Characterization of Coir Fibre Reinforced Geopolymer Composite

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Dissertation submitted in partial fulfilment
of the requirement for the
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CERTIFICATE OF APPROVAL

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A project dissertation submitted to the
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Approved by,

_____

(AP. DR. ZAKARIA BIN MAN)

UNIVERSITI TEKNOLOGI PETRONAS
BANDAR SERI ISKANDAR, PERAK
January 2015

CERTIFICATION OF ORIGINALITY

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

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(KHAIRIL ANWAR BIN MUHAJIR)

ABSTRACT

This paper mainly focused on the development of geopolymer technology by searching for alternative aggregates commonly used, sand substituting with coir fibre as coconut tree is abundant in Malaysia. As we know, sand is a limited source which one day may run out when we used extensively. Thus, an alternative which can conserve this limited resource should being developed for that purpose. In this research, we mainly enhanced the geopolymer by improving with coir fibre with different fibre length and coir fibre mass composition. By conducting different testing to obtain the data, we can evaluate the improvement whether had achieved or not. The testing that had been chosen is Flexural Strength, Scanning Electron Microscope and Water Absorption Test. The result from these testing will then discussed and evaluate the suitable of coir fibre to replace sand as aggregate. This research is hoping give the exposure to development of natural agriculture in enhancement structure application.

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CHAPTER 1: INTRODUCTION

1.1 Background

In construction world currently, the main binder used is Ordinary Portland Cement which mostly known as OPC. Due to the awareness of conservation of the environment, scientists are trying their best to develop a new material binders to which can replace OPC as it is harmful to the environment and costly. Thus, the geopolymer technology was initially applied in the industry around 1934, when kaolinite reaction with alkali initiated in the ceramic industry. Later on in 1970, it was reinvented by a Russian team Berg and et al., yet without any successful implementation in industry. A year before that, Besson and et al. from French Museum of Natural History, Paris conducted the synthesis of hydrosodalite from various phyllosilicates heated at 100^{o}C in concentrated NaOH solution. Due to prospectus future of geopolymer technology, Joseph Davidovits founded a private research company in 1972 prominently known as Cordi-Géopolymère [4].

The geopolymer rapidly involved until the scientists manage to developed fire-resistant wood-chipboards. This first application of geopolymer technology was implemented in building product by J.J Legrand. Later in 1977, the geopolymer technology is applied in ceramic producing a new product call SILIFACE COR70 that has excellent temperature stability and lowest thermal expansion, implemented in the manufacture of electrical fuses of the French company, LEGRAND [5]. However, the project is terminated since the water absorption is not good enough. In the following year later, the geopolymer technology is the spark the revolution in the ceramic industry when the Low-Temperature Geopolymeric Settings (LTGS) was introduced. This new technology is then dramatically enhanced and modernised the traditional ceramic industry.

Joseph Davidovits later stated in his speech the different geopolymer with the ordinary polymer. According to him, by analogy, the organic polymer is derived from oil and undergoes polycondensation. However, geopolymer is inorganic, hard and stable at high temperature which a boost to tremendous creativity and innovation. It is interesting to know that the geopolymer is not only applicable to construction industry yet it is being expanded into aviation industry. Northtrop Aviation used geopolymer composite for the fabrication of carbon/APC2 composite that being designed for US Airforce bomber.

As the year passed by the geopolymer technology is being increased since its characteristic that can solve many problems regarding the mechanical strength, temperature stability and extreme condition such as the acidic environment.

1.2 Problem Statement

In the OPC cement, sand is used as the aggregate of the cement to strengthen the cement by disrupting the arrangement of inside the cement. However, sand is limited sources which will run out someday and the rapid development may worsen the situation. Even in the geopolymer itself, the sand is still being used as aggregate. Thus, there is no alternative in aggregate for construction purpose. In Malaysia, the sand becomes very limited due to the rapid development of the city and even rural area. This has been highlighted in mainstream media.

According to the former chief ministry of Selangor, in 13 July 2010, he worried that Selangor may run off the land for construction and industrial activity in the future if the sand quarry is out of control [17]. He also repeatedly insists that the state government to ban the quarry activity in government land. Although, the government released the permit for the sand quarry on government land, however, when the sand is being dug to 40 metre deep without any conservation act, it will give impact to the environment. From this news report, we may conclude that the sand quarry is mainly used for the construction as being discussed previously and this activity is ruining the environment. It also shows that current situation that happened in Malaysia.

Another article in Kosmo online newspaper written Megat Lutfi Megat Rahim and Amree Ahmad in 7 Mac 2015, reported that there is 8 000 tonne sand being stolen each day. Mohd. Nizam Mahshar from Sahabat Alam Malaysia (SAM) explained the uncontrolled sand quarry activity can cause soil erosion, disrupt the marine life and people safety [11]. Meanwhile, the Selangor state government estimated around 6 000 to 8 000 tonne sand being stolen losing million ringgit from the illegal act. From this article it shows due to high demand of sand for construction, it leading to some greedy people to do illegal quarry. Thus, a new alternative for aggregate that has the sustainability and environment-friendly need to be searched replacing the sand in cement, most specifically in geopolymer.

In our research, we mainly are prospecting the use of coir fibre for this matter. We focusing the suitability of coir fibre reinforce geopolymer composite by analysing the mechanical strength characteristic and as well the water absorption intake. From this analysis, we can make the conclusion whether the coir fibre can be used as aggregate in the future.

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1.3 Objectives

The objectives of this research are to analyse the characteristic of the coir reinforced geopolymer in terms of strength and water absorption and evaluate the coir fibre geopolymer in terms of strength and water absorption properties.

1.4 Scope of Study

The project scopes are the task involved in order to achieve the objectives stated previously. The specimen or sample is being prepared according to the standard varied according to the length of the fibre as well as the composition of the coir. In this project, the scope of the study is mainly involving in the mechanical strength analysis through the flexural testing, water absorption testing and also the surface of composite analysis. The water absorption test is conducted to analyse the water absorptivity of the material. The structure of the composite will be determined by zooming to nanoscale using scanning electron microscope (SEM). From all the data obtained from tests, the composites will be analysed to determine their exact characteristic.

CHAPTER 2: LITERATURE REVIEW AND THEORY

In this chapter we mainly discussing the development of the research to check the possibility of the improvement of the coir fibre embedded inside the geopolymer by using several researchers had conducted previously describing their findings apart of defining the terms that we will use in this research. By having all the literature review related to this research title, we can have a little insight of the possibility of the research.

2.1 Introduction of Geopolymer

According to Konstantinos (2011), a geopolymer is non-crystalline solid with three-dimensional aluminosilicate materials having ceramic-like properties which are produced and hardened at ambient temperature [10]. The geopolymer is produced through a process of geo-polymerization under the high alkaline condition with the presence of alkali hydroxide and silicate solution [6]. The process started when the reactive aluminosilicate dissolving and releasing free silicon tetraoxide [SiO4] and aluminium tetraoxide [AlO4] in solution. The tetrahedral unit formed amorphous geopolymers by sharing oxygen atoms linking alternative to polymeric precursor.

The "monomers" formed in the solution can be presented in 2-dimensions by:- -Si-O-Al-O- [Poly(silalate)], or -Si-O-Al-O-Si-O [Poly(silalate-siloxi)], and etc. where each of oxygen bonds formed due to the condensation reaction tie the neighbouring Si or Al in tetrahedral. The monomers, silicon and aluminium hydroxide molecules then proceed to Poly-condense or known as polymerization to form rigid chain or nets of oxygen bonded tetrahedral by applying mild heat basically around ambient or up until 90^{o}C. We will be discussing the properties of the geopolymer in the literature view part and the result of various researches that had been done previously.

2.1.1 Literature Review of Geopolymer

In thesis entitled "Potential of Geopolymer Technology towards Green Buildings and Sustainable Cities" written by Konstantinos A. Komnitsas stated that geopolymers can harden rapidly and obtained high strength at the initial stage. In his research found that at 28 day later, it strength increased up to or exceed 100MPa. They have less porosity compared to cement or mortar, thus improved the mechanical properties to the superior level. Their final structure and physical properties are influenced by several factors such as water content, particle size, thermal history, alkali metal content and degree of amorphicity. He concluded geopolymerisation has the good potential in the production of "green" concrete and lower carbon footprint construction material [10].

Apart from the strength qualities, it also had been proved that geopolymer also has the acoustic absorption capability. 4 researchers from the Institute of Rock Structure and Mechanics of Academic of Science of the Czech Republic conducted a research by mixing the geopolymer and sand in order to determine the possibility of geopolymer and sand mixture replacing epoxide resin binder in terms of acoustic property which found that the result from this experiment is positive and confirmed to their theory. They also acknowledge that this mixture has fire resistance up to 1200^{o}C [16]. Meanwhile in Vietnam, a group of researchers had done the research to determine the fire resistance of geopolymer by testing geopolymer resins to carbon fibre. From the experiment, only 14 wt. % of carbon fibres is oxidized after the composition is burned up to 800^{o}C. This shows that geopolymer has good thermal dimensional stability [8].

Due to the extreme qualities, thus a group of research concluded that the ideal fly ash geopolymer concrete can be used in a seawater environment due to high compressive, tensile and flexural strength, and low modulus of elasticity, drying shrinkage, water absorption and sorptive [14]. In 2 years later, Francisco (2013) conducted an experiment in order to determine geopolymer concrete (GPC) condition against the extreme condition which is the marine environment. The results show that GPC has high electrical resistivity and corrosion current of GPC beam remained low and constant throughout the duration of the study. The addition of fibre in GPC beam may increase the permeability of GPC as the result shows the sign of corrosion. However, the mass loss due to the corrosion was less than the beam without fibres which show a reduction of damage from the corrosion. Apart from that, the

addition of fibre give greater resistance to crack propagation and performed better in flexural testing as the fibre helped bridge the gap of the crack while allowing greater stress capacity [13].

Before going into the deeper analysis, it will be best to know the fibre that we used in this research. In order to develop strong, light weight and sound removal geopolymer ceiling tile, it is suggested to enhance it by using selected natural fibre which are coconut husk (coir).

2.2 Introduction of Coir

Coconut is scientifically known as Cocos Nucifera [3]. The fruit is categorised as a drupe also called as stone fruit which is an indehiscent fruit that has a seed inside surrounded by a hardened endocarp and covered an outer fleshy part. The fruit is has three layers which are the exocarp, mesocarp and endocarp. The exocarp and mesocarp are the part of the husk of the coconut which will be used for this project to extract the fibre usually known as Coir. Today, the coir has been developed into various kinds of valuable products such as rope, mats, brushes and soil enhancements. The individual fibre cells are narrow and hollow, with thick walls made of cellulose [7]. At immature phase, they are pale colour; slowly they will become hardened and yellowed as a layer of lignin deposited on their walls. Mature brown coir fibres have more lignin yet less cellulose compare to other fibres such as flax and cotton which gives the strength yet less flexible. The average dimension of coir is less than 1.3mm long and have 10 to 20mm diameter. They are made up of small thread each less than 1.3mm long and 10 to 20 mm in diameter. The coir fibre somehow is waterproof and the only natural fibre which can withstand with salt water.

2.2.1 Literature Review of Coir Fibres

According to Jan and et al. (2006) who conducting research by producing binderless board from the whole coconut husk, the husk material surprisingly become an exotherm starting at 140^{o}C which later on this characteristic is vanished in second heating [19]. From their research, they conclude that the mechanical and water absorbing characteristics of coconut husks become the factor affecting the suitability of raw materials for binderless board production and it performance. Meanwhile, these characteristics are determined by the constituent tissue of coconut husks such as coir fibre and pith. Apart from that, they also added that the influence of cultivator toward morphological structural details of mature coconut husk, fibre and pith, coir fibre mechanical properties such as water uptake, swelling and tensile strength and the chemical composition can be negligible [18]. Thus, using coconut husks from any plantation regardless their species type will not give any significance and influence of the result of the experiment.

The result from the analysis mechanical test on the Coir Fiber Reinforced Cement Albumen Composite (CFRCC) conducted by Zuraidah and et al. (2011) from International Islamic University Malaysia found that the length of the fibre has great influence the strength of CFRCC. The longer the fibre length can increase the flexural strength up to 6.719 MPa because longer fibre can cater the higher load while bridge the crack effectively compare to the shorter fibre. Apart from that, short fibre promotes the rapid penetration of cement hydration end up trigger the mineralisation process and loss the fibre flexibility. However, this result is only applicable for the length of fibre up to 5mm. Longer fibre more than 5mm shows the adverse effect because they tend to clot causing reduce the workability as well the strength. Looking into the density aspect, the longer fibre shows slightly drop compare to the shorter one. This happened because the inclusion of long fibre into the composite blend reduced the packing causing disruption on the fibre distribution and producing in high void spaces. Basically, the high void contents lower the density composite as well absorbs more water increasing the moisture content. Thus, longer fibre tends to have higher moisture content. This probably happened due to the presence of hydrophilic natural fibre. Meanwhile, they also conclude that over mixing will cause foam due to the entrapped air. This shows that the high percentage also might upset the strength of fibre composite [20].

Another research conducted shows the benefit of having the low density which in the first place noted as a disadvantage of the coconut husk enhancing material for the structural component. Due to this so called the disadvantage of the characteristic of coconut husk, some researchers suggested that this characteristic actually are fit for the purpose of insulation in building construction. They also find out that the addition of $CaCl_2$ can increased the density of coconut husk composites as well the water absorption properties and the coconut husk particles size have major effects on the strength and sorption properties of the composites. The small husk particles are the best which give relatively denser, stronger and stiffer composites [15]. Another suggestion of enhancing material which strengthen the coir fibre composite is latex. Latex will improve the composite which increase the compressive strength to a certain level [9].

Another interesting finding which found by a group of researchers from Universiti Malaysia Perlis that coir can replace sand as a material in producing concrete as their research working on developing coconut fibre based-green composite. According to Alida and et al., by increasing the percentage content of coconut fibre, the flexural and compressive strength will be increased. In the aspect of fracture behaviour of composite, the high content fibre consists of crack bridging and fibres push-out which help in resisting the crack propagation and improving the strength of the composite [1]. Sahaya and Baskar (2014) approved the theory stated that the addition of coir fibre captures the micro crack in the composite [9]. Mahzan and et al. conclude that coir can react as a good sound proofing from their research on the acoustical characteristic of coconut fibre reinforced composite with the addition of Polyurethra (PU). The Noise Reduction Coefficient (NRC) for 25% of PU produced higher values compared to 35% PU. The result yields 0.24 to 0.32 and 0.1 to 0.29 respectively. The lesser the PU content (high content of coir) performs better in absorbing sound. They also suggested that the optimum composition to have the maximum sound absorbent performance is 40% coconut coir and 60% of recycled rubber [12].

The experiment tested the suitability of resin on coir and compared with the Glass Fibre Reinforced Plastic (GFRP) found that the flexural and impact strength for coir resin is significantly lower compared to the GFRP. The reason for the difference can be determined through the Scanning Electron Micrograph of the broken part, the fibre are detached from resin surface due to the weak interfacial bonding. While the fibre is actually strong as it can

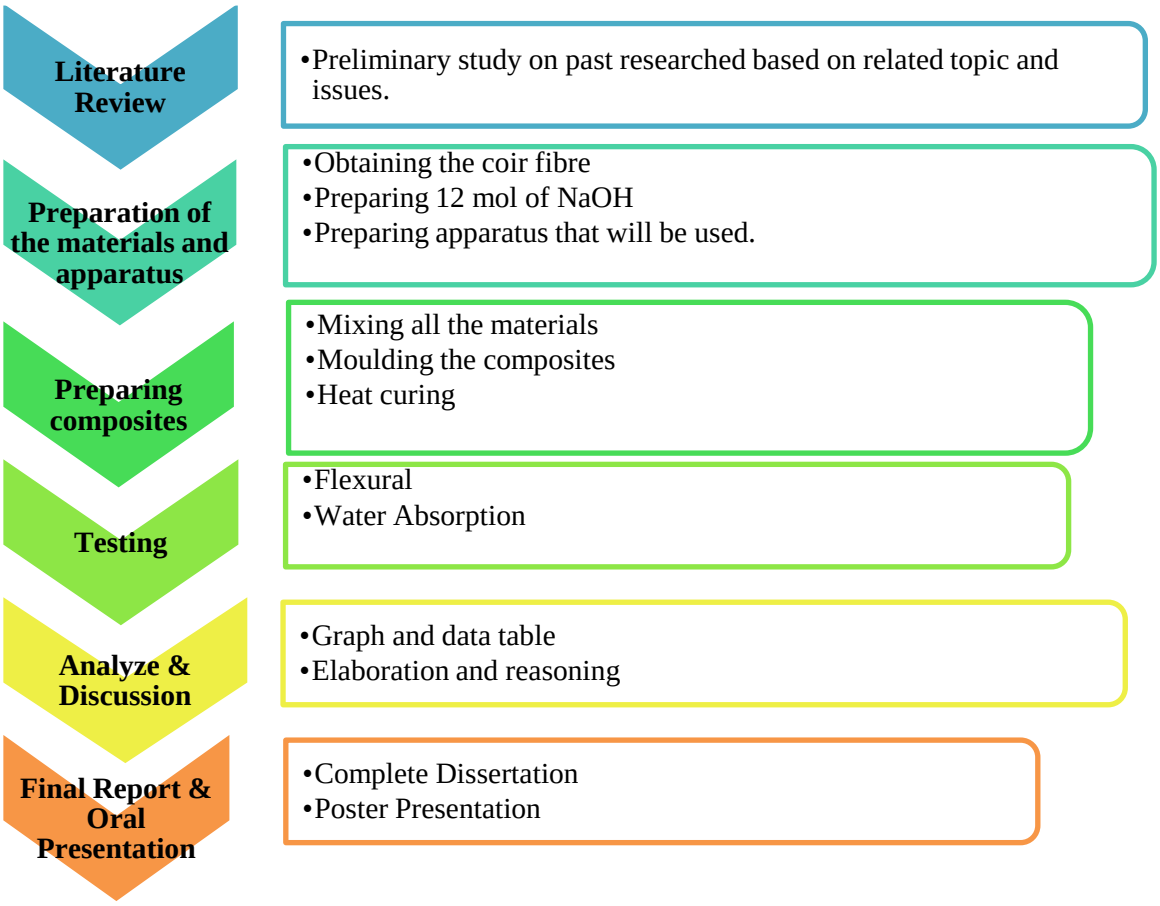
be seen there is void formed due to fibre pull out. Thus, this indicates that coir fibre is strong but it also depends on the adhesive applied on [7].

2.3 Natural Fibre Reinforced Geopolymer

In this part, we are discussing, in general, the research that had been conducted previously which is similar to this research. Basically, most of the researchers are progressing developing cotton fibre reinforced geopolymer. One of the researches is conducted by Alomayri and Low (2013) in Synthesis and Characterization of Mechanical Properties in Cotton Fibre-Reinforced Geopolymer Composites. In this research, they mainly use cotton mixed with fly ash under 8M sodium hydroxide concentration condition and conducted Synchrotron Radiation Diffraction (SRD) test, SEM, Rockwell Hardness test, Compressive Strength test and Impact strength test. For the test hardness, compressive strength test and impact strength, the matrix shows all same trend, as the composition increased up to 5% of cotton fibre composition, the strength is increased, and the strength is decreased as the composition is exceeding more than 5% of cotton fibre composition . [2]

CHAPTER 3: METHODOLOGY

3.1 Project Flowchart



3.2 Gantt chart and Key Milestone

No	Detail / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	Selection of Project Topic														
2.	Preliminary of Research Work														
3.	Submission of Extended Proposal														
4.	Proposal Defence														
5.	Report Writing Continues														
6.	Preparing Coir Fibre:-														
	Drying														
	Cutting														
7.	Submission of Interim Draft Report														
8.	Submission of Interim Report														
9.	Preparation of OPC Concrete, Gypsium, Geopolymer														
10.	Preparation of Coir Fibre Geopolymer Composite														

No	Detail / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	Flexural and Compression Test:-														
	OPC Concrete, Gypsium, Geopolymer	■				■				■					
	Coir Fibre Geopolymer Composite	■	■				■	■		■	■				
2.	Water Absorption Test:-														
	OPC Concrete, Gypsium, Geopolymer	■	■	■	■	■	■	■	■						
	Coir Fibre Geopolymer Composite	■	■	■	■	■	■	■	■						
3.	Submission of Progress Report							●							
4.	Heat Insulation Test:-														
	OPC Concrete, Gypsium, Geopolymer			■											
	Coir Fibre Geopolymer Composite				■	■									
5.	SEM:-														
	OPC Concrete, Gypsium, Geopolymer			●				●			●				
	Coir Fibre Geopolymer Composite				●				●			●			
6.	Analysis of Data			■	■	■	■	■	■	■	■	■	■		
7.	Report Completion												●		
8.	Pre-SEDEX										●				
9.	Submission of Draft Final Report											●			
10.	Submission of Dissertation (soft bound)												●		
11.	Submission of Technical Report												●		
12.	Viva													●	
13.	Submission of Dissertation (hard bound)														●

■ Process ● Milestone

3.3 Materials / chemicals and Equipment used

The materials and chemical used in this research are coir fibre with different fibre length, grease, 10 mol of NaOH solution. Meanwhile the equipment required are disposable nitrile gloves, safety glasses, lab coat, clean paper tissue, mixer, weight scale, universal testing machine, MSDS, beaker, conical flask, oven and mold.

3.4 Experiment Methodology

3.4.1 Sample Preparation

The raw materials that will be used for the project is fibre from coconut husk. Coir is obtained from the coconut that have ripened and fallen from the tree. The ripe coconut then is husked immediately to remove the fruit from the seed. The husk is then undergoing process retting which is the curing process. The husk is buried in pits dug along riverbanks for at least six months to promote the action of microbes naturally. This process is done to decompose partially in order to separate coir fibres and residue called coir pith. The modern machine developed can used to shorten the process of retting into 7 to 10 days which then is crushed. The workers then beat the retted pulp with wooden mallets to separate fibre from the pith and the outer skin, being washed by water to separate the residue and finally dried in the sun.

All the fibre air-dried in an oven at 60^{o}C for 8 hours before used to remove all the impurities. Then they will be cut into 4 different lengths which are 0.5 cm, 1cm, 2cm and 3cm. The fly ashes is mixed with the sodium hydroxide first, later after the mixing is thoroughly, the fibre is inserted and mixed little by little until the fly ashes and sodium is mixed completely with the coir fibre. Finally, the paste is heated at 60^{o}C for 12 hours.

In this project, there are two types of the sizing dimension of testing matrix composite which required for the flexural testing and water absorption testing. This standard dimension is important to ensure the test is complying with the ASTM D7264 for flexural test and BS EN 5669: Part 1 for the water absorption test. The matrix dimension for flexural test and water absorption test are 1.5cm x 8cm x 0.4cm and 5cm x 8cm x 0.4cm respectively. The manipulative data being tested are the length of the coir fibre and the percentage of the composition of the composite. Meanwhile, the compositions of the matrix are based on the

mass percentage of the solid. Since the coir fibre has low density, which means has high volume when compare to fly ash volume, the composition of the coir is limited to 5% and below. Take, for example, 1 kg of fly ash contained for 10mm3; the coir fibre may take 5 times more than the fly ash volume. In this project, the mass solid percentages used are 1%, 2%, 3%, 4% and 5%. The calculation of the mass of the percentage is presented in Appendix B.

Below is the total matrix required in this research:-

1) Flexural = 80 samples.
2) Water Absorption = 16 samples.
3) SEM = 4 samples which are taken from the broken sample of the flexural.

   Total matrix needs to produce = 124

3.4.2 Testing Procedure

There are several tests need to be conducted by making the comparison with two control specimens which are the original geopolymer concrete. The comparison needs to do in order to check whether the addition of natural fibre does increase or lowering the qualities of the geopolymer.

3.4.2.1 Flexural Test

Flexure testing is a common test in springs and brittle materials whose failure behaviours are linear which were done on a universal testing machine under three-point bending mode in accordance with ASTM D7264. This test determines the values for the modulus of elasticity in bending E_f, flexural strain ϵ_f, and flexural stress-strain response of the materials. This method is easy to prepare as well for the execution however the result testing method is sensitive to specimen and loading geometry and strain rate.

$$\sigma = \frac{3FL}{2bd^2} \tag{3.1}$$

Where,

F = Load (force) at the fracture point

L = Length of the support span

b = Width = 2c

d = Thickness

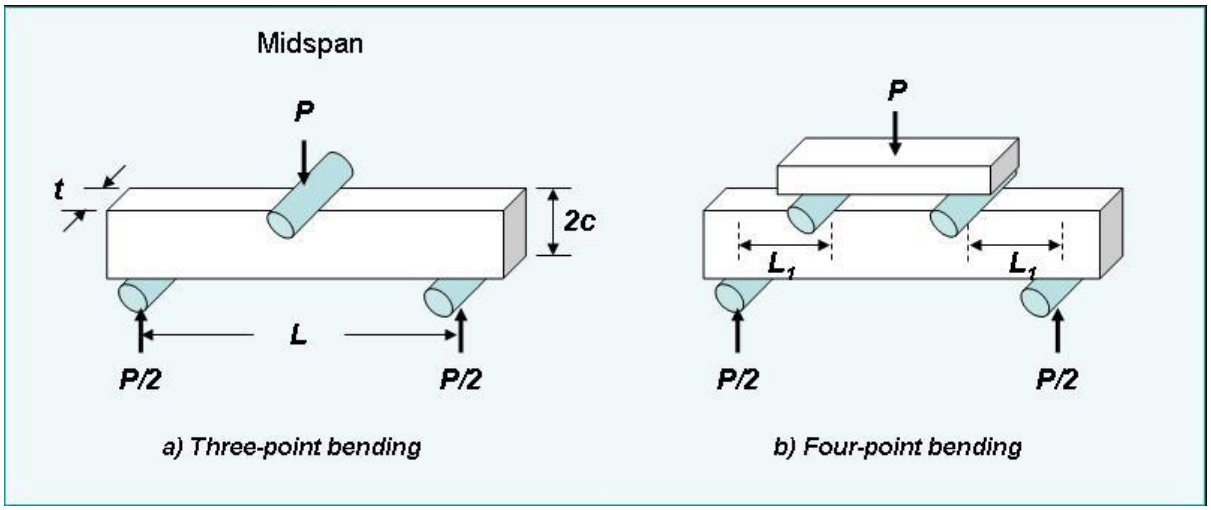


Figure 3.2: Flexural Testing

Table 3.1 Sample data table for Coir Fibre 10mm length fibre thread of flexural test.

Composition of Fibre (%)	10	20	30	40	50
Thickness, t (mm)					
Width, w (mm)					
Span Length, L (mm)					
Maximum Flexural Load, P_{max} (N)					
Maximum Bend Strain, ε_{maxb}, (%)					
Elastic Modulus, EB (MPa)					

Below are the procedures for the testing:-

1) Measure the width and thickness of the specimen.
2) Flexural testing is carried out using a universal testing machine until failure takes place.
3) The machine will compute the flexural strength.
4) Discuss the obtained experimental results and deduce the conclusion from it.

3.4.2.2 Water Absorption Test

Water absorption test is a test to check how much that the specimen will be affected by water. This test will check whether the specimen with variety composition as well the fibre length already improved the water resistance compared to ordinary geopolymer. The testing lasts for 16 days.

$$Percentage\ of\ water\ absorbed = \frac{W - D}{D} \times 100\% \quad (3.2)$$

Where,

W = Weight of the wet sample

D = Weight of the dry sample

Table 3.2 Sample of data table for coir fibre 10%, 10mm fibre of WAT.

Fibre Length (mm)	Mass Composition (%)	Day / Total Mass (g)				
		0	1	2	3	4
Control	0					
5	1					
	2					
	3					
	4					
	5					

In order to know the rate of the water absorption within the period of testing, we used Fick's Law to compare the rate of the absorptivity of the composite and determine the lowest absorption rate.

$$\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{dx^2} \tag{3.3}$$

The non-steady state of diffusion of substance is described by Fickian in Cartesian coordinate: x, y and z.

$$\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2} + \frac{\partial^2 c}{\partial z^2} \tag{3.4}$$

Where:

c = concentrations. (amount / lenght^3)

t = time (s)

D = diffusivity coefficient (m^2/s^{-1})

x = position or length (m)

The analytical solution of equation ... for the concentration profile of diffusing substance in isentropic plane sheet of finite thickness can be described as a function of time, t and

distance, x.

$$\frac{c_{c,t}}{c_{\infty}} = 1 - \frac{4}{\pi}\sum_{m=0}^{\infty}\frac{1}{(2m+1)}exp\left[\frac{D(2m+1)^2\pi^2}{h^2}\right]\sin\left[\frac{(2m+1)\pi x}{h}\right]$$

(3.5)

Where:

c∞ = saturated concentration of absorbed substances.

In order to solve equation 3.1, we need to set boundary conditions.

$$c = 0\ when\ t = 0,$$
$$0 \leq x \leq h,$$
$$c = c_{\infty}\ when\ t = h,$$
$$\frac{\partial c}{\partial x} = 0,$$
$$t > 0,$$

Thus the relative moisture uptake can be expressed as:

$$\frac{M_t}{M_{\infty}} = 1 - \sum_{m=0}^{\infty}\frac{8}{(2n+1)^2\pi^2} \times exp\left[-\frac{D(2n+1)^2\pi^2 t}{h^2}\right]$$

(3.6)

Where:

Mt = mass gained at reduce time

M∞ = maximum mass gain at the equilibrium state

At initial stage of diffusion, equation 3.7 can be approximated by:

$$\frac{M_t}{M_\infty} = 4\left[\frac{Dt}{\pi h^2}\right]^{1/2} \tag{3.7}$$

Thus, the diffusivity, D can be calculated from the initial slope of the moisture gain Mt/M∞ versus time ($t^{1/2}$/h).

$$D = \frac{\pi}{16}\left[\frac{\left(\frac{M_t}{M_\infty}\right)}{\left(\frac{\sqrt{t}}{h}\right)}\right] \tag{3.8}$$

A relationship has been developed to predict the moisture content that has a form similar to equation 3.6.

$$\frac{M_t}{M_\infty} = 1 - exp\left[-7.3\left(\frac{Dt}{h^2}\right)^{0.75}\right] \tag{3.9}$$

Below are the procedures for the testing:-

1) Prepare a water bath which can soak the specimen totally.
2) Weight the specimen before immersed into the water bath.
3) Immersed the specimen at least 8 hours.
4) Weight the specimen. Observed the condition of the specimen.
5) Record the data accordingly.
6) Repeat the step 3 until 5 for at least 10 days.
7) Discuss the obtained experimental result and deduce the conclusion from it.

3.4.2.3 Scanning Electron Microscope (SEM)

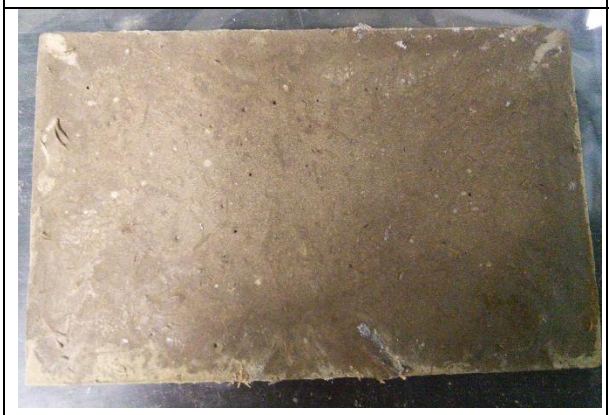
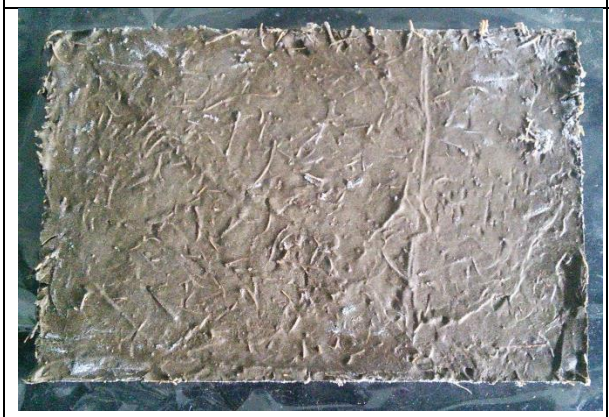
SEM is a type of electron microscope that scans the samples to be reviewed by focusing beam of electron to produce images of the samples. Various signals produced when the electron interact with atoms in the sample which can be detected and providing the details of sample's surface topography and composition. In this research, the fresh sample then will be zoomed into nano-scale to do the analysis upon the deeper structure of the composites as well the fractured sample, sample from water absorption test as well from the heat resistance test.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Sample Surface Observation

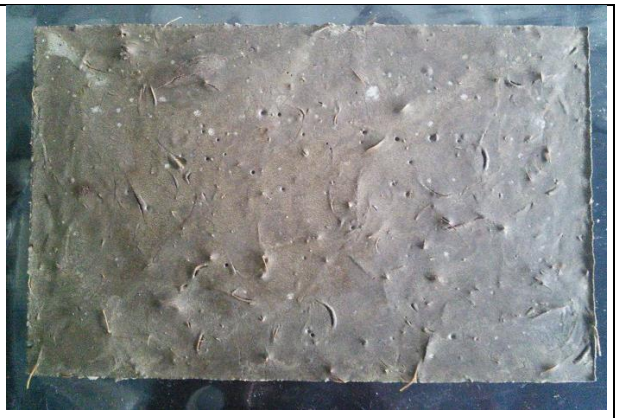
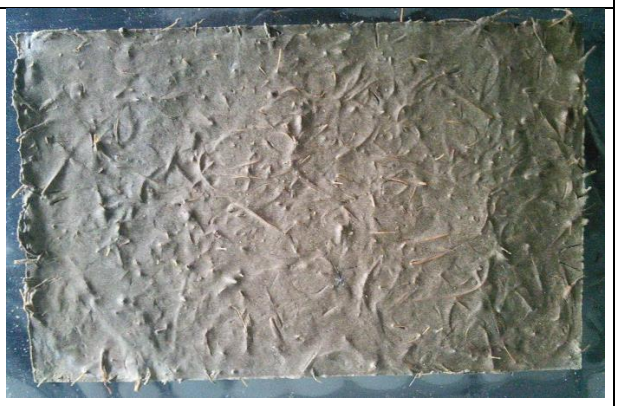
The pictures below show the front surface of 5mm fibre length of geopolymer matrix in ascending from 0% to 5% of coir composition in the front view.

Table 4.1: List of diagram showing the surface of the matrix for 5mm fibre length.

	
0% of coir fibre composition	1% of coir fibre composition
	
2% of coir fibre composition	3% of coir fibre composition
	
4% of coir fibre composition	5% of coir fibre composition

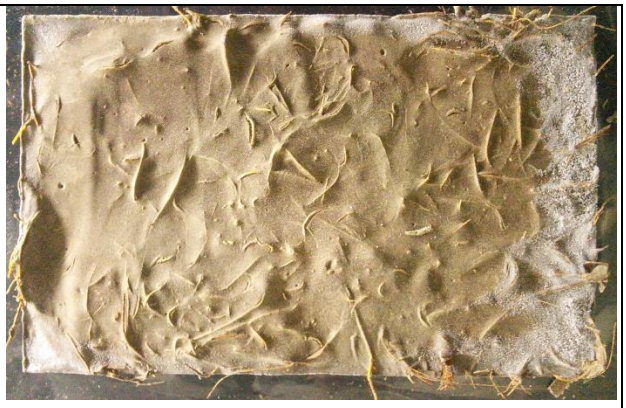
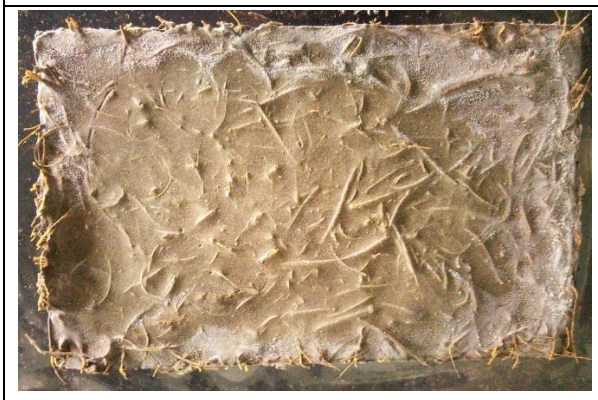
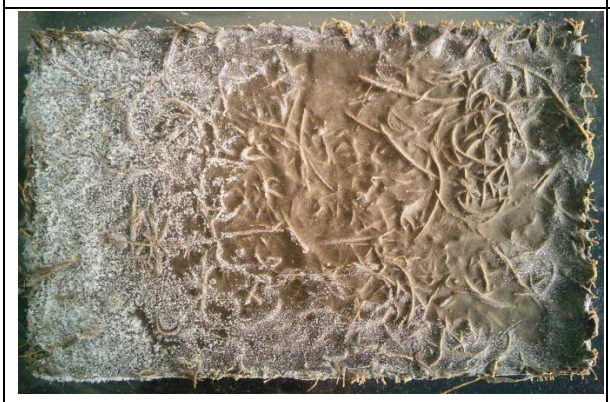
The pictures below show the front surface of 10mm fibre length of geopolymer matrix in ascending from 0% to 5% of coir composition in the front view.

Table 4.2: List of diagram showing the surface of the matrix for 10mm fibre length.

	
0% of coir fibre composition	1% of coir fibre composition
	
2% of coir fibre composition	3% of coir fibre composition
	
4% of coir fibre composition	5% of coir fibre composition

The pictures below show the front surface of 20mm fibre length of geopolymer matrix in ascending from 0% to 5% of coir composition in the front view.

Table 4.3: List of diagram showing the surface of the matrix for 20mm fibre length.

	
0% of coir fibre composition	1% of coir fibre composition
	
2% of coir fibre composition	3% of coir fibre composition
	
4% of coir fibre composition	5% of coir fibre composition

The pictures below show the front surface of 30mm fibre length of geopolymer matrix in ascending from 0% to 5% of coir composition in the front view.

Table 4.4: List of diagram showing the surface of the matrix for 30mm fibre length

	
0% of coir fibre composition	1% of coir fibre composition
	
2% of coir fibre composition	3% of coir fibre composition
	
4% of coir fibre composition	5% of coir fibre composition

From this observation, we can see the surface of the matrix become rougher gradually with the composition of the coir. The degree of the roughness is determined based on the visible amount of coir fibre bulging on the surface. It is also influenced by the length of the fibre itself. Takes, for example, 5% of coir composition of fibre with the length of 5mm is much had quite smoother than 5% of coir composition of fibre with the length of 3mm. This shows that the longer the length of fibre coir used, the matrix will become rougher as the length will denser the matrix with the coir, since the longer fibre make up a large space compared to the shorter. It also displaces some of the geopolymers during the molding process due to that reason that perhaps might also influence the mechanical strength of the matrix.

This observation gives significance in the term of the right proportion of preparing the matrix as the composition of coir fibre in the matrix based on the solid mass which is shown in the Appendices. The acceptable proportion is based on the roughness and the dense of the coir fibre in the matrix. The acceptable term is being used instead the right due to the fact that it is invalid to determine the right proportion of fibre coir with the ash fly based on the surface observation neglecting the mechanical strength value that obtained from the flexural testing as well with the water absorption testing that determine the rate of water intake by the matrix. The acceptable proportion for 5mm and 10mm fibre length is around than 5% of the solid mass composition. Meanwhile for the 20mm fibre length, the suitable proportion is 2% of the solid mass composition. As for 30mm, fibre length is limited to 1% of the solid mass composition and below.

4.2 Flexural Test

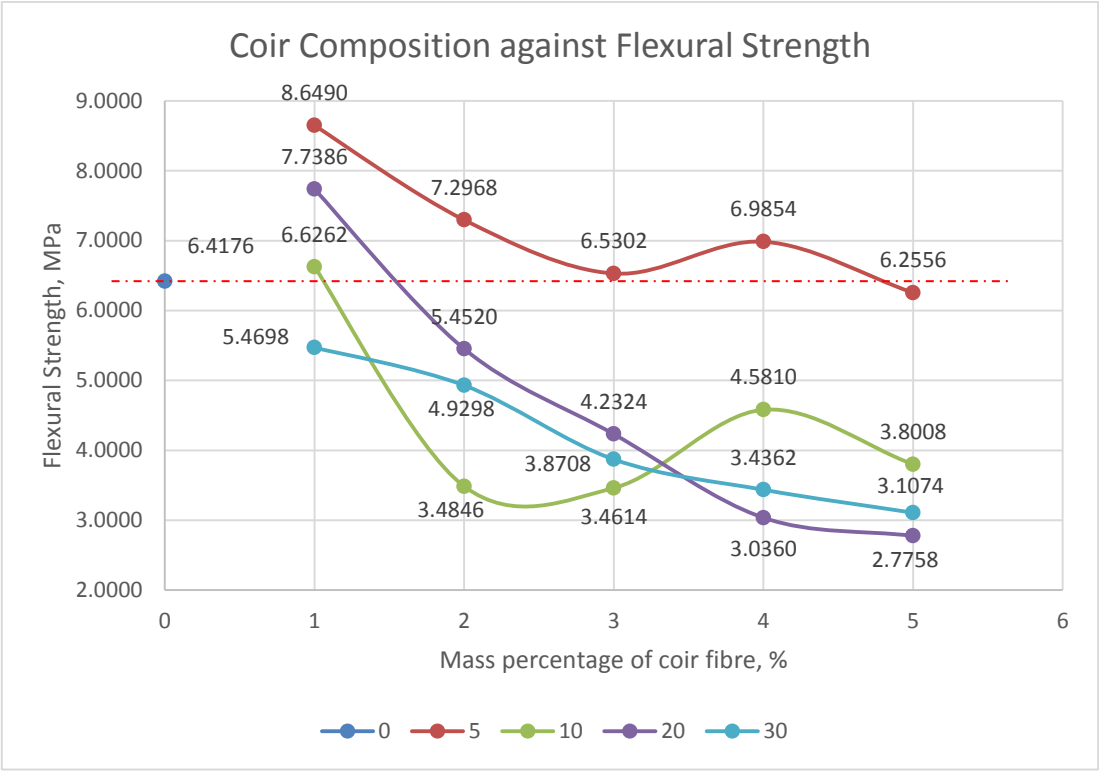


Figure 4.1: Graph of Flexural Strength test data

The graph above is showing the result of flexural test to determine between two distinctive manipulative variables which are the fibre lengths and the composition of coir in the matrix against the flexural strength. All the data is being compared to control specimen which is the ordinary geopolymer matrix without any coir fibre. The blue dot is representing the control specimen meanwhile the red, green, purple and blue representing 5mm, 10mm, 20mm and 30mm coir fibre length respectively. From the graph, most of the data shows the decrease in trend of flexural strength as the increment of composition except for 5mm at 4% of coir mass composition and 30mm at 3% and 4% of coir mass composition. Theoretically, the increment of coir composition will decreased the flexural strength due to the loose pack arrangement of matrix inside as the coir fibre will consume volume of the matrix.

However, when comparing to the control specimen, 5mm, 10mm and 20mm fibre length at 5% mass coir composition shows improvement in terms of strength. Since the presence of fibre will increase the resistance to breaking due to the distribution of the stress and also support provided by the fibre. As the composition increases, only 5mm fibre length enhances the geopolymer up to 4% of mass coir composition while others fail. Meanwhile, 10mm fibre length shows drastically decrease and gradually increases which explained later through SEM analysis. As for 20mm and 30mm fibre length, the flexural decrease gradually. Surprisingly, 20mm fibre length shows the lowest flexural strength at 5% of coir fibre length.

Comparing to Alida and et al. (2011) conducted similar application of coir fibre and test but using the OPC, the flexural strength trend increasing up to 9% wt coir fibre composition unlikely to this research is limited to 5% wt of coir composition. However, their research are added to sand as their aggregates thus increasing the strength instead using coir fibre completely. T. Alomayri (2013) meanwhile obtained similar trend fibre limitation strength enhancement. In his research, the compressive strength is increased up to 0.5% wt of cotton fibre and decreased beyond that composition. Although, T. Alomayri using different natural fibre and different testing, however, it sufficiently validate that natural fibre can only enhance for a certain composition percentage and fail when the composition percentage are beyond to that point.

4.3 Water Absorption Test

Meanwhile, the lowest water absorption rate is expected at shortest fibre length and lowest fibre composition. As it is believed that the long fibre will create cluster, resulting the increasing of space voids in the composite. These space voids become the space where the water tends to be contained. However, a dense composite with coir fibre do not really promising low absorption of water since coir fibre has hydrophilic characteristic.

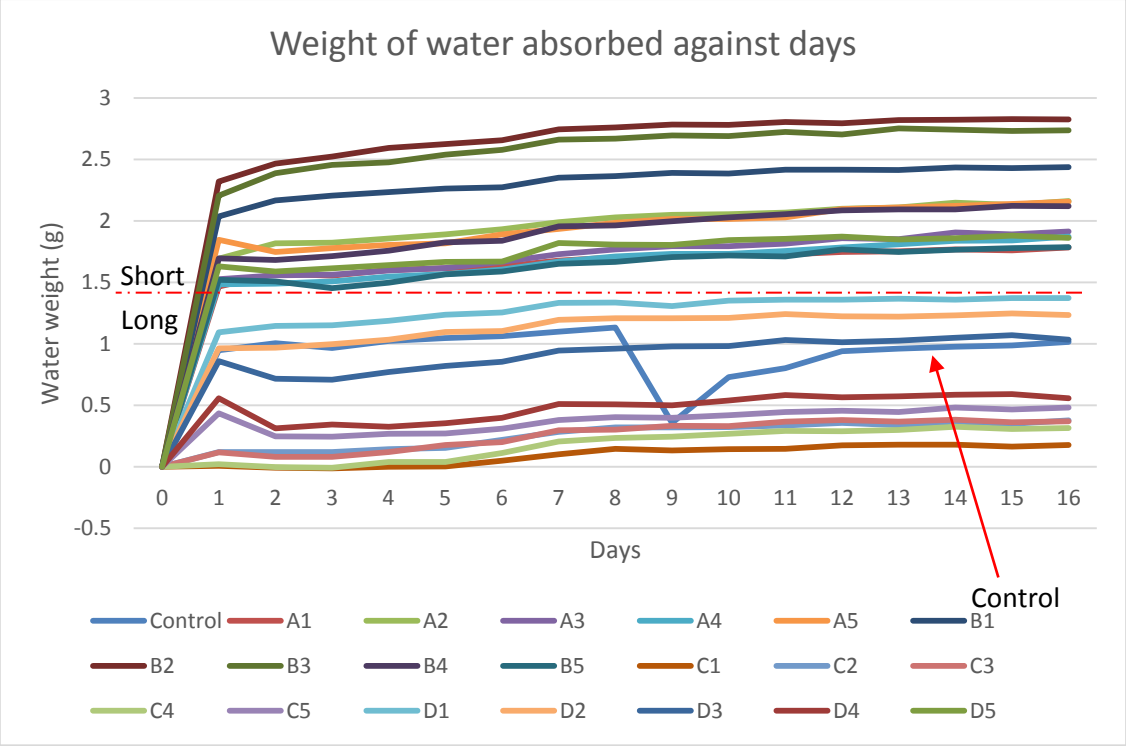


Figure 4.2 Graph of fibre length and composition against water weight for 16 days

The graph in figure 4.5 represent the data of all variable parameters against the water absorption for 16 days. This graph is not represent the diffusivity of water of the matrix however, it represent the water intake that the matrix can hold for a certain period. The alphabet is representing the length of the fibre. The value of fibre length for A, B, C and D are 5mm, 10mm, 20mm and 30mm respectively. Meanwhile, the number stand for the composition of the fibre. The value of coir composition for 1, 2, 3, 4 and 5 are 1%, 2%, 3%, 4% and 5% respectively. According to the theory, as mention previous, the water intake should be lower for those who has the lowest composition of coir and shortest fibre length. Surprisingly, the graph shows contradiction to the theory. Comparing the result obtained by Alida and her team (2011), this result is totally contradicted with their result. According to their findings, the moisture content which we can interpret as the water intake, is increasing according to the increment of fibre composition.

The lowest water absorption for 16 days is C1 which has 20mm fibre length with 1% of coir composition. This is followed by C4, C3, C2, C5, D4 and D3. All this matrix has lower water absorption comparing to the control. The red line represents the partition of the matrix between long lengths with the short length type. As for the composition, it does not significantly contribute to the factor of water intake according to the graph. However, the

graph is not accurate to describe alone the water absorption in the composite since perhaps the thickness and the dimension might have varied from each other. Thus, in order to improve the data, we can develop diffusivity graph.

As for the diffusivity, we used the Equation 3.8 to calculate the diffusivity of the composite matrix. The calculation is being shown in the appendix.

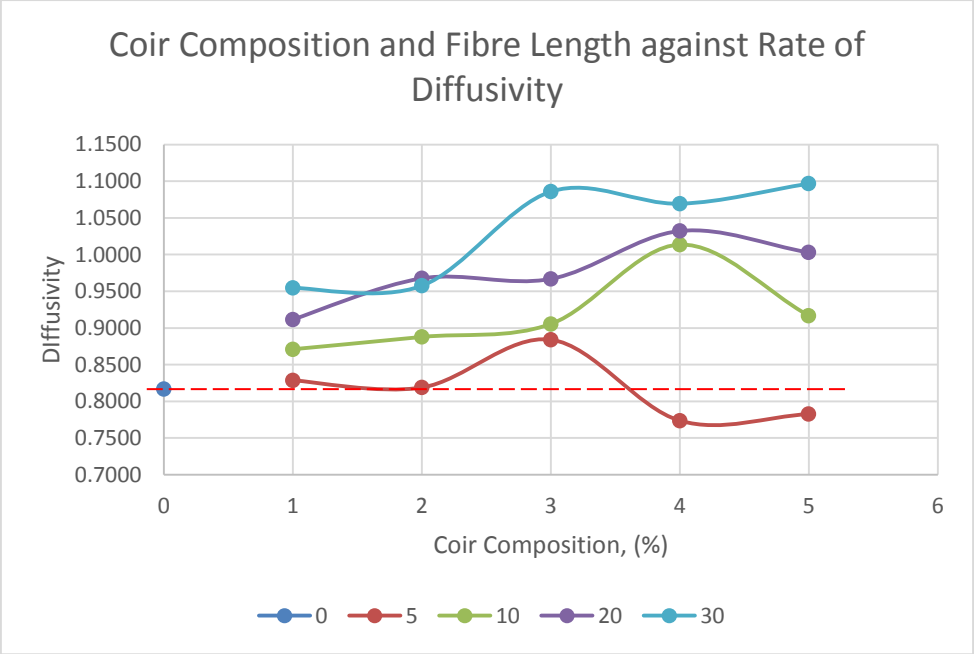


Figure 4.3: Graph of fibre length and coir mass composition against diffusivity rate.

In order to understand the graph, we need to understand the components of the graph first. The x-axis represents the coir composition which later be sorted into a trendline according to their fibre length. Red, green, purple and blue line represent 5mm, 10mm, 20mm and 30mm fibre length respectively. Meanwhile, the blue dots are the control specimen. From the graph, we can observed that longer fibre length will increase the rate of diffusivity of water into the matrix. Most of the trend line described that the increment of mass coir composition will increase the rate diffusivity of the matrix also. This due to the properties of the coir itself that possess hydrophilic fibre. However, at certain point, there are slight decreased at 5mm length fibre, 2% of mass coir composition, 30mm length fibre, 2% of mass coir composition and at 20mm fibre length, 3% of mass coir composition.

However, it is not significantly enough as we can neglect due to the matrix preparation defect. We should focus more on 5mm fibre length from 3% up to 5% of mass coir composition. This perhaps due dense of coir fibre and well-distributed fibre across the matrix causing the fibre to mix well with the geopolymer limiting the space for fibre absorb water as well it treated the porosity within the matrix. This can also be verified by observed the 5mm trendline is close to the control line.

In order to understand the contradiction of our results in graph 4.2 with the theory, we need to analyse the mass loss after the water absorption test is done.

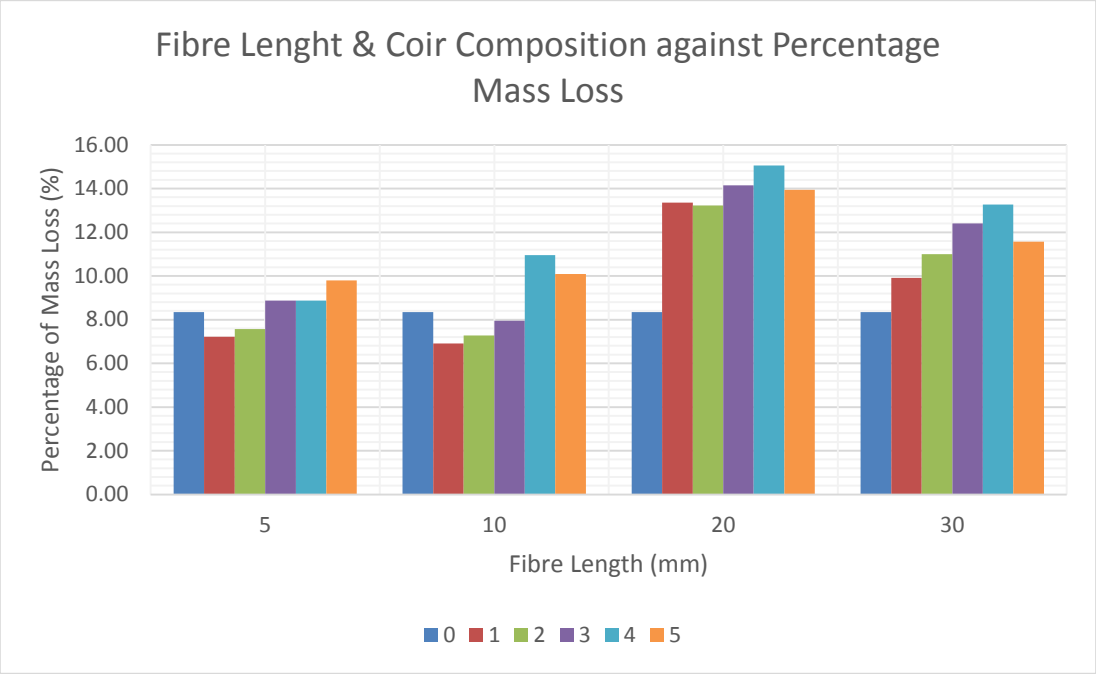


Figure 4.4: Graph of fibre length and coir composition against percentage mass loss

The legend key is described the mass composition of the coir fibre which are 0%, 1%, 2%, 3%, 4% and 5%. The data is categorised according to the fibre lengths from 5mm to 30mm. As the y-axis are the data obtained from the percentage of the different between the initial mass of the matrix with the final mass. From the graph, we can observed that longer fibre length experienced the highest mass loss compare to the shorter fibre length. Generally, all fibre length exhibit a same trend of mass loss percentage, as it shows an increment of mass loss to water surrounding in accordance to the increment of the mass composition of coir fibre. However, there are slightly change for 20mm and 30mm, as 4% of coir fibre composition experience the greatest mass loss. When comparing to the control specimen which are the 0% coir fibre mass composition, the length fibre 5mm and 10mm indicate an

improvement in terms of the mass loss. For 5mm fibre length, 1% and 2% face lower mass loss comparing to the control meanwhile for 10mm fibre length, 1% up to 3% are having lower mass loss too.

This data will affect the water absorption test as it needs to be included in the analysis. Thus, the data for the water absorption test in figure 4.2 need to do an adjustment to have a precise view of the water absorption on coir fibre geopolymer composite. The mass loss data should be included in the water absorption data to obtain the precise water weight.

4.4 Scanning Microscope Electron (SEM)

The SEM analysis is used to observe the surface of the fracture inside the matrix. In this analysis, 4 fractured samples are being used which are the control specimen, 2% composition with 10mm fibre length, 3% composition with 10mm fibre length and 3% composition with 20mm fibre length. As previously in flexural test, the strength become weak as the coir fibre is presence inside the matrix. From the SEM analysis, we know that coir fibre disrupt the arrangement of geopolymer making a gap between the fibre as we can observe from each of the specimen that have coir fibre.

Meanwhile, as the composition increased, the surface of the fracture shows the presence of coir fibre increased which can be interpreted as the density inside the matrix is increased. From the pictures, we can see the fibre pull out that happened when a stress is being loaded on the specimen, this fibre pull out increased the strength by giving the resistance to structure to break. This mainly can be observed through a dark hole that presence.

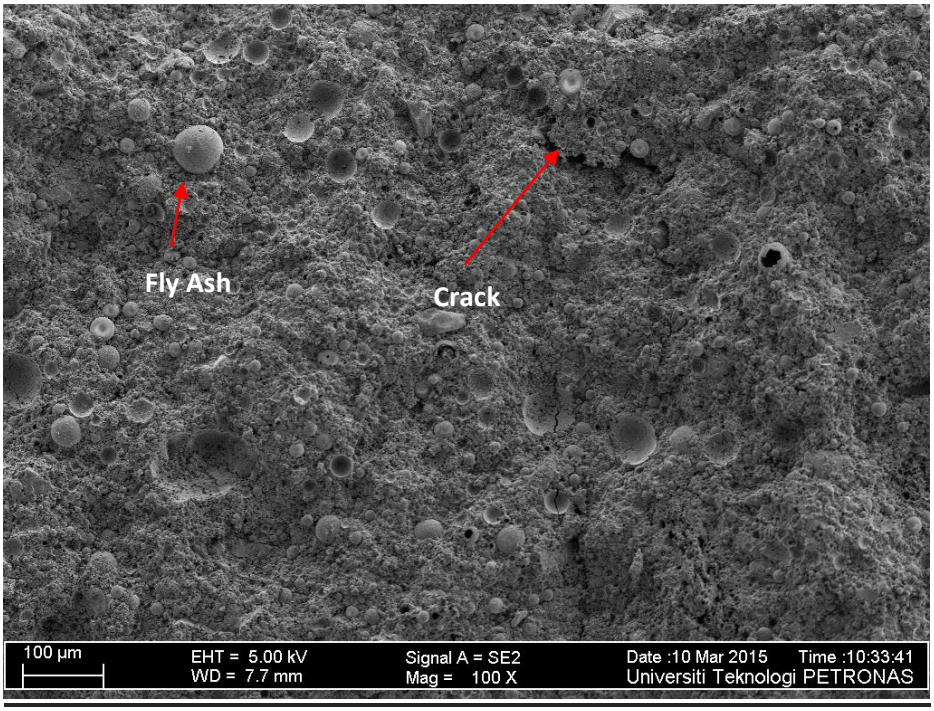


Figure 4.5: Control specimen

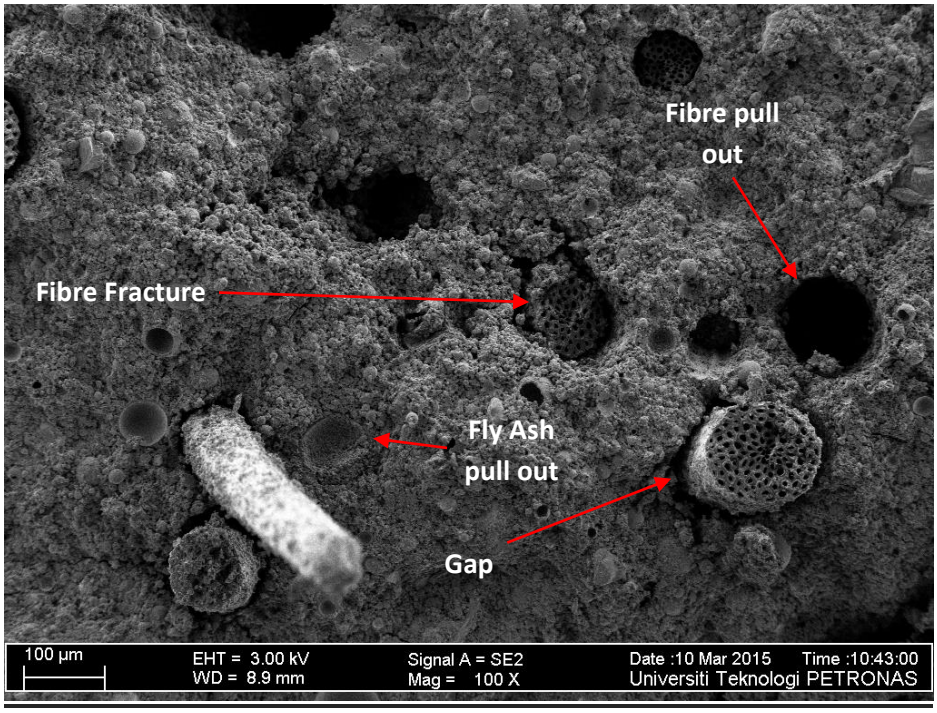


Figure 4.6: 2% coir fibre composition with 10mm fibre length

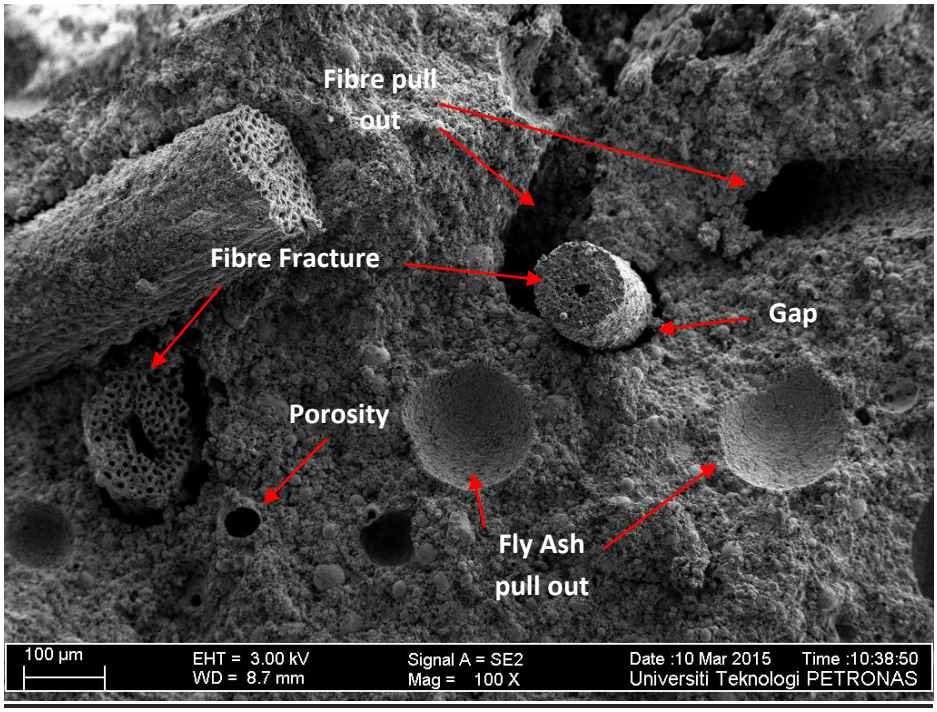


Figure 4.7: 3% coir fibre composition with 10mm fibre length

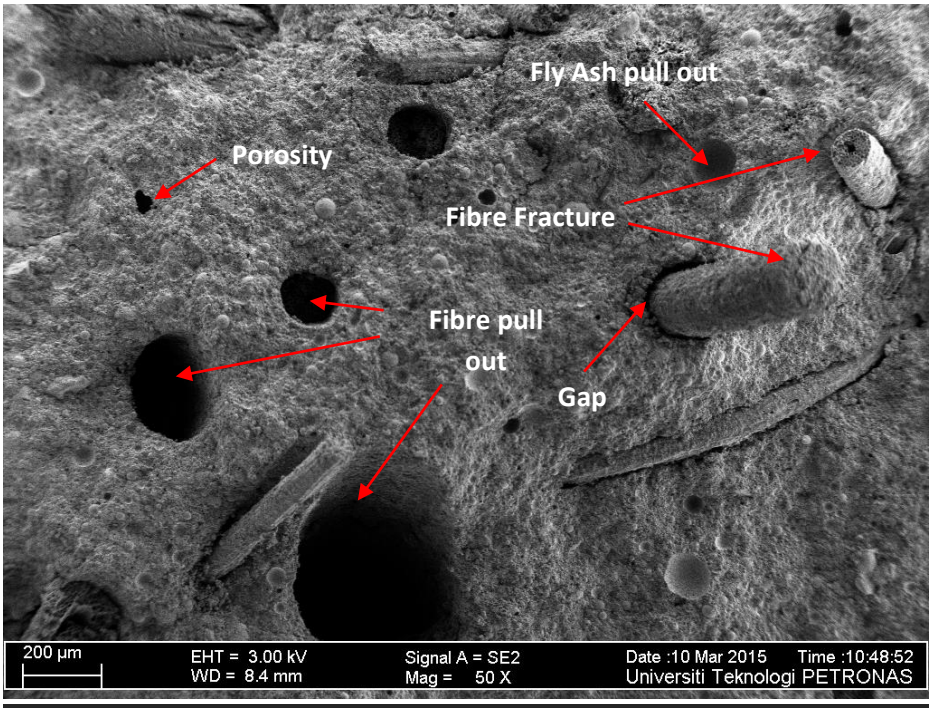


Figure 4.8: 3% of fibre composition with 20mm fibre length

Meanwhile, when we compare the control specimen with coir fibre enhanced geopolymer specimen, we can justify the reason of the decreasing flexural strength. From the flexural data, the presence of coir fibre inside the geopolymer reduces the strength. As we can observe from the SEM, the control specimen almost has none porosity. However, the presence of coir fibre developed many porosities and enlarge according to the fibre length although it already is filled with coir fibre. This is happening due to the water intake competition, as the both coir fibre and fly ash is absorbing water from the sodium hydroxide solution. This causing the fly ash to unevenly dispersion creating the hole as deficiency of water occurred which later is being filled by coir fibre. Yet, this SEM analysis only can described the oddity result in flexural graph 4.1 at 10mm fibre length on 2% and 3% mass coir fibre composition and comparison the highly different flexural strength between 10mm with 20mm fibre length on the same 3% coir fibre mass composition.

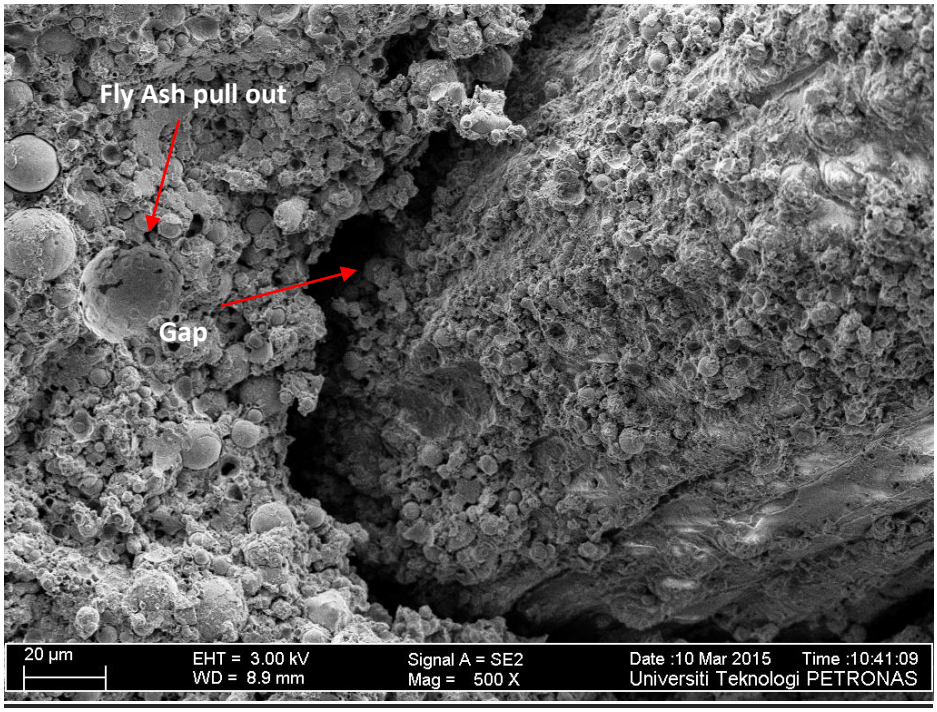


Figure 4.9: The surface of coir fibre

The picture above shows that the coir fibre is fully coated with geopolymer, thus it is shows that the coir fibre is mix well with the geopolymer paste. Thus, approving that coir fibre is well mixed with the geopolymer.

CHAPTER 5: CONCLUSION & RECOMMENDATION

5.1 Conclusion

From the result that already being discussed in previous chapter, we can conclude the presence of coir fibre inside the geopolymer can increased the mechanical strength of the geopolymer. However, when looking in terms water absorptivity, the enhanced matrix is only for 5mm fibre length on 4% to 5% coir mass composition. The best improvement of the matrix mainly focusing on the strength which later follow by the water absorptivity. Thus, the best improvement matrix is 1% of coir mass composition with 5mm fibre length. This finding can be applied for the structural purpose such as wall. As for the enhanced matrix in terms of water absorptivity can be analyse further for their density to look the possibility of application for water resistance structural purpose such as dropped ceiling.

This project might be a new project as it never been proposed before. Although the geopolymer is being vigorously analyse yet the combination of coir fibre with the geopolymer not yet being introduced. Thus, this project can give an idea for deeper analysis in the future. It is a hope that the project will be acknowledged by the community of chemical engineers, providing another research into developing to other new product based on the new materials idea and give benefits to public by giving them a cheaper product in ensuring maintain their living standard.

5.2 Recommendation

For future analysis, this research methodology needs to improvise mainly on the matrix preparation. As the coir fibre is volume consuming that making the matrix preparation harder, a new method of preparation need to be developed. Another consideration needs to be noted as the coir fibre has hydrophilic properties, the will be water intake competition between coir fibre and ash fly. Ash fly required sodium hydroxide to be activated, however, partial of the sodium hydroxide is being absorbed into the coir fibre. Thus, the coir fibre should be treated to reduce its hydrophilic properties first before mix into the paste.

As for the mechanical strength analysis, the compression testing might give the precise data comparing to the flexural testing since this composite matrix is quite brittle and easily to crack. It is recommended for those who intend to further this research to perform

other properties testing to determine the prospect properties that valuable such as acoustical test and heat resistance test. From this testing, we can develop suitable products that serve specifically according optimum the properties of this composite.

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APPENDICES

Appendix A: Calculation of the mass percentage of the composition for the fibre usage in the preparation process.

$$Mass\ of\ liquid = 3\ \times Mass\ of\ solid \qquad Mass\ of\ coir = Mass\ of\ solid\ \times fibre\ composition\ \%$$

Appendix B: Thickness of matrix.

	h_1	h_2	$h_{average}$
Control	4.25	4.07	4.16
A1	4.39	4.05	4.22
A2	4.24	4.1	4.17
A3	4.75	4.55	4.65
A4	4.55	4.292	4.42
A5	5.498	5.491	5.49
B1	4.482	4.389	4.44
B2	4.381	4.661	4.52
B3	4.768	4.454	4.61
B4	5.713	4.992	5.35
B5	4.944	5.021	4.98
C1	5.065	4.219	4.64
C2	5.181	4.674	4.93
C3	4.977	4.87	4.92
C4	5.491	5.021	5.26
C5	5.052	5.267	5.16
D1	4.43	5.293	4.86
D2	5.408	4.344	4.88
D3	5.601	5.458	5.53

Table 6.1: Thickness of matrix data

The thickness is used for the diffusivity calculation. This thickness is taken from each side of the close to the width area. Since the thickness may be different, an average data need to be obtained.

The alphabet is stand for the length of the fibre. A, B, C and D are representing 5mm, 10mm, 20mm and 30mm respectively. Meanwhile the number is stand for the mass composition of the coir. 1, 2, 3, 4 and 5 are representing 1%, 2%, 3%, 4% and 5% of mass coir fibre composition.

Appendix C: Water Absorption test data

Table 6.2: Water Absorption test data 1

Fibre Length (mm)	Mass Composition (%)	Day / Total Mass (g)										
		0	1	2	3	4	5	6	7	8	9	10
Control	0	31.177	32.127	32.182	32.145	32.201	32.224	32.241	32.277	32.311	31.536	31.907
5	1	30.464	31.932	32.035	32.020	32.065	32.079	32.096	32.141	32.167	32.181	32.197
	2	30.495	32.188	32.312	32.318	32.352	32.387	32.429	32.486	32.525	32.544	32.550
	3	33.263	34.791	34.822	34.827	34.859	34.881	34.930	34.993	35.033	35.058	35.058
	4	31.570	33.054	33.059	33.078	33.117	33.139	33.174	33.241	33.282	33.303	33.302
	5	39.672	41.520	41.420	41.450	41.477	41.490	41.562	41.607	41.658	41.687	41.687
10	1	31.800	33.837	33.966	34.006	34.035	34.064	34.073	34.151	34.166	34.191	34.187
	2	32.571	34.891	35.037	35.096	35.166	35.196	35.227	35.315	35.331	35.356	35.353
	3	32.346	34.553	34.734	34.802	34.823	34.885	34.924	35.007	35.015	35.042	35.036
	4	36.868	38.564	38.550	38.581	38.627	38.694	38.707	38.823	38.831	38.866	38.896
	5	36.081	37.603	37.589	37.534	37.579	37.646	37.671	37.732	37.747	37.788	37.800
20	1	37.459	37.469	37.453	37.448	37.460	37.462	37.510	37.562	37.606	37.592	37.603
	2	37.100	37.221	37.222	37.222	37.245	37.254	37.321	37.386	37.421	37.421	37.423
	3	37.849	37.968	37.932	37.932	37.969	38.028	38.050	38.146	38.153	38.184	38.181
	4	36.262	36.285	36.261	36.256	36.301	36.303	36.374	36.469	36.497	36.509	36.532
	5	37.843	38.279	38.091	38.088	38.111	38.115	38.153	38.224	38.247	38.242	38.262
30	1	35.522	36.617	36.668	36.673	36.710	36.761	36.777	36.856	36.858	36.831	36.874
	2	35.574	36.538	36.544	36.572	36.609	36.670	36.678	36.771	36.783	36.782	36.786
	3	38.380	39.240	39.098	39.089	39.152	39.201	39.236	39.325	39.343	39.359	39.363
	4	39.688	40.247	40.001	40.034	40.014	40.043	40.088	40.200	40.198	40.189	40.227
	5	35.300	36.932	36.889	36.915	36.942	36.967	36.971	37.122	37.109	37.104	37.145

Appendix C: Water Absorption test data (CONT')

Table 6.2: Water Absorption test data 1.

Fibre Length (mm)	Mass Composition (%)	Day / Total Mass (g)					
		11	12	13	14	15	16
Control	0	31.980	32.117	32.139	32.155	32.165	32.193
5	1	32.191	32.213	32.217	32.233	32.226	32.248
	2	32.563	32.595	32.605	32.643	32.625	32.658
	3	35.078	35.122	35.116	35.169	35.153	35.178
	4	33.325	33.354	33.381	33.409	33.412	33.442
	5	41.700	41.769	41.782	41.796	41.811	41.828
10	1	34.216	34.216	34.214	34.236	34.230	34.238
	2	35.375	35.366	35.391	35.394	35.400	35.396
	3	35.069	35.050	35.098	35.088	35.078	35.083
	4	38.922	38.954	38.963	38.961	38.990	38.988
	5	37.793	37.849	37.828	37.848	37.860	37.869
20	1	37.605	37.634	37.640	37.639	37.625	37.637
	2	37.437	37.457	37.440	37.467	37.449	37.478
	3	38.217	38.230	38.216	38.234	38.213	38.220
	4	36.554	36.553	36.562	36.589	36.571	36.578
	5	38.290	38.301	38.290	38.326	38.310	38.327
30	1	36.883	36.881	36.891	36.883	36.894	36.894
	2	36.816	36.799	36.797	36.806	36.821	36.808
	3	39.412	39.393	39.408	39.430	39.450	39.414
	4	40.273	40.254	40.263	40.274	40.279	40.245
	5	37.155	37.172	37.149	37.159	37.181	37.163

In order to find the mass of water, the mass on day , d is subtracted with the initial mass. Thus, by doing this, we can tabulate data as below to develop graph for water absorption for 16 days.

Appendix C: Water Absorption test data (CONT')

Table 6.3: Water Absorption test data 2.

Fibre Length (mm)	Mass Composition (%)	Day / Water Mass (g)										
		0	1	2	3	4	5	6	7	8	9	10
Control	0	0	0.95	1.005	0.968	1.024	1.047	1.064	1.1	1.134	0.359	0.73
5	1	0	1.468	1.571	1.556	1.601	1.615	1.632	1.677	1.703	1.717	1.733
	2	0	1.693	1.817	1.823	1.857	1.892	1.934	1.991	2.03	2.049	2.055
	3	0	1.528	1.559	1.564	1.596	1.618	1.667	1.73	1.77	1.795	1.795
	4	0	1.484	1.489	1.508	1.547	1.569	1.604	1.671	1.712	1.733	1.732
	5	0	1.848	1.748	1.778	1.805	1.818	1.89	1.935	1.986	2.015	2.015
10	1	0	2.037	2.166	2.206	2.235	2.264	2.273	2.351	2.366	2.391	2.387
	2	0	2.32	2.466	2.525	2.595	2.625	2.656	2.744	2.76	2.785	2.782
	3	0	2.207	2.388	2.456	2.477	2.539	2.578	2.661	2.669	2.696	2.69
	4	0	1.696	1.682	1.713	1.759	1.826	1.839	1.955	1.963	1.998	2.028
	5	0	1.522	1.508	1.453	1.498	1.565	1.59	1.651	1.666	1.707	1.719
20	1	0	0.01	-0.006	-0.011	0.001	0.003	0.051	0.103	0.147	0.133	0.144
	2	0	0.121	0.122	0.122	0.145	0.154	0.221	0.286	0.321	0.321	0.323
	3	0	0.119	0.083	0.083	0.12	0.179	0.201	0.297	0.304	0.335	0.332
	4	0	0.023	-0.001	-0.006	0.039	0.041	0.112	0.207	0.235	0.247	0.27
	5	0	0.436	0.248	0.245	0.268	0.272	0.31	0.381	0.404	0.399	0.419
30	1	0	1.095	1.146	1.151	1.188	1.239	1.255	1.334	1.336	1.309	1.352
	2	0	0.964	0.97	0.998	1.035	1.096	1.104	1.197	1.209	1.208	1.212
	3	0	0.86	0.718	0.709	0.772	0.821	0.856	0.945	0.963	0.979	0.983
	4	0	0.559	0.313	0.346	0.326	0.355	0.4	0.512	0.51	0.501	0.539
	5	0	1.632	1.589	1.615	1.642	1.667	1.671	1.822	1.809	1.804	1.845

Appendix C: Water Absorption test data (CONT')

Table 6.3: Water Absorption test data 2.

Fibre Length (mm)	Mass Composition (%)	Day / Water Mass (g)					
		11	12	13	14	15	16
Control	0	0.803	0.94	0.962	0.978	0.988	1.016
5	1	1.727	1.749	1.753	1.769	1.762	1.784
	2	2.068	2.1	2.11	2.148	2.13	2.163
	3	1.815	1.859	1.853	1.906	1.89	1.915
	4	1.755	1.784	1.811	1.839	1.842	1.872
	5	2.028	2.097	2.11	2.124	2.139	2.156
10	1	2.416	2.416	2.414	2.436	2.43	2.438
	2	2.804	2.795	2.82	2.823	2.829	2.825
	3	2.723	2.704	2.752	2.742	2.732	2.737
	4	2.054	2.086	2.095	2.093	2.122	2.12
	5	1.712	1.768	1.747	1.767	1.779	1.788
20	1	0.146	0.175	0.181	0.18	0.166	0.178
	2	0.337	0.357	0.34	0.367	0.349	0.378
	3	0.368	0.381	0.367	0.385	0.364	0.371
	4	0.292	0.291	0.3	0.327	0.309	0.316
	5	0.447	0.458	0.447	0.483	0.467	0.484
30	1	1.361	1.359	1.369	1.361	1.372	1.372
	2	1.242	1.225	1.223	1.232	1.247	1.234
	3	1.032	1.013	1.028	1.05	1.07	1.034
	4	0.585	0.566	0.575	0.586	0.591	0.557
	5	1.855	1.872	1.849	1.859	1.881	1.863

Appendix D: Calculation of water diffusivity

By using the below formula, we can find the diffusivity of the matrix:

$$\frac{M_t}{M_\infty} = 4\left[\frac{Dt}{\pi h^2}\right]^{1/2}$$

Table 6.4: Water diffusivity data

Sample	M_t	M∞	T, hr	$h_{average}$	D
Control	1.319	1.319	1	4.16	0.81692
A1	1.619	1.619	1	4.22	0.828703
A2	1.899	1.899	1	4.17	0.818884
A3	1.701	1.757	1	4.65	0.88404
A4	1.499	1.682	1	4.42	0.773717
A5	1.434	1.977	1	5.49	0.782631
B1	2.243	2.243	1	4.44	0.871021
B2	2.64	2.64	1	4.52	0.887811
B3	2.601	2.601	1	4.61	0.905485
B4	1.839	1.907	1	5.35	1.013617
B5	1.56	1.665	1	4.98	0.916735
C1	0.473	0.473	1	4.64	0.911573
C2	0.593	0.593	1	4.93	0.967638
C3	0.596	0.596	1	4.92	0.966852
C4	0.476	0.476	1	5.26	1.032147
C5	0.682	0.689	1	5.16	1.002903
D1	1.504	1.504	1	4.86	0.954677
D2	1.341	1.341	1	4.88	0.957525
D3	1.249	1.249	1	5.53	1.085856
D4	0.846	0.862	1	5.55	1.069362
D5	1.944	1.947	1	5.59	1.096633

The alphabet is stand for the length of the fibre. A, B, C and D are representing 5mm, 10mm, 20mm and 30mm respectively. Meanwhile the number is stand for the mass composition of the coir. 1, 2, 3, 4 and 5 are representing 1%, 2%, 3%, 4% and 5% of mass coir fibre composition.

Appendix E: Mass loss data.

Table 6.5: Mass loss data

Fibre Length (mm)	Mass Composition (%)	Initial Mass (g)	Final Mass (g)	Mass Loss (g)	Percentage Loss (%)
Control	0	31.177	28.575	2.602	8.346
5	1	30.464	28.266	2.198	7.215
	2	30.495	28.189	2.306	7.562
	3	33.263	30.314	2.949	8.866
	4	31.570	28.771	2.799	8.866
	5	39.672	35.789	3.883	9.788
10	1	31.800	29.601	2.199	6.915
	2	32.571	30.201	2.370	7.276
	3	32.346	29.774	2.572	7.952
	4	36.868	32.831	4.037	10.950
	5	36.081	32.443	3.638	10.083
20	1	37.459	32.456	5.003	13.356
	2	37.100	32.194	4.906	13.224
	3	37.849	32.496	5.353	14.143
	4	36.262	30.805	5.457	15.049
	5	37.843	32.569	5.274	13.937
30	1	35.522	31.999	3.523	9.918
	2	35.574	31.663	3.911	10.994
	3	38.380	33.621	4.759	12.400
	4	39.688	34.425	5.263	13.261
	5	35.300	31.215	4.085	11.572

Appendix F: Result of Flexural testing.

Table 6.6: Flexural test data

Fibre Length (mm)	Mass Composition (%)	Flexural Strength (MPa)
Control	0	6.4176
5	1	8.6490
	2	7.2968
	3	6.5302
	4	6.9854
	5	6.2556
10	1	6.6262
	2	3.4846
	3	3.4614
	4	4.5810
	5	3.8008
20	1	7.7386
	2	5.4520
	3	4.2324
	4	3.0360
	5	2.7758
30	1	5.4698
	2	4.9298
	3	3.8708
	4	3.4362
	5	3.1074