FABRICATION OF BINDER-LESS “GREEN” PARTICLE BOARD FROM OIL PALM RESIDUE

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CERTIFICATION OF APPROVAL

Fabrication of Binder-less “green” particle board using

oil palm residue

By

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A project dissertation submitted to the
Chemical Engineering Programme
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(CHEMICAL ENGINEERING)

Approved by,

____

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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 expect 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

(NOR HAZIQ NAQIUDDIN BIN HAMLI)

ABSTRACT

Nowadays, the energy demand in Malaysia has increase, so the alternative sources such as Oil Palm which leaves abundance of waste product such as Oil Palm Kernel Shell (PKS) and Oil Palm Frond (OPF). Many of the industries in Malaysia will burn the waste to generate electricity through steam. Although the burning of the waste product seems to have settle the problem, the increasing of the waste problem increase year by years which can be utilized into other product such as bio-composite materials. The content of lignocellulosic material inside the oil palm waste which is consists of cellulose, hemicelluloses and lignin. This is a greater possibility to reduce the solid-waste problem. Bio-composite material is very important nowadays because it can be used widely such as, replacing the petro-based plastic and used as once-use material. This is because; the bio-composite is biodegradable which is easy to dispose. Hence, the production of the bio-composite material by using oil palm waste is important and should be further study. From this project, through the three main analysis which is Fourier Transform Infrared (FT-IR), Thermalgravimetric Analysis (TGA) and Field Emission Scanning Electron Microscopy (FESEM), the particle board A show more preferable choice because the number of lignin-cellulose component inside the particle based on FTIR show higher compared to C and D while lower than B. Although the particle board A show lower composition than B, the FESEM result show lower pores volume compared to other. Thus, the particle board A is more preferable choice compared to particle B, C and D.

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CHAPTER 1: INTRODUCTION

1.1 Background study

This project is related to pre-treatment of oil palm biomass which is the waste product in the production of the palm oil such as Palm Oil kernel shell (PKS) and Oil Palm Frond (OPF). The production of palm oil increase as to overcome the demand of energy in Malaysia which is very high. In order to overcome the energy demand, a new source of renewable energy was implemented which is using palm oil. As the production of the palm oil increase, the waste from the production also increases. The waste product usually uses to generate electricity by burning the waste but the increasing of the waste years by years will give an extra waste. Hence, the way to utilize the waste product is by converting it into more useful other than burning all the waste which could reduce the environment issues. *Figure 1* shows that the possible way to utilize the biomass.

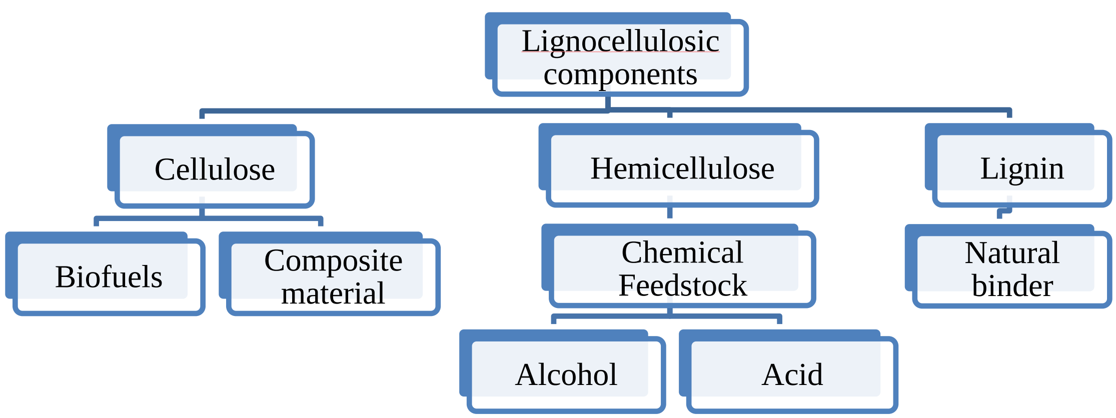


Figure 1: Possible way to utilize the biomass

There are three components which contains inside palm oil biomass which called Lignocellulosic material. The research shows that it has a high possibility to be used in other industries such as shown in *Figure 1* which one of the components cellulose that can be converted to biofuel which is the most crucial way to utilized palm oil biomass. Other than that, cellulose also use in the construction company which can be manufacture into particle board or other polymer. Hemicellulose is used to make alcohol and acids through fermentation process. In fermentation, the enzyme will break down the hemicellulose which undergoes aerobic or anaerobic reaction which produces acetic acid and lactic acid in the reaction to produce ethanol. For this project, the focus is on cellulose and lignin which have the function to manufacture composite material such as particle board. The function of lignin is to produce in-situ binder that binds together the PKS and OPF together to produce particle board.

This project focuses on Palm Oil because around 47% of the world's supply of Palm Oil came from Malaysia [1]. The continuous increasing in demand in Palm Oil, the number is predicted to be increasing years by years. One of the factors which make the increasing demand of palm oil is the production of bio-diesel. Bio-diesel becomes one of the important prospects for the world nowadays because of the certain characteristic which is environmental friendly and also energy supply security reasons. Other reasons for this Palm Oil bio-diesel becomes important to the world is that bio-diesel is biodegradable, non-toxic and also low emissions than petroleum-based diesel when burned which give a lot of benefit towards the environment

The oil palm is very popular plantation. It is originated from West Africa where it was growing wild and later developed as agricultural crop. The plantation is very suitable at tropical weather. Thus it can be cultivated easily in Malaysia. The production of the palm oil has been predicted to keep increasing as shown in *Table 1*. The prediction shows that, at the years 2016 – 2020 the production of palm oil increase around 37.7% which is estimated around 15,400 million tons per years and around 40,800 million tons per years for world total production.

Table 1: present and forecasted production of palm oil for year 2000 – 2020 in MnT

Year	Malaysia (MnT)
Annual Production	
2000	10,100 (49.3%)
2001	10,700 (48.1%)
2002	10,980 (48.4%)
2003	11,050 (47.7%)
2004	10,900 (45.6%)
2005	11,700 (45.6%)
Five-year averages	
1996 – 2000	9022` (50.3%)
2001 – 2005	11,066 (47.0%)
2006 – 2010	12,700 (43.4%)
2011 – 2015	14,100 (40.2%)
2016 – 2020	15,400 (37.7%)

As discuss above, Malaysia was one of the largest producer and exporter of Palm Oil and leading palm-oil producing country, the researcher will find the alternative way to utilize the biomass production which increase corresponding to the increasing of palm oil production. *Figure 2* shows that the initiatives of utilizing the biomass as renewable energy. *Table 2* stated the types of biomass and quality produced by the palm oil

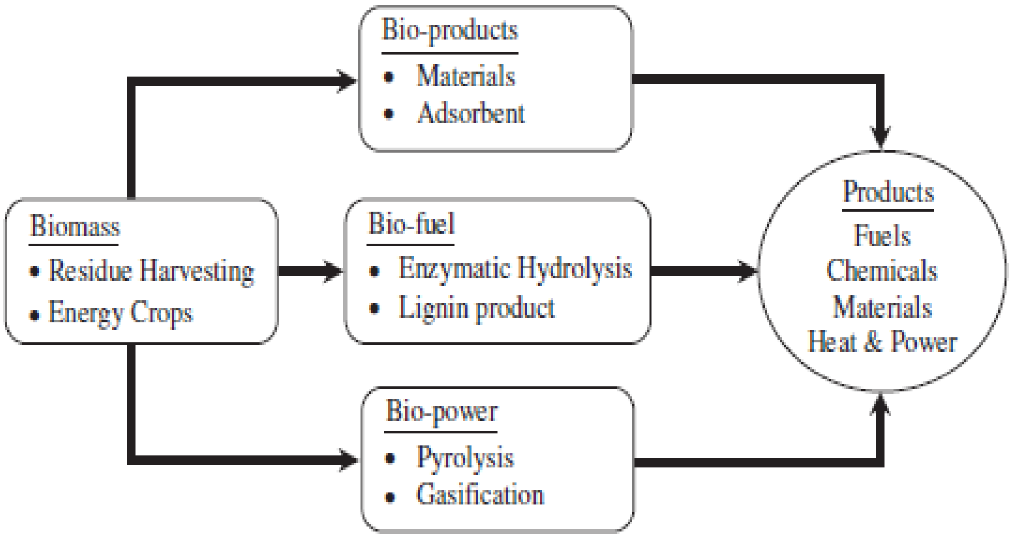


Figure 2: Biomass initiatives as renewable energy

Table 2: Types of biomass and quantity produced

No.	Type of Biomass	Quantity/annum (MnT)
1	Empty fruit bunch (EFB)	15.8
2	Fronds	12.9
3	Mesocarp fiber (MF)	9.6
4	Trunk	8.2
5	Shell	4.7

Biomass, in the industry is referring to the living and recently living biological material, which can be used as fuel of for industrial production. In *Figure 2*, Biomass can be obtained from the residue harvesting which in this case is the residue from the palm oil after the extraction of oil for example empty fruit bunch (EFB). Other way to obtain the biomass is by energy corps which for example, the ash from the palm oil used for burning process to generate electricity. All this biomass can be converted into bio-product, bio-fuels, and bio-power. In this project the biomass mostly focused on converting into bio-product which is bio-composite materials.

The analysis form the *Table 2* shows that, the quantity of the biomass produce from the palm oil is mainly Empty fruit bunch (EFB) which around 15.8 million tons per years follows by Oil Palm Fronds (OPF), Mescocarp fiber (MF) and Trunk with 12.9, 9.6 and 8.2 million tons per years respectively. Lastly is the production of Palm Oil Kernel Shell (PKS) with 4.7 million tons per years. Based on the statistical shows, the project will be using two of the largest biomass production which is OPF and PKS. This is because, the chosen biomass most probably suitable for the production of bio-product.

To prevent the global warming the reduction of the carbon emissions to the environment is very crucial. The burning of the biomass instead of fossil fuels as the energy source will reduce the carbon emission release. This shows that the oil palm biomass is important. Although the combustion of palm oil biomass not entirely contribute to the amount of carbon in the atmosphere, the amount of carbon release during the transportation to the certain destination. Nevertheless, biomass is regard as waste product and further utilization of the biomass product into the bio-product which make the country not dependable towards the perto-based materials which have similar characteristic which is in this project is the production of binder-less particle board.

This is because, the cellulose-based composites have become widely use in the construction company. This is because the natural properties of the cellulose as natural fiber or polymer inside the biomass. Thus, it will increase the price of wood product due to excessive deforestation. Hence, the research and development committee have to find an alternative way to reduce the deforestation and found a new lignocellulosic material. This project which deals with lignocellulosic material from the palm oil biomass can overcome this problem regarding increasing of the price for wood product. Furthermore, OPF have been found to have a potential in the production of the particle board without the adding of external binder and PKS can be made as a filler material which give extra lignin as the in-situ binder inside the particle board.

In this project, the Oil Palm Kernel Shell (PKS) and also Oil Palm Frond (OPF) used because inside the biomass containing cellulose, hemicelluloses and lignin that widely used in the production of bio-composite materials. Besides that, the PKS and OPF will mix together in certain ratio which was varied throughout the experiment. The particle board with different ratio of OPF and PKS was examined using Fourier Transform Infrared Spectroscopy (FTIR) to check the structure of the molecule. Besides that, Scanning Electron Microscopes (SEM) is used to find the morphology of the bio-composite materials. Other than that, the sample will undergo Thermogravimetric analysis (TGA) to identify at what temperature the samples will decompose and compare with conventional particle board which has been manufacture worldwide.

1.2 Problem Statements

As the production of Palm Oil increase, the waste products also increase and some of the industrial company tends to burn the waste products to generate electricity through steam. However, as the waste product from the palm oil plantation keep increasing years by years, an alternative way to utilize the waste product is needed. The biomass from the palm oil mainly from PKS and OPF has a potential to use as wood based particle board which is one way to utilize the biomass from oil palm. However, most of the particle board used a binder such as formaldehyde.

Formaldehyde that used as a binder derived from the petroleum resources which became scarce. Besides that, formaldehyde also classified as a known human carcinogen which can cause nasal sinus cancer. Other than that, the agricultural residue from palm oil industry has created environmental problem.

1.3 Objective

Based on the problem statements stated earlier, this project aim to produce the particle board from oil palm residue such as Oil Palm Frond (OPF) and Palm Oil Kernel Shell (PKS). The sample was varied using different ratio of OPF and PKS to see the various results. The summary of the main objective of the project is list as below:

1. Fabrication of “green particle board” from oil palm biomass without any external binder.
2. Performance analysis of the product by Fourier Transform Infrared (FT-IR) and Thermalgravimetric Analysis (TGA) techniques
3. Analyze the morphology under Field Emission Scanning Electron Microscopy (FESEM).
4. Compared the result with the conventional particle board.

1.4 Scope of Study

From the objective and throughout the discussion from the literature review, the scope of study for this project is to produce binder-less particle board which has the same characteristic as conventional particle board that can be uses as below:

1. Replace wood product
2. Easy dispose material
3. Reduce solid waste problem

1.5 Relevancy of Project

This project is important as it deals with the current issue in utilizing the waste product from the palm oil plantation other that burning it to generate electricity. The waste product can be in production of particle board by using three main components inside the waste product such as cellulose, hemicelluloses, and lignin which is call lignocellulosic materials. Hence, this project is relevant as the usage of biomass palm oil to be used as the bio-composite material is not been done commercially.

1.6 Feasibility of Project

This project is feasible as it deals with narrowed scope of experiments whereby only two type of biomass used to test the strength and characteristic of the composite material with different ratio of PKS and OPF. It is within the capability to be executed with the helps and guidance from the supervisor and the coordinator. It is positive that this project can be completed within the time allocated with the acquiring of equipment and materials needed.

CHAPTER 2: LITERATURE REVIEW

Nowadays, global warming becoming one of the main topics debated because it can be the greatest threat to the world community and it has been very challenging in reducing the effect towards global warming. One of the reasons is emission of CO_2 toward the surrounding. Malaysia is one of the largest producers of Palm Oil and generating huge quantities of the biomass. The only way to reduce the waste, most of the oil palm plantation industries tends to burn the waste to ash. Hence it will increase the emission of CO_2.

Todays, there are many alternative way to reduce the environmental effect is by converting it into renewable source such as biofuels and biocomposite material. The government of Malaysia has supported this action by enforcing the 5^{th} fuel policy. This policy stated that "To supplement the convetional energy supply, new sources such as renewable energy will encouraged and biomass such as oil palm, wood waste as well as rice husk will be used on the wider basis" [2]. This includes the different way to use the biomass from the palm plantation to produce biocomposite material.

For the past 8 years, Malaysia has become second largest palm oil industry which resulting the huge amount of biomass from its plantation. In the year 2006, Malaysia produces 15.88 million tonnes or 43% of the total supply as shown in *Figure 3*. With the growth of palm oil production, 50 – 70 tonnes of biomass residues from one hectar of oil palm plantation with the figure around 55.73 million tonnes of oil palm biomass was recorded.[3]. The type of biomass produced from oil palm industry includes OPEFB.

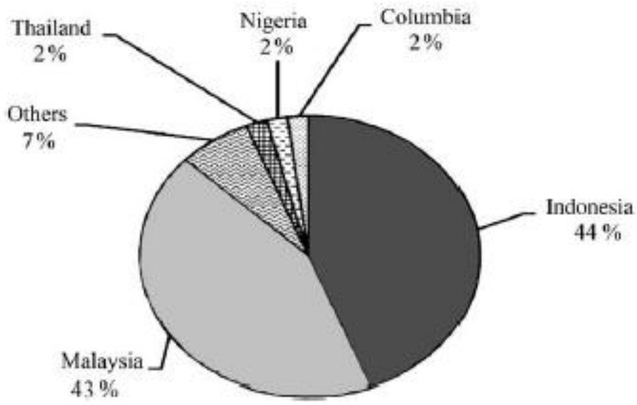


Figure 3: World producers of oil palm in 2006{3}

The important measurement for sustainability of oil palm biomass is the carbon balance for oil palm biomass utilization such as burning to generate energy [3]. To prevent the global warming the reduction of the carbon emissions to the environment is very crucial. The burning of the biomass instead of fossil fuels as the energy source will reduce the carbon emission release. This shows that the oil palm biomass is important. Although the combustion of palm oil biomass not entirely contribute to the amount of carbon in the atmosphere, the amount of carbon release during the transportation to the certain destination. Nevertheless, biomass is regard as waste product and further utilization of the biomass product into the bio-product which make the country not dependable towards the perto-based materials which have similar characteristic.

Some of the potential utilization of the palm oil biomass is EFB and frond which have been included in fibrous crop residue which easily makes it into hardwood or many more. The research shows that the morphology structure of the frond fibers in similar to the hardwood. Besides that, the examining on the physical and chemical structure for the frond also shows the comparable characteristic with the conventional hardwood. Other than that, the palm fiber can be used as thermoplastic and thermoset composite which has been use commercially by Malaysian national carmaker (PROTON) together with Palm Oil Research Institute of Malaysia (PORIM) to develop thermoplastic and thermoset composites and used it in the PROTON car [3].

The reason why the palm oil is suitable in the production of thermoplastic and thermoset composite or also known as bio-composite material is because of the present of lignocellulosic Material which is very commonly found in agricultural residues such as corn stove, wheat straw, palm oil biomass and many other biomass products. lignocellulosic biomass of palm oil contains cellulose, hemicellulose and lignin. This will contribute in the manufacture of bio-composite film has different properties. Composition of palm oil biomass is 37.3 – 46.5%, while hemicellulose and lignin content are 25.3 – 33.8% and 27.6 – 32.5% respectively [4] as shown in *Figure 4*.

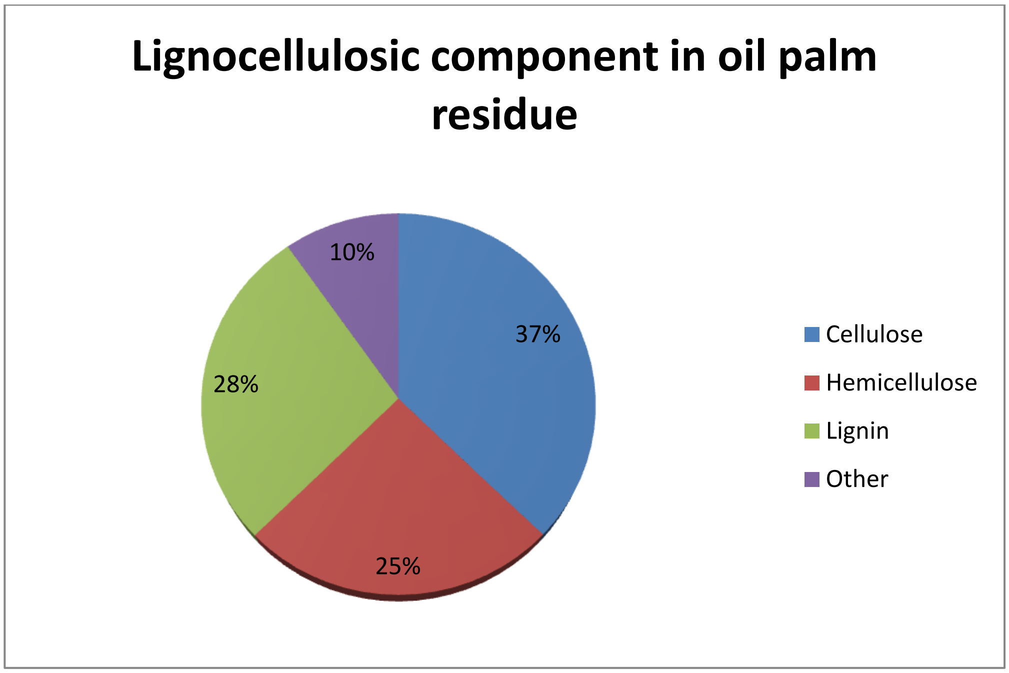


Figure 4: Lignocellulosic components inside oil palm residue

The above components are naturally abundant and have many advantages when making bio-based polymer apart from environment gains, are low cost, not depending on the petroleum sources, available for renewable resources and enabling to replace some synthetic polymer [5]. However, there are some disadvantages for using this three main component for the production of bio-composite material which is relatively low tensile property and high water absorbance. Both tensile strength and water absorbance are related because as the water absorbance increase, the volume of water will make the tensile strength decrease due to the viscous part of the material that dispersed energy.

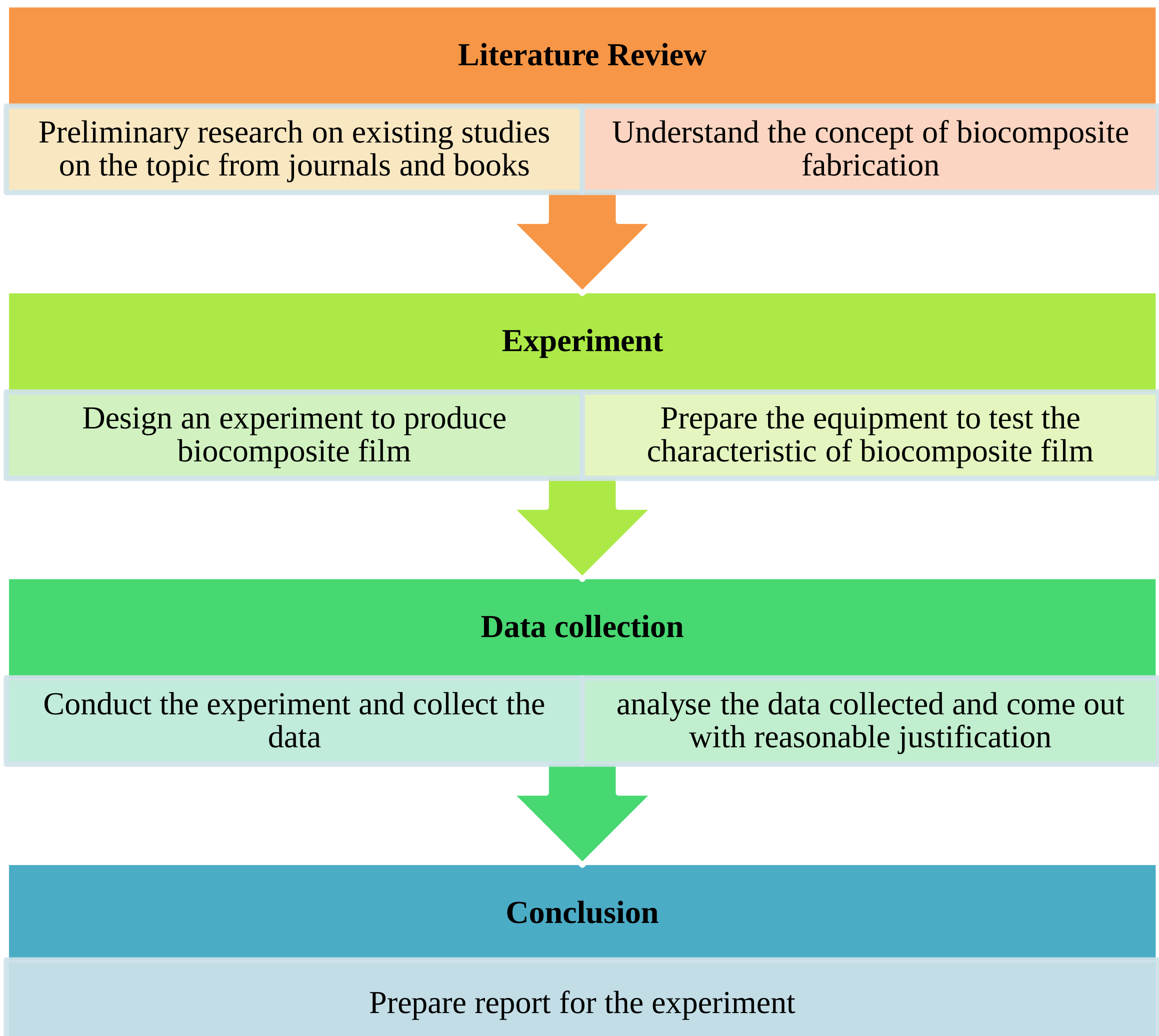
Besides that, the poor solubility and also the process ability of cellulose become limited and give limited application of cellulose. Furthermore, all of the three main components cannot melt and cannot be process like other thermoplastic polymer which greatly affects the usage of biomass as the bio-composite material.

Many researchers have try blending the three components with natural polymer such as using the blending of cellulose/starch and many more. This blend can enhance the properties of the bio-composite polymer which maintaining the biodegradable properties. However, with the blending process, the cost production will also increase due to the level of complicacy of blending process of the polymer. It is important to preserve the biodegradability, low cost and to improve the mechanical strength of the final product the research regarding the combination of this lignocellulosic material together with the natural polymer is important.

In the last decades, the increasing demand for alternatives to fossil fuels, composites based on polymer and natural fibers are very attractive. This is because of the mechanical properties, sustainability and environmental-friendly connotation. The use of natural fibers as reinforcing elements in bio-composite material give a lot of advantages compared when using inorganic material. The properties of bio-composite materials is biodegradability, high availability, low cost, low energy consumption, low density, high specific strength and modulus, and easy processing ability due to their flexibility and non-abrasive nature [5]. This makes the bio-composite film suitable for making food packaging, cutlet such as fork and spoon which are once-used product.

CHAPTER 3: METHODOLOGY

3.1 Project Flow Chart



3.2 Gantt Chart and Key Milestone

No	**Detail Work**	**Week**													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Literature Review														
2	Sample Preparation • Grinding of the biomass Kernel Shell (PKS) and Oil Palm Frond (OPF) < 0.25 mm • Making particle board using Compression Molding														
3	Characterization using Fourier Transform Infrared (FTIR)/ Thermogravimetric analysis (TGA)/ Deferential Scanning														

	Chromatograph (DSC)														
4	Submission of Progress Report														
7	Pre-EDX														
8	Submission of Draft Report														
9	Submission of Dissertation (soft-bound)														
10	Submission of Technical Paper														
11	Oral Presentation														
12	Submission of Dissertation (hard-bound)														

3.3 Experiment Methodology

3.3.1 Equipment and Material

For this research, the equipment that we used is divided in two categories which are the sample preparation equipment and analytical instrument.

The sample equipment that used in this research is Oven, grinding machine and also compression molding. The oven is used to dry the sample to remove the humidity inside the sample of PKS and OPF. This process is important because the humidity will affect the sample when the undergo compression molding. The set up for drying process is shown in *Figure 5*. *Table 3* shows the condition for drying process.

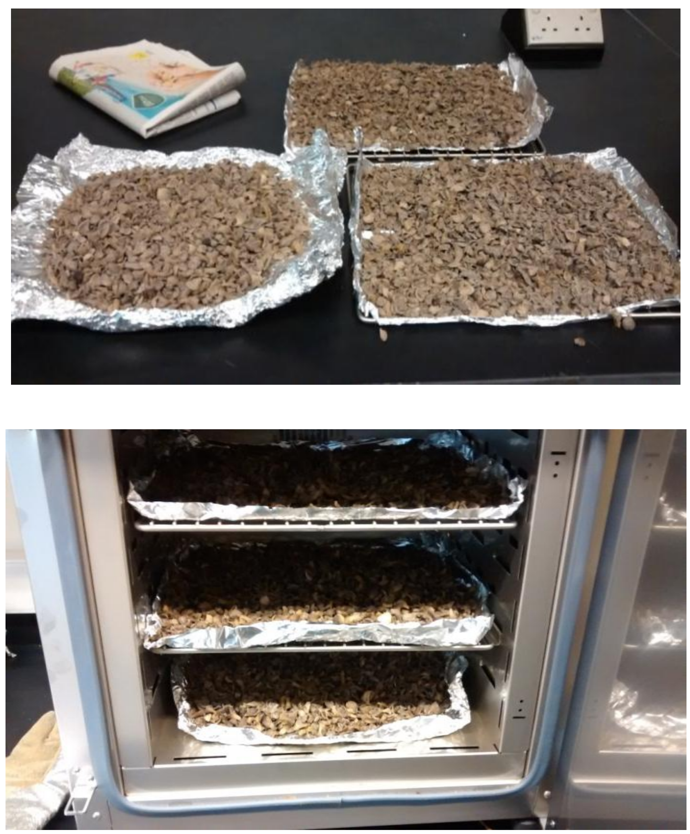


Figure 5: Drying process using Oven

Table 3: Condition for drying process

Parameter	Condition
Temperature (°C)	80
Time (h)	24

After the drying process, the sample will undergo grinding process which grinds the sample into the powder. This step is important because the mechanical strength of the sample depends on the size of the sample after the grinding. The equipment use for this grinding process is automatic grinder which will automatically sieve the sample with the desired size. After the grinding process, then the sample can be send to the lab for compression molding. *Figure 6* shows the grinding machine and *Figure 7* shows the sample after grinding.

Figure 6: Grinder use for grinding process

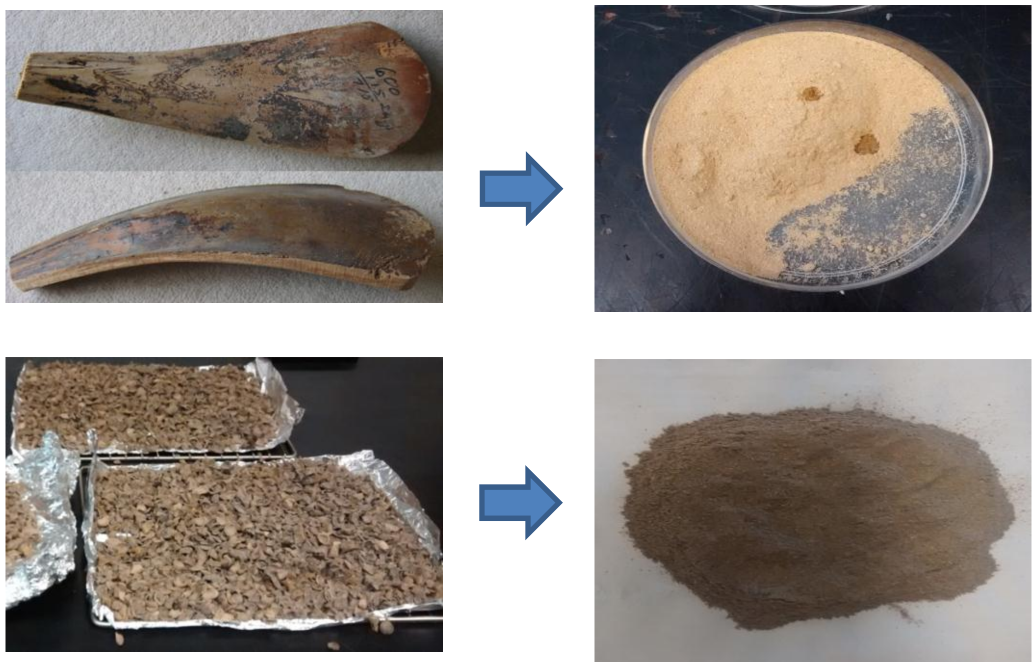
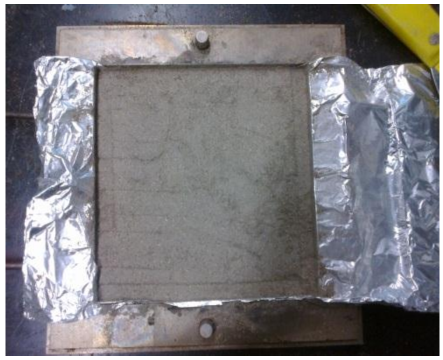


Figure 7: Sample after grinding

After all the preparation of the sample finish grinding, the sample can undergo compression molding which compress the sample into the particle board. The purpose of choosing compression molding other than extrude molding because the high pressure is need and also high temperature. The condition for this process is around 26 MPa and temperature as high as 210 °C for around 10 minutes. If the condition is not meet, the particle board will break or will not form it shape according to the molding.

When doing the compression molding, the paraffin wax need to be wipe around the molder and place the aluminum folder to avoid the particle board to stick to the molder. This step unsure we can maintain the volume of the particle board according to the calculation before the experiment starts.



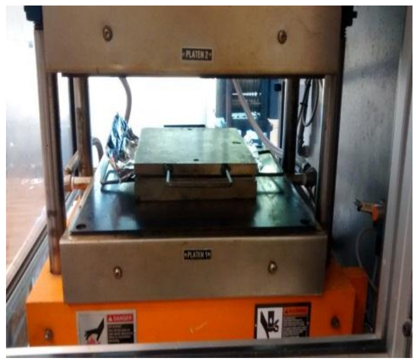


Figure 8: Compression Molding

The sample is mix to vary the ratio. This is because this project aims to identify the effect of changing the components inside the sample to form binder-less particle. The component for this particle board is mainly using the OPF as the fiber which contain high cellulose and PKS as the filler which high lignin as a binder as shown in *Table 4*.

Table 4: Parameter for experiment

Sample	Condition
A	100% OPF
B	90% OPF + 10% PKS
C	80% OPF + 20% PKS
D	70% OPF + 30% PKS

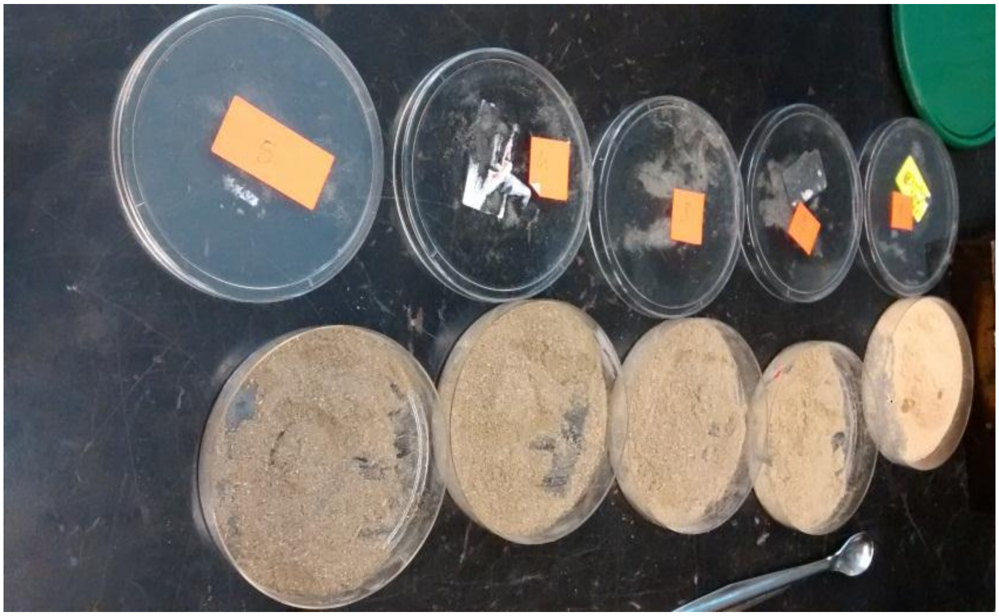
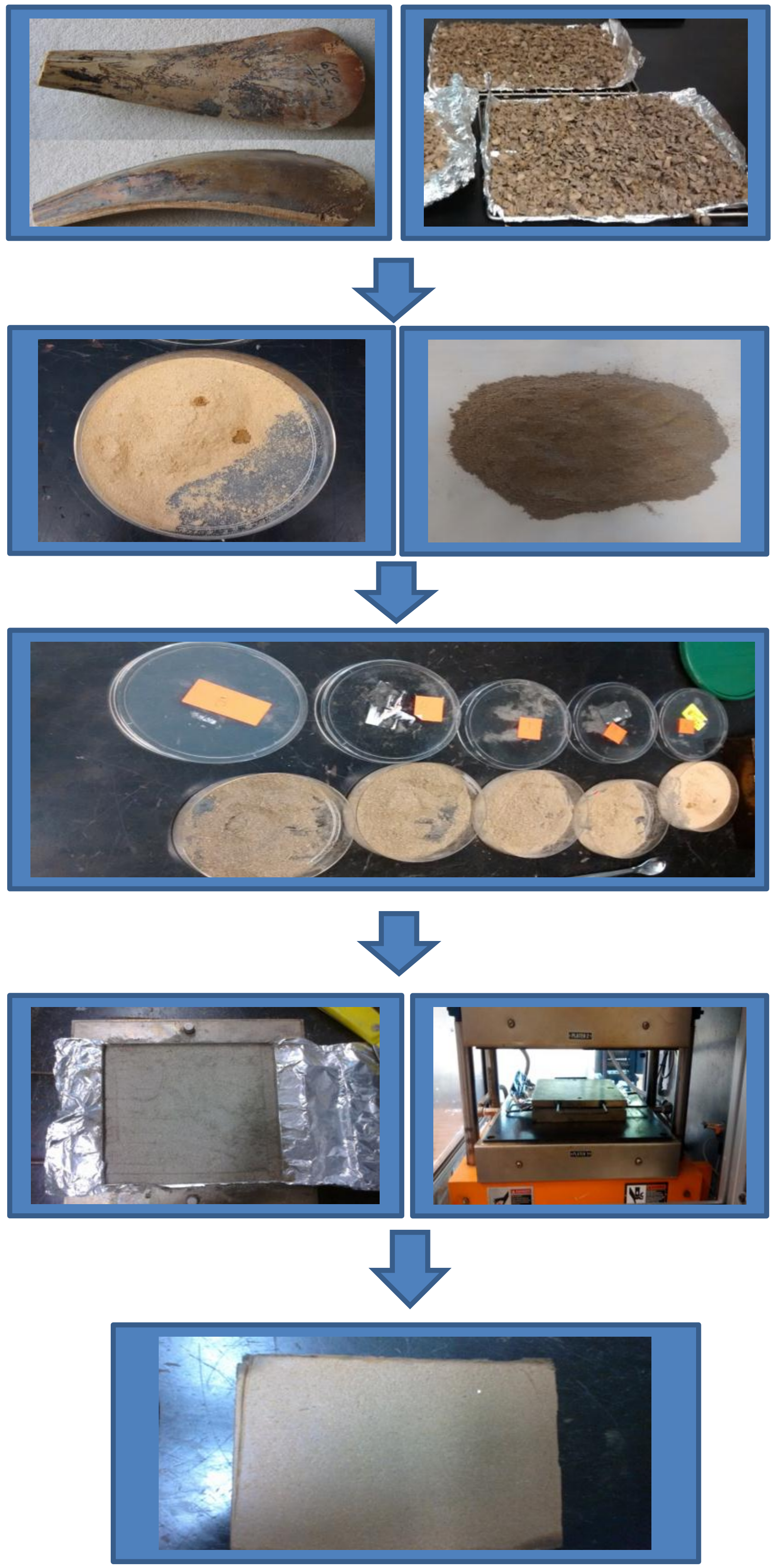


Figure 9: sample mixture between OPF and PKS with different ratio

In this project, the sample will undergo three main analytical procedures which is Fourier Transform Infrared (FT-IR) which will determine the composition of the particle board after the compression molding, Thermalgravimetric Analysis (TGA) to analyses the maximum temperature where the particle board start to decompose and the third instrument is Field Emission Scanning Electron Microscopy (FESEM) which monitor the morphology of the composition after the compression molding to form a particle board. These are the analytical instrument that use throughout the project.

3.3.2 Overall Experiment Procedure



CHAPTER 4: RESULT AND DISCUSSION

4.1 Experiment Result

4.1.1 Fourier Transform Infrared (FTIR)

The first experimental analysis is using Fourier Transform Infrared (FT-IR). This test is to analyses the composition remaining inside the particle board after the compression molding. From the FTIR result, the component can be identify and compared with several other previous result to see the similarity.

For this project, the components that need to be identified were cellulose and also the lignin. This is because the cellulose is use as the fiber inside the particle board and lignin acts as the internal binder inside the particle board. If the one of the component shows different, the properties of the particle board might chance according to the component inside the particle board.

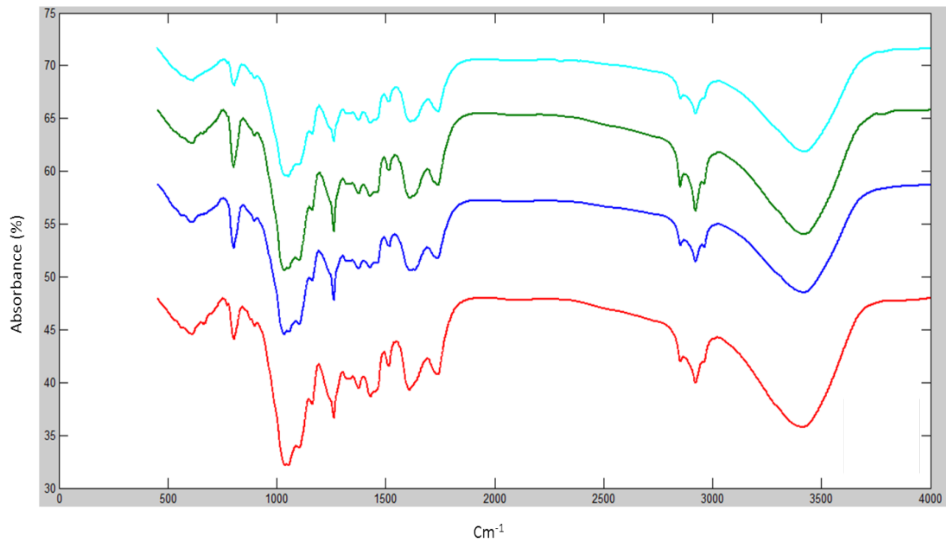


Figure 10: FTIR result for particle board

Figure 10 shows all four results for the FTIR which illustrate that all the result show the same peak which can be summarize as the same component which occurs inside the particle board. The difference between the each sample is through the absorbance (A) which varied according to the volume of the component inside the sample.

For this project, the focus is on the cellulose and lignin composition inside the particle board. Based on the literature review, the composition wavelength of cellulose is around 3423 cm^{-1} and lignin is on the 1037 cm^{-1}as shown in *Table 5*. In the FTIR, it depends on the vibration of the component which then sends the certain frequency to the monitor. Every composition has its own frequency. Thus, the component can be determined using FTIR.

Table 5: Wavelength for component in FTIR

Wavelength	**Functional Group**
3423	Hydrogen bonding C-H stretching
1037	Lignin

Sample A which have 100% OPF show the result as shown in *Figure 11*. The cellulose compositions which occur at wavelength 3423 cm^{-1} have the absorbance of 55%. Using Equation 1, the transmittance can be determined hence can identify the amount of the cellulose inside the particle board. It goes the same with the lignin composition inside the particle board.

$$A = log\frac{1}{T}$$ ………….. Eq. 1

Where, A = Absorbance

T = Transmittance

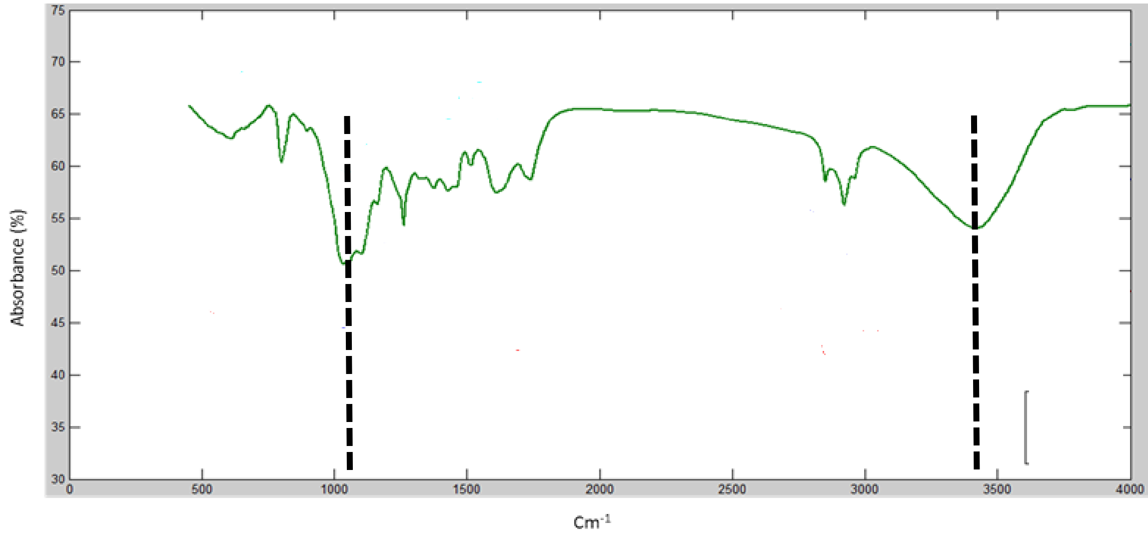


Figure 11: Result FTIR for sample A

From the graph, the transmittance can be calculated. And based on the calculation, the conclusion can be related to the mechanical strength and the particle board properties because of the variation of the cellulose-lignin composition. For the sample B, C, and D, the result is shown in *Figure 12*, *13* and *14* respectively

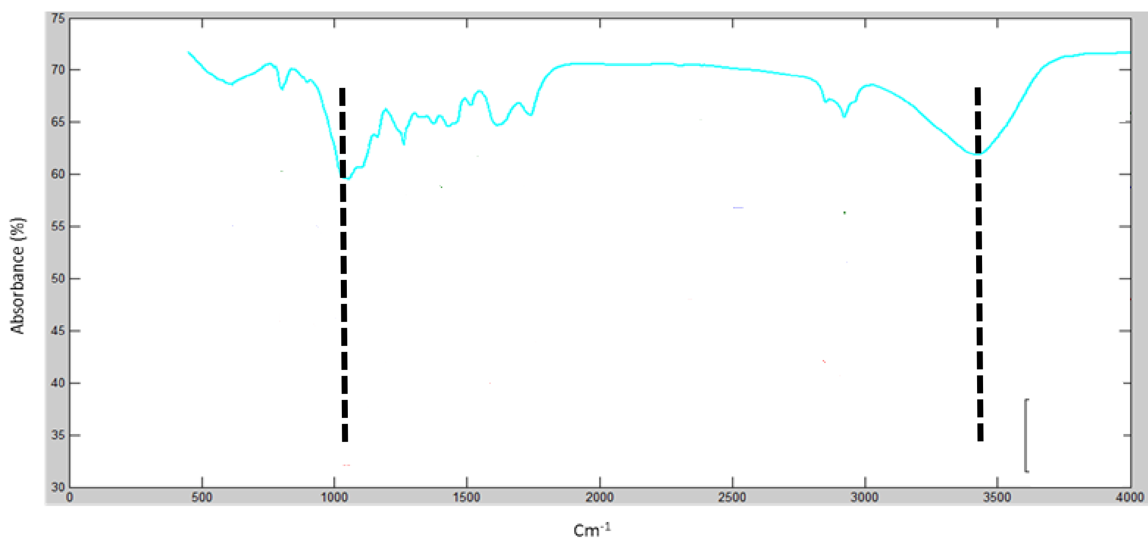


Figure 12: Result FTIR for sample B

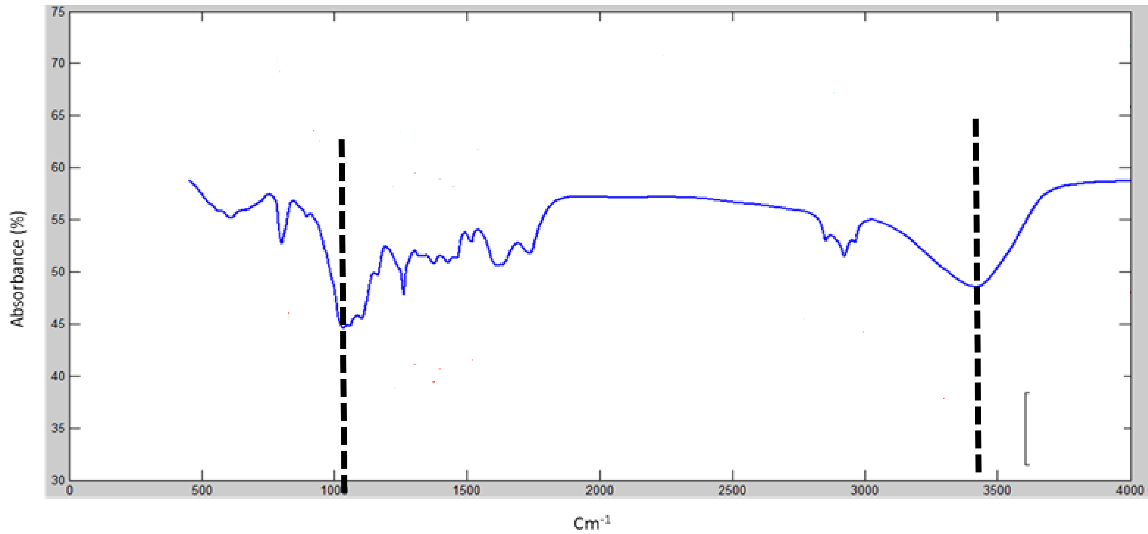


Figure 13: Result FTIR for sample C

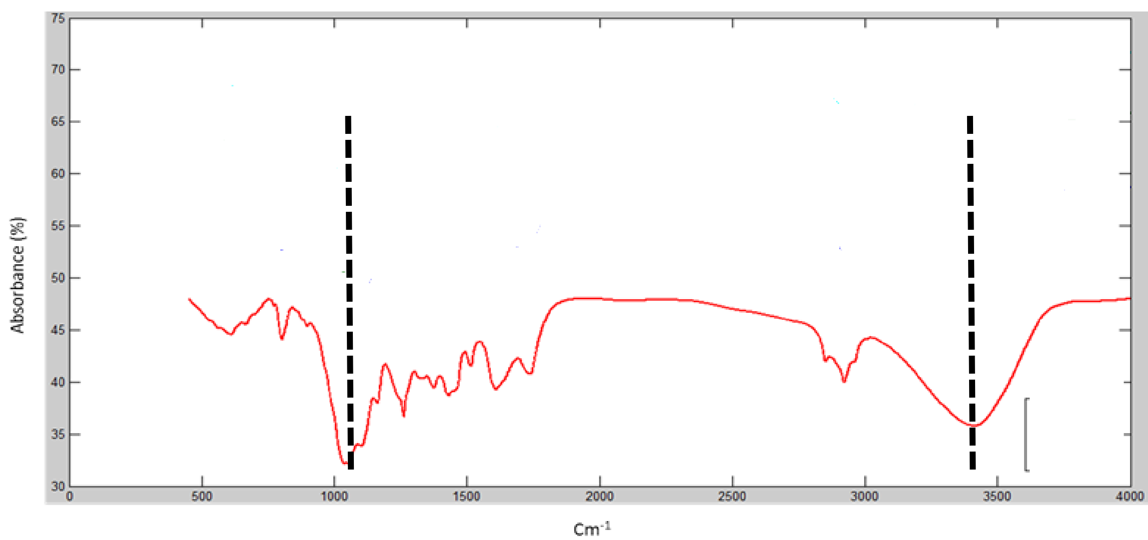


Figure 14: Result FTIR for sample D

From all the result, the transmittance can be calculate and tabulated in *Table 6*.

Table 6: composition each sample particle board

Sample	Absorbance (%)	
	Cellulose	Lignin
A	55	53
B	64	62
C	48	45
D	25	30

From the result, we can conclude that, the sample B have the highest composition of cellulose and lignin which condition is 90% OPF and 10% PKS. Follow by sample A, C and D respectively.

4.1.2 Thermogravimetric Analysis (TGA)

Second analysis is Thermogravimetric analysis (TGA). The function of this analysis is to determine the decomposition temperature for the particle board sample. This analysis is important because this analysis determine the maximum temperature that the particle board can withstand.

For the usage commercially, the maximum temperature is indeed important. This analysis shows that what happen if the binder-less particle board is manufacture. The maximum temperature for binder-less particle board needs to be similar or close to the maximum temperature for conventional particle board. *Figure 15* shows the TGA result for all four samples.

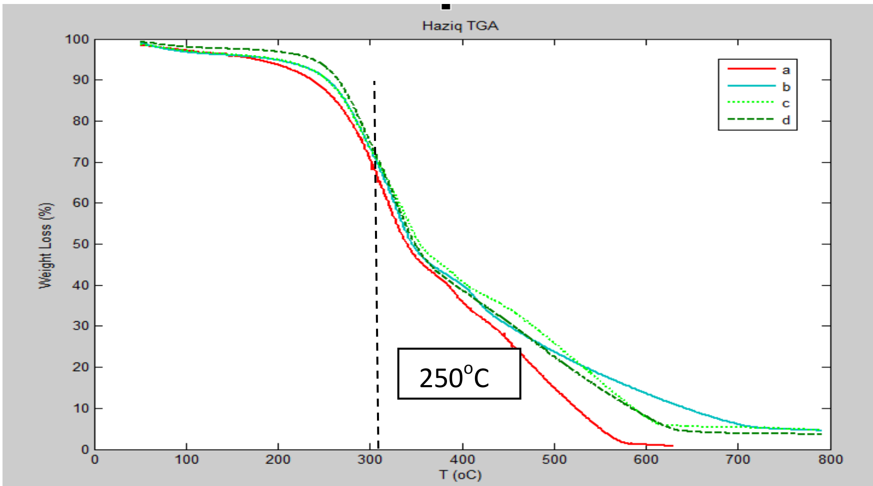


Figure 15: Thermogravimetric Analysis (TGA) result

Table 7: TGA result

Sample	Decomposition Temperature (^{o}C)
A	250
B	250
C	250
D	250

Result in *Table 7* shown that the decomposition temperature for all the samples is around 250^{o}C. This is because at 250^{o}C, the graph decrease gradually and this shown that the particle board start to decompose as the weight of the sample decrease.

4.1.3 Field Emission Scanning Electron Microscopy (FESEM) analysis

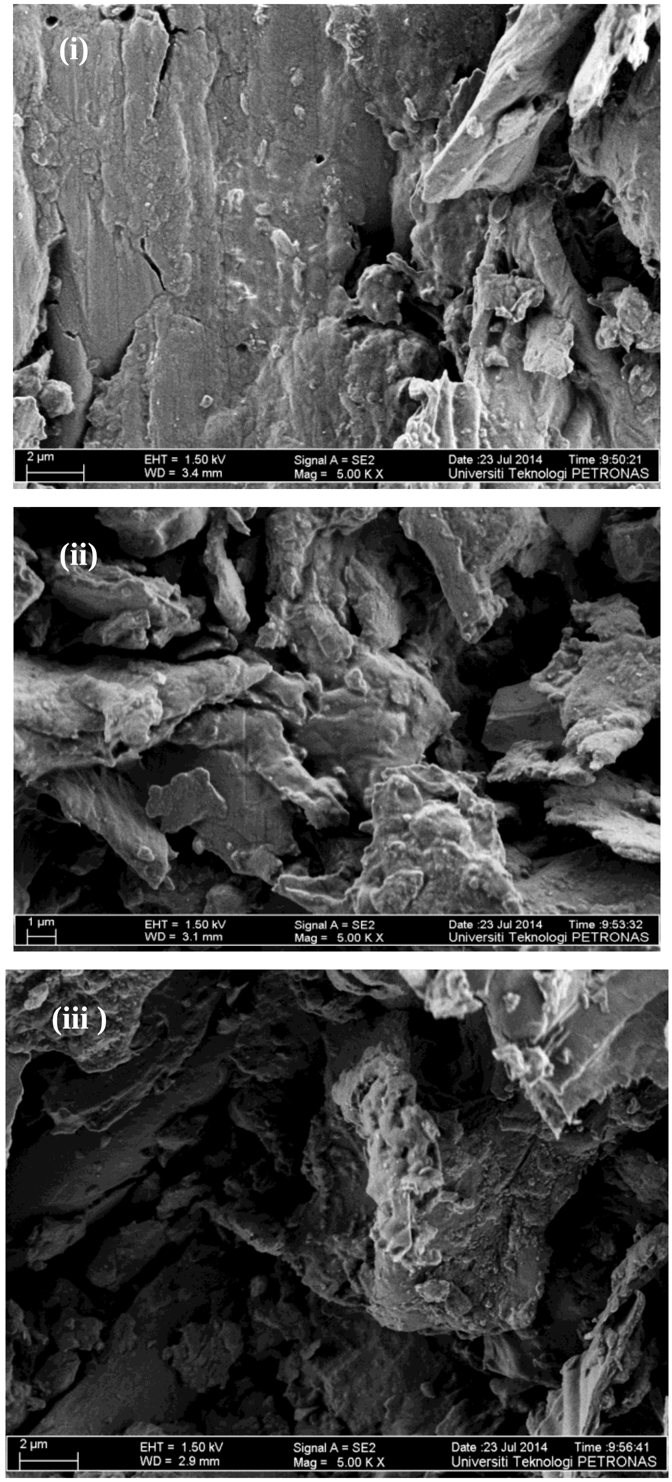


Figure 16: FESEM result (i) sample A (ii) sample B (iii) sample C (iv) sample D

Figure 16 shows the FESEM result which have magnify around 1-2 μm. Based on the result, there are many black dots which represent pores inside the particle board. The pores can be related to the mechanical strength of the particle board. As the pores numbers increase, the mechanical strength of the particle board decreases.

There are two type of mechanical strength that can relate to the numbers of pores which is water absorption and mechanical testing. The water absorption can be test by submerge the particle board in the water and left it around 1 day and weight to see the weight of particle board after the water absorption. Based on the FESEM result, as the pores numbers increase, the water absorption increase because there is more pores where the water molecules can enter which increase the weight of the particle board. Therefore, according to the result, particle board A which 100% OPF show less pore compared to other which give lower water absorption.

Other than water absorption, the FESEM result can also relate to the mechanical strength of the particle board. If the pores increase, the strength of the particle board will decrease. This is because, when applied stress or strain, the molecules in the particle board can easily move since there is pores inside while if there is no pores, the molecule becomes static and can withstand a lot of stress or strain. Hence particle board A have a higher mechanical strength compare to others.

4.2 Experiment Discussion

Based on the result from Fourier Transform Infrared (FTIR), the composition of the entire sample shows that the presents of three main component which is Lignin, Hemicellulose, and Cellulose which the structured been modified as the binder in the particle board. The absorbance of the particle board decrease as we increase the ratio and decrease again at certain ratio. This is because the bond between the particles is strong as the present of PKS which give extra binder toward the composition of the particle board.

For the TGA, the decomposition of the particle board with almost the same around 250^{o}C. This shown that the particle board can withstand the heat as high as 250^{o}C before decomposes. The lignin that acts as the binder will destroy if the temperature is increase and will burn which make it decrease in mass. Therefore, to manufacture this biocomposite particle board, the temperature must be lower than 250^{o}C.

For the FESEM result, as the ratio between the OPF and PKS increase, the particle become more porous, this can be seen in the *Figure 14*. There are more void space in sample D, follow by sample C, B and lastly sample A which can be seen very smooth. This result can be effected the mechanical strength of the sample which is very important. As the void or free space increase, the water absorption can increase, thus it is not very suitable for particle board and for the mechanical strength, the higher pores give less strength compared to the lower pores number because the molecule can move if there is the pores inside the particle board.

Hence, the particle board A which is 100% OPF is suitable to make particle board because of the less number of pores compare to other. Although the value of lignin is much lower compared to the particle board B, the mechanical strength show it is more reasonable to manufacture as particle board based on the FESEM and TGA result.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

As conclusion, this project is important as it deals with alternative way to use the underutilized waste biomass from Palm Oil plantation to fabricate the "green" particle board. This is important to replace the wood product which is becoming scarce due to the excessive usage. Hence, this project can identify the new possibility to replace wood product.

The result prove that the structure of the particle board depend on the ratio of the OPF and PKS which in this project shows that the 100% OPF give solid structure compared to other sample ratio which have certain free volume which increases the mechanical strength of the particle board.

As a recommendation, a future work may be done to study the strength of the particle board and the effectiveness of the particle board to be used as replacement of wood product.

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