Physical Properties Characterization of Biomass Fuel Briquette

Made from Oil Palm Mill Residues

Muhammad Shafiq bin Yusof

A project dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

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Universiti Teknologi PETRONAS

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Perak DarulRidzuan

CERTIFICATION OF APPROVAL

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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 except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(MUHAMMAD SHAFIQ BIN YUSOF)

ABSTRACT

Malaysia has involved in palm oil industry over the last four decades and since then it has been generating vast quantities of palm biomass, mainly from milling and crushing palm kernel. Through concerted research and development efforts by many research organizations including Malaysian Oil Palm Board, this co–products from palm oil industry has been found to be a good resource for many applications.

The products generated from palm oil mill are crude palm oil and kernels, as primary product and biomass as a secondary product. A typical mill has many operating units. This comprises of sterilization, stripping, digestion and pressing, clarification, purification, drying and storage. The palm oil industry generates vast amounts of palm biomass. Converting palm biomass into a solid fuel through briquetting process should be attractive in upgrading its properties and adding value to the loosely-bounded biomass. The major byproducts produced in the production of crude palm oil are palm oil mill effluent, empty fruit branch (EFB), palm kernel shell and mesocarp fiber. Mostly, the biomass, like empty fruit bunch, palm kernel shell and mesocarp fiber are utilized as fuel in the mill in the loose form with high moisture content.

Realizing the potential of palm oil waste especially palm kernel shell and palm fiber to generate fuel, briquettes will produced by mixing the palm kernel shell and palm fiber with EFB, palm frond, saw dust and sugar cane waste. Their physical properties, mechanical strength will be analysed. In this research, the author will study the physical characteristics of these biomasses product in improving the handling and transportation method of this type of biomass fuel product.

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LIST OF ABBREVIATIONS

PKS	-	Palm Kernel Shell
PF	-	Palm Fiber
EFB	-	Empty Fruit Bunch
PFr	-	Palm Frond
SD	-	Sawdust
SC	-	Sugarcane waste
UTM	-	Ultimate Tensile Machine
SEM	-	Scanning Electron Microscope

CHAPTER 1: INTRODUCTION

1.1 Background of Study

The Malaysia palm oil industry grew tremendously over the last four decades. Since then, Malaysia has succeeded to maintain its position as among the world's premier palm oil producing country. However, this industry also generated vast quantities of palm biomass, mainly from milling and crushing palm kernel. In order to reduce the quantity of industrial waste as well as maximize the usage of biomass, producing biomass fuel briquettes is one of the appropriate solutions.

Biomass briquetting is the densification of loose biomass material to produce compact solid composites of different sizes with the application of pressure. Briquetting is conducted with the application of pressure, heat and binding agent on the loose materials to yield the briquettes. There are several benefits of fuel briquettes, listed as follows [1]:

i) This is one of the alternative methods to save the consumption and dependency on fuel wood.

ii) They are easy to handle, transport and store.

iii) They are uniform in size and quality.

iv) This process helps to solve residual disposal problem.

v) Fuel wood and deforestation can be reduced.

vi) Indoor air pollution decreased.

In Malaysia, palm oil residues, such as shell and fiber, were transformed into briquettes with a gross calorific value of 16.4 MJ kg^{-1}, ash content of 6%, and the moisture content of 12% [2]. In this context, biomass from oil palm industries appears to be a very promising alternative as a source of raw materials including renewable energy in Malaysia. So, biomass from oil palm residuals has very good potential to become a clean renewable energy source that can help significantly diversify fuels through the world.

Converting palm biomass into a uniform and solid fuel through the briquetting process appears to be an attractive solution in upgrading its properties and add value as reported by [1] [2] [3]. Biomass briquetting is converting low bulk density biomass into high density and energy concentrated fuel briquettes. The biomass briquette plant is of various sizes which converts biomass into a solid fuel. Biomass briquettes are non-conventional source of energy, renewable in nature, eco–friendly, non-polluting and economical [4]. The process of converting biomass into solid fuel is a non-polluting process. It involves drying, cutting, grinding, and pressing with or without the adding of a binder.

This study will examine the effect of binder type, particle size, briquette shape and compressive force on the physical properties of briquettes produced from palm oil mill residues. Palm oil mill residues include shell, fibre, empty fruit bunch and palm frond will be ground into powder form and mix with other materials that works as a binder. Then, the mixture powder will be poured into a mould and compressed with different values of force. The physical properties of the fuel briquettes will be analysed using several types of test. These tests results give some parameters that will be used to measure the strength and durability of the fuel briquettes.

1.2 Problem Statement

The palm oil industry generates an abundance of oil palm biomass such as oil palm shell, oil palm fibre, Empty Fruit Bunch (EFB), shell, frond, and trunk. From 241 oil palm mills in Malaysia, 4.46 million tonnes of PKS, 7.73 million tonnes of PF and 21.34 million tonnes of EFB were generated each year [5]. Briquetting of this oil palm biomass can be a good alternative to achieve zero-waste, as well as minimizing energy cost, in this industry. Therefore, the use of oil palm mill residues will be studied to find the best ingredient to produce strong, durable and good quality fuel briquette for industrial use. Nowadays, the critical issue that affected the use of fuel briquette is the strength and durability of the fuel briquette during handling, transportation and storage.

1.3 Objective and Scope of the Project

This project is primarily to investigate and characterize the mechanical properties of biomass solid fuel briquette made from oil palm shell and fiber with different type of binder ingredients. The finding of this project will be made as a reference to study the suitable procedure/system for collecting, storing and handling.

1.4 The Relevancy of the Project

The physical properties of the oil palm fuel briquettes are crucial as it will be used as a parameter to investigate the factor that affecting the strength and durability of the fuel briquettes that were produced. All the data obtained from this study can become a source for another researcher and industrial people for further improvement to produce high quality fuel briquettes. To produce good quality (i.e., high strength and durability) densified products from biomass feedstock whose densification characteristics are unknown, directions or ways to make strong and durable densified products are needed [4].

CHAPTER 2: LITERATURE REVIEW

2.1 Biomass Briquetting

Biomass briquetting represents a set of procedure for the conversion of biomass into a solid fuel. Biomass briquetting makes its mark to improve the handling characteristics of the materials for transportation and storage [6]. Biomass briquetting takes place after drying the oil palm residues. Biomass briquetting requires compaction. The dried powder form of oil palm residues be compacted in a die mould with a suitable dimension and pressed under specific pressure to form the solid biomass briquette. Biomass material is pressed at modest pressure of 5–7 MPa because at this range of pressure, the briquette could be pressed manually by using a hand press [7].

After the briquetting process, the briquette now can be handled and stored easily. This procedure can help in expanding the use of biomass in energy production, since it reduces the cost of transportation, ease in storage and handling [6].

2.2 Parameter Affecting Quality of Solid Fuel Briquette

Briquettes quality, as a fuel material made of biomass is affected by a lot of factors. The main parameters are:-

- Binder Effect
- Particle size effect
- Briquette shape effect
- Compressive force effect

2.2.1 Binder Effect

The strength and durability of briquettes depend on the physical forces that bond the particle together. There were 5 major characterizations on the binding forces that act between individual particles in the densified product [4]. They are (i) solid bridges, (ii) attraction forces between solid particles, (iii) mechanical interlocking bond, (iv) adhesion and cohesion forces, and (v) interfacial forces and capillary pressure. These five binding mechanisms have been observed and estimate for the densification of biomass materials [8] .Solid bridging may be developed by diffusion of molecules from one particle to another particle. Solid bridge usually formed after cooling or drying the densified product.

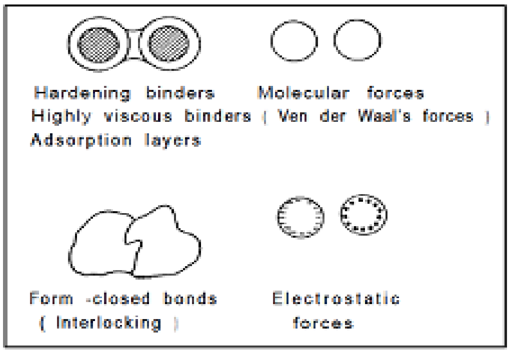


Figure 2.1: Binding Mechanism

Practically, the greater the quantity of binder used in manufacture, the greater the resulting briquette density and durability of the briquettes [7]. Required strength of the final product is depended on the amount of the binder that was used, so that it is able to withstand handling, transportation and storage.

2.2.2 Particle Size Effect

Particle size one of important factors that affect the pellet durability. The finer the grind, the higher the durability. Fine particles usually accept more moisture than larger particles and, therefore, undergo a higher degree of conditioning. Also, large particles are fissure points that cause cracks and fractures in pellets [9]. The recommended particle size for good pellet quality is 0.6–0.8mm [10]. Franke and Rey [10] recommended a particle size of 0.5–0.7mm to produce durable pellets. In their research, they also mentioned that particle sizes of greater than 1.0mm will act as predetermined breaking points in the pellet.

Despite fine particles produce more durable pellets, fine grinding is undesirable because of increased cost of production. A mixture of different particle sizes would give optimum pellet quality because the mixture of particles will make inter particle bonding with nearly no inter-particle spaces [9]. Table 2.1 presents the suggested feed particle size distribution to produce good quality pellets [11].

Table 2.1: Feed Particle Size Distribution to Produce Good Quality Pellets

Sieve size (mm)	Percentage of material retained on the sieve (%)
3.0	Up to 1%
2.0	Up to 5%
1.0	Around 20%
0.5	Around 30 %
0.25	Around 24%
<0.25	Not less than 20%

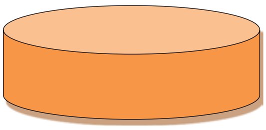
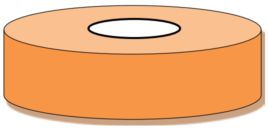
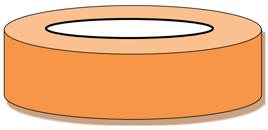
2.2.3 Briquette Shape Effect

The compression strength (in kg/cm^2) is determined by crushing the egg- or pillow-shaped briquettes between two plane-parallel faces [13]. Egg- or pillow-shaped briquettes have to be face-ground before tested. However, the ascertained strength corresponds to the actual internal briquette strength based on definite assumptions [13]. The factors that influence the strength are the height, volume, mass as well as dimensions of the briquette in relation to the area of the test ram and its compression speed. The crushing or breaking strength is ascertained by destroying the briquette between two stamps. The load occurs according to the elastic behaviour of the briquettes more or less in points. The strength is indicated as the load in kg at the point of failure. A defined rupture occurs only in brittle briquettes. However, some bitumen-bound briquettes or briquettes made of clay, with an extensive plastic behaviour only deform and loose shape and hence no definite ultimate or breaking load can be measured. The hardness of the briquette is related to the mechanical properties, especially elastic and plastic properties of coal. Further, non-uniformity in a briquette (as measured by Brinell hardness Number) always exists irrespective of its shape but in cylindrical briquettes compacted in a single direction, the maximum hardness or maximum density is found in the upper portion of the cylinder near the die wall, while in the lower portion a zone of maximum hardness occurs in the centre [13]. As such the friction effect between the powders and the die walls is the main cause of the non-uniformity in briquettes.

When ovoid- or pillow-shaped briquettes are compressed by the flat surfaces of the plunger and the anvil, the load cannot be expressed as pounds per square inch because the reading of the resistance to crushing is affected by the shape and dimensions of the briquette. Therefore, comparisons between briquettes of different shapes must be obtained by the method used by Parry and Goodman [12], i.e., filling parallel surfaces on the briquette to be tested or by cutting samples of cylindrical shape and standard dimensions from the briquettes to be tested.

The briquette shapes of interest in this study were full disc shape and doughnut shape with different inner diameter.

Table 2.2: Briquette Shapes

Disc shape	Doughnut shape	Doughnut shape
Outer Diameter=40mm	Outer Diameter=40mm Inner Diameter=8mm	Outer Diameter=40mm Inner Diameter=15mm
		

2.2.4 Compressive Force Effect

Application of pressure by the densification equipment to the biomass particles enables different binding mechanisms. On the basis of compaction, the briquetting procedure can be divided into:

- High pressure compaction
- Medium pressure compaction with a heating device
- Low pressure compaction with a binder.

For all these compaction techniques, solid particles are the starting materials. The individual particles are still identifiable to some extent in the final product of solid biomass briquette. If fine materials which deform under high pressure are pressed, no binders are required since the strength of such compacts is caused by Van Der Waals' forces, valence forces, or interlocking [6]. Natural components of the material may be activated by the existing high pressure forces to become binders [6]. However, some of the materials require binders even under high pressure conditions [6].

Under high pressure, the natural binding components such as starch, protein, lignin, and pectin in the feed or biomass materials are squeezed out of the particles, which contribute to inter-particle bonding. In a pellet mill, pressures of 100– 150 MPa (and more) are expected [14]. Usually, the effect of pressure is studied in the laboratory using a closed-end-die and piston assembly, where the pressure is applied to the powder mass by a universal testing machine or hydraulic press. Increasing pressure increased the abrasive resistance, impact resistance and compressive resistance of logs made from these biomass materials [1]. Table 3 shows that increasing pressure increased the quality of pellets/briquettes made from wood and biomass materials [15].

Table 2.3: Effect of Pressure on the Physical Quality of Densified Products [15].

Feed material	Forming pressure (MPa)	Durability densified products (%)	Compressive strength of densified products (MPa)
Oak sawdust (a typical hardwood; MC – 8.9 w.b.)	34	Not available	25
	69	93.3	28
	103	94.0	45
	138	98.3	49
Pine sawdust (a typical softwood; MC – 8.4% w.b.)	34	Not available	25
	69	71.2	35
	103	91.7	44
	138	93.2	45
Corn stover (MC – 10.0% w.b)	30	60	Not available
	60	7.1	Not available
	100	49.5	Not available
	130	51.7	Not available
	150	61.6	Not available

2.3 Mechanical Tests to Measure the Strength and Durability of Briquettes

Several characteristics such as strength and durability must be considered. Parameters that show strength of certain briquettes are compressive strength, impact resistance, water resistance and several others.

The compressive strength is the maximum crushing load that briquettes can withstand before cracking or breaking and determined by diametrical compression test. The test will be carried out by placing a single briquette between two flat parallel platens which have a bigger area than the projected area of the briquette. Increasing loads were applied to the briquettes until it is cracking or breaking. After that, the fracture load will be recorded on a stress-strain curve, will be taken as the compressive strength. Some research that was conducted before, mentioned that it was difficult to obtain repeatability of the result from the compressive strength test for the same quality of briquettes/pellets. During the compression test, it was observed that sawdust logs were shortened by approximately 1/3 of the original size. [15]. Thus, the compression strength test may not tell the true compressive strength of the densified product.

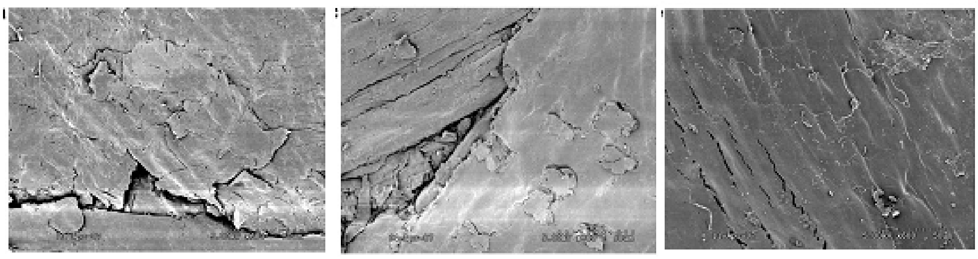
The relative durability of briquettes also can determine by dropping them four times from a height of 1.85 m onto a flat steel plate and measuring the weight retained after each drop. The durability percent was taken as the ratio of final mass retained by the briquette after the four drops to the initial mass. [16] Durability is probably the most crucial criteria for evaluating the quality of densified biomass. The briquette durability test is determined to simulate the ability of densified units to withstand the rigours of handling such that they keep their mass, shape, and integrity [16].

The water resistance of the briquette was quantified by taking the time that a briquette required to fully disintegrate in water. The sawdust briquette could hardly disintegrate in water – the water merely wetted the briquette from the side and thus, the time recorded was the time the sawdust was fully wetted by water [17]. This property is important for considering the storage method or location of the briquettes.

2.4 Scanning Electron Microscopy (SEM) for Microstructure Analysis.

SEM plays an important role in the characterization of nanoscale and sub-micron particles. Densification (briquetting, pelleting, or cubing) of particulate matter is achieved by forcing the particles together by applying mechanical force to create inter-particle bonding, which makes well-defined shapes and sizes such as briquettes, pellets, and cubes. The bonding of particles in briquettes, pellets, or cubes can be understood at the microscopic or macroscopic level. Microscopically, the binding forces between the particles can act through two binding mechanisms: (i) bonding without a solid bridge, and (ii) bonding with a solid bridge between particles [18]. Without a solid bridge, attraction forces between solid particles help bond the particles. Short-range forces such as molecular [valance forces (i.e. free chemical bonds), hydrogen bridges, and van der Waals' forces], electrostatic, and magnetic forces can cause solid particles to adhere to each other if the particles are brought close enough together

Scanning Electron Microscopy (SEM) (Hitachi S3500N) images were taken for corn stover and switch grass grinds, and cross-sections (i.e. fractured surfaces) of the lab briquettes, roll-press briquettes, and pellets. To prepare the samples for taking the SEM images, the samples were mounted on a stub and sputter coated with gold. The metallization conditions were 0.33 mbar (250 l Hg) argon gas pressures and 10 mA coating current. SEM observations were made at a magnification of 600X.



(a) (b) (c)

Figure 2.2: (a)-(c) Three Samples of Scanning Electron Microscopy (SEM) (Magnification At 600X) Images of Cross-Sections (I.E., Fractured Surfaces) of Corn Stover Briquettes Made In The Laboratory at a Compression Pressure of 150 MPa and Corn Stover Grind Particle Size of 0.66 mm [18]

CHAPTER 3: METHODOLOGY/ PROCESS WORK

This project research can be divided into seven main parts. They are collecting raw material, drying/moisture removing, fabricating mould, grinding, weighing and mixing, briquetting press and conducting mechanical test.

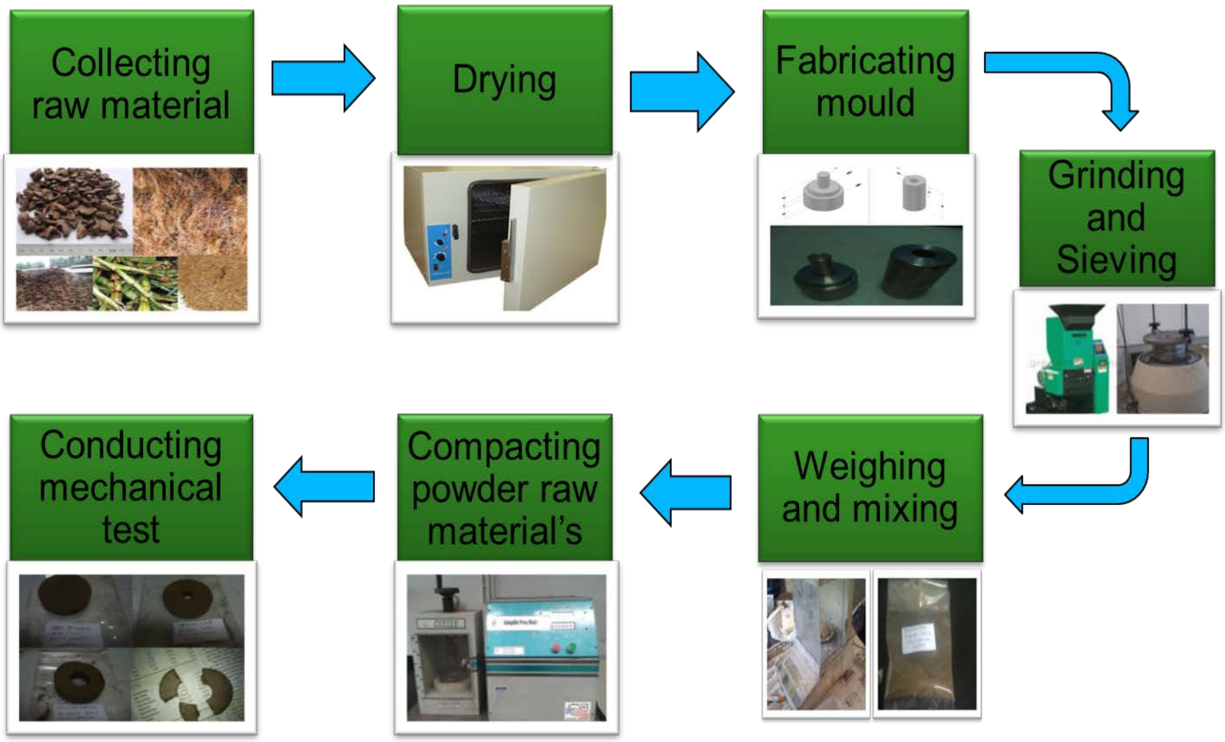


Figure 3.1: Process Flow in Developing Biomass Briquette

3.1 Collecting Material

Palm kernel shell, palm fiber, empty fruit bunch, sugar cane waste, sawdust and palm frond are collected from the suitable locations near to UTP area. The high quality of samples should be chosen for the research to obtain accurate result and produce good quality of briquettes.

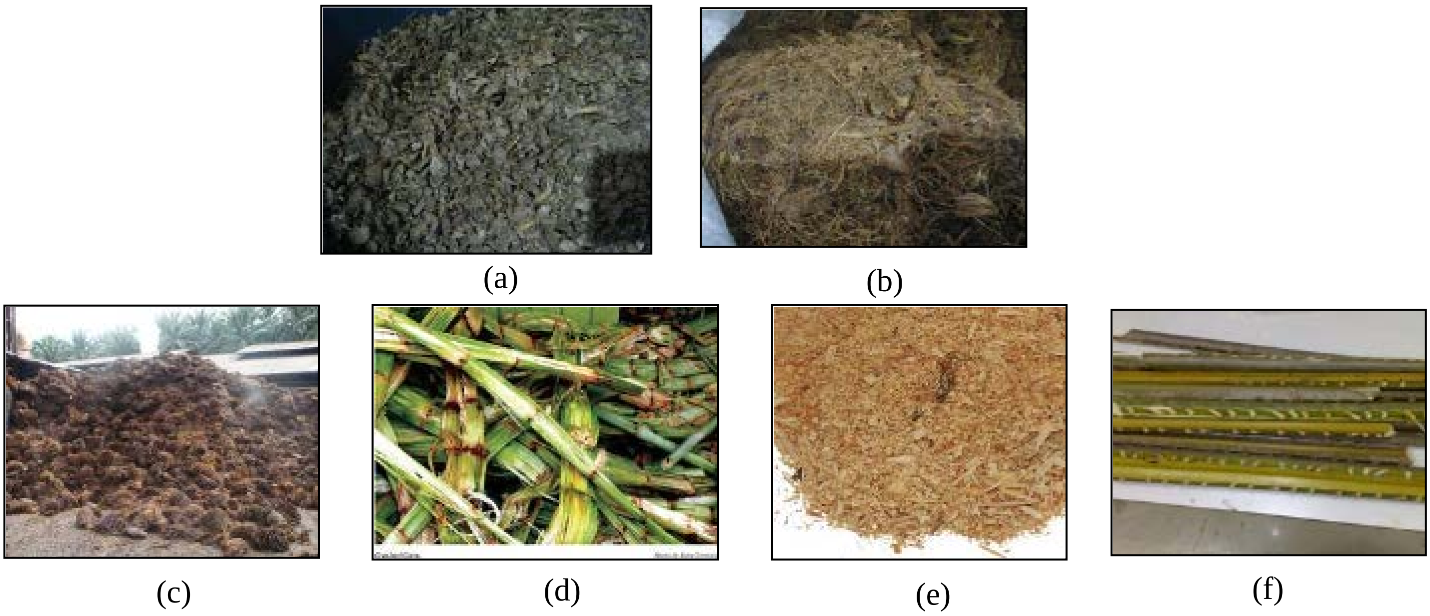


Figure 3.2: (a)-(f) Biomass Raw Materials (a) Palm Kernel Shell (PKS) (b) Palm Fiber (PF) (c) Empty Fruit Bunch (EFB) (d) Sugar Cane Waste (SC) and (e) Sawdust (SD) (f) Palm Frond (PFr)

The first step for this project is collecting the PKS, PF, EFB, SC, SD and PFr from the nearest location from UTP. It is very easy to complete this task because UTP is surrounded by oil palm estate industry in Bota. This is the convenient solution for this project in terms of reducing time and cost of travelling to the location. The sugar cane waste collected from the food stall that sells sugar cane juice. However, the PKS, PF, EFB, PFr and SD need to be collected from the respective factories. For this purpose, the author visited FELCRA Nasaruddin Palm Factory at Bota.

(a)

(b)

(c)

(d)

Figure 3.3: (a)-(d) FELCRA Nasaruddin Palm Factory (a) Assisted by Workers to Collect the Oil Palm Waste (b) Collecting EFB from Conveyor (c) Palm Kernel Shell Waste Collection Center, (d) Palm Fiber Waste Collection Center

3.2 Drying

All the material that have been collected will be put in the oven with temperature of 105°C to remove the moisture content. The moisture content of the samples can be calculated by subtracting the weight of samples (before entering the oven) with the new weight (after removing the moisture content).

3.3 Mould Fabrication

A lab scale mould will designed and built to make the fuel briquettes. There were three shapes of mould that were design.

Table 3.1: Mould specification

SHAPE	OUTER DIAMETER	INNER DIAMETER
Full Disk	40mm	-
Doughnut	40mm	8mm
Doughnut	40mm	15mm

(a)

(b)

(c)

Figure 3.4: (a)-(c) Briquette Moulds (a) Full Disc Shape Mould, (b) Doughnut Shape Mould With 8mm Inner Diameter, (c) Doughnut Shape Mould With 15mm Inner Diameter

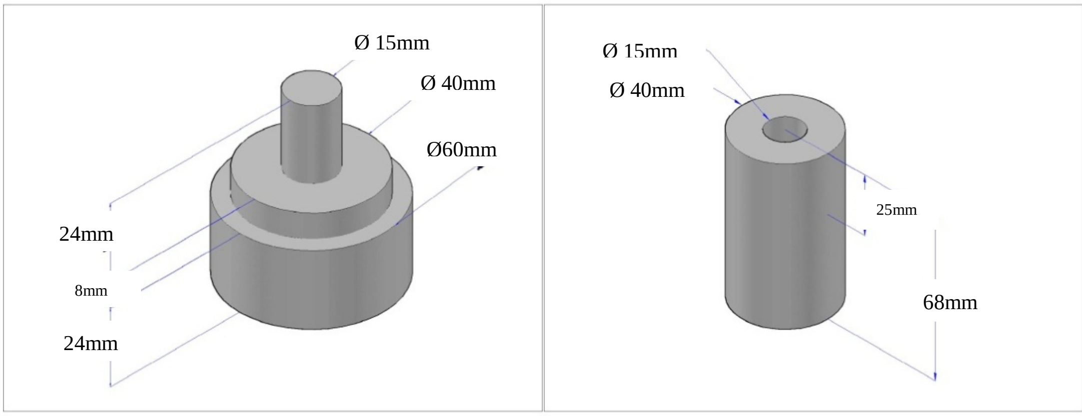


Figure 3.5: Design of 15mm Inner Diameter Mould Using AutoCAD

3.4 Grinding and Sieving

The samples are grinded into powder form using the grinder. This is an important part to make the biomass briquette because the Auto Pellet Press Machine can only produce the briquette after the samples has been grind into the powder form. The powder was dividing into two groups of powder size.

Table 3.2: Group of powder size after sieving

<table>
<tr><th colspan="2" rowspan="2">Material</th><th colspan="2">Powder size</th></tr>
<tr><th>Small particle</th><th>Big particle</th></tr>
<tr><td rowspan="2">Main Material (90%)</td><td>PKS</td><td><600 µm</td><td>>600 µm</td></tr>
<tr><td>PF</td><td><600 µm</td><td>>600 µm</td></tr>
<tr><td rowspan="4">Binder (10%)</td><td>EFB</td><td><425 µm</td><td>>425 µm</td></tr>
<tr><td>PFr</td><td><425 µm</td><td>>425 µm</td></tr>
<tr><td>SC</td><td><425 µm</td><td>>425 µm</td></tr>
<tr><td>SD</td><td><425 µm</td><td>>425 µm</td></tr>
</table>

3.5 Weighing and Mixing

The sample that have been ground will be weighted and mix as shown in Table 3.3.

Table 3.3: Weight and mixing ratio

Sample	Fuel briquette ingredient (weight=10g)
Sample 1	6.0g PKS + 4.0 PF
Sample 2	5.4g PKS + 3.6g PF + 1g EFB
Sample 3	5.4g PKS + 3.6g PF + 1g palm frond
Sample 4	5.4g PKS + 3.6g PF + 1g sugar cane waste
Sample 5	5.4g PKS + 3.6g PF + 1g sawdust

3.6 Briquetting Press

The powder form sample then will pour into the mould and then pressing using Auto Pellet Press Machine. There will two compressive forces that will be used for the briquetting press process 100kN and 200kN.

Figure 3.6: Auto Pellet Press Machine

Briquette Design

There are three (3) designs of briquette which were considered in this project.

- Disk shape

  Similar to Y.S Chin [19], 40mm in diameter. 10gram sample is used per sample yielding 7 - 8mm in height.

  This design is chosen based on the results obtained in Y.S Chin [19].

- Doughnut shape with 8mm hole
- Doughnut shape with 15mm hole

  Resemble the first design but incorporating a hole of 8mm and 15mm diameter at the centre. The reason of introducing a hole in the briquette is primarily to improve the combustion characteristic due to the greater surface exposed to the flame

Figure 3.7: Three Types of Briquette Shape

3.7 Mechanical Test

The important properties for the fuel briquette are its durability, stability, toughness and its design. There are numerous experiments/test that have been identified applicable to use in this project.

3.7.1 Crack test

This test will conduct to know how the briquettes of the different material crack. The briquettes will be dropped from 1 meters of height and then the results of cracks will be observed and analyse.

3.7.2 Compressive Strength Test

This test will use the Ultimate Tensile Machine (UTM) to get the graph of load and stroke variation. The plot of the graph then will be analysed from original briquettes to briquettes at failure.

3.7.3 Immerse Test

The immerse test will conduct to analyse the water resistance of the fuel briquettes. The briquette will put in a basin with constant volume and the time for the fuel briquettes to fully immerse will be taken.

3.7.4 Stability Analysis

Stability analysis conducts to know how good the briquettes will maintain their dimension. The method carry out by measured the diameter of the briquettes every week using calliper. This measurement will take for minimum three weeks. The data then will gather to analyse which briquettes that loss minimum dimension.

3.7.5 Durability Analysis

Durability analysis will conduct to know how well the briquettes can survive in harsh environments of power plant. The test will conduct by drop the briquettes from 1.8 meters height on the designated steel plate.

3.7.6 Microstructure Analysis

The morphological structures of the inside and outside of the briquettes will be observed and analyses using Scanning Electron Microscope (SEM). These analyses carry out to see how the bonding of the particle affects the strength and durability of the briquette.

3.8 Equipment Used For Research

1. Grinder – to grind the specimens. In this project, 2 types of grinder are used:
   i) Granulator – to break hard and large sample into smaller size and smoother condition of the sample.
   ii) Mortar Grinder – to grind all materials into powder
2. Oven – to remove the moisture of the samples.
3. Auto pallet Press Machine – to produce briquettes.
4. SEM machine- microscopic analysis
5. UTM machine- compressive strength test
6. Stop watch-immerse test
7. Vernier caliper-stability test
8. Mass balance-to weight the mass of the samples

CHAPTER 4: RESULT AND DISCUSSION

4.1 Prepared Sample

All samples has been successfully weighted, stored and labelled in the small plastic bags.

Figure 4.1: Weighted and Label Samples

Figure 4.2: Material Being Pours Into Mould And Compress Using Auto Pellet Machine.

Sixty pieces of briquette sample with different parameters were prepared using auto pellet machine. The briquetting process was quite difficult as the sample is too brittle and easy to break while removing it from the mould. So several repetitions need to be done to get the sample in good shape. Some fuel briquettes prepared were label as Table 4.1.

Table 4.1

Powder Size = Small Particle

Compressing force = 100kN

Material	Disk Shape	Doughnut shape-8mm inner diameter	Doughnut shape- 15mm inner diameter
PKS+PF			
PKS+PF +PFr			
PKS+PF +EFB			
PKS+PF +SC			
PKS+PF +SD			

Figure 4.3: All 60 Briquettes That Have Been Prepared

4.2 Compressive Strength Test

The compressive strength test were carried out on twelve (12) PKS+PF+PFr briquettes with different type of powder size, compressing force and briquette shape. The test was conduct using UTM (Ultimate Tensile Machine) that have maximum 100kN working load. However the working load using on this test had to be limited to 80kN only for safety purpose and to avoid damaged to the machine. The UTM were set up until it compresses half of the briquette thickness or until the briquette fail.

(a) (b) (c)

Figure 4.4: (a)-(c) Compressive Strength Test (a) Briquette Ready to Compress (b) Briquette after Being Compress (c) Resulted Briquette after Compress

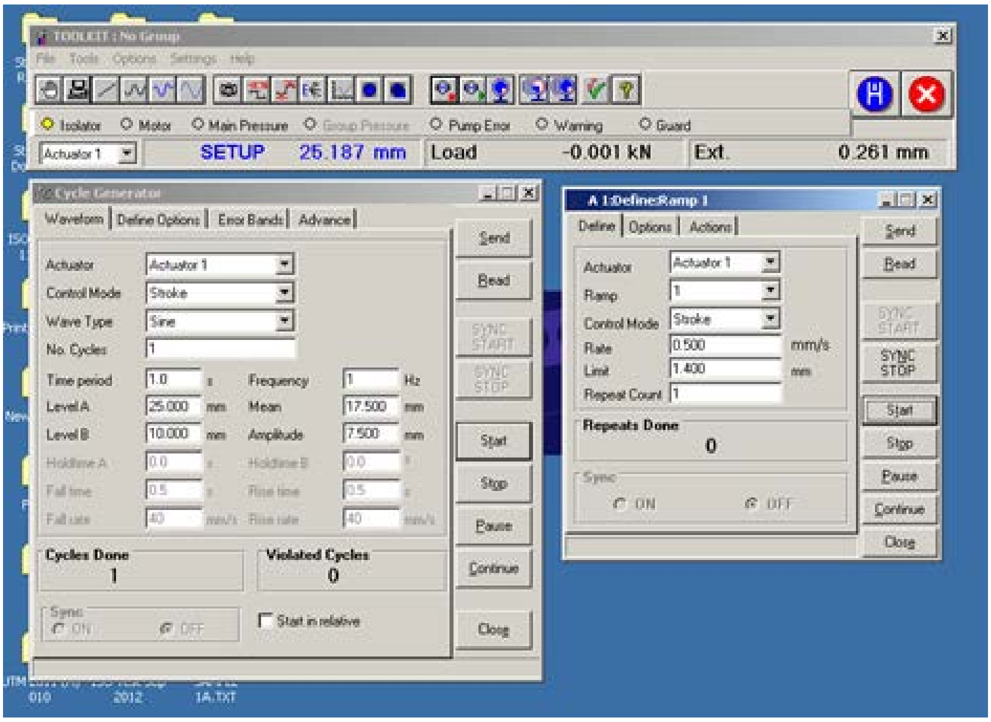


Figure 4.5: UTM Software Setting for Compressive Strength Test

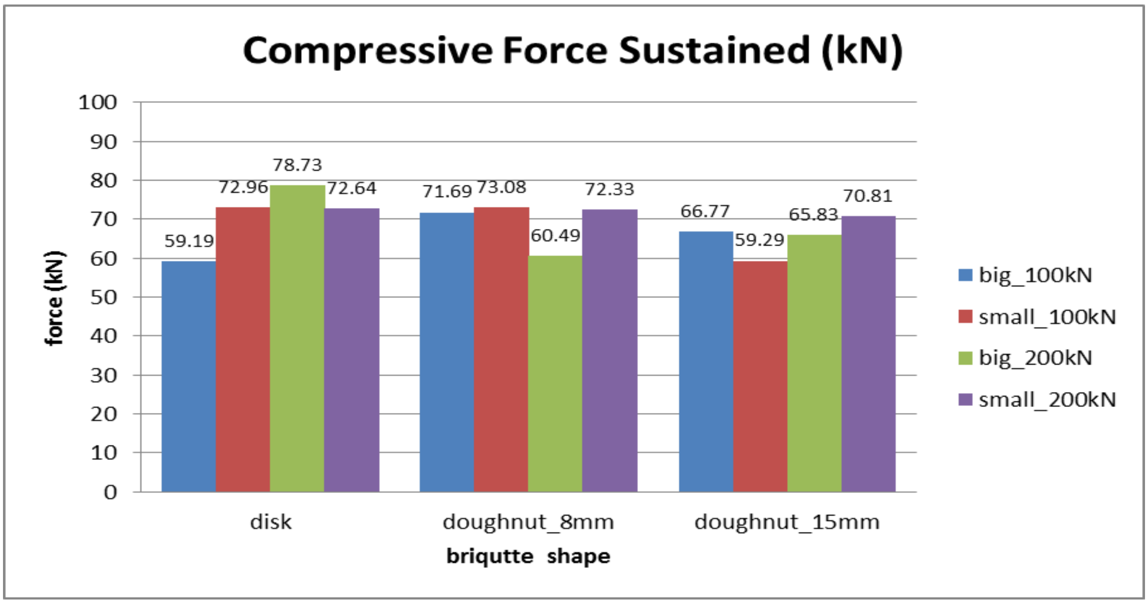


Figure 4.6: Compressive Strength Test Result of 12 Different Types of PKS+PF+PFr Briquettes

It is found that the values of compressive force sustained by PKS+PF+PFr briquette are within the range of 59.19 to 78.73 kN.

Briquette shape effect

From the bar chart, it shows that most of the disk shape briquette was having higher compressive force sustained than doughnut shape briquette with inner diameter of 8mm and 15mm. Presence of big hole in doughnut shape briquette has created large stress concentration point at the hole. The stress concentration points at the hole weakens the briquette and make them easier to fail when be applied by the force using the UTM.

Powder size effect

Most of the results from this test show that briquette with small particle powder can sustain higher compressive force than briquette with big particle powder size. These shows that produce a briquette produced by using small powder are more preferred because it can help in improve the strength of the briquette.

Compressing force effect

From the result, most of briquette made at 200kN compressing force can sustain more compressive force in UTM test than briquette made at 100kN. Thus, higher compressing force used to make a briquette can help the briquette have higher strength and sustain more unexpected external force during handling, transportation and storage.

4.3 Immerse Test

The water resistant of the briquette is evaluated by recording the time of the briquette to totally disintegrate in constant volume of distilled water. This analysis is important decide the storage method and location of the briquettes.

The immerse test done on the 60 different type of briquettes show that the PKS+PF briquette with properties of 200kN compressing force, made from small particle powder size and have a disk shape is taken the longest time to fully immerse, 3772 seconds. The PKS+PF+SD briquette is the second best briquette having good water resistant characteristic, it took 2237 second to fully immerse.

From the result show at the bar chart, it show that the PKS+PF briquette without binder take the longest time to fully immerse followed by PKS+PF+SD briquette, PKS+PF+EFB briquette, PKS+PF+SC briquette and PKS+PF+PFr briquette. This show that adding another natural binder does not help in improving the water resistant of the briquette. This was probably due to the fibrous properties of natural binder. The fibrous material will act as a sponge to absorb the water and make the briquette took shorter time to become wet and sink. The PKS+PF briquette without binder taken longer time to immerse due to the quantity of palm kernel shell in the briquette is more than others briquette with natural binder. The properties of palm kernel shell that dispense some oil when compressed using auto pellet machine help slowed down the invasion on water into the briquette.

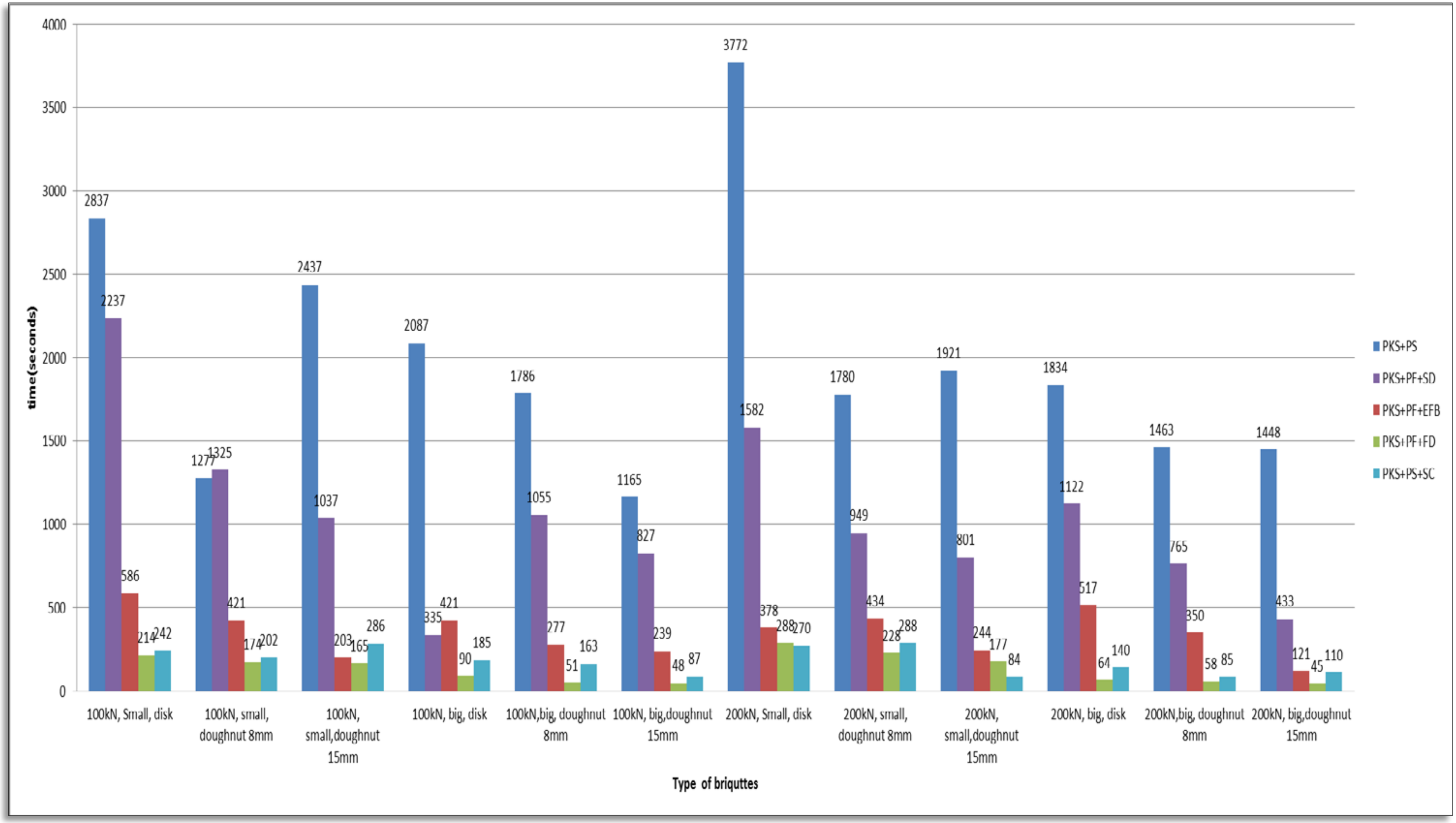


Figure 4.7: Immerse Test Result

Briquette shape effect

From the bar chart, it show that most of the briquette with disk shape taken longer time to immerse in the water than the doughnut shape briquette with 8mm and 15 mm inner diameter.

This happen probably because by incorporating hole to the briquette, greater surface exposed to the water thus, make water easily penetrate into the briquette, losing the bonding between particles. As the consequence, incorporating hole to the briquette reduces water resistant characteristic.

Figure 4.8: (a)-(c) Three Shape of Briquette Having Immersed Test (a) Disk Shape Briquette, Water Penetrate Around The Briquette (b) and (c) 8mm and 15mm Doughnut Shape Briquette, Water Penetrate into Briquette at The Hole and Around The Briquette.

Powder size effect

Most of the briquettes with small particle powder size were taking longer time to sink than briquettes with big particle powder size. The reason is due to the big particle powder size particle having higher absorption rate than the small particle powder size.

Compressing force effect

From the immerse test result, the briquette made using 200kN compressing force is slightly take longer time to sink. This shows that using higher compressing force can help in improve briquette’s water resistant ability. The higher compressing force may made the particle arrangement become more compact thus make the water absorption rate lower.

4.4 Stability Test

From the stability test, it was found out that briquette made from PKS+PF without binder is relatively stable in retaining its dimensions compared to other briquette with binders as shown in bar chart below. The briquette that mix with SD as binder show the most stable compared to others threes briquette with binder (EFB, PFr, and SC).

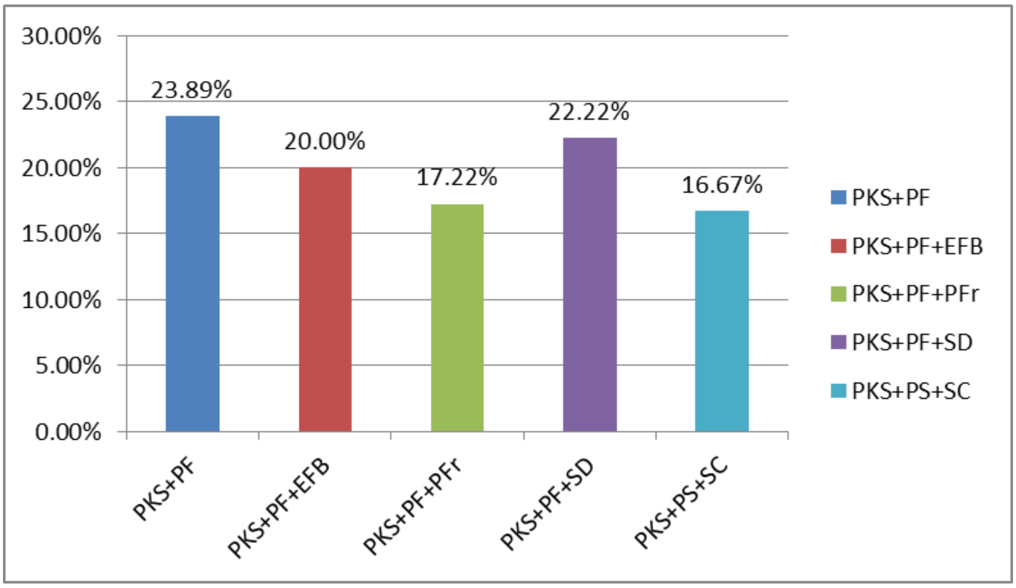


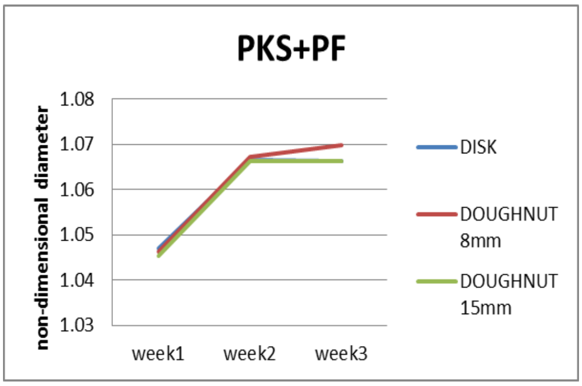
Figure 4.9: Stability Test

The result from the bar chart was obtained from the weightage table (see Appendix H). The weightage table were done based on the analysis of graph obtained from the stability raw data (see Appendix F and G)

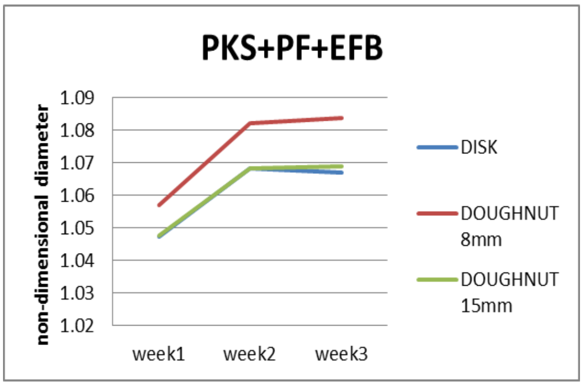
The reason for PKS+PF briquette for being relatively more stable could be the quantity of PF in briquette mixture is slightly higher compared to others briquette with binder. The PF were found out to be the most stable from the stability test result obtained by Y.S Chin [19].

As for the PSK+PF+SD briquette being the most stable compared to other briquette with binder due to the fibrous structure that have in sawdust is more agglomerate (shown in SEM image) which help the briquette to maintain the dimension better.

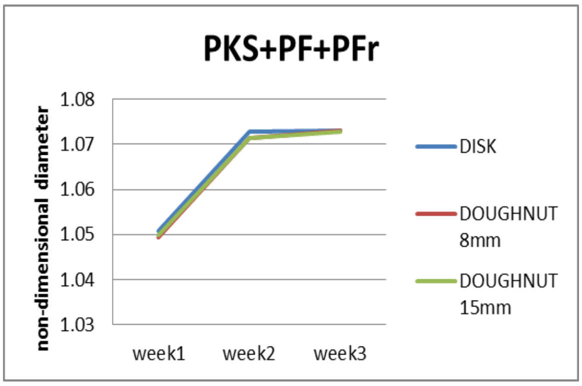
Briquette shape effect



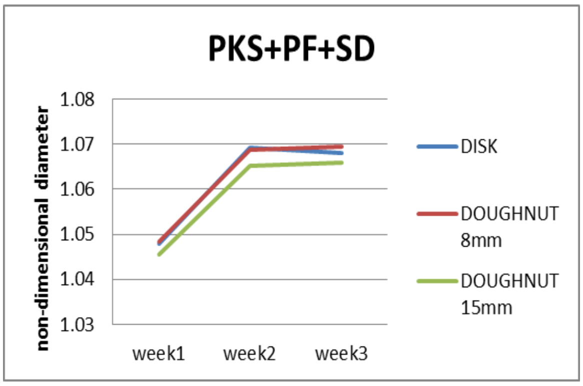
(a)



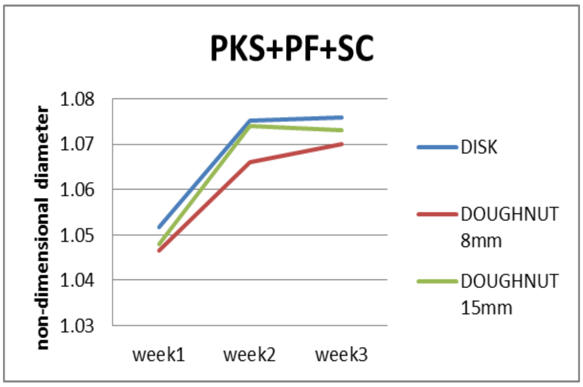
(b)



(c)



(d)

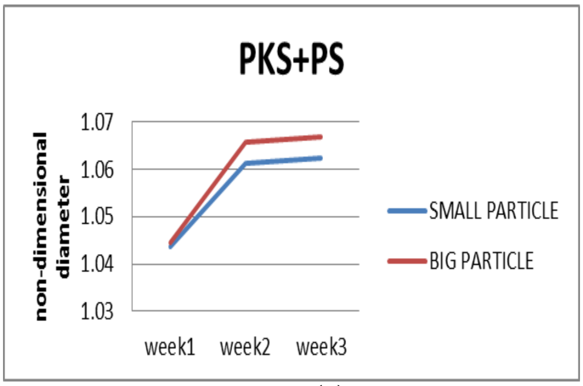


(e)

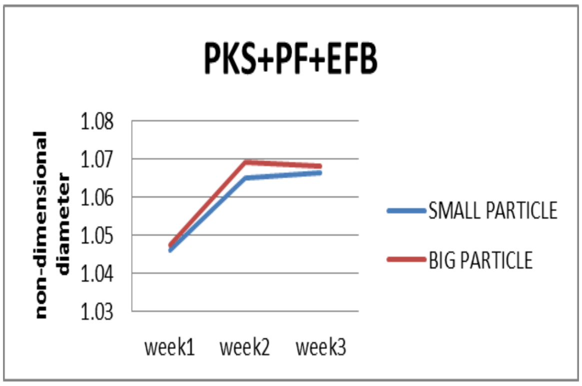
Figure 4.10: (a)-(e) Effect of Briquette Shape

From the Figure 4.1.0, it shown that the disk shape briquettes shown more stable in maintain their dimension compared to others shape with hole. Briquette with 15mm hole compared to briquette with disk shape and 8 mm hole has shown slightly decrease in the capability of the briquette to sustain its dimension. This could be happening due to the greater surface area exposed, thus greater possibility of humidity from environment to come in, loosen the bonding between particles, make the briquette easier to expand.

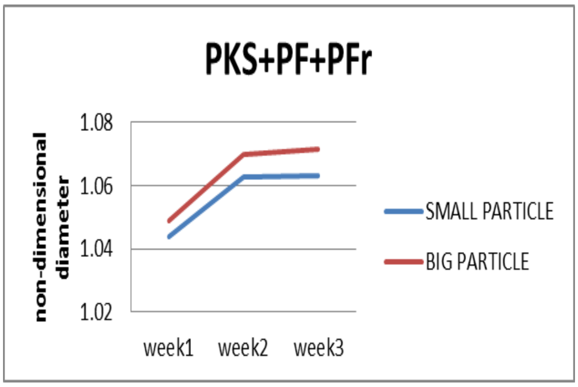
Powder size effect



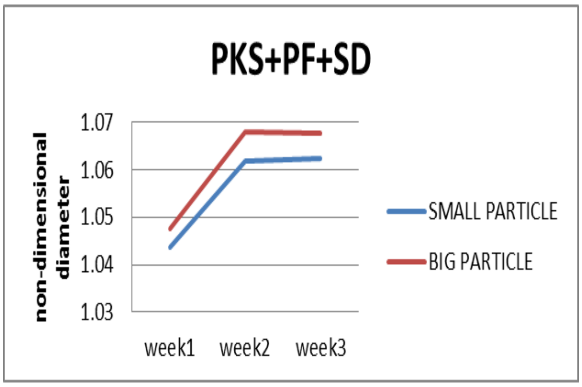
(a)



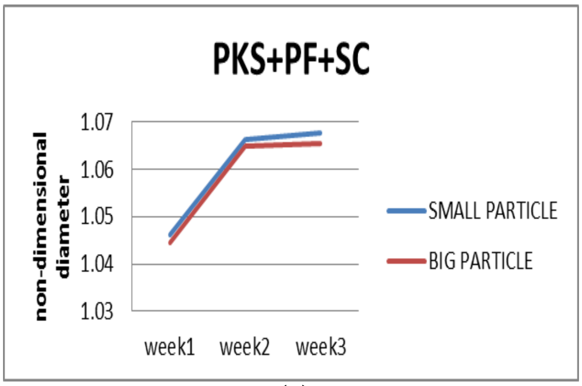
(b)



(c)



(d)

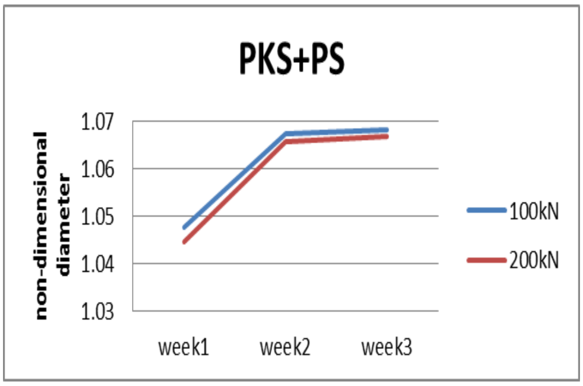


(e)

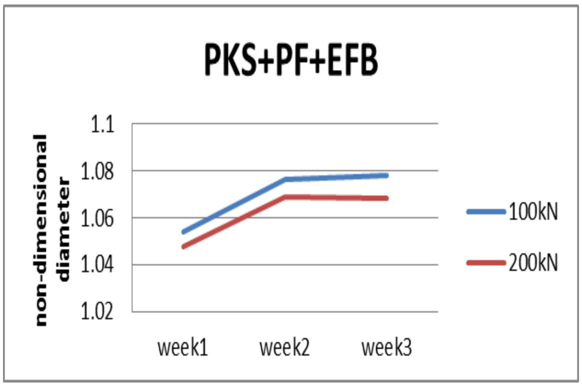
Figure 4.11: (a)-(e) Effect of Powder Size

From the graph in Figure 4.1.1 all five type of briquettes with different ingredient shown that the briquette made from powder with small particle size is more stable than briquette made from powder with big particle size. Fine particles or small particle size usually accept more moisture than larger particles and, therefore the moisture will act as another natural binding agent, which help the briquette to maintain the dimension better.

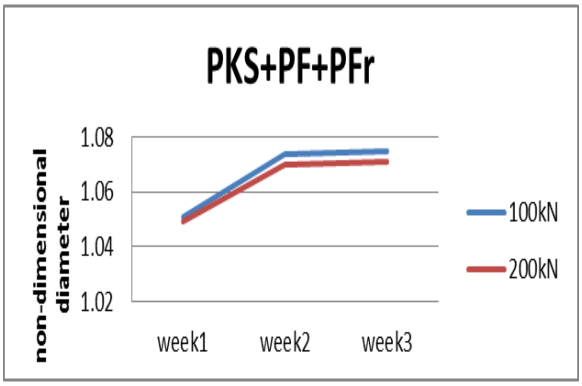
Compression force effect



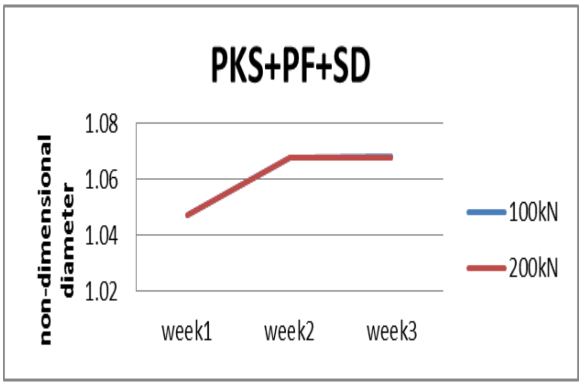
(a)



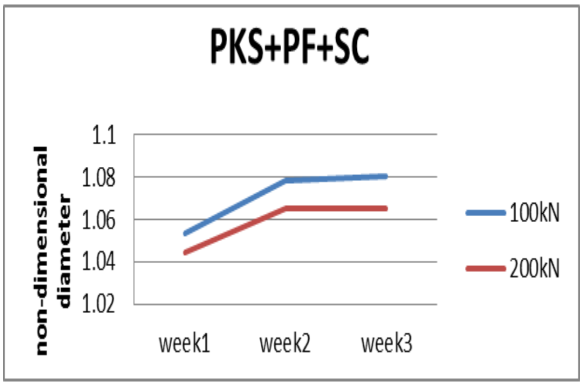
(b)



(c)



(d)



(e)

Figure 4.12: (a)-(e) Effect of Compressing Force

From the graph, briquette that made by applying 200kN pressure give the most stable result. All the graph shows that the all five type of briquettes is stable in sustaining it dimension were produced by applying 200kN compression force during the briquetting process. The higher pressure may have squeeze out the natural component such as protein, starch, lignin and pectin from the biomass material particle which contribute to inter-particle bonding and help the briquette to sustain it dimension strongly.

4.5 Durability Test

Durability test were carried out on PKS+PF+PFr disk shape briquette. The briquettes have different parameters of powder size and compression force. The result obtain shown in Figure 4.1.3.

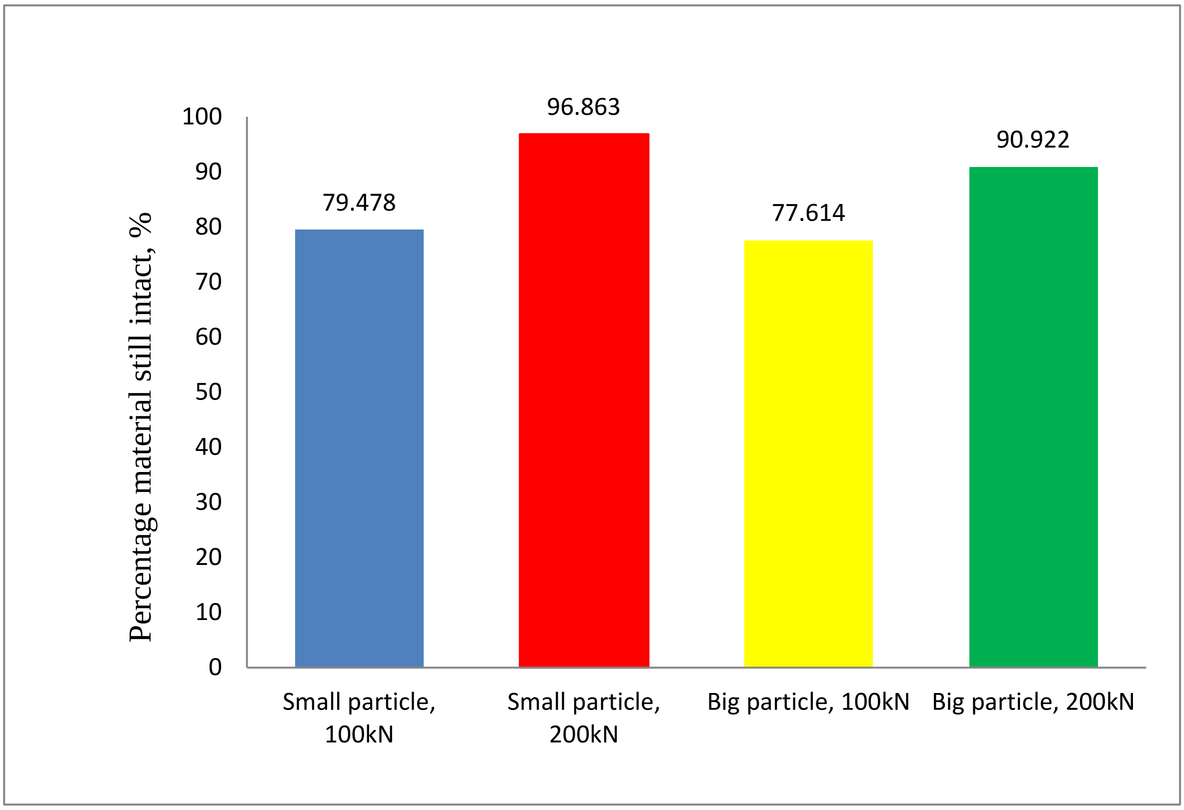


Figure 4.13: PKS+PF+PFr Disk Shape Briquette Durability Test

From the chart in Figure 4.1.3, the briquette with parameter small particle powder size and 200kN compressing force show a good indication in durability with the highest percentage material still intact (96. 863%) after a few drops.

Particle size effect

From the chart in Figure 4.1.3, it shows the briquette with parameter small particle powder size and 200kN compared to briquette with same compression force but have big particle powder size has higher percentage of material still intact(96.863%). As we compared with another two that have 200kN compression force, the briquette that made from small particle powder size has the higher percentage of material still intact (79.478). This happens because small particles usually accept more moisture than larger particle and, therefore, undergo a higher conditioning. Moisture will act as the binding agent to lock up the particle, forming cohesive force between particles and thus make it relatively more durable.

Compressing force effect

Bar chart in Figure 4.1.3 shown out of the four samples, the briquette having 200kN compressing force have higher durability than briquette with 100kN compressing force. This happen because when briquette was applied by high pressure force, the natural component may be activated to become binders which will help the bonding of the particle become stronger. Form the chart also, the briquette with small powder size and 200kN compressive force have the highest percentage of material still intact. The high percentage of this briquette is cause by Van Der Waals's forces, valence force, or interlocking due to the small particle which deform under application of high pressure.

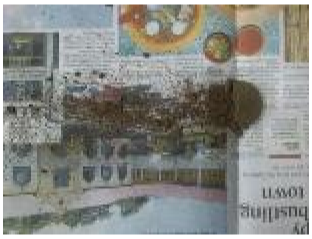
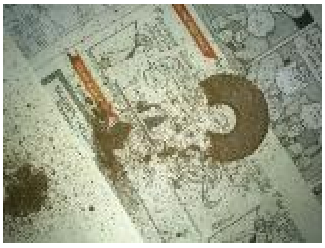
High durability reflects the capability of briquette to sustain its dimension when subjected to handling and storage. It is best suited for measuring the relative resistance to breakage when handled in thin layers such as during transportation and storage.

4.6 Crack Test

Table 4.1 show the picture of briquette after the sample been drop from 1 meter of height.

Table 4.2: Powder size = Small particle

Compressing force = 100kN

Material	Disk Shape	Doughnut shape-8mm inner diameter	Doughnut shape- 15mm inner diameter
PKS+PF			
PKS+PF+PFr			
PKS+PF+EFB			
PKS+PF+SC			
PKS+PF+SD			

From the analysis, briquette made from palm kernel shell, palm fiber and sawdust is the most tough in maintain its shape. This may be due to the properties of sawdust that have fibrous particle in it. The presences fibrous material helps in reinforce the bonding between particles in the briquette.

Briquette shape effect

From the overall observation, all the briquettes are tending to break. The most easily to break is the briquette that have 15mm hole. The crack also found near the hole that made the briquette easily to break. The reason for this might probably due to the presence of big hole to the briquette has created large stress concentration point. This stress concentration point weakens the briquette and makes them susceptible to crack and fail.

Powder size effect

The briquettes with small particle powder size are more harden than the briquette with big particles powder size. This might probably due to the fact that fine particle have the higher durability than the large particle. The large particle is easily to break due to its low durability.

Compression force effect

Most of the briquette that made by applying 200kN compression force gave good result in crack test. Most of them especially having also small particle powder size were only having small crack and have low possibility to fail. The higher compression force will make the briquette having stronger mechanical bonding thus help in the briquette sustain it shape when having an sudden external force during handling and storage.

4.7 Microstructure Analysis

The image shown is the image taken using FESEM machine at magnification of 600X. Four samples were sent to the lab to capture the surface image of the briquette. The details of the sample are:

1) PKS+PF+EFB

2) PKS+PF+PFr

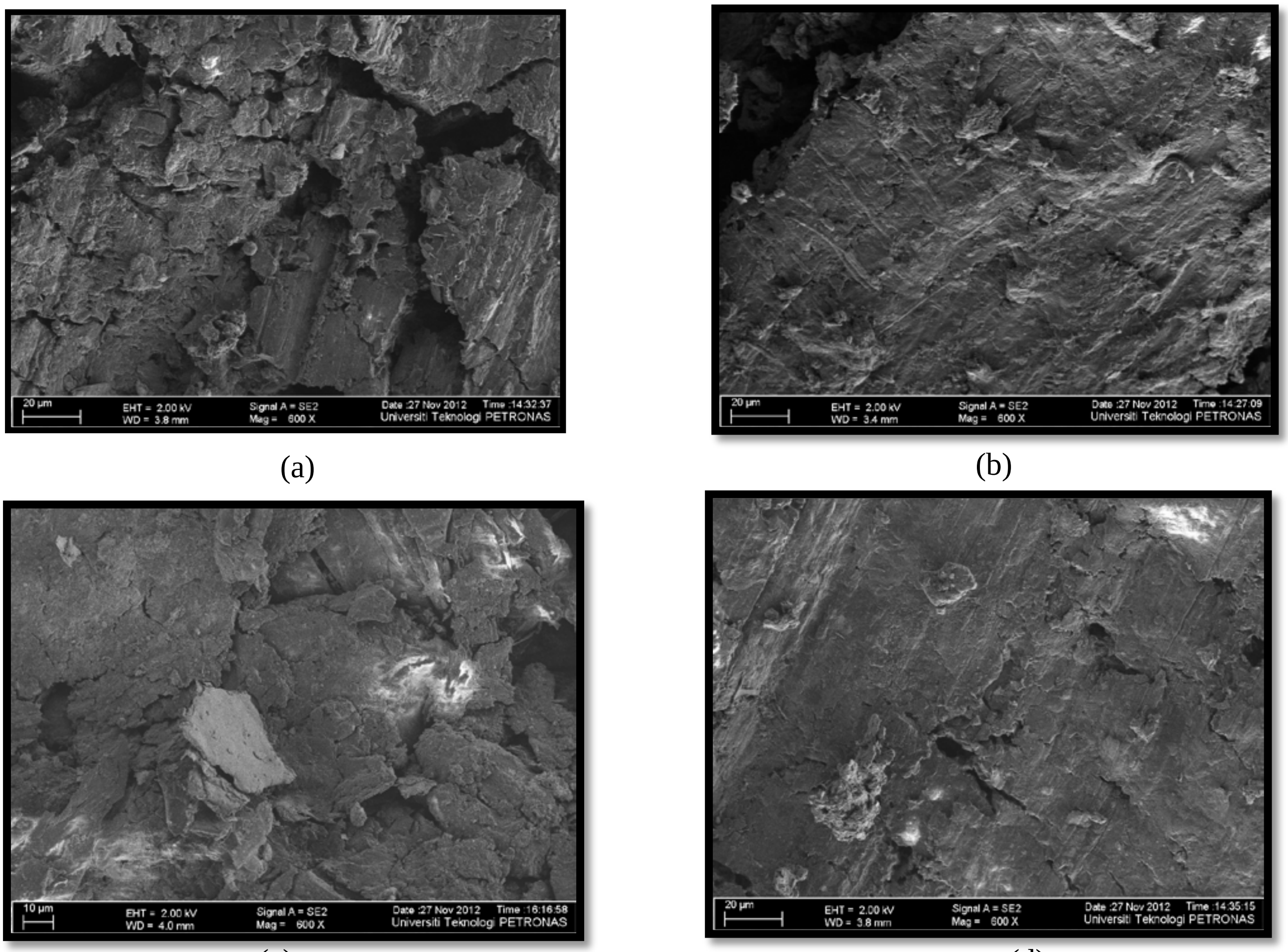
3) PKS+PF+SD

4) PKS+PF+SC

All the briquettes having same parameter as below

- Shape= Disk
- Powder size=Small particle
- Compressing force=200kN

Figure 4.14: FESEM (Field Emission Scanning Electron Microscope) Equipment at UTP Centralized Analytical Laboratory. Manufacturer: Cal Zeiss AG, Germany, Model: SUPRA 55VP



(a) (b) (c) (d)

Figure 4.15: (a)-(d) SEM Image at Magnification of 600X (a) PKS+PF+EFB (b)PKS+PF+PFr (c) PKS+PF+SC (d) PKS+PF+SD

From the observation on the structure of the SEM image, it was found out that the Figure 4.1.5 (d) have smoother surface compared to others three briquettes. It show that the particles in the briquette with SD as it natural binder are bound in a way that is better than the others. This finding proves why the PKS+PF+SD briquette were most stable maintaining its shape in the stability test.

It was found out that the particle in figure 4.1.5 (d) have compact and agglomerate structure. The more compactness created by the particles can be classified by the binding mechanism of “solid bridges” between particles. The solid bridges were created by the particle and the release of natural binding components in the briquette material. The larger number of solid bridges particles created may have improved the binding of particles, and thus, the higher compressive strength.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Biomass briquetting improve the handling characteristic of the material during transportation and storage. Having biomass in briquette form can help in widen the use of biomass in energy production since it can reduce the cost of transportation and storage, ease in handling. Investigating the mechanical properties of the material becomes an important for handling and storage of the biomass fuel briquette.

From all the experiment that have been carried out, it found out that the briquette using material PKS+PF only as its ingredient have good mechanical properties in maintaining its shape and have better water resistant characteristic. The stability of this briquette can be good properties in storing the briquette for longer time before used it.

Using sawdust (SD) as natural binder slightly can improve the bonding of the particle in the briquette. This was proving in the stability test and microstructure analysis. The fibrous particles structure in sawdust help in strength up the mechanical bonding in the briquette.

Incorporating larger hole as in doughnut shape briquette with inner diameter of 15mm does not improve its mechanical properties. It might be good for combustion characteristic but at the expense of mechanical strength.

Using small particle powder size in developing fuel briquette is more preferable. The small particle powder size give better mechanical properties compared to the powder with big particle size.

Briquettes made by applying 200kN compressing force give better mechanical properties than the briquette with 100kN compressing force. This show that high compressing force increase abrasive resistance, impact resistance and compressive resistance which help give better mechanical properties to the biomass briquettes.

5.2 Recommendations

For the future work, as the briquettes that were produced are brittle, it recommended to add in some commercial binding agent such some starch in the ingredient of the biomass briquette.

Investigate the dwell time during densification process of the briquette also recommended as it will improve the strength of the briquette.

For the microstructure analysis, the author would suggest to add in the analysis using light microscopy and Ultraviolet auto-fluorescence (UV-AF) microscope. Light microscopy use to observe the natural binder coatings on the particles, local melting of biomass components and mechanical interlocking while Ultraviolet auto-fluorescence (UV-AF) microscope can show the distribution of the natural binders of the fractured surfaces of the briquettes.

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APPENDIX A: Procedures of Mechanical Test and Analysis

Ultimate Strength Test

Compressive strengths of the briquettes were determined using a 100kN Ultimate Tensile Machine (UTM).

1. The flat surface of the briquette sample was placed on the horizontal metal plate of the machine.
2. A load was applied using stroke mode at a constant rate of 0.5 mm/s until the briquette failed by cracking or breaking half from its original thickness.
3. For safety reason, the machine was setup to apply a maximum load of 80kN as the limit of the machine is only 100kN.
4. Twelve samples PKF+PF+Pfr briquette were tested and the load sustained by the briquetted (kN) versus stroke (mm) was plot in graph and analyzed.

Immerse Test

1. Filled the container until half of the container volume.
2. Carefully put the briquette sample on the water surface.
3. As the briquette touching the water, the time for the briquette to fully immerse was record using stop-watch.
4. Repeat the procedure using other samples.
5. The times taken of all briquettes were recorded and analyze.

Stability Test

1. Measure the diameter of the briquette right after it removes from the mould using Vernier caliper.
2. Take three reading and calculate the average.
3. Store the measured briquettes at closed and dark place.
4. Repeat the step for others samples of the briquette.
5. The briquette diameters were taken again on every week until third week.
6. Record all the data for the analysis.

Durability Test

1. Weight the samples using mass balance.
2. The height of 1.8 meters was measured to set the point where the briquette will drop.
3. Drop the briquette onto steel plate from 1.8 meters height.
4. The remaining intact samples after dropped were collect back and weight using mass balance.
5. Repeat the procedure using anther samples.
6. Record all the initial weight and final weight after drop.

Crack Test

1. Drop the samples one by one from the height of 1 meter onto the flat surface.
2. Take the picture of the briquette after the drop.
3. Analysis and observe the crack and condition of the briquette after drop.
4. Observations were recorded for every sample that has been drop.

Microstructure Analysis

The analyses use the Field Emission Scanning Electron Microscope (FESEM).

1. Four type of briquette sample with different type of ingredient were prepared.
2. The small piece of sample were taken and put on the stud of the SEM machine and been observe at 3.8 mm working distance and magnification of 600X.
3. The images were taken and save in the cd.
4. The structures of the image were observed and analyze.

APPENDIX B: Prepared Briquettes

Table B1

Powder size = small particle

Compressing force = 200kN

Material	Disk Shape	Doughnut shape-8mm inner diameter	Doughnut shape- 15mm inner diameter
PKS+PF			
PKS+PF +PFr			
PKS+PF +EFB			
PKS+PF +SC			
PKS+PF +SD			

Table B2

Powder size = big particle

Compressing force = 100kN

Material	Disk Shape	Doughnut shape-8mm inner diameter	Doughnut shape- 15mm inner diameter
PKS+PF			
PKS+PF +PFr			
PKS+PF +EFB			
PKS+PF +SC			
PKS+PF +SD			

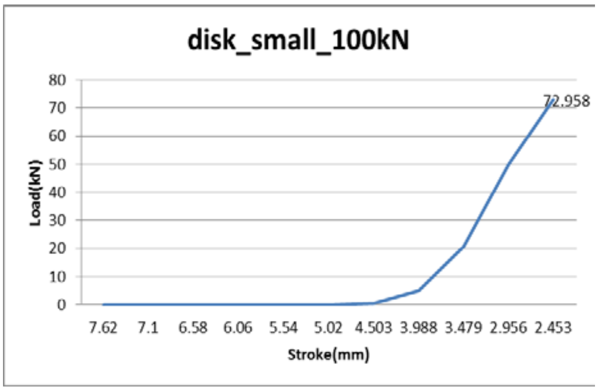
Table B3

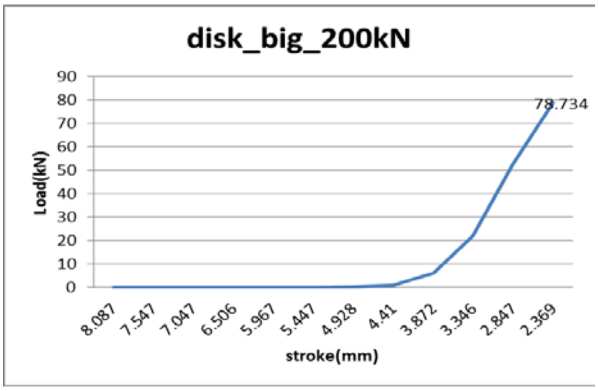
Powder size = big particle

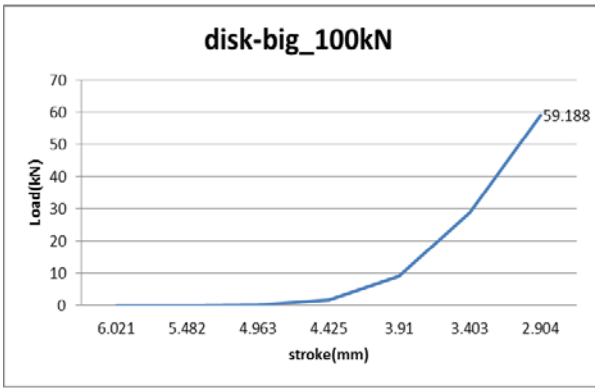
Compressing force = 200kN

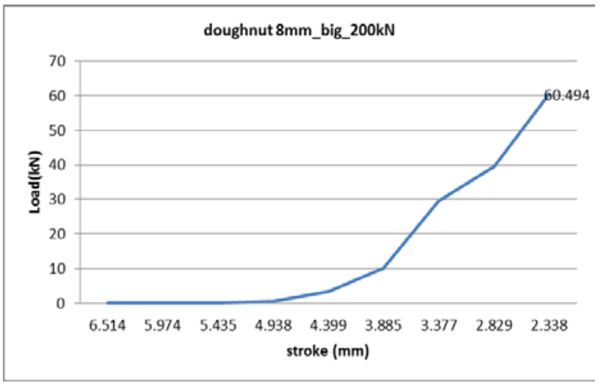
Material	Disk Shape	Doughnut shape-8mm inner diameter	Doughnut shape- 15mm inner diameter
PKS+PF			
PKS+PF+ PFr			
PKS+PF+ EFB			
PKS+PF+ SC			
PKS+PF+ SD			

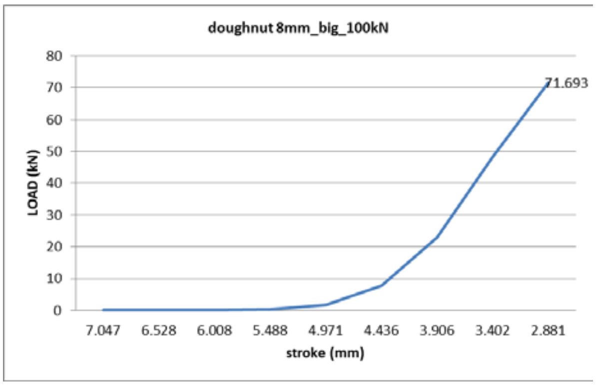
APPENDIX C: Graph Obtain From Compressive Strength Test Using UTM

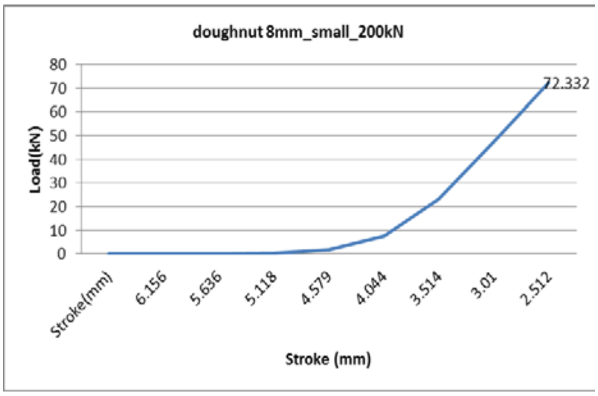


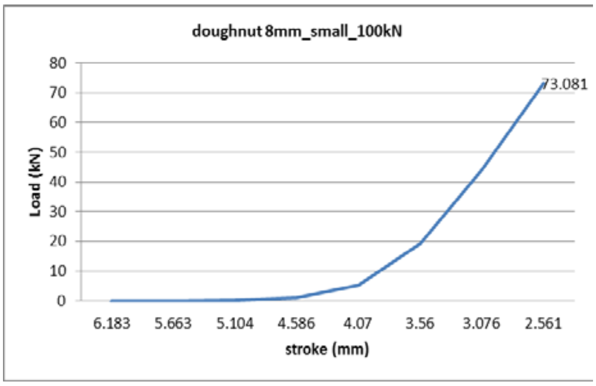


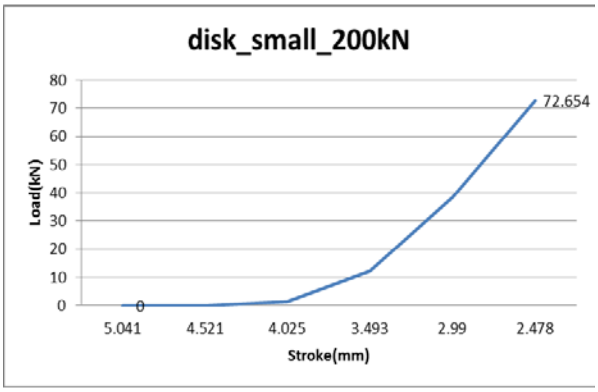


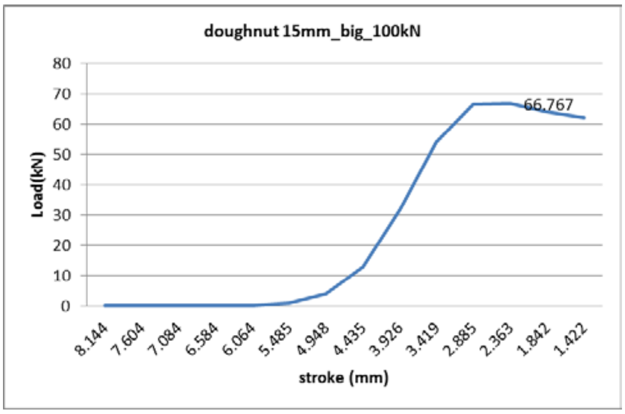


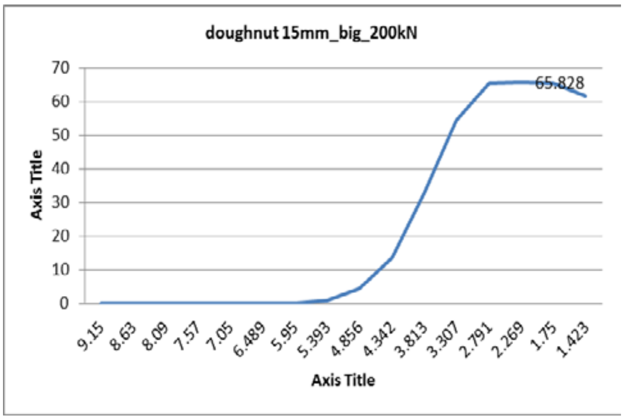


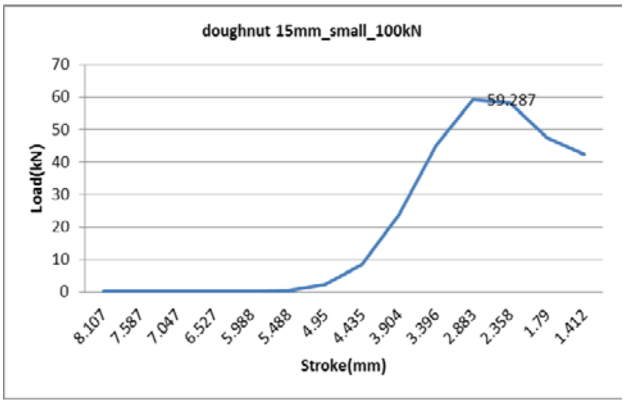


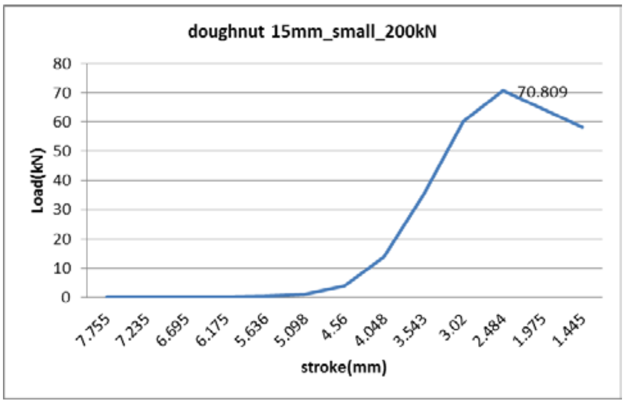












APPENDIX D: Table of Compressive Force Sustained

shape	Type of briqutte	compressive force sustained (kN)
disk	disk_big_100kN	59.19
	disk_small_100kN	72.96
	disk_big_200kN	78.73
	disk_small_200kN	72.64
doughnut_8mm	doughnut 8mm_big_100kN	71.69
	doughnut 8mm_small_100kN	73.08
	doughnut 8mm_big_200kN	60.49
	doughnut 8mm_small_200kN	72.33
doughnut_15mm	doughnut 15mm_big_100kN	66.77
	doughnut 15mm_small_100kN	59.29
	doughnut 15mm_big_200kN	65.83
	doughnut 15mm_small_200kN	70.81

APPENDIX E: Table of Immerse Test Result

type	group	sample	time to fully immerse	time(seconds)
		PKS+PS	47m17s	2837
		PKS+PF+EFB	9m46s	586
	100kN, Small, disk	PKS+PF+PFr	3m34s	214
		PKS+PF+SD	37m17s	2237
		PKS+PS+SC	4m2s	242
		PKS+PS	21m17s	1277
		PKS+PF+EFB	7m1s	421
1	.00kN, small, doughnut 8mn	PKS+PF+PFr	2m54s	174
		PKS+PF+SD	22m5s	1325
		PKS+PS+SC	3m 22s	202
		PKS+PS	40m53s	2437
		PKS+PF+EFB	3m23s	203
	00kN, small,doughnut 15mr	PKS+PF+PFr	2m45s	165
		PKS+PF+SD	17m17s	1037
		PKS+PS+SC	4m46s	286
		PKS+PS	34m47s	2087
		PKS+PF+EFB	7m1s	421
	100kN, big, disk	PKS+PF+PFr	1m30s	90
		PKS+PF+SD	5m35s	335
		PKS+PS+SC	3m5s	185
		PKS+PS	29m46s	1786
		PKS+PF+EFB	4m37s	277
2	100kN,big, doughnut 8mm	PKS+PF+PFr	0m51s	51
		PKS+PF+SD	17m35s	1055
		PKS+PS+SC	2m43s	163
		PKS+PS	19m25s	1165
		PKS+PF+EFB	3m59s	239
	100kN, big,doughnut 15mm	PKS+PF+PFr	0m48s	48
		PKS+PF+SD	13m47s	827
		PKS+PS+SC	1m27s	87
		PKS+PS	62m52s	3772
		PKS+PF+EFB	6m18s	378
	200kN, Small, disk	PKS+PF+PFr	4m54s	288
		PKS+PF+SD	26m22s	1582
		PKS+PS+SC	4m30s	270
		PKS+PS	29m40s	1780
		PKS+PF+EFB	7m14s	434
3	00kN, small, doughnut 8mn	PKS+PF+PFr	3m48s	228
		PKS+PF+SD	15m49s	949
		PKS+PS+SC	4m48s	288
		PKS+PS	32m01s	1921
		PKS+PF+EFB	4m04s	244
	00kN, small,doughnut 15mr	PKS+PF+PFr	2m57s	177
		PKS+PF+SD	13m21s	801
		PKS+PS+SC	2m24s	84
		PKS+PS	30m34s	1834
		PKS+PF+EFB	8m37s	517
	200kN, big, disk	PKS+PF+PFr	1m04s	64
		PKS+PF+SD	18m42s	1122
		PKS+PS+SC	2m20s	140
		PKS+PS	24m23s	1463
		PKS+PF+EFB	5m50s	350
4	200kN,big, doughnut 8mm	PKS+PF+PFr	0m58s	58
		PKS+PF+SD	12m45s	765
		PKS+PS+SC	1m25s	85
		PKS+PS	24m8s	1448
		PKS+PF+EFB	2m1s	121
	200kN, big,doughnut 15mm	PKS+PF+PFr	0m45s	45
		PKS+PF+SD	7m13s	433
		PKS+PS+SC	1m50s	110

APPENDIX F: Stability Test Data

		week 0	week1					week 2					week 3				
group	sample		1	2	3	average	Non-dimensional diameter	1	2	3	average	Non-dimensional diameter	1	2	3	average	Non-dimensional diameter
100kN, Small, disk	PKS+PS	40	42.51	42.50	42.52	41.8825	1.047	42.56	42.57	42.58	42.5700	1.064	42.51	42.55	42.55	42.5367	1.0634
	PKS+PF+EFB	40	42.32	42.37	42.32	41.7525	1.044	42.62	42.63	42.40	42.5500	1.064	42.36	42.44	42.52	42.4400	1.0610
	PKS+PF+PFr	40	42.41	42.48	42.39	41.8200	1.046	42.56	42.64	42.56	42.5867	1.065	42.65	42.42	42.48	42.5167	1.0629
	PKS+PF+SD	40	42.55	42.32	42.42	41.8225	1.046	42.62	42.71	42.53	42.6200	1.066	42.50	42.53	42.73	42.5867	1.0647
	PKS+PS+SC	40	43.05	43.06	43.06	42.2925	1.057	43.60	43.35	43.53	43.4933	1.087	43.36	43.44	43.51	43.4367	1.0859
100kN, small, doughnut 8mm	PKS+PS	40	42.45	42.23	42.22	41.7250	1.043	42.63	42.46	42.34	42.4767	1.062	42.52	42.44	42.34	42.4333	1.0608
	PKS+PF+EFB	40	43.37	43.36	43.35	42.5200	1.063	43.72	43.34	43.14	43.4000	1.085	43.71	43.74	43.98	43.8100	1.0953
	PKS+PF+PFr	40	42.31	42.27	42.28	41.7150	1.043	42.54	42.47	42.38	42.4633	1.062	42.59	42.66	42.67	42.6400	1.0660
	PKS+PF+SD	40	42.37	42.35	42.35	41.7675	1.044	42.38	42.48	42.44	42.4333	1.061	42.43	42.50	42.51	42.4800	1.0620

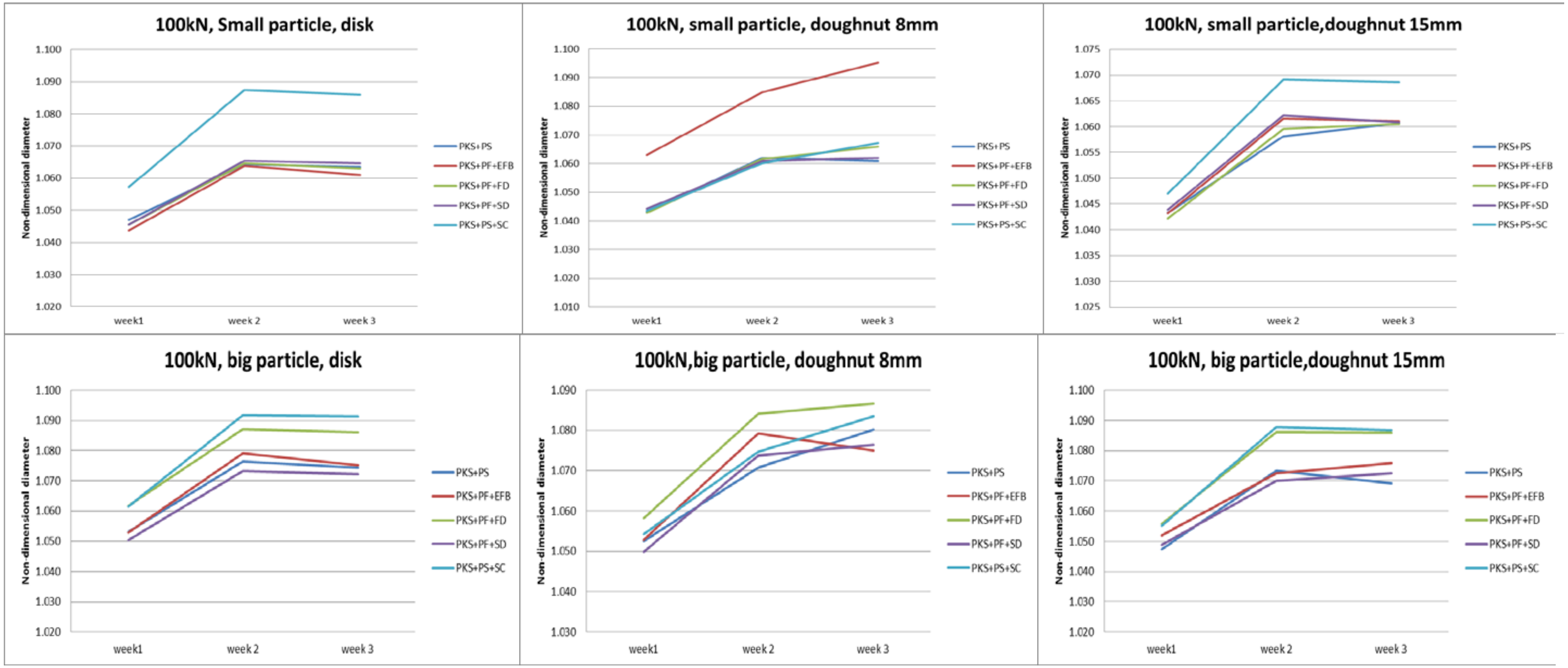
	PKS+PS+SC	40	42.25	42.41	42.30	41.7400	1.044	42.47	42.38	42.37	42.4067	1.060	42.60	42.91	42.56	42.6900	1.0673
100kN,small, doughnut 15mm	PKS+PS	40	42.31	42.30	42.31	41.7300	1.043	42.38	42.29	42.30	42.3233	1.058	42.35	42.35	42.58	42.4267	1.0607
	PKS+PF+EFB	40	42.36	42.21	42.34	41.7275	1.043	42.41	42.43	42.54	42.4600	1.062	42.31	42.41	42.61	42.4433	1.0611
	PKS+PF+PFr	40	42.29	42.20	42.25	41.6850	1.042	42.51	42.30	42.33	42.3800	1.060	42.37	42.43	42.47	42.4233	1.0606
	PKS+PF+SD	40	42.29	42.30	42.43	41.7550	1.044	42.51	42.45	42.50	42.4867	1.062	42.49	42.40	42.41	42.4333	1.0608
	PKS+PS+SC	40	42.55	42.48	42.49	41.8800	1.047	42.75	42.94	42.60	42.7633	1.069	42.74	42.75	42.74	42.7433	1.0686
100kN, big, disk	PKS+PS	40	42.82	42.83	42.84	42.1225	1.053	43.15	43.12	42.89	43.0533	1.076	43.19	42.85	42.88	42.9733	1.0743
	PKS+PF+EFB	40	42.86	42.85	42.75	42.1150	1.053	42.99	43.42	43.10	43.1700	1.079	43.34	42.78	42.89	43.0033	1.0751
	PKS+PF+PFr	40	43.34	43.29	43.25	42.4700	1.062	43.52	43.31	43.62	43.4833	1.087	43.34	43.42	43.57	43.4433	1.0861
	PKS+PF+SD	40	42.84	42.60	42.63	42.0175	1.050	43.03	42.87	42.89	42.9300	1.073	43.08	42.73	42.85	42.8867	1.0722
	PKS+PS+SC	40	43.39	43.19	43.25	42.4575	1.061	43.62	43.74	43.64	43.6667	1.092	43.54	43.85	43.58	43.6567	1.0914
100kN,big, doughnut 8mm	PKS+PS	40	43.03	42.69	42.68	42.1000	1.053	42.76	42.61	43.13	42.8333	1.071	43.39	43.09	43.14	43.2067	1.0802
	PKS+PF+EFB	40	43.57	43.64	43.63	42.7100	1.068	43.86	43.89	43.90	43.8833	1.097	44.04	43.68	44.26	43.9933	1.0998
	PKS+PF+PFr	40	43.07	43.13	43.11	42.3275	1.058	43.39	43.27	43.43	43.3633	1.084	43.25	43.45	43.70	43.4667	1.0867
	PKS+PF+SD	40	42.64	42.69	42.65	41.9950	1.050	42.86	42.90	43.09	42.9500	1.074	43.37	42.86	42.94	43.0567	1.0764

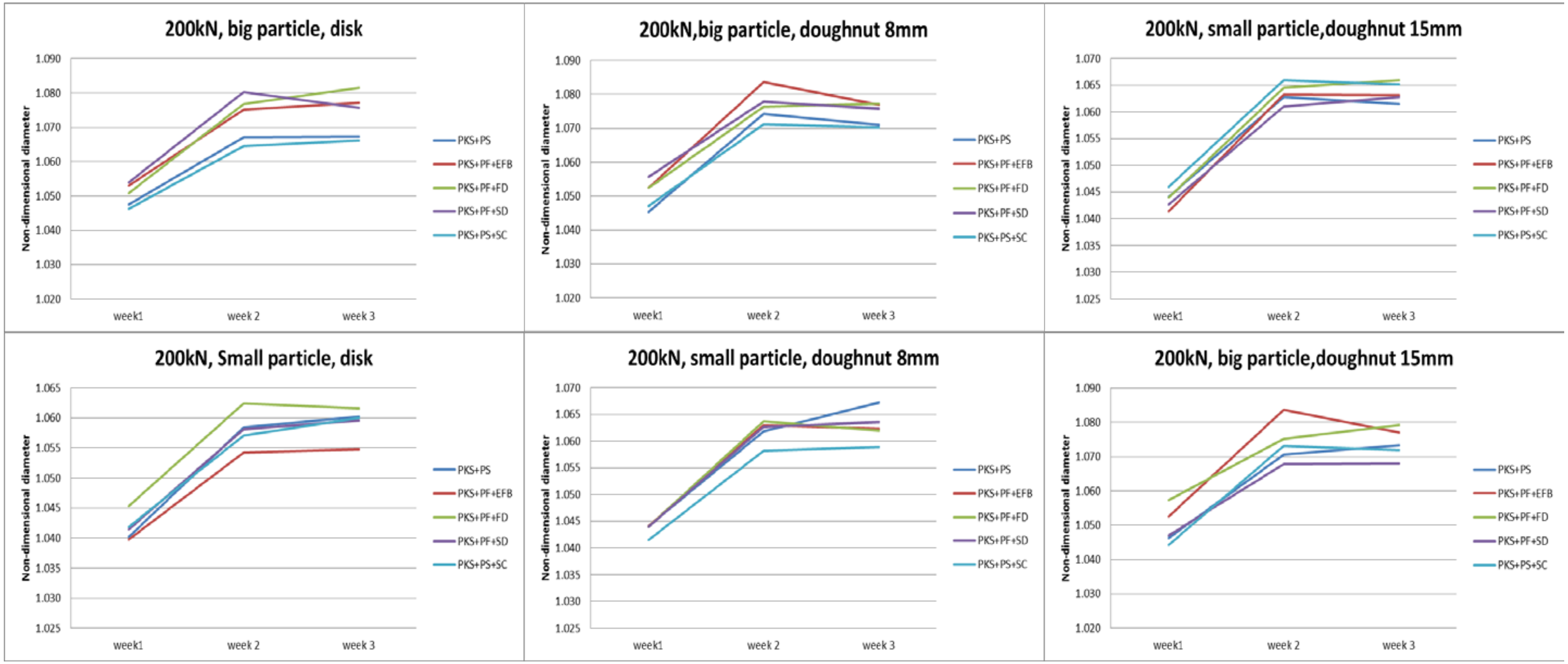
	PKS+PS+SC	40	42.80	43.10	42.78	42.1700	1.054	42.89	43.01	43.06	42.9867	1.075	43.30	43.44	43.29	43.3433	1.0836
100kN, big,doughnut 15mm	PKS+PS	40	42.76	42.24	42.57	41.8925	1.047	42.78	43.05	42.97	42.9333	1.073	42.64	42.70	42.97	42.7700	1.0693
	PKS+PF+EFB	40	42.98	42.57	42.78	42.0825	1.052	42.72	43.10	42.89	42.9033	1.073	42.98	43.27	42.86	43.0367	1.0759
	PKS+PF+PFr	40	43.14	42.79	42.98	42.2275	1.056	43.52	43.39	43.42	43.4433	1.086	43.33	43.46	43.51	43.4333	1.0858
	PKS+PF+SD	40	42.71	42.38	42.71	41.9500	1.049	42.86	42.87	42.68	42.8033	1.070	43.07	42.77	42.87	42.9033	1.0726
	PKS+PS+SC	40	43.02	42.82	42.98	42.2050	1.055	43.41	43.59	43.54	43.5133	1.088	43.13	43.48	43.79	43.4667	1.0867
200kN, Small, disk	PKS+PS	40	42.17	42.11	42.15	41.6075	1.040	42.19	42.35	42.48	42.3400	1.059	42.30	42.36	42.57	42.4100	1.0603
	PKS+PF+EFB	40	42.26	42.05	42.06	41.5925	1.040	42.22	42.07	42.22	42.1700	1.054	42.23	42.14	42.20	42.1900	1.0548
	PKS+PF+PFr	40	42.35	42.46	42.45	41.8150	1.045	42.51	42.39	42.59	42.4967	1.062	42.53	42.39	42.47	42.4633	1.0616
	PKS+PF+SD	40	42.30	42.16	42.17	41.6575	1.041	42.33	42.36	42.29	42.3267	1.058	42.32	42.48	42.36	42.3867	1.0597
	PKS+PS+SC	40	42.23	42.25	42.22	41.6750	1.042	42.29	42.31	42.25	42.2833	1.057	42.54	42.34	42.32	42.4000	1.0600
200kN,small, doughnut 8mm	PKS+PS	40	42.57	42.24	42.25	41.7650	1.044	42.66	42.45	42.31	42.4733	1.062	42.86	42.66	42.55	42.6900	1.0673
	PKS+PF+EFB	40	42.30	42.37	42.38	41.7625	1.044	42.52	42.53	42.51	42.5200	1.063	42.44	42.61	42.43	42.4933	1.0623
	PKS+PF+PFr	40	42.31	42.39	42.33	41.7575	1.044	42.46	42.63	42.56	42.5500	1.064	42.51	42.40	42.53	42.4800	1.0620
	PKS+PF+SD	40	42.27	42.39	42.38	41.7600	1.044	42.45	42.53	42.54	42.5067	1.063	42.47	42.54	42.63	42.5467	1.0637

	PKS+PS+SC	40	42.27	42.18	42.20	41.6625	1.042	42.34	42.34	42.31	42.3300	1.058	42.37	42.29	42.41	42.3567	1.0589
200kN,small, doughnut 15mm	PKS+PS	40	42.46	42.29	42.30	41.7625	1.044	42.39	42.68	42.47	42.5133	1.063	42.44	42.49	42.45	42.4600	1.0615
	PKS+PF+EFB	40	42.35	42.12	42.15	41.6550	1.041	42.36	42.59	42.64	42.5300	1.063	42.42	42.48	42.67	42.5233	1.0631
	PKS+PF+PFr	40	42.33	42.36	42.34	41.7575	1.044	42.46	42.67	42.62	42.5833	1.065	42.47	42.82	42.63	42.6400	1.0660
	PKS+PF+SD	40	42.38	42.20	42.25	41.7075	1.043	42.37	42.64	42.32	42.4433	1.061	42.58	42.49	42.46	42.5100	1.0628
	PKS+PS+SC	40	42.65	42.36	42.35	41.8400	1.046	42.55	42.78	42.58	42.6367	1.066	42.59	42.58	42.64	42.6033	1.0651
200kN, big, disk	PKS+PS	40	42.42	42.76	42.43	41.9025	1.048	42.84	42.61	42.60	42.6833	1.067	42.74	42.59	42.75	42.6933	1.0673
	PKS+PF+EFB	40	42.96	42.75	42.76	42.1175	1.053	43.05	43.04	42.93	43.0067	1.075	43.24	42.95	43.06	43.0833	1.0771
	PKS+PF+PFr	40	42.67	42.67	42.80	42.0350	1.051	43.17	43.21	42.84	43.0733	1.077	43.17	43.34	43.28	43.2633	1.0816
	PKS+PF+SD	40	42.87	42.87	42.89	42.1575	1.054	43.24	43.14	43.24	43.2067	1.080	43.09	43.08	42.92	43.0300	1.0758
	PKS+PS+SC	40	42.47	42.48	42.46	41.8525	1.046	42.56	42.47	42.71	42.5800	1.065	42.72	42.62	42.59	42.6433	1.0661
200kN,big, doughnut 8mm	PKS+PS	40	42.39	42.44	42.43	41.8150	1.045	42.91	43.07	42.92	42.9667	1.074	42.64	42.69	43.20	42.8433	1.0711
	PKS+PF+EFB	40	42.87	42.75	42.78	42.1000	1.053	43.33	43.36	43.35	43.3467	1.084	43.18	42.98	43.08	43.0800	1.0770
	PKS+PF+PFr	40	42.88	42.77	42.75	42.1000	1.053	43.15	43.07	42.95	43.0567	1.076	42.98	43.46	42.84	43.0933	1.0773
	PKS+PF+SD	40	43.11	42.90	42.89	42.2250	1.056	43.07	42.96	43.31	43.1133	1.078	42.98	43.08	43.04	43.0333	1.0758

	PKS+PS+SC	40	42.51	42.49	42.52	41.8800	1.047	42.81	42.76	42.97	42.8467	1.071	42.67	42.83	42.93	42.8100	1.0703
200kN, big, doughnut 15mm	PKS+PS	40	42.52	42.45	42.44	41.8525	1.046	42.68	42.96	42.83	42.8233	1.071	42.71	43.16	42.94	42.9367	1.0734
	PKS+PF+EFB	40	42.85	42.92	42.91	42.1700	1.054	43.03	42.97	43.01	43.0033	1.075	42.93	43.01	43.06	43.0000	1.0750
	PKS+PF+PFr	40	42.81	43.24	43.12	42.2925	1.057	43.12	42.85	43.06	43.0100	1.075	43.15	43.27	43.09	43.1700	1.0793
	PKS+PF+SD	40	42.60	42.45	42.46	41.8775	1.047	42.70	42.74	42.69	42.7100	1.068	42.72	42.71	42.73	42.7200	1.0680
	PKS+PS+SC	40	42.35	42.47	42.25	41.7675	1.044	42.91	42.83	43.03	42.9233	1.073	42.97	42.84	42.82	42.8767	1.0719

APPENDIX G: Stability Test Graph Interpret from Stability Test Data




200kN, big particle, disk
200kN,big particle, doughnut 8mm
200kN, small particle,doughnut 15mm
200kN, Small particle, disk
200kN, small particle, doughnut 8mm
200kN, big particle,doughnut 15mm
Non-dimensional diameter
week1
week 2
week 3
PKS+PS
PKS+PF+EFB
PKS+PF+FD
PKS+PF+SD
PKS+PS+SC

APPENDIX H: Table for Weightage Analysis on Stability Graph

Graph	Material	Ranking	Weightage
100kN, Small particle, disk	PKS+PS	1	10
	PKS+PF+EFB	2	8
	PKS+PF+PFr	3	6
	PKS+PF+SD	4	4
	PKS+PS+SC	5	2
100kN, small particle, doughnut 8mm	PKS+PS	1	10
	PKS+PF+EFB	5	2
	PKS+PF+PFr	4	4
	PKS+PF+SD	2	8
	PKS+PS+SC	3	6
100kN, small particle, doughnut 15mm	PKS+PS	2	8
	PKS+PF+EFB	3	6
	PKS+PF+PFr	4	4
	PKS+PF+SD	1	10
	PKS+PS+SC	5	2
100kN, big particle, disk	PKS+PS	1	10
	PKS+PF+EFB	3	6
	PKS+PF+PFr	4	4
	PKS+PF+SD	2	8
	PKS+PS+SC	5	2
100kN,big particle, doughnut 8mm	PKS+PS	2	8
	PKS+PF+EFB	5	2
	PKS+PF+PFr	3	6
	PKS+PF+SD	1	10
	PKS+PS+SC	4	4
100kN, big particle, doughnut 15mm	PKS+PS	1	10
	PKS+PF+EFB	2	8
	PKS+PF+PFr	3	6
	PKS+PF+SD	4	4
	PKS+PS+SC	5	2
200kN, Small particle, disk	PKS+PS	5	2
	PKS+PF+EFB	1	10
	PKS+PF+PFr	2	8
	PKS+PF+SD	4	4
	PKS+PS+SC	3	6
200kN, small particle, doughnut 8mm	PKS+PS	5	2
	PKS+PF+EFB	3	6
	PKS+PF+PFr	2	8
	PKS+PF+SD	4	4
	PKS+PS+SC	1	10
200kN, small particle,doughnut 15mm	PKS+PS	1	10
	PKS+PF+EFB	4	4

	PKS+PF+PFr	5	2
	PKS+PF+SD	3	6
	PKS+PS+SC	2	8
200kN, big particle, disk	PKS+PS	1	10
	PKS+PF+EFB	4	4
	PKS+PF+PFr	5	2
	PKS+PF+SD	3	6
	PKS+PS+SC	2	8
200kN,big particle, doughnut 8mm	PKS+PS	5	2
	PKS+PF+EFB	3	6
	PKS+PF+PFr	4	4
	PKS+PF+SD	1	10
	PKS+PS+SC	2	8
200kN, big particle, doughnut 15mm	PKS+PS	4	4
	PKS+PF+EFB	1	10
	PKS+PF+PFr	2	8
	PKS+PF+SD	3	6
	PKS+PS+SC	5	2

APPENDIX I: Durability Test

Material and parameters	sample	initial weight(g)	final weight(g)	Weight loss(g)	% weight loss	%Remaining	average % remaining
Material= PKS+PF+PFr Powder size=small particle Compression force =100kN	s1	10.685	9.321	1.364	12.766	87.234	79.478
	s2	10.703	6.292	4.411	41.213	58.787	
	s3	10.66	9.851	0.809	7.589	92.411	
Material= PKS+PF+PFr Powder size=small particle Compression force =200kN	s1	9.778	9.561	0.217	2.219	97.781	96.863
	s2	10.684	10.639	0.045	0.421	99.579	
	s3	10.826	10.093	0.733	6.771	93.229	
Material= PKS+PF+PFr Powder size=big particle Compression force =100kN	s1	10.181	8.497	1.684	16.541	83.459	77.614
	s2	9.968	7.399	2.569	25.772	74.228	
	s3	9.125	6.858	2.267	24.844	75.156	
Material= PKS+PF+PFr Powder size=big particle Compression force =200kN	s1	10.673	9.481	1.192	11.168	88.832	90.922
	s2	10.452	10.178	0.274	2.622	97.378	
	s3	10.645	9.214	1.431	13.443	86.557	

APPENDIX J: Crack Analysis

Table J1

Powder size = small particle

Compressing force = 200kN

Material	Disk Shape	Doughnut shape-8mm inner diameter	Doughnut shape- 15mm inner diameter
PKS+PF			
PKS+PF +PFr			
PKS+PF +EFB			
PKS+PF +SC			
PKS+PF +SD			

Table J2

Powder size = big particle

Compressing force = 100kN

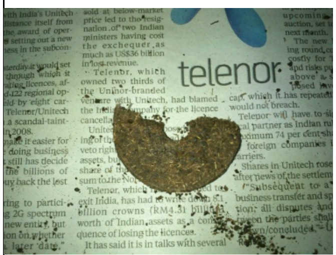
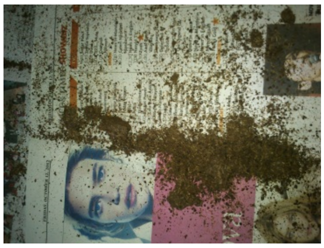
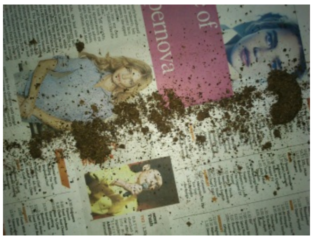
Material	Disk Shape	Doughnut shape-8mm inner diameter	Doughnut shape- 15mm inner diameter
PKS+PF			
PKS+PF +PFr			
PKS+PF +EFB			
PKS+PF +SC			
PKS+PF +SD			

Table J3

Powder size = big particle

Compressing force = 200kN

Material	Disk Shape	Doughnut shape-8mm inner diameter	Doughnut shape- 15mm inner diameter
PKS+PF			
PKS+PF+ PFr			
PKS+PF+ EFB			
PKS+PF+ SC			
PKS+PF+ SD			

APPENDIX K: Project Gantt Chart

Gantt Chart & Key Milestone for FYP 1

Weeks / Tasks	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Topic selection & allocation														
Preliminary Research Work / Literatures Review														
Submission of Extended Proposal														
Study on mechanical properties of fuel briquettes made from oil palm residues.														
Proposal Defence														
Collect palm fiber, palm kernel shell, EFB, rice husk, sawdust and sugar cane waste														
Drying, grinding and briquette pressing														
Submission of interim report														

Gantt Chart & Key Milestone for FYP 2

Weeks / Tasks	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Crack test	■													
Compressive Strength test Using Ultimate Tensile Machine (UTM)		■												
Immerse Test			■											
Stability Analysis				■	■	■	■	■						
Durability Analysis					■									
Microstructure analysis Using Scanning Electron Microscopy (SEM)										■				
Prepare the Progress Report	■	■	■	■	■	■	■	■						
Submission of Progress Report								■						
Evaluation and analysis of all mechanical test result									■	■				
Submission of FYP poster											■			
Submission Of Dissertation And Technical Report												■		
VIVA Presentation													■	
Submission Of Final Report (Hardbound)														■