PALLETIZATION AND CHARACTERIZATION OF TORREFIED OIL PALM EMPTY FRUIT BUNCH (OPEFB) BIOCHAR

by

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A report submitted in fulfilment of the requirement for the degree of Bachelor of Applied Science (Sustainable Science)

FACULTY OF EARTH SCIENCE

UNIVERSITI MALAYSIA KELANTAN

2021

THESIS DECLARATION

I hereby declare that the work embodied in this Report is the result of the original research and has not been submitted for a higher degree to any universities or institutions.

Signature: ________________________________

Name: AMIR ADILAH MOHAMED @ MOHAMED JAMAL

Date: 31/12/2020

I certify that the Report of this final year project entitled Palletization and Characterization of Torrefied Oil Palm Empty Fruit Bunch (OPEFB) Biochar by Amir Adilah Binti Mohamed Jamal, matric number E17A0004 has been examined and all correction recommended by examiners have been done for the degree of Bachelor of Applied Science (Sustainable Science) with Honours Faculty of Earth Science, University Malaysia of Kelantan.

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ACKNOWLEDGMENT

First and foremost, I would like to sincerely thank my supervisor Assoc. Prof. Ts.Dr. Mohamad Faiz Bin Mohd Amin for his guidance, understanding, and patience and most importantly, he has provided positive encouragement and a warm spirit to finish this thesis.

I would like to thank to Mr Mohd Sukhairi Mat Rasat as my research team leader who had guided me in a lot task during the entire process of this thesis writing. It has been a great pleasure and honour to have him as research team leader. I would also want to thanks the lecturers and staffs of Faculty of Earth Science for their advice and contribution during completing this report.

Deepest thanks and appreciation to my beloved parents, Mohamed Jamal and Noraini, family, special mate of mine, and others for their cooperation, encouragement, constructive suggestion and full of support for the report completion, from the beginning till the end. Also thanks to all of my friends and everyone, that have been contributed by supporting my work and help myself during the final year project progress till it is fully completed.

May God shower the above cited personalities with success and honour in their life.

PALLETIZATION AND CHARACTERIZATION OF TORREFIED OIL PALM EMPTY FRUIT BUNCH (OPEFB) BIOCHAR

ABSTRACT

Dependence on fossil fuel as the main energy source has led to various negative impact upon human and environment. Uncontrolled use of fossil fuel leads to emission of greenhouse gases which later caused problems such as global warming and acid rain. Instable price of fossil fuel also caused variety of problems to daily life of human. Malaysia is well known as among world largest exporter of palm oil products; therefore providing us with abundant source of palm oil wastes. These bio wastes are highly potential as a replacement for the current fossil fuel; one of it is palm oil empty fruit bunch (POEFB). Torrefaction has been identified as a suitable pre-treatment process to increase the qualities of untreated POEFB. Torrefaction is mild pyrolysis process under low oxygen condition to imitate decomposition of long hydrocarbon process in POEFB. Instead of torrefection, palletization of torrrefied biochar such an improvement can be made on the final desired product. This research would like to study the improvement on pelletized torrefied with natural binder as an additive. The final product was characterized using Carbon, Hydrogen, Nitrogen and Sulphur (CHNS) analyzer, SEM and FTIR. The clay as a natural binder with different ratio successfully proved that it could turn to a better quality bio-pellet compared to raw OPEFB pellet. The durability also shown that raw OPEFB and torrefied biochar is the weakest sample with 0% durability compared with torrefied pelletied biochar with the highest number percentage of durability which is 72.8%. Morphology and bonding behaviour analysis demonstrated strong bonds within the internal structures of produced bio-pellet samples and it was influenced by the degradation of the lignocellulose, hemicellulose, cellulose and lignin

PALLETIZASI DAN KARAKTERISASI KEATAS TANDAN BUAH KELAPA SAWIT YANG TELAH DIBAKAR

ABSTRAK

Kebergantungan pada bahan bakar fosil sebagai sumber tenaga utama menyebabkan pelbagai kesan negatif terhadap manusia dan alam sekitar. Penggunaan bahan bakar fosil yang tidak terkawal menyebabkan pelepasan gas rumah hijau yang kemudiannya menimbulkan masalah seperti pemanasan global dan hujan asid. Harga bahan api fosil yang tidak stabil juga menyebabkan pelbagai masalah dalam kehidupan seharian manusia. Malaysia terkenal sebagai antara pengeksport produk minyak sawit terbesar di dunia; oleh itu memberi kita banyak sumber sisa minyak sawit. Sisa ini sangat berpotensi sebagai pengganti bahan bakar fosil semasa; salah satunya ialah tandan buah kosong kelapa sawit (POEFB). Torrefaction telah dikenal pasti sebagai proses pra-rawatan yang sesuai untuk meningkatkan kualiti POEFB yang tidak dirawat. Torrefaction adalah proses pirolisis ringan dalam keadaan oksigen rendah untuk meniru penguraian proses hidrokarbon panjang dalam POEFB. Daripada pencegahan semula, palletisasi biochar torrrefied peningkatan seperti itu dapat dibuat pada produk akhir yang diinginkan. Penyelidikan ini ingin mengkaji penambahbaikan pada torrefied pelet dengan menambah pelekat semula jadi sebagai bahan tambahan. Produk akhir dicirikan menggunakan penganalisis Karbon, Hidrogen, Nitrogen dan Sulfur (CHNS), SEM dan FTIR. Tanah liat sebagai pelekat semula jadi dengan nisbah yang berbeza berjaya membuktikan bahawa tanah liat dapat berubah menjadi bio-pelet berkualiti lebih baik berbanding pelet OPEFB mentah. Ketahanan juga menunjukkan bahawa OPEFB mentah dan biochar torrefied adalah sampel paling lemah dengan ketahanan 0% berbanding dengan biochar pelet torrefied dengan peratusan ketahanan paling tinggi iaitu 72.8%. Analisis morfologi dan tingkah laku ikatan menunjukkan ikatan yang kuat dalam struktur dalaman sampel bio-pelet yang dihasilkan dan ia dipengaruhi oleh penurunan lignoselulosa, hemiselulosa, selulosa dan lignin.

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LIST OF ABBREVIATION

OPEFB	Oil Palm Empty Fruit Bunch
EFB	Empty Fruit Bunch
UTM	Universal Testing Machine
GHG	Greenhouse Gaseous
RE	Renewable Energy
FTIR	Fourier Transformation Infrared
IR	Infrared
OPT	Oil Palm Trunk
PKS	Palm Kernel Shell
POME	Palm Oil Mill Effluent
RSM	Response surface method
SEM	Scanning Electron Microscope
CO2	Carbon dioxide

LIST OF SYMBOLS

kN	Kilonewton
mm/min	Micrometer per Minute
Kg	Kilogram
%	Percentage
Cm	centimeter
cm^{-1}	Wavenumber
℃	Degree Celcius

CHAPTER 1

INTRODUCTION

1.1 Research Background

Demand for energy is increasing worldwide. Energy is a social and economic necessity of every country. Energy consumption around the world is expected to increase as the population grows. Electricity is essential for economic growth and the rising standard of living of the population. Therefore, without sufficient basic power supply, people are unable to meet their domestic needs such as cooking, ripping perishable items and other necessities that require electricity.

Palm oil is now the largest source of edible oil in the world. It is anticipated that the world demand for palm oil will increase due to population growth, food demand, and industry. Crude palm oil (CPO) produces excessive waste of biomass. These residues can be converted into energy. Oil Palm biomass has long been identified and used as renewable energy but its use in power plants is not uncommon. Due to its heating value, it can be used as fuel for electricity production (Abas et el., 2011). Indonesia and Malaysia, the world's largest oil producing countries, account for 53.6% and 36.8% of their world oil production of 33.4 and 19.9 million tonnes respectively (Abdullah et al., 2013). They generate electricity from biomass waste and other products.

Biomass for energy is a major contributor to renewable energy worldwide, with almost 10% of total energy consumption in 2006 coming from biomass (Eickemeier et al., 2014). Many of these products can be used as energy sources, either for electricity or heat production, or as a raw material for biofuel production. According to the Renewable Fuel Standard (RFS) from the Energy Independence and Security Act of 2007, the minimum annual quantity of renewable fuel in the US transportation sector should be increased from 9 billion in 2008 to 36 billion gallons in 2022. In order to sustain production demanded by the RFS significant amounts of biomass has to be collected, stored, and converted into biofuel.

In order to convert biomass to biopellet, thermochemical conversion technologies which is torrefaction and palletization were applied. Torrefaction, sometimes also referred to as mild-pyrolysis, is a thermochemical process conducted in the temperature range between 200 and 300°C. In this research the influence of torrefaction reaction time, temperature, and particle size of torrefied OPEFB and pelletized OPEFB was investigated.

1.2 Problem Statement

According to global issues, burning of fossil fuels' as a source of energy for heat, transport, and electricity is known to be a major contributing factor to global warming (Idris et al., 2010). The world is moving from a non-renewable conventional energy source to a renewable energy source due to the change and environmentally friendly nature.

Malaysia is among the top most important oil palm producers in the world and experiencing a robust development in new plantations and palm oil mills through giant government companies. Every year, a large number of oil palm biomasses including stems, petals, fibers, clams and empty bunches (EFBs) are produced in Malaysia. The waste by-product from palm oil extraction process enormously could achieve 70–80 million tons per annum meanwhile in the palm oil mill, palm oil consists only 10% of the total biomass, while the rest (90%) biomass are discarded as wastes (Abd Rahman et al., 2017). To address the matter, these oil palm wastes such as oil palm empty fruit bunch (OPEFB) will be replicate of fossil fuel in generate energy through process of pelletization.

Moreover, the biomass has a tendency to spring back when compressive force is release during pelletization process because of lack of elasticity (Bruhn et al., 1959). The pellet that has been produced by previous study shows a bad quality of physical and texture. The pellet of OPEFB biochar becomes less compressible causing the OPEFB pellet to melt and break down and last longer less than 2 days after palletization process. Therefore, this study was using starch as an additive into OPEFB biochar during palletization process and followed by study their characteristic of pellet from OPEFB biochar through Scanning Electron Microscopy (SEM) and Fourier-transform Infrared Spectroscopy (FTIR)

1.3 Objective

The objectives of this study are as follows :

a) To identify the morphology and bonding behaviour of torrefied pelletized OPEFB biochar by using SEM and FTIR

b) To study the performance of pelletized torrefied OPEFB biochar by adding natural binder (clay) as additive

c) To analyze the comparisons of durability on raw OPEFB, torrefied biochar and torrefied pelletized OPEFB biochar

1.4 Scope of Study

The scope of this study has been conducted to identify the ability of OPEFB as the energy resources by undergoing torrefection and palletization process based on several independent variables which is ratio between starch and biochar, holding temperature and residence time. During the torrefection process, the particle size of OPEFB is 750mm were heated at 270℃ and 90 minutes of their residence time. The pellet of OPEFB biochar was produced by using Universal Testing Machine (UTM) with a pellet mold. The pelletized torefied biochar has been characterized their morphology and bonding behavior using SEM and FTIR. Therefore, at the end of this research the production of biofuels could shift from the usage of fossil fuels which may help in reducing the emission of greenhouse gases and climate change. It may contribute to reduce the discharge of waste from palm oil mill, which can lessen the burden for disposal process and operating cost.

1.5 Significant of Study

The significant study of this research is to build some alternative ways that could be used as the energy resources in Malaysia. Energy demand is currently on the rise worldwide due to the increase in world population. Biomass has a positive effect on energy production and contributes to a healthy environment and economy. Uses of biomass to reduce pollution and environmental pollution and provide a safe source of energy for future development. The palletization process for biomass can utilize the entire waste as a renewable alternative energy source for power generation.

CHAPTER 2

LITERATURE REVIEW

2.1 Energy Overview

Energy is important because it is a fundamental requirement for national development. Society relies on energy sources for daily routines. Energy is divided into two sources which is renewable and non-renewable energy. Renewable energy is a source of energy that can be extracted from non-depleting indigenous resources (Act 275, 2016). Meanwhile, non-renewable energy is a source that cannot be replenish in a thousand years and will eventually run out. Both sources are capable of generate energy to meet the world's energy demand. However, non-renewable energy will negatively impact the environment as it is restricted and not a clean source of energy.

2.2 Sustainable Energy

Sustainable development defines as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. The strategy for sustainable development aims to promote harmony among human beings and between humanity and nature.

The relationship between energy production and use and sustainable development has two important features. One is the importance of adequate energy services for satisfying basic human needs, improving social welfare, and achieving economic development—in short, energy as a source of prosperity. The other is that the production and use of energy should not endanger the quality of life of current and future generations and should not exceed the carrying capacity of ecosystems. Throughout the 20th century, the ready availability of commercial energy fuelled global economic development. But much of the developing world continues to rely on non-commercial energy sources, mainly fuelwood, and has limited access to modern energy such as electricity and liquid fuels. Lack of capital and technological capacity hinders the development of adequate supplies, with deleterious effects on economic and social development.

2.3 Renewable energy

Renewable energy in Malaysia has immense potential to grow in the future to replace the non-renewable fuel that will end one day. The countries have great potential because of the large number of renewable energy sources that do not actively exploited such as biogas, biomass, mini hydro and solar. Renewable energy consumption has contributed to the reduction of environmental pollution, lower cost - savings, and less natural resources (Suhaimi et al., 2013). As a developing country, Malaysia's population continues to grow and life expectancy depends on the future energy supply.

The government have took part in nurturing sustainable development in Malaysia that focus on the RE topic. Malaysia also used renewable energy for energy generation. Renewable energy used to generate energy by harnessing sources from the nature such as heating and electricity. However, renewable energy is least option due some barriers such as to lack of knowledge and technology to harness the energy (Kurnia & Jundika, 2016)

2.4 Biomass

Biomass is classified a renewable and sustainable energy resources because the formation of biomass is originated from the interaction between carbon dioxide (CO_2), soil, sunlight, water and air with the present of animal and plants. Microorganisms will break down the biomass after the living organism are dead by producing water (H_20), CO_2 and potential energy (Shinn, 2018) the CO_2 produces are due to the process of microorganism degradation and combustion activities. Hence, the biomass combustion will be not increasing the total of CO_2 in the atmosphere that also known as greenhouse neutral or GHG neutral.

Biomass can be transformed into clean energy and/or fuels by a variety of technologies, ranging from conventional combustion process to advanced biofuels technology. Besides recovery of substantial energy, these technologies can lead to a substantial reduction in the overall biomass waste quantities requiring final disposal, which can be better managed for safe disposal in a controlled manner while meeting the pollution control standards. Biomass conversion systems reduces greenhouse gas emissions in two ways. Heat and electrical energy is generated which reduces the dependence on power plants based on fossil fuels. The greenhouse gas emissions are significantly reduced by preventing methane emissions from decaying biomass.

Moreover, biomass energy plants are highly efficient in harnessing the untapped sources of energy from biomass resources and helpful in development of rural areas.

Biomass is a potential alternative to replacing fossil fuels but is not yet feasible at this time because of its characteristics such as high-water content, bulk density, and low energy content (Kongpaya et al., 2014). Besides, it also requires high costs, limited availability, and difficult mobilization of raw materials. This shows the need for further development in the biomass energy sector is high, so that in the future, this renewable energy source will become the world's main energy producer. This development continues because of the depletion of the availability of fossil energy sources that have always been used as the main energy source. This biomass energy source is believed to be able to replace fossil energy sources, so that the availability of energy sources in the future will always be available. In Indonesia, the use of biomass as a renewable energy source has considerable potential. The palm oil industry has the greatest potential in producing electricity sources, which is 12,654 MW. Thus, the potential utilization of biomass, especially oil palm, is promising.

2.4.1 Biomass in Malaysia

Malaysia is gifted with conventional energy resources such as oil and gas as well as renewables like hydro, biomass and solar energy. As far as biomass resources in Malaysia are concerned, Malaysia has tremendous agricultural biomass and wood waste resources available for immediate exploitation. This energy potential of biomass resource is yet to be exploited properly in the country. Taking into account the growing energy consumption and domestic energy supply constraints, Malaysia has set sustainable development and diversification of energy sources, as the economy's main energy policy goals. The Five-Fuel Strategy recognises renewable energy resources as the economy's fifth fuel after oil, coal, natural gas and hydro. Being a major agricultural commodity producer in the region Malaysia is well positioned amongst the ASEAN countries to promote the use of biomass as a source of renewable energy.

2.4.2 Biomass as Energy

Biomass power is generated from the organic waste in order to reduce the waste that goes to the landfill or being burned. Energy form from the biomass by the heat released when the biomass is burned. Heat produced will form steam that will run the turbine to generate electricity. Energy from biomass also can reduce the carbon emission compared to fossil fuel that emits high carbon into the atmosphere, hence able to be a pollution control. Biomass was the oldest energy sources will able to be a substitute to the non-renewable energy of fossil fuel. Thus, reducing the carbon which is greenhouse gases emission and impact to the environment (Ribeiro et el., 2018) the abundance of biomass supply is able to secure the sources of energy supply for biomass energy production.

Biofuels are originated from biomass including firewood, wood pellets, pellets, fruits such as olive, avocado, and crust. Moreover, cut and chopped firewood is the least processed, and is usually burned directly in household appliances such as kitchens and boilers. This chip comes from the destruction of agricultural and forest biomass, whose size varies depending on the process in which it originated. Finally, pellets are the most complex biofuels, and are made up of small cylinders of 6 to 12mm in diameter and 10 to 30mm in length obtained by pressing the biofuel with fasteners. Pellets are used primarily in fuels with low power / volume ratios (William et all, 2018). Fruit and cereals, as well as fruit husks, although used less than other fuels such as firewood, wood chips and pellets, are also widely used biofuels. This fact, along with increasing production of side products around the world, makes it very attractive for heat generation, as well as reducing CO2 emissions. Biomass is found in a variety of materials: wood, sawdust, straw, seed waste, dirt, paper waste, household waste, wastewater, etc. (Perea-Morena et al., 2019)

2.4.3 Biomass from Oil Palm Plantation

Palm oil is considered as the most important agricultural crops in Malaysia, with the oil industry being the fourth largest contributor to Malaysia's Gross National Income (GNI), according to the National Biomass Strategy which could generate billions of ringgit. Palm oil production is associated with large amounts of biomass and one of the main challenges is the disposal of biomass (Konga et al., 2014). There are six biomass generated from palm oil, palm oil (OPF), palm oil (OPT), empty fruit bunches (EFB), the kernel shell mesocarp (SME) and palm oil mill POME).

Different components of oil palm biomass have different potential uses including as fuel for electricity generation, biochemical products, fertiliser, and biofuel. This also means that different components may require different processing methods to be converted into each of their usable forms. Oil palm biomass further categorized into solid and liquid waste, with a total of 83 million tons of solid waste and 60 million tonnes of liquid waste generated, respectively, most of the biomass is left in the fields. Approximately 75% of solid waste consisting of OPF and pests that was in the fields, while the remainder of the EFB, MF and SMEs accounted for the remaining 25% to the factory (Awalludin., 2015). The rapid growth of oil palm plantations has its challenges, one of which is the quantity of biomass produced on farms. The rest of the palm oil is sustainable and alternative way to produce energy for the supply. Table 2.1 further provides an overview of oil palm-biomass-based products and their commercialisation stage in Malaysia

Table 2.1: Oil Palm Biomass-based Products and the Commercialisation Stage in Malaysia

	Pellets	Biofuel	Biogas	Green Chemicals	Biofertiliser	Biochar	Biocomposites	Other
Empty fruit bunch (EFB)	EFB Pellets	Bioalcohol	Syngas	Industrial Sugars/Chemical	Organic Compost	Carbon Fibers	Fibreboard	Pulp Fibremat
Palm kernel shells (PKS)	Coal substitute					Activated Carbon		
Trunkc (OPT)	OPT Pellets	Bioalcohol	Syngas	Industrial Sugars/Chemical	Organic Compost	Biochar	Engineered Lumber	
Fronds (OPF)	OPF Pellets	Bioalcohol	Syngas	Industrial Sugars/Chemical	Organic Compost	Biochar		Phytochemicals
Palm kernel cake (PKC)	PKC Pellets			Biopolymers				Animal Feed
POME		Bioalcohol	Methane	Biopolymers	Organic Compost			

= Commercialised = Development Stage = Potential

(Source: MIGHT, Malaysian Biomass Industry Action Plan, 2013)

2.5 Oil Palm Empty Fruit Bunch (OPEFB)

Empty fruit bunches are by product or waste generated after the pressing oil process. It is rich in organic matter and nutrients. EFB does not contain any chemicals or mineral additives, and depending on the proper operation of the plant, it is free of foreign elements such as pebbles, nails, bark, waste and so on. However, it is saturated with air due to biological growth combined with the sterilization vapour in the plant. The moisture content in the EFB is about 67% of the bites must be dried before being considered a source of biomass fuel. Raw EFB is very wet and in a greasy condition of about 10-20cm long (Abdullah et all, 2011). OPEFB can produce fuel by converting EFB into pellets or bales once processed. EFB is a kind of sustainable energy source because it is renewable energy.

The EFB can be useful in crop production. However, the process of incinerating EFB, to be used for the aforementioned purposes, releases harmful pollutants – this process is therefore restricted by the Department of Environment Malaysia. Nevertheless, EFBs are produced in large amounts in Malaysia and are particularly applied as fertiliser and mulch in plantations. They are also used in power generation. Apart from that, EFBs are also used in the production of wood fibre boards and paper

2.6 Pellet Production

Converting biomass to pellets allows producers to immediately capitalise on available biomass. In Malaysia, many pellet producers generate about 1,000 to 3,000 tonnes of pellets per month – these pellets are made using sawdust as feedstock. Table 2.2 shows calorific Value and Moisture Content of Oil Palm Biomass

Table 2.2 : Calorific Value and Moisture Content of Oil Palm Biomass

Biomass	Calorific Value (GJ/ton)	Moisture Content (%)
PKS	17.3	12
Fiber	11.1	35-37
EFB	5.3	65-67
POME (Biogas)	20 MJ/m3	98-99

(Source: YTL SVCarbon, 2010)

There are a wide variety of pellets from oil palm in the biomass industry including mesocarp pellet, EFB pellet, and tree trunk pellet, among others. Two main factors influencing the production of pellets are the calorific value and moisture content of the feedstock used. Among the oil palm solid biomass, PKS contains the highest calorific value, whereas the EFB contains the highest moisture content. This is illustrated in the table above. Biomass from oil palm, particularly EFB offers great potential as a cost-effective feedstock for producing pellets. The EFB pellet is also the more widely-known oil palm pellet in the market

2.6.1 Palletization

Pellets of biomass is a famous bio fuel, it is derived from agriculture residues, forestry residues and wood waste. Biomass palletization process is a method to produce high density, solid energy carriers from biomass. Pellets is making of variety sizes and scales. Basically, the pellet has a cylindrical shape of 6-22mm in diameter and 3-50 mm in length (Salman Zafar., 2019). A biomass pellet can reduce space and reduce transportation cost compared to original biomass. Biomass pellet can be handle and store safely and cheaply. It also have flowability characteristic same with those cereal grain. Biomass pellet have high density that could compact storage and rational transport for long distance or journey. Production of biomass pellet for export is a part of global commitment to address climate change issues that involves in many countries. By the concerns about energy security and the impact of the climate change associated by the use of non-renewable energy had led to the realization of using biomass fuel pellets for alternatives renewable sources. by the year of 2020, the demand of biomass pellet is projected to be in range of 16 million tonnes.

Biomass palletization process is a method to produce high density, solid energy carriers from biomass. Pellets are produce in various type as a biofuels for household, building, industrial, energy power plant and other application. Pellets is making of variety sizes and scales. The preparation of raw material which is should select a raw that suitable for the process including filtration, storage and protection. Filtration will be conducted to remove unwanted material. The moisture content in biomass should be low but natural moisture in biomass is high which is up to 50-60% and it should be reduce to 10-15% using superheated dryer. The drying process of biomass can increase efficiency of biomass and produce no smoke on combustion

2.7 Natural Binder as Improve Quality Biopellet

Biomass is a limited of elasticity so binders will be added to produce higher quality pellets. The biomass have tendency to spring back when compressive force is release during palletization process (Bruhn et al,. 1959). In order to prevent this problem occur, the natural binder which from starch will be introduce. The natural binder that will be use could increase the pellet durability. The addictive is organic binder which is maize starch. In the case of organic binders, maize starch will give an improvement of tensile strength when amount of them is add into OPEFB biochar (Razuan et all, 2011)

The quality of EFB pellet is determined by a few key parameters including moisture content (MC), calorific value, amount of fines, mechanical durability, particle density, ash content, and ash melting point. These parameter values are defined in the prEn 14961-1 (EU) and PFI (United States of America) standards. The values of these physical and thermal parameters are affected by using different binding agents or additives in pellet production. According to the EU standards, additives that improve fuel quality, decrease emissions, or boost burning efficiency can make up to a maximum of 2% of the total mass of the wood pellets [10]. The most commonly used additives are lignosulphonate, starch, dolomite, corn or potato flour, and some vegetable oils. These binding agents or additives also affect the production economics of the final product

2.8 Torrefaction

Biomass torrefaction is a process of heating biomass in a low-oxygen environment and process of biomass/waste that produces carbon rich products (biochar) that have better fuel properties than the original biomass. There is some variation in the reported temperatures used in torrefaction. In existing literature, torrefaction ranges were found from 220 - 300℃ (428 - 572^{0}F). These temperatures are much lower than those often related to fast pyrolysis (400- 600℃) or gasification (900℃ or higher).

Raw material is typically dried to 10% moisture content (or less) prior to torrefaction. This drying can be accomplished in a separate step. After torrefaction, the moisture content can be reduced to <3%. In addition to the biomass source, particle thickness can play an important role in torrefaction (Lipinksy et al, 2002. In torrefaction systems that use a screw-type auger for continuous processing, heat transfer occurs as the EFB particles come into contact with heated surfaces (Li and Gifford, 2001). This equipment requires a particle size of 10 mm or less. For systems that use a batch process, heat transfer occurs through conduction. Batch systems are not as sensitive to particle size.

EFB properties undergo changes when processed at temperatures associated with torrefaction. EFB biomass consists of hemicelluloses, cellulose, lignins, and extractives. Torrefaction releases water and volatile organic compounds. Some of the lignin is devalitized and the remaining lignin is loosened. Hemicellulose is released and the remaining bio-char is a product of the torrefaction process. It is an intermediate product between EFB and charcoal and has most of the advantages of both products. Compared to the coal it replaces, biomass reduces sulfur dioxide (SO2), nitrogen oxides (NOx), and net greenhouse gas emissions of CO2 (Lipinski et al, 2002). Co-firing torrefied EFB is more attractive than using raw biomass because the torrefied EFB is friable and can be blended, pulverized and co-fired with coal. Moreover, torrefied biomass could makes grinding easier than fresh biomass, Storage of torrefied material is easier due to biological degradation and waste minimization.

2.9 Particle Density and Mechanical Durability

Particle density is the ratio of the sample mass and its volume including pore volume (Temmermana et al., 2006). Single pellet density is variable and depends on pellet machine packaging pressure and OPEFB species. Extremely high density is not good for combustion efficiency, as the access to oxygen is prevented when the EFB elements are very tightly packed, and that consequently degrades the burning process. These strength parameters are particularly important for storage and transportation of EFB pellets over long distances, as it is important to minimize dust and fracture formation during storage and transportation. However, according to the German and Austrian standards, a single pellet density should be between 1000 and 1400 kg/m^3 (Hahn et al., 2004).

Mechanical durability is defined as abrasion resistance and mechanical strength as compressive and impact resistance. According to the European standards, high-class pellet mechanical durability should not be less than 97.5%, and according to the PFI standard, this parameter should not be less than 96.5%. MC, particle size, and raw-material chemical composition affect wood pellet mechanical durability (T. Wilson., 2010). The mechanical durability of wood pellets is stable with MC values ranging between 9% and 14%, and the influence of abrasion disappears for MC values between 8% and 12%. If the raw material MC is lower than 7%, pellets will not have the necessary strength characteristics, as there will not be enough moisture for lignin to form a strong bond with the pellet particles.

2.9.1 Bulk Density and Pellet Size

Bulk density is a parameter, which directly affects storage and transportation costs, as higher bulk density promotes product compactness in the shipping container. Bulk density depends on pellet size (both length and diameter), single pellet density, and moisture content. Pellet size further impacts the pellet strength, as a longer pellet can be easily broken as compared to a shorter one. The bulk density of 6 mm diameter pellets (with average particle density of 1764 kg/m^3) is found to be 609 kg/m^3, compared to the bulk density of 8 mm diameter pellets (with average particle density of 1687 kg/m^3), which is found to be 621 kg/m^3 (Schott et all., 2011). Pellet size (length) also affects the burning efficiency. The use of binding agents as additives has been found to have an effect on the pellet length. Stahl et al. (2012) found that starch additive significantly increases the EFB pellet length. Other additives, such as lignosulphonate and different types of starch, decrease the moisture content of pellets, thereby increasing the bulk density of the product.

2.10 Morphological Characterization

A surface morphology study was performed on the OPEFB biochar to observe the effects of various OPEFB feedstock ash contents on the physical characteristics of OPEFB biochar from previous study. According to Adilah et al., (2014) SEM analysis was performed to observe structural changes in OPEFB biochar. High-resolution images of OPEFB biochar were obtained using a JEOL JSM 6400 LV model scanning electron microscope, which was operated at 15 kV. A Quantachrome Autosorb-1 Surface Analyzer was used to determine the BET surface area of the OPEFB biochar.

2.11 Properties of various oil palm

The cell wall structure of oil palm fibers consists of primary layer (P) and secondary layer (S1, S2 and S3). In general, oil palm fibers have varied variations in size, shape and structure of cell walls. Almost all the fiber structures are round. The layers of S1, S2 and S3 are strongly bonded and form structures such as sandwiches where microfibrils S1 and S3 corners are parallel to S2 layers. This sandwich structure provides additional strength to fiber for resistance to water strain, curve resistance to compressive strength, and bending stiffness to bending force. The primary walls of all oil palm fibers look like a thin layer. Some primary walls are clearly distinguishable between the middle lamella to each other.

2.12 Bonding Behaviour Characterization

FT-IR spectroscopy is a powerful tool for the study of polysaccharide ' physicochemical and conformation properties. Peaks at 1,044 and 3,419 cm-1 corresponding to C-O and O-H groups, respectively, are present in OPEFB and OPF fibers. According to (Khalil et al., 2008), the existence of O-H groups is due to the moisture content. The hydroxyl group is found in cellulose, hemicelluloses, and lignin. The prominent peaks at 1,739 cm-1 and 1,732 cm-1 represent carbonyl stretching (C=O) for acetyl groups in hemicelluloses and carbonyl aldehyde in lignin, respectively. A previous study reported that a peak at 1,378 cm-1 indicates the presence of C=O stretching frequency of the carboxylic group in hemicelluloses. Intense peaks at about 882 cm-1 and 1507 cm-1 indicates the stretching of the aromatic group such as in lignin.

From previous study also shows the differences in chemical composition between the various types of oil palm fibers. Extractive content was highest in OPT fiber (5.35%) compared to other fibers. This result was in the agreement with the results of a previous study, even though the value of the extractive content obtained is higher (9.8%). OPT fiber is also believed to have a high dimensional stability because its high extractive content (especially oil and wax) will reduce the hygroscopic fiber property. The utilization of OPT fiber in paper production will also reduce the pulp yield. This is because most extractive have a bad impact on chemical and mechanical pulping.

CHAPTER 3

MATERIALS AND METHODS

3.1 Material

The raw material that has been used in this study was oil palm empty fruit bunch (OPEFB). The raw of OPEFB was obtained from fibre mill at Penang. OPEFB was chosen because it has high energy content and a potential source of renewable biomass as it is widely available in Malaysia. As shown in Figure 3.1 was the raw material of extracted fiber that was used to further shredded for torrefaction and palletization process.

Figure 3.1: Raw of OPEFB

3.2 Method

This study was divided into some stages which were the sample preparation, torrefaction of OPEFB into torrefied biochar, palletization of OPEFB biochar with added natural binder and. Next, the pellet of OPEFB biochar were undergo characterization and data analysis, thus, the physical appearance, morphology, thermal behaviour, bonding behaviour, mass yield, and its physical properties were studied.

Research Flowchart

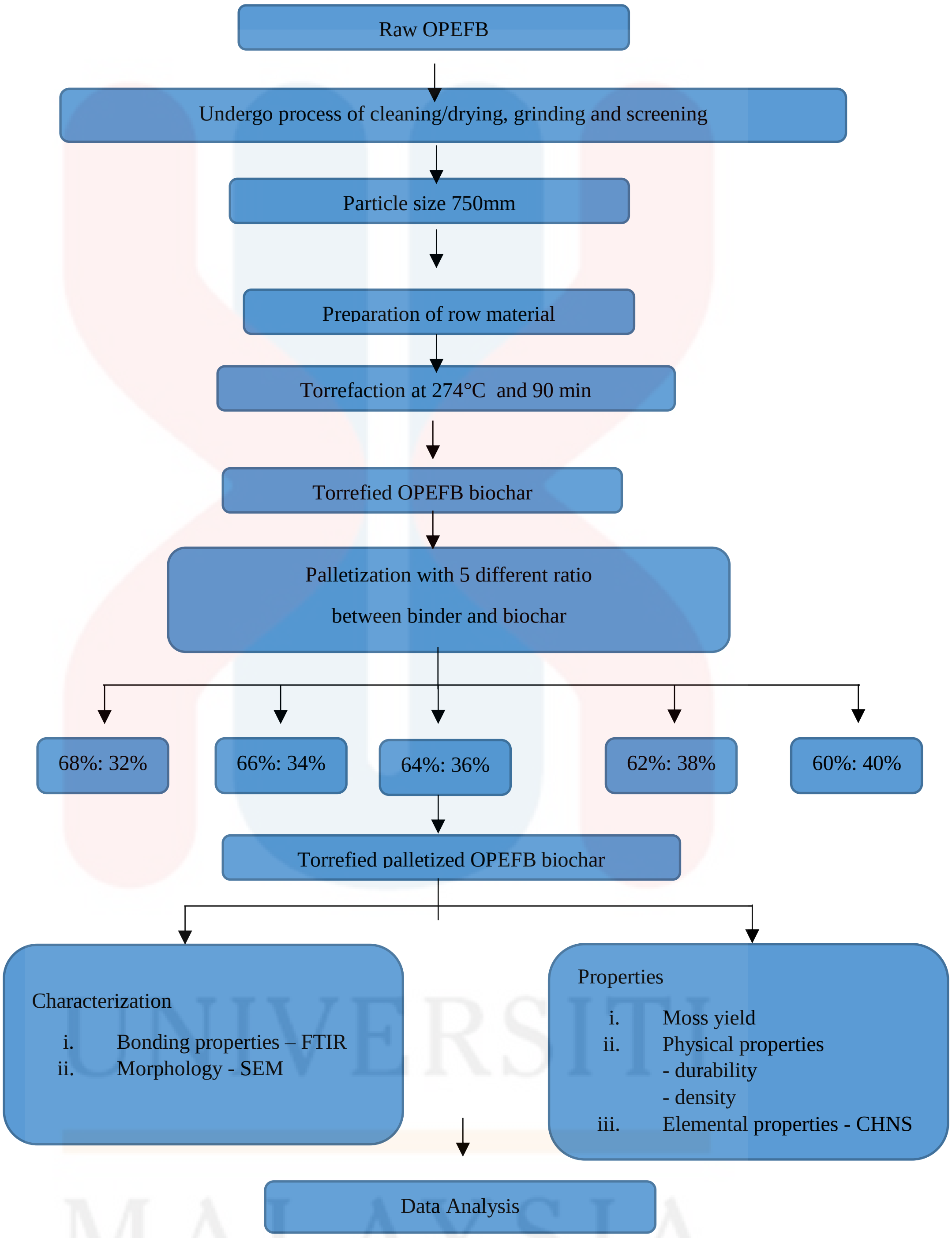


Figure 3.1 : Flow chart of overall process

3.2.1 Sample Preparation

The raw of OPEFB was undergo cleaning process by using water to remove the oil residues and any contaminant left in the fruit bunch. Then, the OPEFB was shredded into fibre and was leaved to sun-dried for 24 hours. Next, the raw materials were undergo preheated treatment in the oven at the temperature of 103±2°C for 1 hour to remove any moisture content to prevent biodegradation of the sample. The preheat treatment also allow the sample to be easily process into smaller size during grinding.

After preheated was done, the sample were left to allow it to cool down in a room temperature and then OPEFB fibre were cut into small pieces to make it more grindable to obtain the desire particle size during grinding. The samples were ground using blender until fine particles of OPEFB were produced. The screening of the particle size of the OPEFB was done by using siever of 750 μm.

3.2.3 Torrefaction Process

In this process, 25g of sample which the particle size at 750mm was placed and spread in the aluminium foil to undergo thermochemical treatment process. The thermochemical treatment that used in this study is torrefaction process. The aluminium foil that full with sample then was placed at the center of the furnace and was continuously purged with nitrogen to get rid of oxygen and maintain an inert atmosphere throughout the process. The oil palm biomass samples were heated up using a furnace at a heating rate of 10°C min. The holding temperature was going to be at 270°C without the presence of oxygen and residence time was being at 90 minutes (Rose., 2019). After 90 min of holding time at the desired torrefaction temperature, the furnace was turned off and allowed to cool down until it reached low temperature and the torrefied sample were collected as a torrefaction product and then continued with paletization process (Syamsiro et al., 2019). The raw material of OPEFB after torrefation process are called torrefied OPEFB biochar. This process was repeated for 27 times.

3.2.3 Palletization Process

The torrefied OPEFB biochar were undergoing palletization process which is OPEFB biochar and the additive was mix with different ratio. The additive that has been used in this study was clay. There were four different ratio between clay and OPEFB biochar which is 68% : 32%, 66% : 34%, 64% : 36%, 62% : 38%, 60% : 40% respectively. After sample preparation according to particle size and amount ratio, the sample were loaded approximately into the pellet mold and compressed with the desired pressure by using an universal testing machine (UTM) at "bengkel perkayuan" FBKT, UMK Jeli Kelantan. Figure 3.3 shows a pellet mold where cylindrical die comprised an opening of 10 mm in diameter which were made of carbon steel. Pressure was given to the pellet mold with a 20kN test speed, at length of 129mm of the compression length was released after 10s and the piston were removed.

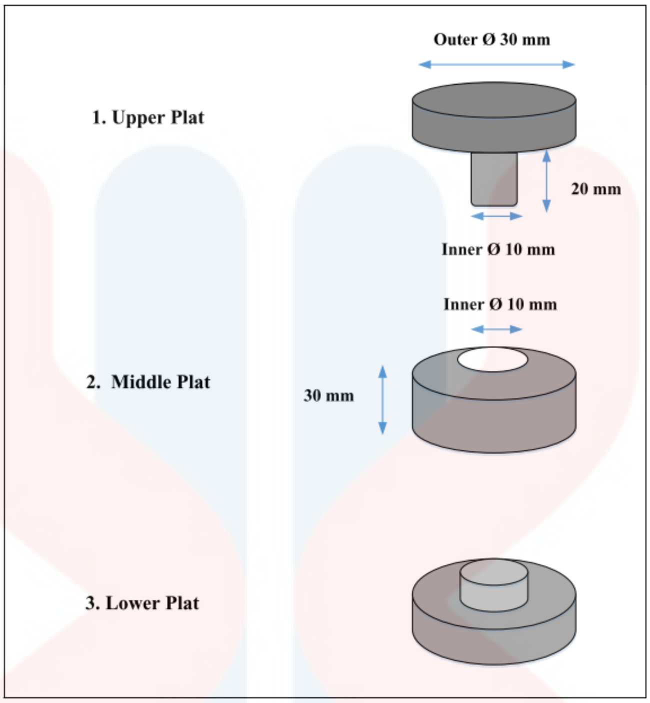


Figure 3.3: Schematic diagram of pellet mold
(Source: Ahmad et al., 2018)

3.2.4 Natural Binder as Additive

Clay as an additive has been added into torrefied biochar during palletization process. Clay that can increase the production rate of pellet has been blend together with torrefied biochar before the sample will compress into pellet mold to produce biopellet. There were five different ratio of biochar and clay that already calculated which is 68% biochar : 32% clay, 66% biochar : 34% clay, 64% biochar : 36% clay, 62% biochar : 38% clay, 60% biochar, 40% clay respectively. Tbale 3.1 shows the ratio between torrefied OPEFB biochar and natural binder

Table 3.1: The ratio between torrefied OPEFB biochar and natural binder

Number of Sample	The Ratio Between Torrefied OPEFB biochar and Natural Binder (clay)
1	32% binder : 68% biochar
2	34% binder : 66% biochar
3	36% binder : 64% biochar
4	38% binder : 62% biochar
5	40% binder : 60% biochat

3.2.5 Mass Yield of Torrefied Biochar OPEFB

The mass yield (MY) of the torrefaction process was the actual mass of the torrefied OPEFB biochar obtained. So, in this study the percentage yield can be calculated as the final (theoretical) mass of the product with the initial mass of product, giving the percentage figure for the reaction. The percentage of the MY in this process was worked out from the Equation (3.1) as followed:

$$MY = \frac{Weight\ of\ mass\ after\ torrefaction}{Mass\ of\ raw\ OPEFB} \text{ X } 100 \tag{3.1}$$

3.2.6 Physical Properties of Torrefied Pelletized Biochar

I. Density

In order to determine the initial pellet density, the mass, length, and diameter of each pellet were measured right after the extrusion from the die cylinder. The length and the diameter of each pellet were measured using a digital caliper while the weight of the pellet was measured using an analytical balance. These measurements were repeated after storing the pellets for 24 h and the data was represented as the relaxed pellet density.

II. Durability

Durability (DU (%)) is considered the most important indicator of solid biofuel mechanical quality, describes the abrasion resistance (material loses) of tested samples. the tumbling test was performed using standard ISO 17831-1 (2015) with the tumbling can Pellet tester PT 500 device. Result values were calculated by using the following formula Equation (3.2) :

$$DU = (mA/mE) \cdot 100 \qquad (3.2)$$

Where DU is the mechanical durability (%), mA is the mass of sieved pellets after the tumbling treatment (g), and mE is the mass of the pre-sieved pellets before the tumbling treatment (g). Final bio-pellet samples mechanical durability DU (%) was expressed in the form of the percentage of fines after testing.

3.2.7 Characterization of Torrefied Pelletized Biochar

The morphology of the fracture surface of composites was analysed using COXEM Dual-30, Taiwan, scanning electron microscopy (SEM). The samples was coated by gold sputtering before the SEM analysis was performed. The sample was mounted on aluminium holders using double-sided prior to analysis.

3.2.8 Elemental Properties of Torefied Peletized Biochar

CHNS analyzer model CHN-900/CHNS-932 manufactured by LECO was used for ultimate analysis. Biomass sample was prepared using micro balance provided. Sample was prepared in range from 1.5 mg to 2 mg into small tin capsule. After that, tin capsule was fold and weighed again. Sample weight was recorded. The analysis was carried out by technician.

3.2.9 Data Analysis

Result data were primarily organized and sorted and converted into graphs and tables using Microsoft Office Excel. The morphology and bonding behaviour has been evaluated, analyzed based on the data obtained

CHAPTER 4

RESULT AND DISCUSSION

4.1 Mass Yield of Torrefied Biochar

Biomass that undergo torrefaction process has lost the moisture, oxygen that contained organic compound and volatiles. Mass yield was calculated by using Eq (3.1) to know how much the biomass remains after torrefaction. The torrefaction of biomass is usually performed at temperature of around 200-300 °C, and the thermal treatment at higher temperature is referred to as pyrolysis. In this study, all the 27 run experiments, the temperature and residence time was set up at optimum number which is 274℃ and 90 minutes of time.

Since this torrefaction process was not optimized, the run of experiment has been done for 27 times with a sufficient sample of biochar OPEFB for the next palletization process. The mass yield of the OPEFB showed decreasing value from the initial weight compared to the final weight after being torrefied. The initial weights were approximately 20g for all 27 times run. The final weight of OPEFB after torrefaction process showed that all biomass samples occurred mass loss. The final mass yields were calculated. The higher the mass yield, the higher the energy sources in the OPEFB samples. Based on the result in the table at appendix, lowest mass yield was 46.65% while the highest mass yield 68.00%. The decrease in mass yield during torrefaction is primarily due to drying, partial devolatization and the breakdown of hemicellulose.

4.2 Physical Properties of Torrefied Pelletized Biochar

4.2.1 Density

The chart shows the highest density is torrefied pellet with 36% of binder which is 0.58%, while the lowest density is torrefied pelletized at 40% ratio of binder which is 40%. In the past research, the higher compaction pressure or higher die temperature is required to increase the density of torrified pellets. The reason why decreasing of pellet density is mainly related to the loss of chemically bonded water and low-melting point compounds which act as a binding agent when. In previous research, density of torrefied EFB pellets must be lower than raw EFB pellets due to loss of chemically bonded water and low melting point compounds during torrefaction. For comparison, the torrefied pelletized sample shows the low density compared with raw sample. Figure 4.1 shows the density result of five torrefied pelletized OPEFB biochar with different ratio.

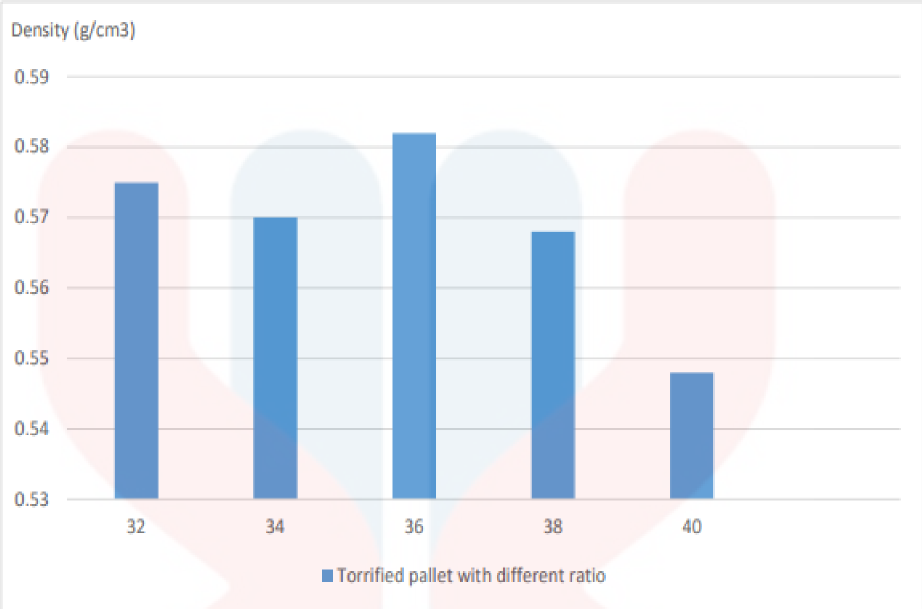


Figure 4.1: Density on torrefied pelletized with five different ratio between biochar and binder

4.2.2 Durability

The result shows the pellet durability average percentage for the biomass that had been torrefied, raw and torrefied pelletized empty fruit bunch. The highest pellet durability was the biomass pellet with ratio 38% of natural binder mix with 62% of biochar that had undergo torrefaction at 274°C which is 72.8% durability, followed by pellet 36%, pellet 40%, pellet 34%, pellet 32%, raw and char respectively. The durability of the torrefied biochar and raw OPEFB is 0% as the pellet is destroyed completely during the tumbling process, the untorrefied EFB is the raw biomass that is remain untreated and it shown as the weakest pellet that have no durability. Statistical analysis was performed to draw a conclusion. The one-way analysis of variance (ANOVA) was used to determine whether there are any statistically significant differences between the means of seven groups. Since the p-value is less than the set significance level which is 0.05, the data is considered statistically significant.

Figure 4.2 shows the pellet durability average percentage for the biomass that had been torrefied, untorrefied raw empty fruit bunch and torrefied pelletized OPEFB with five different ratio

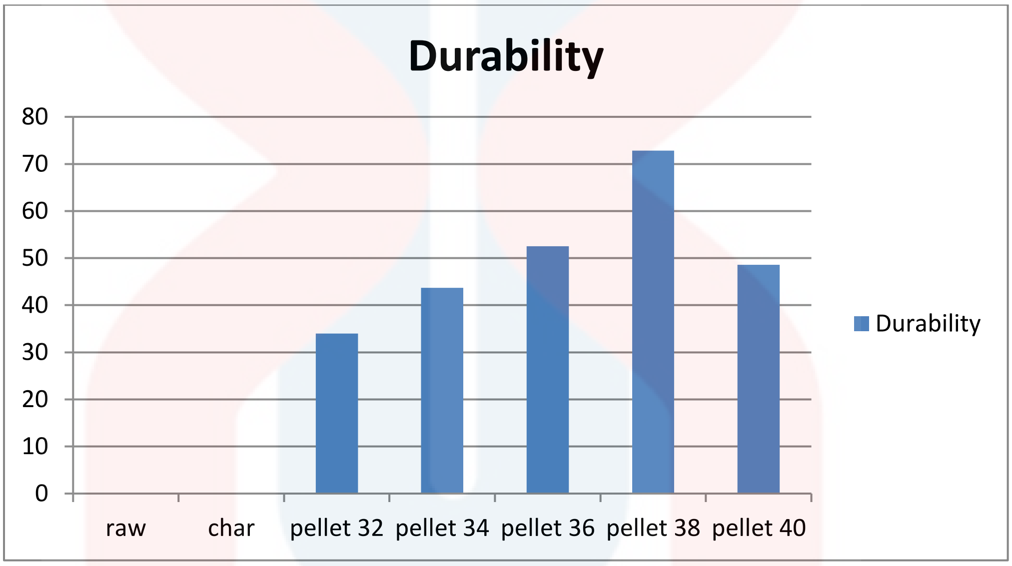


Figure 4.2 : Durability percentage of raw OPEFB, torrefied biochar OPEFB and torrefied pelletized OPEFB biochar with five different ratio

4.3 Physical Appearance and Morphology of Pelletized Biochar

4.3.1 Physical Appearance of raw, biochar and pellet of OPEFB

Figure 4.3 presents the raw feedstock oil palm EFB, torrefied products and biochar pellet at different ratio between biochar and binder. The samples are denoted; a – Raw 750mm particle size (untorrefied) EFB, b – Torrefied at 274 ºC until 90 mins, c – Torrefied pellet at ratio 68% biochar : 32% binder, d – Torrefied pellet at ratio 66% biochar : 34% binder, e – torrefied pellet at ratio 64% biochar : 36% binder, f – Torrefied pellet at ratio 63% biochar : 38% binder and g – Torrefied pellet at ratio 60% biochar : 40% binder.

The physical appearance of OPEFB after torrefied can be observed by the colour changes of them and being compared with the raw OPEFB. As can be observed, the colour of torrefied oil palm EFB changed progressively from greyish brown to black with temperature 274°C and residence time 90 min. The progressive change in colour EFB is primarily due to the feedstock devolatization and increase in carbon content during torrefaction as mention by Bevan et al (2016).

Based on the figure 4.3 shown down below, start from C – G it was torrefied pellet OPEFB according to ratio between biochar and natural binder. There were five ratio and lots of pellet has been produced. All the physical appearance of the pellet shows insignificant differences between them. Meanwhile, it was obviously the presence of whiteness on the body part of the pellet in each pellet. It was because of natural binder that was bind together with biochar during pelletization process. The more the percentage of binder added into biochar, the more the whiteness appeared on the pellet body.

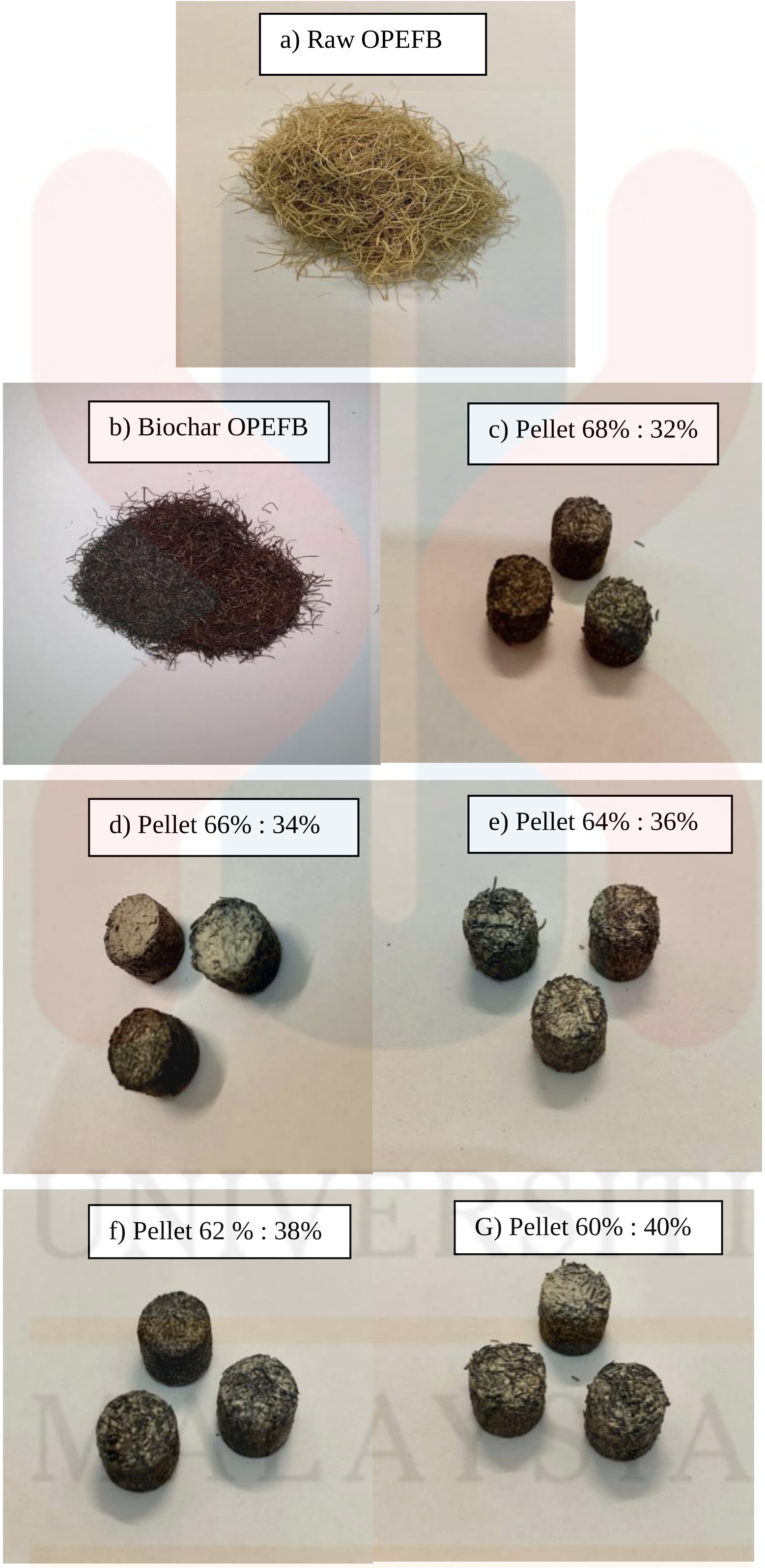


Figure 4.3 : (a) Phyisical appearance of raw OPEFB, (b) torrefied OPEFB biochar, (c-g) torrefied pelletized OPEFB biochar with different ratio

4.3.2 Morphology

To obtain deeper insight into the changes of surface structure by torrefaction and palletizationn process, SEM was employed. All the Figure 4.4 represented the images of raw, torrefied biochar EFB, and pellet of torrefied biochar with five different ratio of binder.

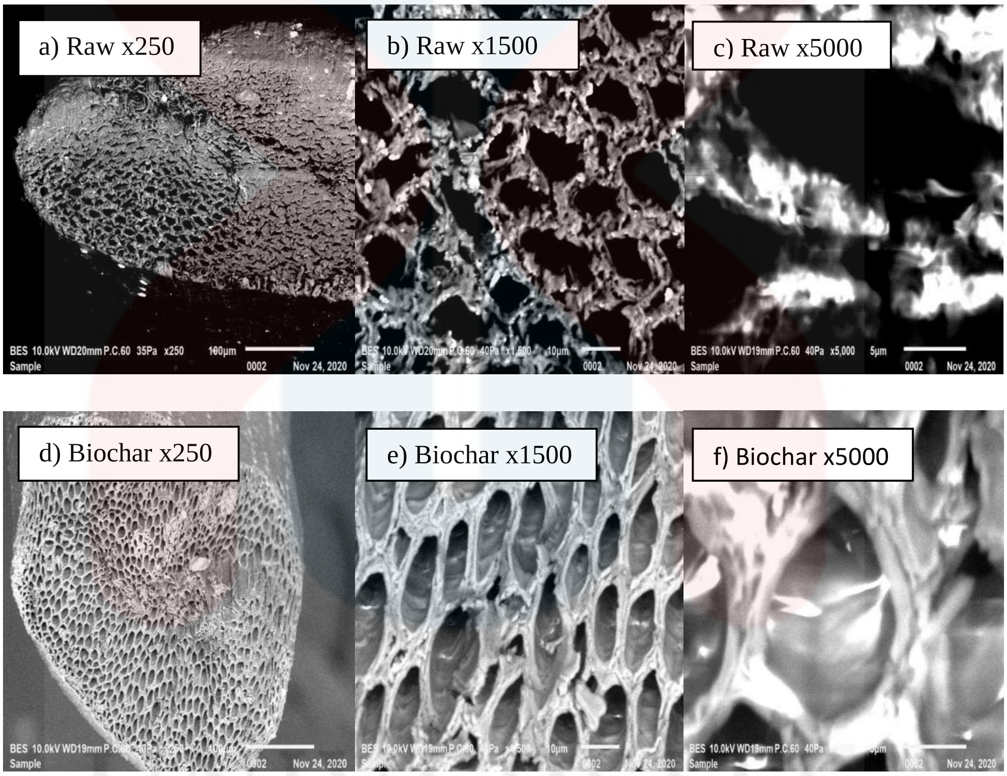
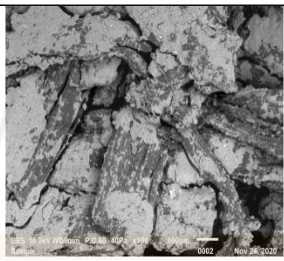
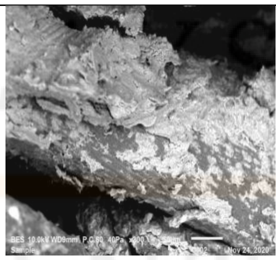
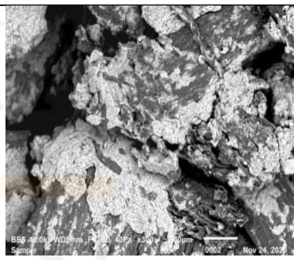


Figure 4.4 : SEM images of (a-c) raw OPEFB and (d-f) torrefied biochar surface structure sieved 750µm magnification x250, magnification x1500, magnification x5000

Structure of EFB and torrefied EFB was perceived using scanning electron microscope (SEM) under magnifications of ×750, x270, x1500 and x5000 were shown in Figs. 4.4 respectively. Raw EFB as shown in Fig. 4(a) at maginificant x250 indicates a smooth surface compared to biochar. There were possibilities of pores, voids or inter-particle gaps presence in the structure of raw EFB, but they were not clearly determined due to the irregular fiber arrangements.

When compared to the morphology image of torefied biochar in figure 4 (d-f) respectively, spongy-like structure was shown as the effect of torrefaction process. It was shows the 90 minutes' residence time and 274°C of torrefaction process where at the formation of porous were observed and determined. In generally, torrefied EFB shows a similar structure as raw EFB. This was because of the low temperature was used in the torrefaction process which is 274°C and almost unaffected the structure.

TABLE 4.1 : Surface Electron Microscopy (SEM) image of torrefied pelletized with five different ratio. (A) – torrefied pelletized with ratio 32% : 68%, (B) – 34%: 66% , (C) – 36% : 64%, (D) – 38% : 62%, (E) – 40% :60%

MAGNIFICATION	SIDE BODY	TOP BODY
x 30		
x 100		
x 300		

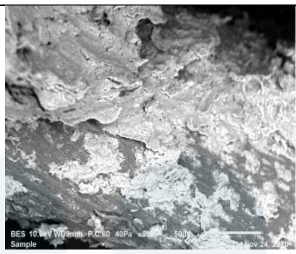
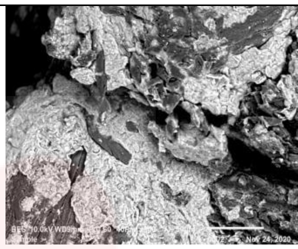
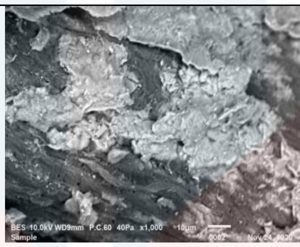
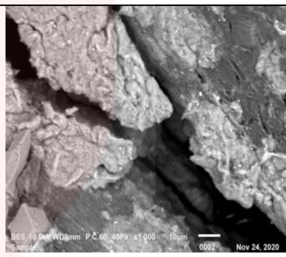
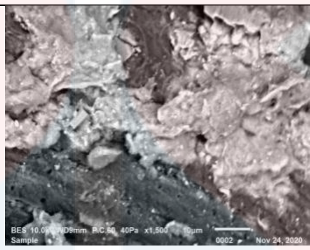
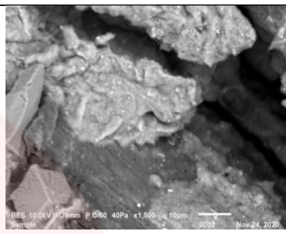
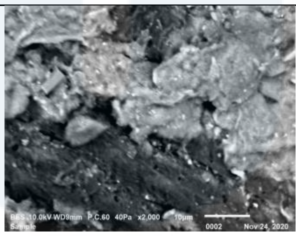
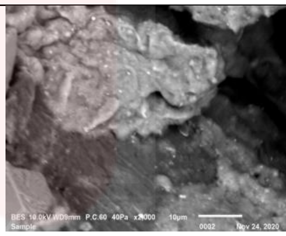
x 500		
x 1000		
x 1500		
x 2000		

Table 4.1 : (B)

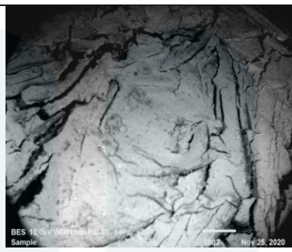
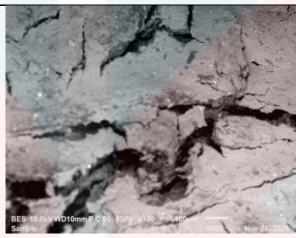
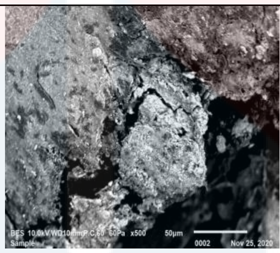
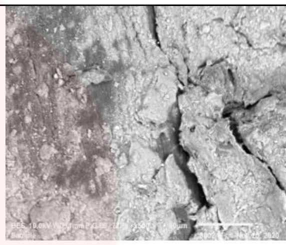
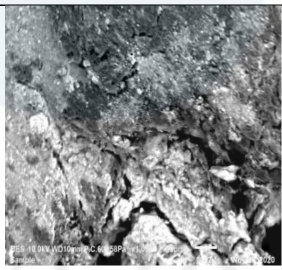
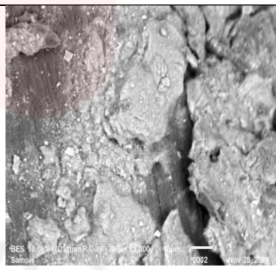
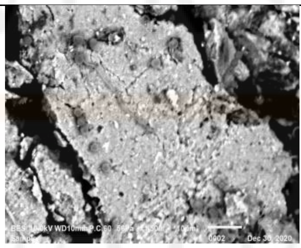
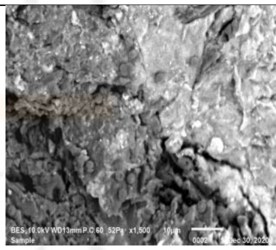
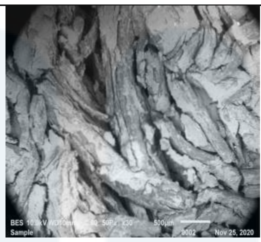
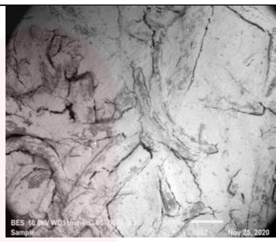
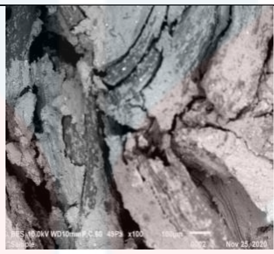
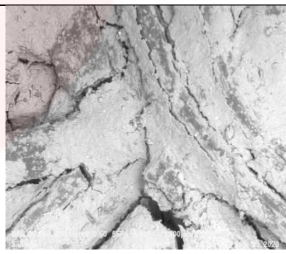
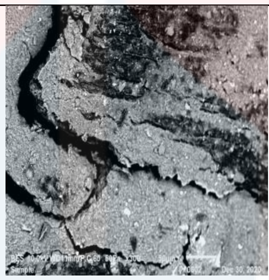
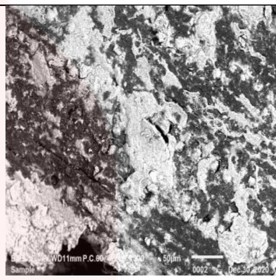
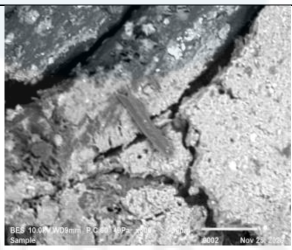
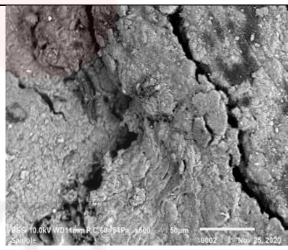
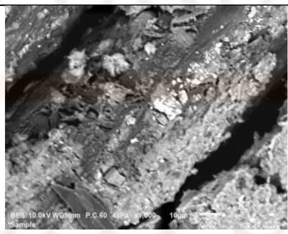
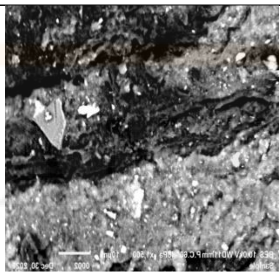
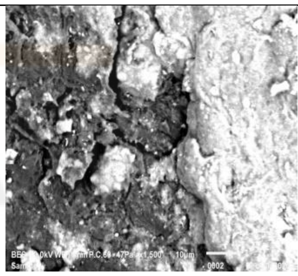
MAGNIFICATION	SIDE BODY	TOP BODY
x 30		
x 100		
x 500		
x 1000		
x 1500		

Table 4.1: (C)

MAGNIFICATION	SIDE BODY	TOP BODY
x 30		
x 100		
x 300		
x 500		
x 1000		
x 1500		

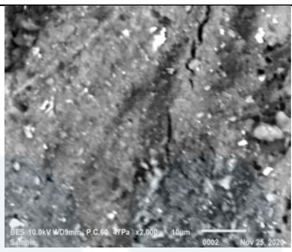
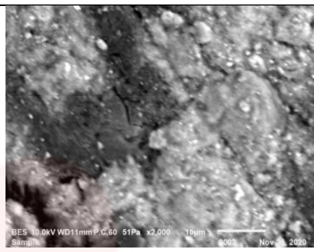
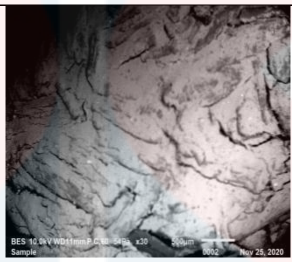
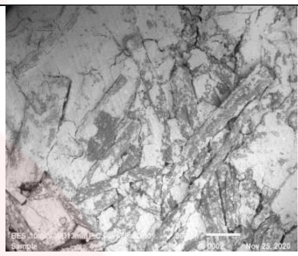
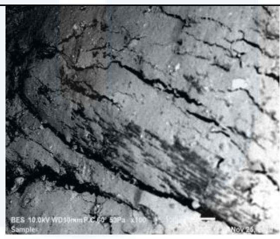
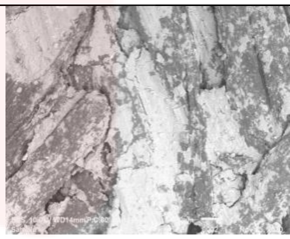
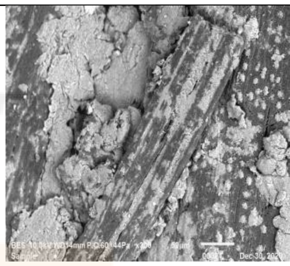
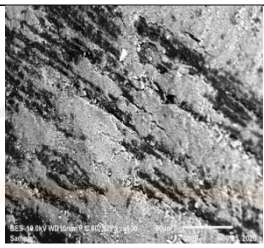
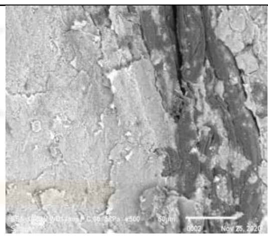
x 2000		

Table 4.1: (D)

MAGNIFICATION	SIDE BODY	TOP BODY
x 30		
x 100		
x 300		
x 500		

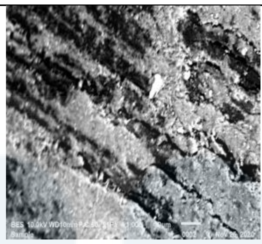
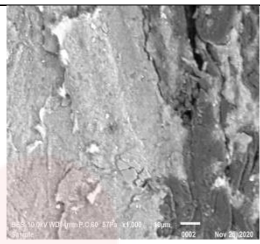
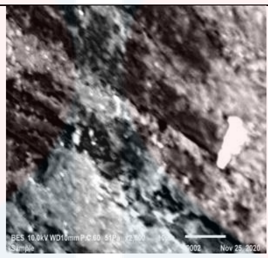
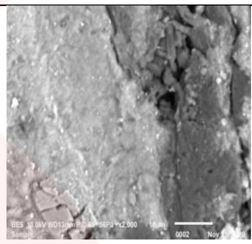
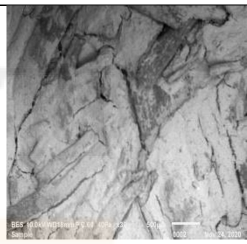
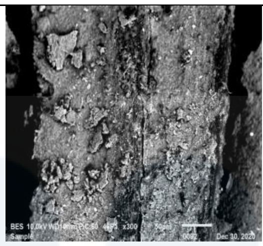
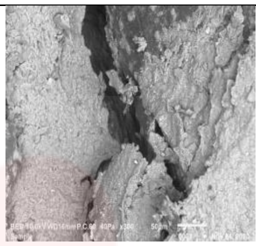
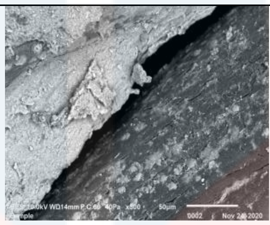
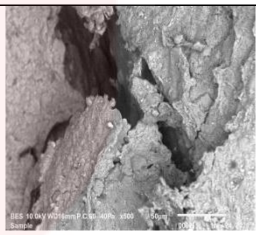
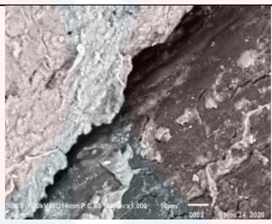
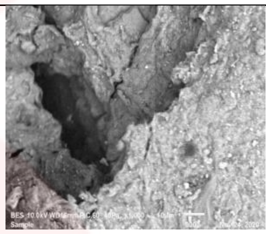
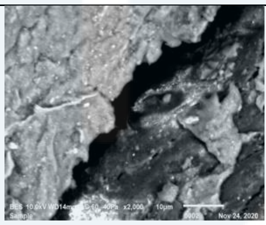
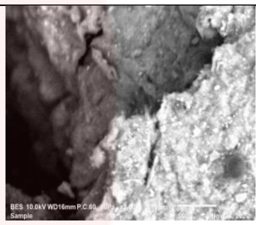
x 1000		
x 1500		
x 2000		

Table 4.1: (E)

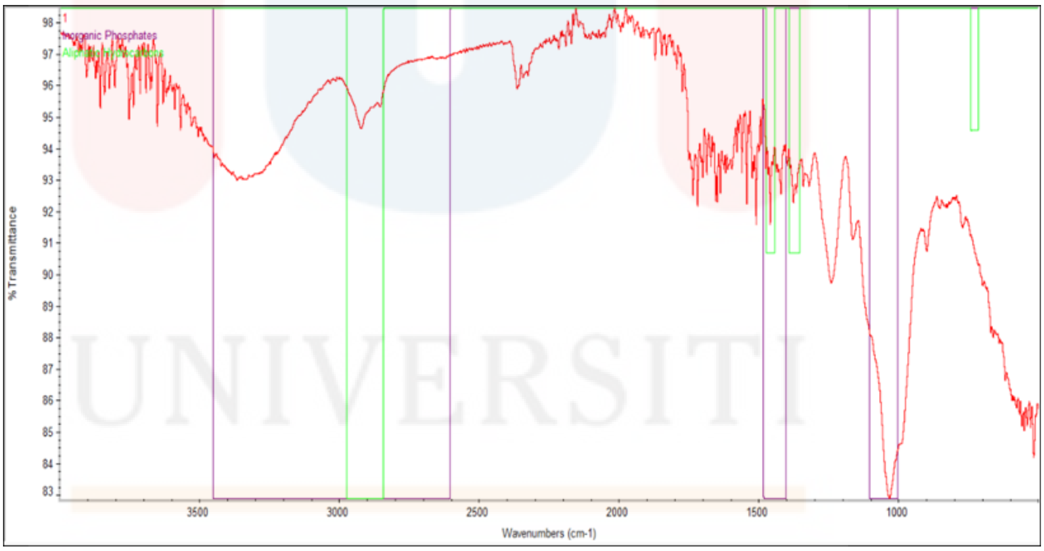
MAGNIFICATION	SIDE BODY	TOP BODY
x 30		
x 100		

x 300		
x 500		
x 1000		
x 2000		

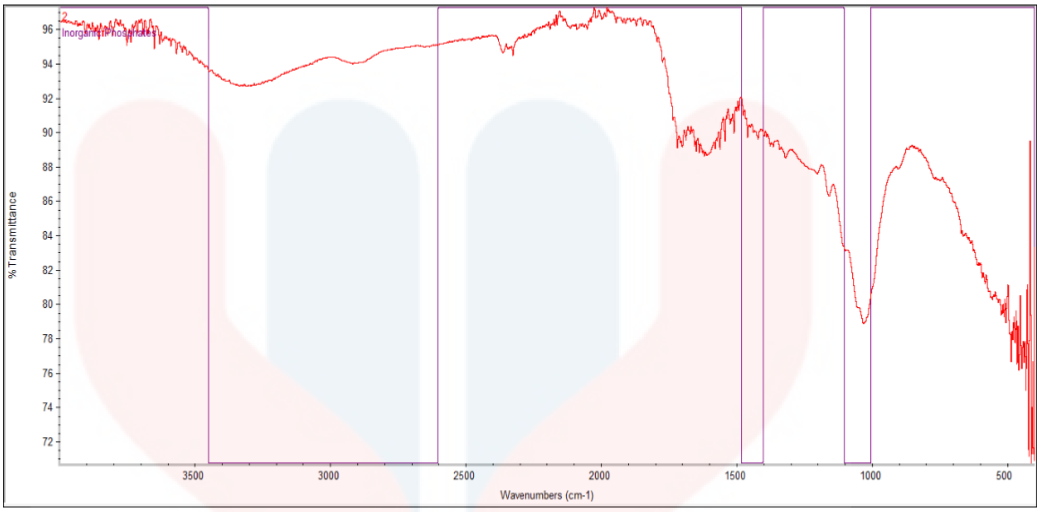
The morphology of the produced bio-pellet samples was observed, the outer surface of the bio-pellet samples exhibited a regular flat surface but the integrity of the surface was disturbed by cracks of different shape. All the image of pellet with 5 different ratios exposing a clear image of ruptured at the surface structure. The stretching of ruptured surface structures was caused by the degradation of lignocellulose. The clause of breakage of wall surface was contributed by the rupture impact as the decomposition of cellulose and hemicellulose take places. Also, the ruptured images contributed to the degradation of lignocellulose, the porosity also participated in the degradation. The more amount of ratio added into biochar causing a large amount of hemicellulose and cellulose were destroyed (Nasri et al,.2013). Since the cellulose was degraded, the fiber wall became thinner as residence time was longest, 90 minutes. When looked up closely at highest magnification which is ×1000, x1500 and x2500 magnification, the fiber was torn apart.

4.4 Bonding Behaviour of Torrefied Pelletized Biochar

FTIR spectroscopy was used to investigate the IR Spectral Infra and functional group presence in the raw OPEFB, torrefied biochar and torrefied pelletized with 6 different ratio. The figure 4.5 below denoted : A- raw OPEFB and B - torrefied OPEFB biochar.



(A) – Raw Opefb



(B) – Torrefied OPEFB

As can observed, in raw OPEFB graph (a) there were inorganic phosphate and Aliphatic Hydrocarbon. The result was explained by MONIC software which stated that Inorganic Phosphate have very characteristic spectra. There are two strong bands at around $1000cm^{-1}$ and $550cm^{-3}$. There was also typically water bands around $3400cm^{-3}$. Meanwhile, Aliphatic Hydrocarbon group were found in many compounds that infrared spectroscopist is likely to encounter. The most important vibrational modes are the C-H deformation modes around $3000cm^{-1}$ and the -CH deformation modes around $1460cm^{-1}$ and $1380cm^{-1}$. Moreover, for torrefied and others five pellets only shows for Inorganic Phosphate absence. Aliphatic Hydrocarbon was loss due to torrefection process as well as pelletization because the pellet produced was from torrefied biochar.

Figure 4.4 shows the result of bonding behaviour of raw OPEFB , torrefied biochar and torrefied pelletized with 5 five different ratio in one graph.

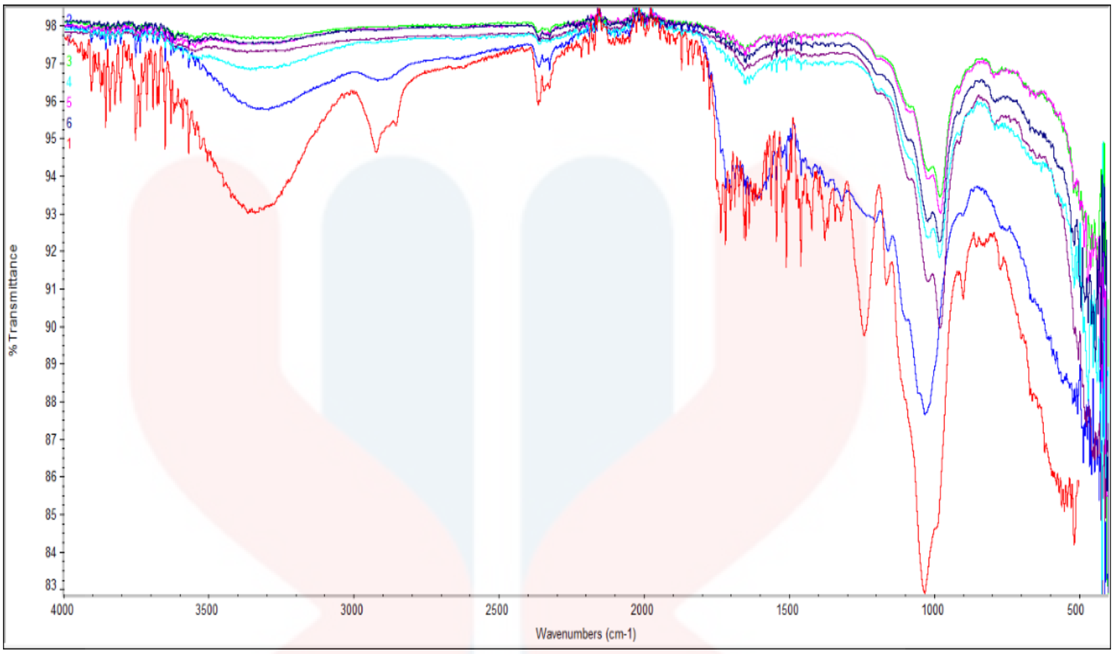


Figure 4.4 : Bonding behaviour of raw OPEFB, torrefied OPEFB biochar, five torrefied pelletized OPEFB biochar

A strong and broad absorption was observed at a wavenumber of 3355 cm-1 which is related to the stretching of H-bonded in hydroxyl group of cellulose, respectively. The other prominent one around wavenumber of 2900 cm-1 is due to the C-H stretching of CH2 from the CH2-OH group in cellulose (Suradi,Yunus et all,. 2009) . In addition, the area of 1800 to 600 cm-1 is called the fingerprint area of spectra which has many sharp and well defined absorption bands due to the various functional groups presence in each component of OPEFB.

The peak at around wavenumber of 1733cm-1 can be seen from the spectra, which occur due to the C=O stretching of the acetyl and uronic ester groups of the hemicellulose ester. The peak also represents the carbonyl ester linkages of the carboxylic groups of ferulic and p-coumaric monomeric lignin (Kumar, Mago et al,. 2009). The peak at 1635 cm-1 was correspond to the bending vibration of the hydroxyl groups of cellulose. Sun and Cheng also reported that the band around 1600 cm-1 was probably due to the bending mode of water, since hemicelluloses have strong affinity for water. The absorption band 1244 and 1541 cm-1 are arise mostly from aromatic ring of lignin, while the band around 1635, 1375, 1049 and 667 cm-1 are mainly due to carbohydrates and have no significant contribution from the lignin (Sun, jing,. 2011

4.5 Elemental Properties of Torrefied Pelletized Biochar

CHNS analyzer will used to determine percent of carbon, hydrogen, nitrogen and sulphur contents. The ultimate properties for raw, torrefied biochar and torrefied pelletized with 5 different ratio is listed in graph 4.8

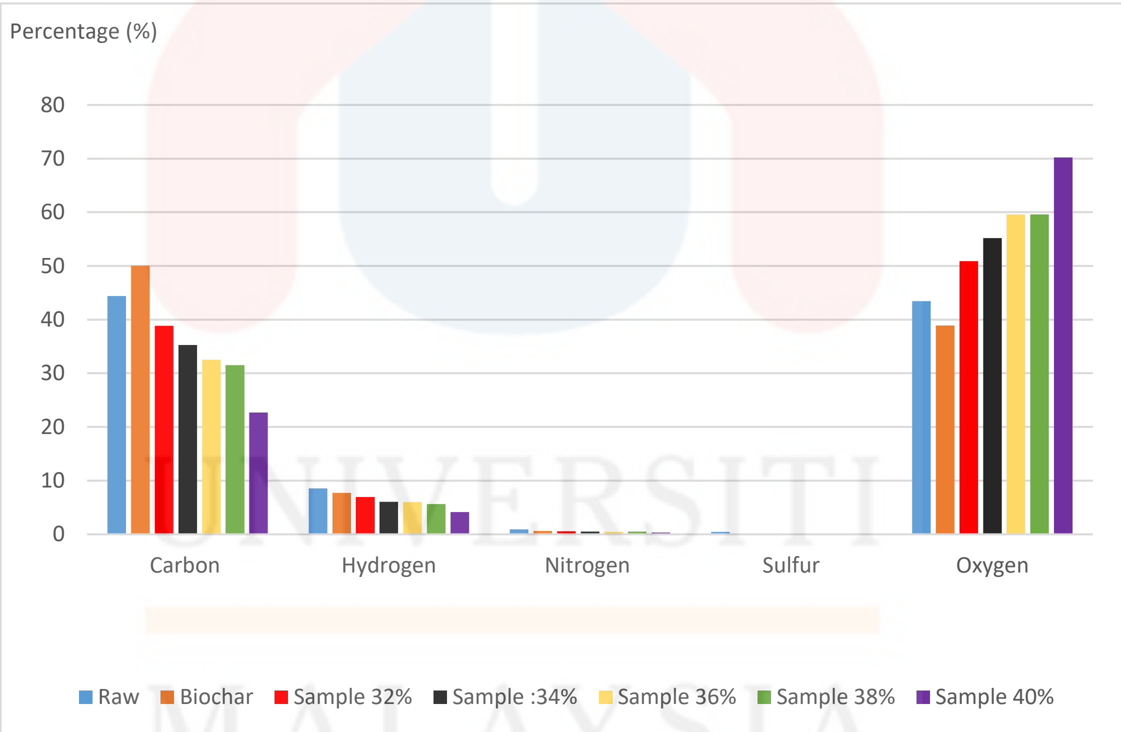


Figure 4.8: The ultimate analysis percentage of raw, torrefied biochar and torrefied pelletized biochar

The ultimate analysis shows the percentage of carbon, hydrogen, nitrogen and sulfur. The main elements of biomass are C, H and O, while N and S are possibly found in small amount. From the table 4.2, it was obviously the data shows that

Nitrogen and Sulfur has the smallest amount of number percentage. The percentage of oxygen was obtained by subtracting the overall CHNS percentage from lOO. From the analysis, all samples shows carbon percentage of 22-50%. The hydrogen percentage of the samples is 4-8%. Sulfur and Nitrogen content in the all sample is the lowest >1.0% while Oxygen's percentage is 41-72%.

Comparisons were conducted with respect to the composition of each element. For carbon content percentage, torrefied biochar is the highest with 50.06% followed by raw with 44.38% while the pellet with 40% of ratio is the lowest carbon content among all. As for hydrogen content, raw sample is the highest while torrefied pelletized with 40% ratio indicates the lowest. Pellet with 40% ratio has the lowest nitrogen content amongst all the samples while torrefied biochar shows the highest which is 0.61%. Raw EFB shows the highest content for sulfur while pellet with 38% and 40% of ratio shows the lowest sulfur content. Pellet 40% indicates the highest oxygen content while torefied biochar the lowest. From the percentage of the composition, the C:H, H:C and 0:C ratios were determined.

CHAPTER 5

CONCLUSION & RECOMENDATION

5.0 CONCLUSION

The main aim of performed investigation was to determine the suitability of waste biomass from palm oil mill, i.e., primarily composed of oil palm empty fruit bunches (EFB), for the production of bio-pellet fuel. The torrefied pelletized OPEFB biochar was tested, thus, complex evaluation of such bio-pellet fuel quality was performed with satisfactory results. The clay as a natural binder with different ratio successfully proved that it could turn to a better quality bio-pellet compared to raw OPEFB pellet that has been produced before by previous study. The torrefied pelletized biochar could last longer from the first day of produced on October until December compared to raw OPEFB pellet that only last for 3 days.

The result obtain from durability, the raw biomass that is remain untreated and torrefied biochar it shown as the weakest sample that have no durability with 0% compared with torrefied pelletied biochar with the highest number percentage of durability which is 72.8%. Moreover, the result of mass yield also shows the decrease number of percentage after torrefection which is the highest mass yield was 68.00% while the lowest mass yield 46.65%. The decrease in mass yield during torrefaction is primarily due to drying, partial devolatization and the breakdown of hemicellulose.

Morphology and bonding behaviour analysis demonstrated strong bonds within the internal structures of produced bio-pellet samples and it was influenced by the degradation of the lignocellulose, hemicellulose, cellulose and lignin. In general, it can be assumed that the used methodology and its specific steps were adequate for statement of sustainability of bio-pellet fuel produced from torrefied EFB biochar.

5.1 RECOMENDATION

This research was study of torrefied pelletied using clay as a natural binder to improve the performance of biofuel pellet. Since there are various types of natural binder can be used for additive in pelletization OPEFB biochar such as starch, I would suggest and recommend for future study to use others natural binder and compare their characteristic or study the properties of OPEFB pelletized. Lastly, other than EFB there are abundance of oil palm biomass such as OPT, OPF, MF and PKS to be pelletized as biomass energy. Future study can compare on the effectiveness of the pelletized OPEFB and other oil palm biomass with different types of natural binder.

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APPENDIX

APENDIX – A

Table A.1: mass yield

Run	Particle Size (µm)	Holding Temperature (℃)	Residence Time (min)	Initial Weight (g)	Final Weight (g)	Mass Loss (%)	Mass yield (%)
1	750	274	90	20	11.42	42.99	57.01
2	750	274	90	20	12.01	39.95	60.05
3	750	274	90	20	12.33	38.39	61.61
4	750	274	90	20	11.87	40.65	59.35
5	750	274	90	20	12.29	38.58	61.42
6	750	274	90	20	13.56	32.05	67.95
7	750	274	90	20	10.23	48.85	51.15
8	750	274	90	20	9.81	50.95	49.05
9	750	274	90	20	11.71	41.45	58.55
10	750	274	90	20	11.54	42.93	57.07
11	750	274	90	20	11.48	42.96	57.04
12	750	274	90	20	11.12	44.94	55.06
13	750	274	90	20	9.33	53.35	46.65
14	750	274	90	20	10.80	46.00	54.00
15	750	274	90	20	12.11	39.45	60.55
16	750	274	90	20	10.53	47.35	52.65
17	750	274	90	20	12.40	38.00	62.00
18	750	274	90	20	11.94	40.93	59.07
19	750	274	90	20	11.19	44.05	55.95
20	750	274	90	20	12.17	39.15	60.85
21	750	274	90	20	13.21	33.95	66.05
22	750	274	90	20	13.60	32.00	68.00
23	750	274	90	20	13.23	33.85	66.15
24	750	274	90	20	11.95	40.25	59.75
25	750	274	90	20	12.35	38.25	61.75
26	750	274	90	20	13.07	34.65	65.35
27	750	274	90	20	13.11	34.45	65.55

Table A.2 : Density

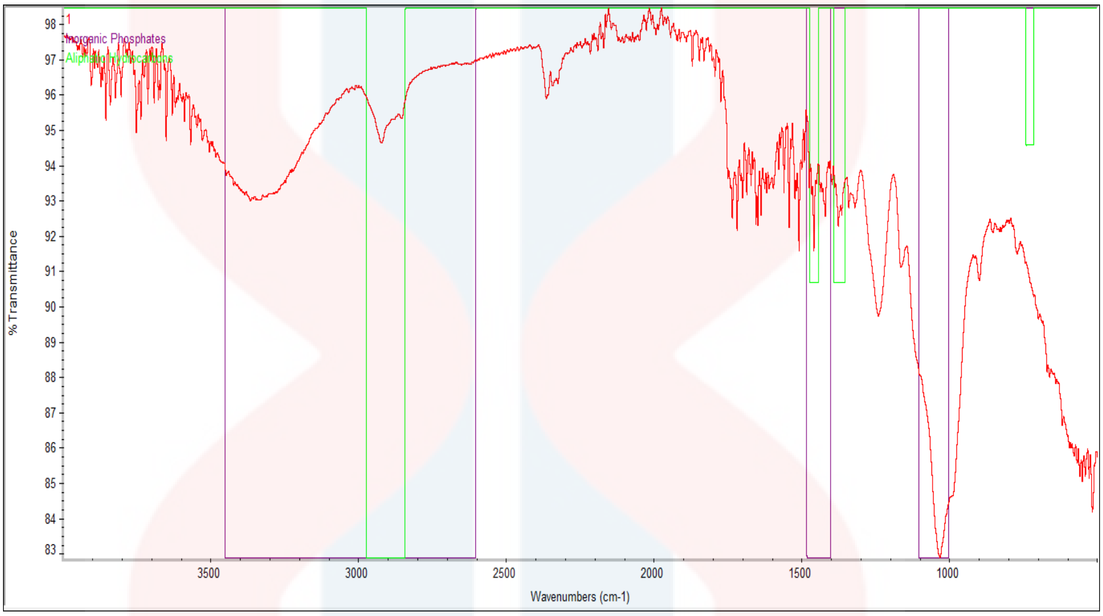
				πr2	Area x height	m/v	
Pallet	Replicate	Mass(g)	Height(mm)	Area (r=5)	Volume(mm3)	Density(g/cm3)	Average
32	**1**	0.5117	10.46	78.55	821.633	0.62278414	**0.575**
	2	0.4828	10.38	78.55	815.349	0.59213907	
	3	0.4483	10.31	78.55	809.8505	0.55355896	
	4	0.4616	10.47	78.55	822.4185	0.56127142	
	5	0.4516	10.14	78.55	796.497	0.56698268	
	6	0.4487	10.34	78.55	812.207	0.55244537	
	7	0.4436	10.33	78.55	811.4215	0.54669491	
	8	0.4565	10.29	78.55	808.2795	0.56477988	
	9	0.4652	10.32	78.55	810.636	0.57387039	
	10	0.5065	10.41	78.55	817.7055	0.61941616	
34	**1**	0.4401	10.50	78.55	824.775	0.53360007	**0.57**
	2	0.5128	10.49	78.55	823.9895	0.62233803	
	3	0.4593	10.41	78.55	817.7055	0.56169367	
	4	0.4515	10.40	78.55	816.92	0.55268570	
	5	0.4580	10.43	78.55	819.2765	0.55902983	
	6	0.4238	10.39	78.55	816.1345	0.51927715	
	7	0.4500	10.32	78.55	810.636	0.55511968	
	8	0.4814	10.28	78.55	807.494	0.59616542	
	9	0.4732	10.32	78.55	810.636	0.58373919	
	10	0.4780	10.30	78.55	809.065	0.59080544	
36	**1**	0.4723	10.29	78.55	808.2795	0.58432757	**0.562**
	2	0.4672	10.25	78.55	805.1375	0.58027356	
	3	0.4754	10.34	78.55	812.207	0.58531877	
	4	0.5067	10.34	78.55	812.207	0.61701861	
	5	0.4400	10.37	78.55	814.5635	0.54016660	
	6	0.4432	10.24	78.55	804.352	0.55100255	
	7	0.4943	10.33	78.55	811.4215	0.60917784	
	8	0.4887	10.27	78.55	806.7085	0.60579503	
	9	0.4814	10.46	78.55	821.633	0.58590636	
	10	0.4492	10.40	78.55	816.92	0.54987024	
38	**1**	0.4518	10.37	78.55	814.5635	0.55465289	**0.568**
	2	0.4704	10.38	78.55	815.349	0.57693086	
	3	0.4632	10.37	78.55	814.5635	0.56864812	
	4	0.4677	10.28	78.55	807.494	0.57919935	
	5	0.4647	10.41	78.55	817.7055	0.56829751	
	6	0.4514	10.44	78.55	820.062	0.55044619	
	7	0.4575	10.36	78.55	813.778	0.56219264	
	8	0.4579	10.31	78.55	809.8505	0.56541300	
	9	0.4611	10.38	78.55	815.349	0.56552470	
	10	0.4726	10.34	78.55	812.207	0.58187137	
40	**1**	0.4255	10.36	78.55	813.778	0.52286987	**0.548**
	2	0.4625	10.43	78.55	819.2765	0.56452248	
	3	0.4909	10.40	78.55	816.92	0.60091563	
	4	0.4597	10.40	78.55	816.92	0.56272340	
	5	0.4383	10.37	78.55	814.5635	0.53807960	
	6	0.4408	10.36	78.55	813.778	0.54167107	
	7	0.4534	10.38	78.55	815.349	0.55608089	
	8	0.4467	10.27	78.55	806.7085	0.55373161	
	9	0.4174	10.31	78.55	809.8505	0.51540377	
	10	0.4489	10.27	78.55	806.7085	0.55645875	

Table A.3: The ultimate properties for raw, torrefied biochar and torrefied pelletized with 5 different ratio

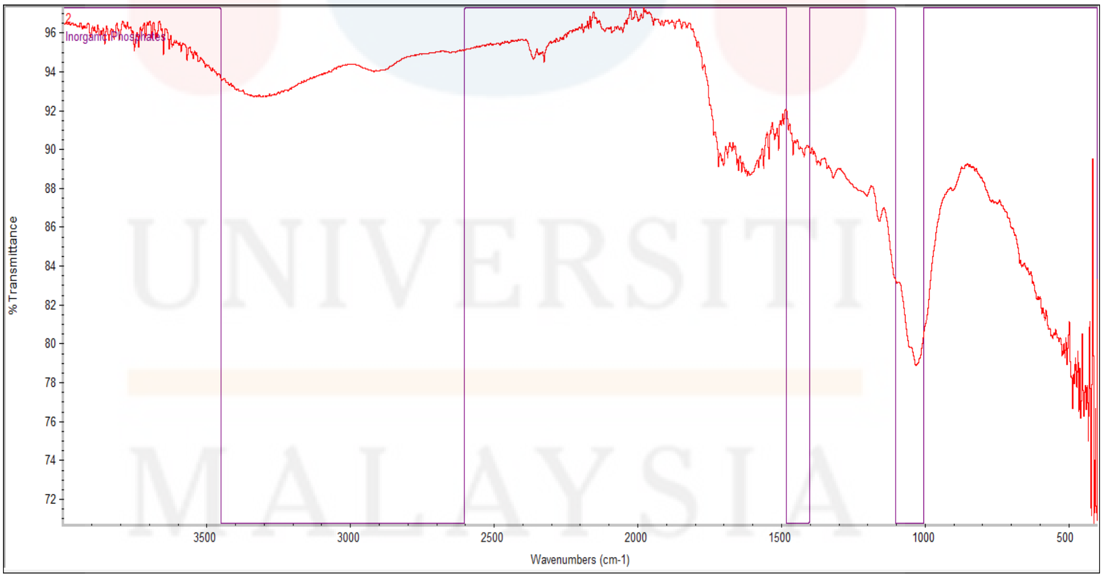
Type Of Sample	Weight (%)	Carbon (%)	Hydrogen (%)	Nitrogen (%)	Sulfur (%)	Oxygen (%)
Raw	2.259	44.38	8.54	0.92	0.43	43.47
Biochar	2.579	50.06	7.71	0.61	0.11	38.93
Pellet 32%	2.696	38.83	6.94	0.57	0.07	50.89
Pellet 34%	2.936	35.30	6.06	0.51	0.01	55.18
Pellet 36%	2.762	32.55	6.0	0.46	0.01	59.60
Pellet 38%	2.746	31.50	5.63	0.52	0	59.60
Pellet 40%	2.573	22.70	4.14	0.33	0	70.25

APPENDIX B

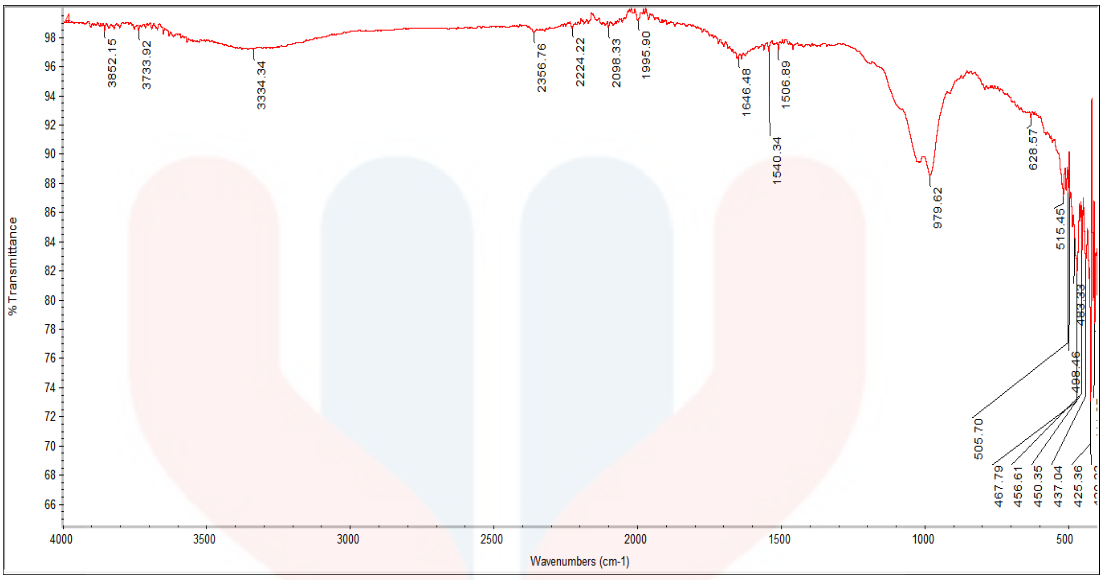
FIGURE B.1 : Bonding behaviour of raw OPEFB, torrefied OPEFB biochar and each torrefied pelletized OPEFB biochar with five different ratio.



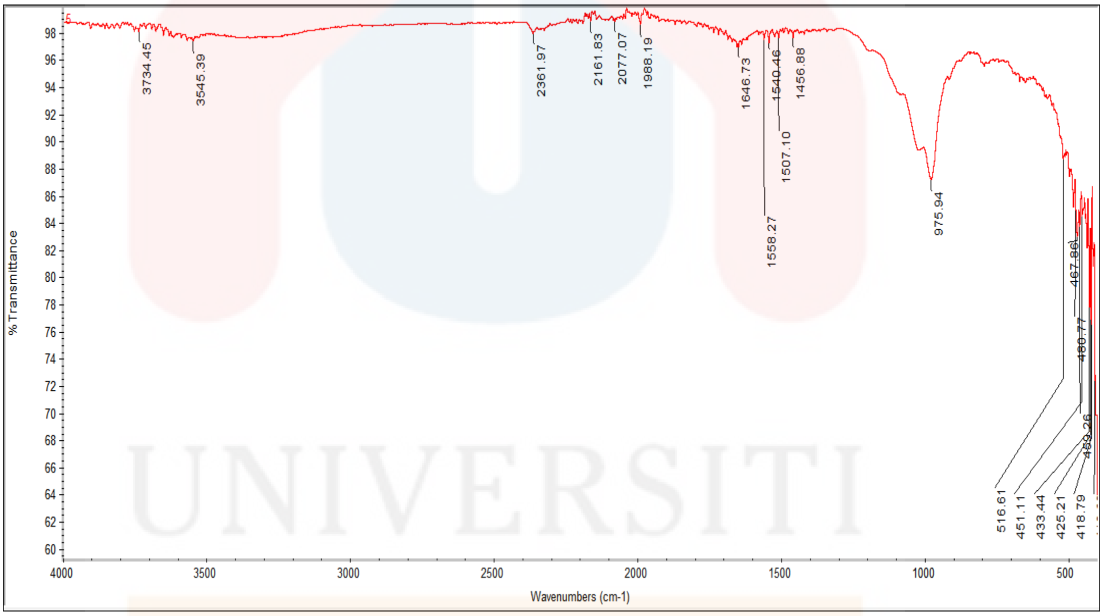
(A) - Raw OPEFB



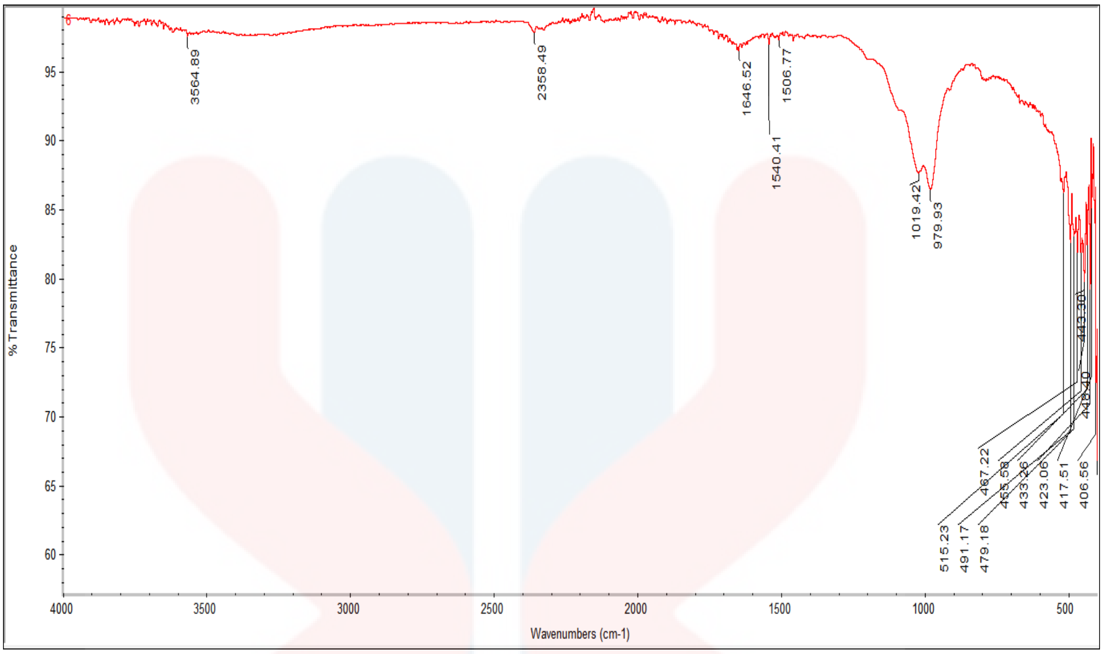
(B) – Torrefied Biochar



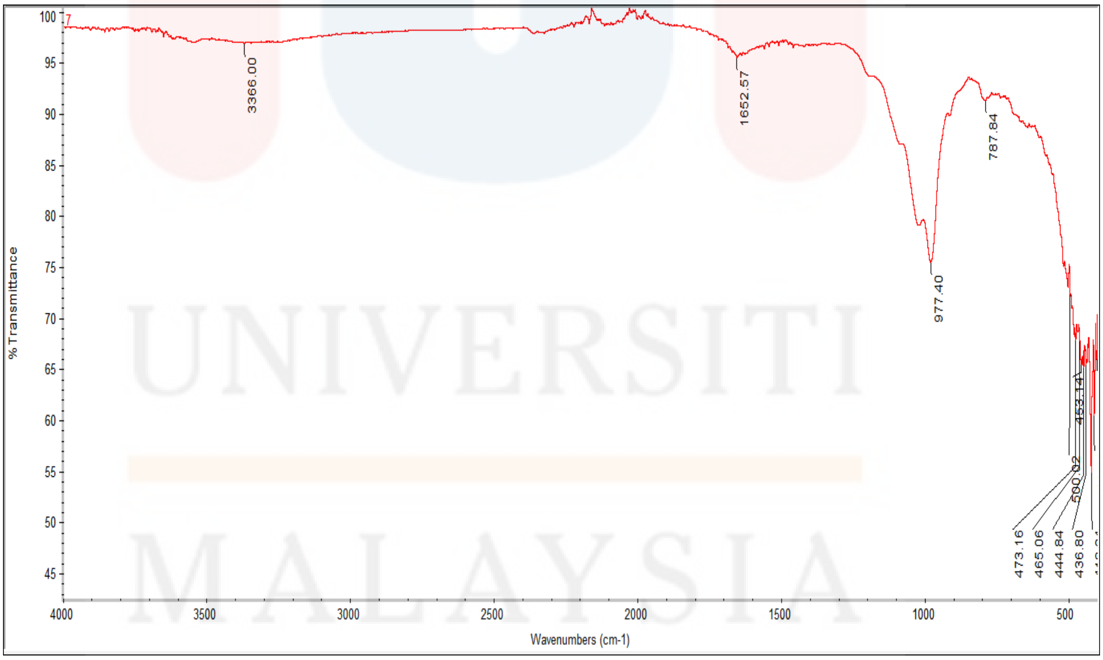
(C) – Torrefied Pelletized OPEFB biochar with 34% ratio



(D) - Torrefied Pelletized OPEFB biochar with 36% ratio



(E) - Torrefied Pelletized OPEFB biochar with 38% ratio



(F) - Torrefied Pelletized OPEFB biochar with 40% ratio