temp	60^{O}C	Room.Temp
1	10M	224.500	266.200	226.000	262.100	0.226	0.262	1808.000	2096.800
2		229.900	261.600						
3		223.600	258.500						
1	12M	230.500	263.800	229.000	260.133	0.229	0.260	1832.000	2081.067
2		227.300	266.900						
3		229.200	249.700						
1	14M	238.400	274.500	242.333	277.733	0.242	0.278	1938.667	2221.867
2		245.600	280.800						
3		243.000	277.900						

Effect of
NaOH

Compressive Strength

Pace rate 0.9

Num	Molarity	Comp. Strength (Mpa)		Max. Load, kN		Avg. Comp. Strength (Mpa)	
		$60^{O}C$	Room.Temp	$60^{O}C$	Room.Temp	$60^{O}C$	Room.Temp
1	10M	40.610	8.123	101.500	20.300	26.365	7.468
2		12.120	6.813	30.300	17.000		
1	12M	45.020	6.028	103.500	15.100	51.545	6.303
2		58.070	6.578	145.200	16.400		
1	14M	55.250	5.711	138.100	14.300	32.027	4.824
2		8.803	3.936	22.000	9.800		

Effect of
NaOH

Water Absorption

Volume (m3) 0.000125

		Before		After			After			Water Absorbtion (%)		
Num	Molarity	Mass (g)		Mass (g)			Water Absorption Mass (g)					
				1hr	2hr	3hr	1hr	2hr	3hr	1hr	2hr	3hr
3	10M	60^{O}C	223.600	257.000	257.300	258.2	33.400	33.700	34.600	14.94%	13.11%	13.45%
		Room.Temp	258.500	263.300	262.800	262.4	4.800	4.300	3.900	1.86%	1.63%	1.48%
3	12M	60^{O}C	229.200	260.200	260.500	260.6	31.000	31.300	31.400	13.53%	12.03%	12.05%
		Room.Temp	249.700	251.500	250.400	250.2	1.800	0.700	0.500	0.72%	0.28%	0.20%
3	14M	60^{O}C	243.000	271.8	271	270.5	28.800	28.000	27.500	11.85%	10.30%	10.15%
		Room.Temp	277.9	278.4	278.6	278.8	0.500	0.700	0.900	0.18%	0.25%	0.32%

Setting time

Molarity (M)	Setting Time (min)
10M	40
12M	36
14M	25

- Lightweight geopolymer (coarse rice husk)

Effect of Coarse Rice Husk

Density

Volume (m3) 0.000125

Molarity	R.H (%)	No.	Mass(g)		Avg Mass (g)		Avg Mass (kg)		Density = mass/volume (kg/m3)	
			60OC	Room.T	60OC	Room.T	60OC	Room.T	60OC	Room.T
14M	15%	1	176.400	238.800	175.900	236.633	0.176	0.237	1407.200	1893.067
		2	177.200	234.800						
		3	174.100	236.300						
	10%	1	219.000	259.200	226.067	261.767	0.226	0.262	1808.533	2094.133
		2	219.300	263.300						
		3	239.900	262.800						
	5%	1	234.200	266.200	233.700	267.233	0.234	0.267	1869.600	2137.867
		2	229.100	263.800						
		3	237.800	271.700						
12M	15%	1	178.500	194.400	179.100	193.333	0.179	0.193	1432.800	1546.667
		2	179.000	203.500						
		3	179.800	182.100						
	10%	1	230.300	267.800	221.767	264.700	0.222	0.265	1774.133	2117.600
		2	219.100	266.500						

		3	215.900	259.800						
	5%	1	231.500	278.000	231.800	273.067	0.232	0.273	1854.400	2184.533
		2	229.900	274.400						
		3	234.000	266.800						
10M	15%	1	160.700	184.400	162.433	181.667	0.162	0.182	1299.467	1453.333
		2	158.200	176.500						
		3	168.400	184.100						
	10%	1	210.100	258.500	216.500	260.767	0.217	0.261	1732.000	2086.133
		2	217.700	263.600						
		3	221.700	260.200						
	5%	1	202.400	253.800	209.633	254.567	0.210	0.255	1677.067	2036.533
		2	212.200	257.300						
		3	214.300	252.600						

Effect of Coarse Rice Husk

Compressive Strength

Pace rate 0.9

Molarity	R.H (%)	No.	Comp. Strength (Mpa)		Avg. Comp. Strength (Mpa)		Max. Load, kN	
			$60^{O}C$	Room.T	$60^{O}C$	Room.T	$60^{O}C$	Room.Temp
14M	15%	1	32.360	0.480	22.430	0.540	80.900	1.200
		2	12.500	0.600			28.300	1.500
	10%	1	11.170	5.700	10.564	5.777	27.900	14.300
		2	9.957	5.853			21.900	14.600
	5%	1	28.510	7.190	28.010	6.235	71.300	18.000
		2	27.510	5.279			67.900	13.200
12M	15%	1	15.020	3.975	9.665	14.428	37.600	9.900
		2	4.310	24.880			10.800	62.200
	10%	1	11.720	5.965	9.755	6.053	29.300	14.900
		2	7.790	6.141			19.500	15.400
	5%	1	3.499	3.697	8.720	3.805	8.700	9.200
		2	13.940	3.912			34.800	9.800
10M	15%	1	5.509	5.087	5.902	4.530	8.700	12.700
		2	6.294	3.972			34.800	19.900
	10%	1	11.560	7.681	11.255	8.516	28.900	19.200
		2	10.950	9.350			27.400	23.400
	5%	1	17.430	6.973	15.810	8.100	43.800	17.400
		2	14.190	9.227			35.500	23.100

Effect of Coarse Rice Husk

Water Absorbtion

Volume (m3) 0.000125

				Before	After			After			Water Absorbtion (%)		
Molarity	R.H (%)	No.	Cure	Mass (g)	Mass (g)			Water Absorbtion Mass (g)					
					1hr	2hr	3hr	1hr	2hr	3hr	1hr	2hr	3hr
14M	15%	3	60^{O}C	174.1	191.1	185.6	183.4	17.000	11.500	9.300	9.76%	6.61%	5.34%
			Room.T	236.3	253.3	251.2	249	17.000	14.900	12.700	7.19%	6.31%	5.37%
	10%	3	60^{O}C	239.900	264.800	258.000	257.800	24.900	18.100	17.900	10.38%	7.54%	7.46%
			Room.T	262.800	264.100	263.200	263.000	1.300	0.400	0.200	0.49%	0.15%	0.08%
	5%	3	60^{O}C	237.800	243.800	245.600	246.900	6.000	-7.800	-9.100	2.52%	-3.28%	-3.83%
			Room.T	271.700	272.300	272.900	273.400	0.600	-1.200	-1.700	0.22%	-0.44%	-0.63%
12M	15%	3	60^{O}C	179.800	223.000	222.400	222.100	43.200	42.600	42.300	24.03%	23.69%	23.53%
			Room.T	182.100	201.000	193.600	193.300	18.900	11.500	11.200	10.38%	6.32%	6.15%
	10%	3	60^{O}C	215.900	228.300	229.000	228.700	12.400	13.100	12.800	5.74%	6.07%	5.93%
			Room.T	259.800	264.700	262.700	262.200	4.900	2.900	2.400	1.89%	1.12%	0.92%
	5%	3	60^{O}C	234.000	245.000	246.800	247.400	11	12.8	13.4	4.70%	5.47%	5.73%
			Room.T	266.800	268.200	269.100	268.700	1.4	2.3	1.9	0.52%	0.86%	0.71%
10M	15%	3	60^{O}C	168.400	196.400	197.000	196.500	28	28.6	28.1	16.63%	16.98%	16.69%
			Room.T	184.100	193.700	194.800	191.700	9.6	10.7	7.6	5.21%	5.81%	4.13%

	10%	3	60^{O}C	221.700	240.800	241.400	241.300	19.100	19.700	19.600	8.62%	8.89%	8.84%
			Room.T	260.200	261.500	261.600	261.400	1.300	1.400	1.200	0.50%	0.54%	0.46%
	5%	3	60^{O}C	214.300	232.400	236.600	237.900	18.1	22.3	23.6	8.45%	10.41%	11.01%
			Room.T	252.600	252.300	253.300	254.100	-0.3	0.7	1.5	-0.12%	0.28%	0.59%

Setting time

Molarity	R.H (%)	Setting Time (min)
		Room.T
14M	15%	8.000
	10%	20.000
	5%	25.000
12M	15%	10.000
	10%	35.000
	5%	38.000
10M	15%	12.000
	10%	45.000
	5%	30.000

- Lightweight geopolymer (fine rice husk)

Effect of Fine Rice Husk

Density

Volume (m3) 0.000125

Molarity	R.H (%)	No.	Mass(g)		Avg Mass (g)		Avg Mass (kg)		Density = mass/volume (kg/m3)	
			60OC	Room.T	60OC	Room.T	60OC	Room.T	60OC	Room.T
14M	15%	1	161.200	219.000	158.500	214.367	0.159	0.214	1268.000	1714.933
		2	158.400	214.300						
		3	155.900	209.800						
	10%	1	211.400	250.700	212.233	248.833	0.212	0.249	1697.867	1990.667
		2	214.700	247.500						
		3	210.600	248.300						
	5%	1	211.800	256.100	212.600	258.000	0.213	0.258	1700.800	2064.000
		2	217.000	259.500						
		3	209.000	258.400						
12M	15%	1	203.300	227.100	198.833	227.033	0.199	0.227	1590.667	1816.267
		2	197.600	230.900						
		3	195.600	223.100						
	10%	1	211.700	249.300	216.700	247.167	0.217	0.247	1733.600	1977.333
		2	218.400	247.200						

		3	220.000	245.000						
	5%	1	211.200	246.900	207.900	249.667	0.208	0.250	1663.200	1997.333
		2	208.900	251.500						
		3	203.600	250.600						
10M	15%	1	173.000	205.000	176.067	201.167	0.176	0.201	1408.533	1609.333
		2	181.000	213.700						
		3	174.200	184.800						
	10%	1	213.900	253.900	214.700	246.667	0.215	0.247	1717.600	1973.333
		2	219.800	245.900						
		3	210.400	240.200						
	5%	1	215.400	250.900	213.833	248.867	0.214	0.249	1710.667	1990.933
		2	211.100	250.200						
		3	215.000	245.500						

Effect of Fine Rice Husk

Compressive Strength

Pace rate 0.9

Molarity	R.H (%)	No.	Comp. Strength (Mpa)		Avg. Comp. Strength (Mpa)		Max. Load, kN	
			$60^{O}C$	Room.T	$60^{O}C$	Room.T	$60^{O}C$	Room.Temp
14M	15%	1	8.555	0.440	9.378	0.480	21.400	1.200
		2	10.200	0.520			25.500	1.300
	10%	1	8.390	6.566	9.600	6.818	21.000	16.400
		2	10.810	7.070			27.000	17.700
	5%	1	51.230	4.277	55.550	4.233	128.100	10.700
		2	59.870	4.189			149.700	10.500
12M	15%	1	17.400	4.003	10.953	7.852	43.500	19.300
		2	4.506	11.700			11.300	29.200
	10%	1	32.260	2.600	31.560	4.760	81.100	6.500
		2	30.860	6.920			77.000	17.500
	5%	1	30.810	8.359	34.595	8.363	76.500	20.900
		2	38.380	8.367			95.900	20.900
10M	15%	1	19.120	3.663	21.940	4.369	47.800	9.200
		2	24.760	5.074			61.900	12.700
	10%	1	21.220	9.088	24.245	10.694	53.000	22.700
		2	27.270	12.300			68.200	30.800
	5%	1	6.949	11.860	20.925	12.645	17.400	29.600
		2	34.900	13.430			87.300	33.600

Effect of Fine Rice Husk

Water Absorbtion

Volume (m3) 0.000125

				Before	After			After			Water Absorbtion (%)		
Molarity	R.H (%)	No.	Cure	Mass (g)	Mass (g)			Water Absorption Mass (g)					
					1hr	2hr	3hr	1hr	2hr	3hr	1hr	2hr	3hr
14M	15%	3	60^{O}C	155.900	165.200	166.600	167.100	9.300	10.700	11.200	5.97%	6.86%	7.18%
			Room.T	209.800	206.800	206.200	206.000	-3.000	-3.600	-3.800	-1.43%	-1.72%	-1.81%
	10%	3	60^{O}C	210.600	217.900	218.600	218.800	7.300	8.000	8.200	3.47%	3.80%	3.89%
			Room.T	248.300	251.400	251.200	250.800	3.100	2.900	2.500	1.25%	1.17%	1.01%
	5%	3	60^{O}C	209.000	216.100	217.500	217.900	7.100	8.500	8.900	3.40%	4.07%	4.26%
			Room.T	258.400	259.000	258.300	258.000	0.600	-0.100	-0.400	0.23%	-0.04%	-0.15%
12M	15%	3	60^{O}C	195.600	218.500	219.600	220.100	22.900	24.000	24.500	11.71%	12.27%	12.53%
			Room.T	223.100	226.700	227.000	227.000	3.600	3.900	3.900	1.61%	1.75%	1.75%
	10%	3	60^{O}C	220.000	221.400	222.100	222.700	1.400	2.100	2.700	0.64%	0.95%	1.23%
			Room.T	245.000	242.700	243.000	243.400	-2.300	-2.000	-1.600	-0.94%	-0.82%	-0.65%
	5%	3	60^{O}C	203.600	210.100	212.000	212.800	6.500	8.400	9.200	3.19%	4.13%	4.52%
			Room.T	250.600	251.900	252.500	252.700	1.300	1.900	2.100	0.52%	0.76%	0.84%
10M	15%	3	60^{O}C	174.200	201.600	202.400	202.800	27.400	28.200	28.600	15.73%	16.19%	16.42%

			Room.T	184.800	192.200	195.700	196.200	7.400	10.900	11.400	4.00%	5.90%	6.17%
	10%	3	60^{O}C	210.400	213.400	214.300	214.900	3.000	3.900	4.500	1.43%	1.85%	2.14%
			Room.T	240.200	237.600	237.400	237.100	-2.600	-2.800	-3.100	-1.08%	-1.17%	-1.29%
	5%	3	60^{O}C	215.000	222.100	223.300	223.600	7.100	8.300	8.600	3.30%	3.86%	4.00%
			Room.T	245.500	247.800	248.100	248.500	2.300	2.600	3.000	0.94%	1.06%	1.22%

Setting time

Molarity	R.H (%)	Setting Time (min)
		Room.T
14M	15%	120.000
	10%	26.000
	5%	22.000
12M	15%	14.000
	10%	15.000
	5%	29.000
10M	15%	8.000
	10%	10.000
	5%	21.000

Appendix C – Pictures of the samples and machines:

Tools/Equipments

Some Samples: