EFFECT OF PLA AS BONDING AGENT ON THE PROPERTIES OF PINEAPPLE LEAF FIBRE-STARCH COMPOSITE

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This report is submitted
in fulfillment of the requirement for the degree of
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DECLARATION

I declare that this project report entitled "Effect of PLA As Bonding Agent on The Properties of Pineapple Leaf Fibre-Starch Composite" is the result of my own work except as cited in the references

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SUPERVISOR'S APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Structure & Materials).

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ABSTRACT

Recent study has shown interest on green composite material based on plant fibre compared to the synthetic material due to its abundant supply source and renewable material. It also eco-friendly and does not bring harm to the human or environment due to its biodegradable nature. Pineapple Leaf Fibre (PLF) is one of the natural fibres that has abundantly supply resource that can be found in every part of the country. Due to its higher cellulose content which making a good mechanical properties compared to other fibres, PLF should not be wasted just like that. For this study, PLF is used as the reinforcement material while starch (SH) is used as the matrix material or binder. By adding Poly-Lactic Acid (PLA) as bonding agent, the adhesion of interface between the composite are hope to increase. Several compositions ratio of PLF/(SH/PLA) composites were tested in this project which are 50PLF/(50SH/PLA), 60PLF/(40SH/PLA) and 70PLF/(30SH/PLA). The fibre has gone through an alkaline treatment to increase the strength of the fibre. All the samples have gone through four different tests such as flexural test, hardness test, density test and macrostructure analysis to determine their mechanical properties. Based on the results, the sample with composition of 60PLF/(40SH/PLA) has the highest result for flexural stress which is 36.19 MPa. PLF with the composition 70PLF/(30SH/PLA) has the highest result in the hardness which is 60.7. In term of density measurement, the composition that shows higher result is 50PLF/(50SH/PLA) with the value of 1.228 g/cm^3.

ABSTRAK

Kajian terkini telah menunjukkan minat kepada bahan komposit hijau berdasarkan serat tumbuhan berbanding bahan sintetik kerana ia mempunyai sumber bekalan yang banyak dan selain boleh diperbaharui. Ia juga mesra alam dan tidak membawa kemudaratan kepada manusia atau alam sekitar kerana sifat mesra alam itu. Serat Daun Nanas (PLF) adalah salah satu daripada gentian semula jadi yang mempunyai sumber bekalan yang banyak dimana ia boleh didapati di setiap bahagian di negara ini. Oleh kerana kandungan selulosanya yang lebih tinggi dan menghasilkan sifat mekanikal yang baik berbanding dengan gentian lain, PLF tidak boleh disia-siakan begitu sahaja. Untuk kajian ini, PLF digunakan sebagai bahan tetulang manakala kanji (SH) digunakan sebagai bahan matriks atau pengikat. Dengan menambah Asid Poli-Laktik (PLA) sebagai ejen ikatan, diharap lekatan antara muka antara komposit dapat meningkat. Terdapat beberapa nisbah komposisi bagi komposit PLF/(SH/PLA) telah diuji dalam projek ini iaitu 50PLF/(50SH/PLA), 60PLF/(40SH/PLA) dan 70PLF/(30SH/PLA). Gentian serat ini telah melalui rawatan alkali untuk meningkatkan kekuatan gentian. Semua sampel telah melalui empat ujian yang berbeza seperti ujian lenturan, ujian kekerasan, ujian ketumpatan dan analisis struktur makro untuk menentukan sifat-sifat mekanikal mereka. Berdasarkan keputusan, sampel, dengan komposisi 60PLF/(40SH/PLA) mempunyai hasil yang paling tinggi untuk tekanan lenturan iaitu 36.19 MPa. PLF dengan komposisi 70PLF/(30SH/PLA) pula mempunyai hasil yang tertinggi dalam ujian kekerasan dengan nilai 60.7. Dari segi pengukuran ketumpatan pula, komposisi yang menunjukkan hasil yang lebih tinggi adalah 50PLF/(50SH/PLA) dengan nilai 1.228 g / cm^3.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

PLF	Pineapple Leaf Fiber
SH	Starch
PLA	Poly-Lactic Acid
PP	Polypropylene
MA	Maleic Anhydride
GFRP	Glass Fibre Reinforced Polymeric
CMC	Ceramic Matrix Composite
MMC	Metal Matrix Composite
PMC	Polymer Matrix Composite
CFRC	Ceramic Fibre Reinforced Ceramic
C	Carbon
SiC	Silicon Carbide
Al_2O_3	Alumina
Al_2O_3–SiO_2	Mullite
FRPs	Fibre Reinforced Polymers
Tg	Glass Transition Temperature
T_m	Melting Temperature
NaOH	Sodium Hydroxide
ASTM	American Standard Testing Method
sec	second
g	gram
min	minute
w.t	weight

LIST OF SYMBOLS

/	Per
^{0}C	Degree Celsius
%	Percent
g/cm^3	gram per centimetre cube
MPa	Mega-Pascal
^{o}	Degree
N	Newton
mm	millimetre
σ_f	Flexural Stress
ε_f	Flexural Strain
E_f	Modulus of Elasticity

CHAPTER 1

INTRODUCTION

1.1 Background

Green composites is actually a compound of polymers with the natural fibres and consist of two component which is binder and reinforced materials [1]. One acts as a structure and the other one as matrix inside the element. Green composite material based on plant fibre had given an intense competition to the synthetic material due to its abundant supply source and renewable material. It also eco-friendly and does not bring harm to the human or environment due to its biodegradable nature. In this study, the pineapple leaf fibre (PLF) will be the reinforced material and the starch (SH) as its binder. By adding poly-lactic acid (PLA) as bonding agent to this combination of two materials, the result will unveil some properties that are different from each material properties.

Since this study is about using PLF, SH and PLA as the materials to find their physical and mechanical properties, it is not wrong to say that the project is focused on to produce bio-degradable composites. Bio-degradable composites can be defined as a compound of bio-degradable matrix material reinforced with bio-degradable natural fibre [2]. The word bio-degradable itself brings a meaning that the material is eco-friendly material where it is easily degrade and the resources is renewable [3]. This awareness about bio-degradable composites is raised from the issues of reduction in petroleum resources as well as about the environmental problem [4]. Researcher come out with the alternative way to overcome this problem by using green materials associated with agriculture waste.

In industry such as plastic and packaging application, wide-range of oil-based polymer as well as many different materials are used including glass, metals, paper or pulp, plastics or combinations of more than one material as compound. All of these material is surely not easily degrade and difficult to recycle or reuse. Waste from this industry contribute to a larger scale of solid waste where it brings a problem to the environment as well as the nature [5]. Figure 1.1 below shows the classification of bio-composites.

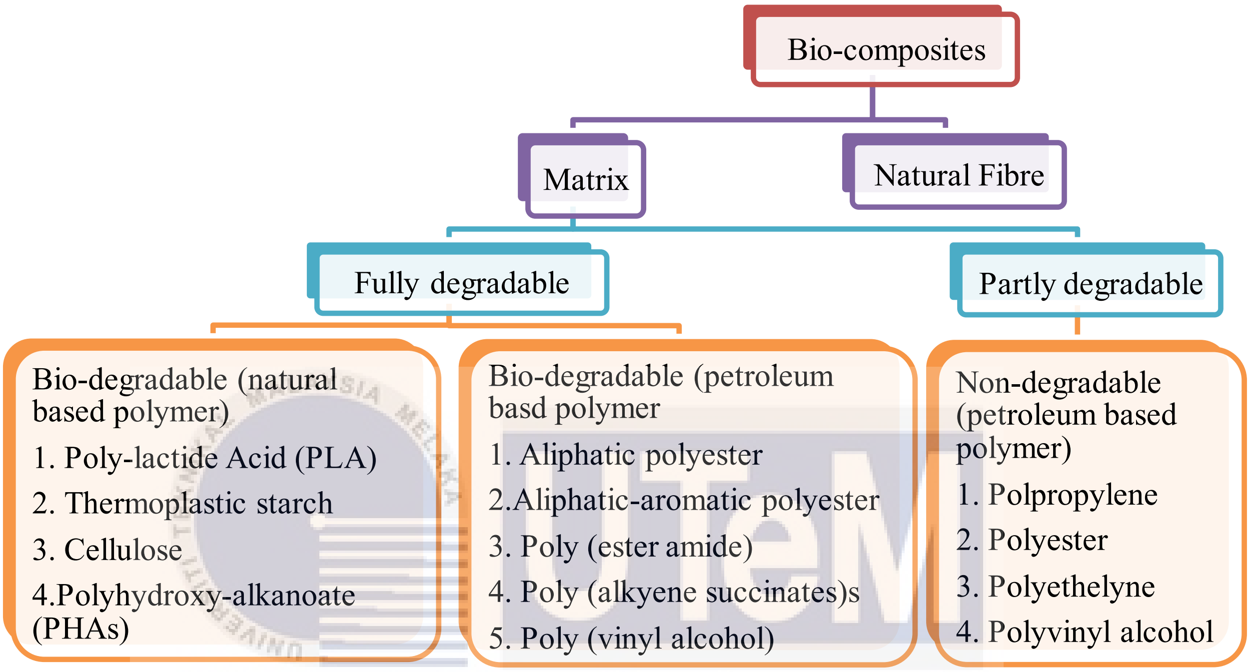


Figure 1.1 Classifications of bio-composites [6]

Previous research has shown about the potential to improve the composite performance by using resin-fibre interface but unfortunately the method is too costly and not safe for the environment [7]. The study about the composite by using PLF is also not new since scientist had discovered the good properties of compound between PLF and SH in term of mechanical and physical properties. However the result for properties is depended on the length of fibre used, the matrix ratio and also the arrangement of the fibre (orientation) [8]. Using natural fibre in reinforced composite instead of synthetic fibre reinforced composites is a good solution for improving the level of life while saving the nature.

Conversely, the utilization of natural fibre has several deficiency need to be considered. The PLF are receptive to humidity and has high moisture absorption [1]. The higher moisture of absorption will make the fibre swelling which brings to consequent loss of strength of the material thus leading to low mechanical performance of composite [7]. The fibre also has poor wettability with some polymer where it need to be taken care first before undergone any test. The solution to handle this is by doing treatment such as alkaline treatment to improve the surface of the fibre. The effect of PLA as bonding agent is to increase the interaction of adhesion between two compounds before using hot press compression moulding machine to produce the composite [9].

Strength and stiffness of the composite are generally increase with the increase of fibre loading as fibres are normally stronger and stiffer than matrix itself. Yet, this properties relies on having good fibre-matrix interfacial strength. Some cases like using hydrophobic matrices such as polypropylene (PP) reinforced with natural fibre, the resulted strength might be reduced. In this case, a bonding or coupling agent is needed to increase the interfacial adhesion between matrix and the fibre [10]. Bonding agents can be defines as a substances that are used in small quantities to treat a surface so that bonding occurs between it and other inter-surfaces [11]. Bonding agents will act as bridges that link composite constituents plus display strong secondary interactions [12]. Among material that being used as bonding agent are Maleic anhydride (MA), isocyanates and triazine. These materials are popular bonding agent that used under graft copolymerisation method where this method is involved with the reaction between the three stated material and cellulose [13].

1.2 Problem Statement

Previous study shows that fibre reinforced plastic is well known composite that being used in structure engineering. However, the used of synthetic fibre as material for reinforced composites will affect the environment and cause pollution to the soil as there are non-renewable, non-biodegradable and not eco- friendly even though it has good mechanical properties [14]. Compared with the synthetic fibre, natural fibre gives more advantages and easy to re-supply. It is low cost and weight, less damage to processing equipment and improved surface finish of moulded parts composite [15]. The implementation of natural fibre in reinforced composite brings good effect in term of the performance and to the environment due to its biodegradable composite properties. The applications of natural fibre are growing in many sectors such as automobiles, furniture, packing and construction. From recent research shows that the current compound of PLF and SH had produce good combination result.

So in this project, the idea is to improve the result better than existing result by adding PLA as bonding agent or in other word as an additives to increase the matrix adhesion. The composition of PLA will be vary in the range of 20 up to 40 % in SH/PLA matrix. The compound then will be tested to determine the mechanical properties of the material. Next the focused will be on PLF/(SH/PLA) composite where combination SH/PLA as a matrix will be vary from 30 up to 50 %. In determining the effect of SH/PLA as a matrix in PLF/(SH/PLA) composite, the related tests will be conducted such as tensile or flexural test, hardness and density test plus macrostructure analysis. These all tests will determine about mechanical and physical properties of the composite.

1.3 Objective

The objective of this project are as follows:

1. To determine the effect of PLA as binder loading on the physical and mechanical properties of SH/PLA composition.

2. To determine the effect of PLF loading on the properties PLF/(SH/PLA) composite.

1.4 Scope of Project

The scope of this project is to study the effects of PLA loading on the mechanical properties of PLF / SH composite with the selected ratio of composition between them. The composite was fixed to 70/30, 60/40 and 50/50. Before that, an alkaline treatment will be conducted first to extract thin PLF bundles. Besides, this process is needed to enhance the PLF properties before using hot-press compression moulding machine to form the structure. The mechanical properties that are going to be determined from the experiment are tensile test, flexure test, hardness test, density measurement and macrostructure analysis. To achieve the objectives, the correct method to prepare the specimen need to be emphasized and understand clearly.

CHAPTER 2

LITERATURE REVIEW

2.1 Composite

Composites are one of the most widely used materials because of their adaptableness to vary situations and the relative ease of combination with other materials to achieve specific purposes and show desired properties. The constituent that make up a composite materials are known as binder or matrix inside the element and reinforcement [16]. Reinforcement material provide the structural rigidity while the matrix will hold the component together.

Undeniably, the competitiveness of green composite material is increasing greatly since it has abundant source, good to nature, low cost besides the properties that they exhibit almost has same quality as the synthetic glass fibre reinforced polymeric (GFRP) composite [7]. Since the purpose of composite is to let the new material possess a strength from the combination, no wonder all these composites had been widely used in electronics, aviation, automobile and many other application due to their excellent properties.

2.1.1 Types of composites

Composite material can be divided into 3 sub-group according the material used where all the purpose is to enhance the matrix properties. The 3 sub-group are:

2.1.1.1 Ceramic Matrix Composite (CMC)

CMC is a non-brittle structural ceramics for application at high temperatures. It is a combination of ceramic fibres with ceramic matrix. This combination is called Ceramic Fibre Reinforced Ceramic (CFRC) where it is designed to overcome technical problems of conventional ceramic which is low fracture toughness and brittleness [17]. Example of ceramic fibres that commonly used are carbon I, silicon carbide (SiC), alumina (Al_2O_3) and mullite (Al_2O_3–SiO_2).

2.1.1.2 Metal Matrix Composite (MMC)

MMC is a combination of at least two different element inside the composite material where the first element is from the metal and reinforced with another material. The second material can be another metal or ceramic such as silicon carbide or graphite. Same case with CMC, MMC were designed to improve strength and wear. MMCs are impervious towards fire, able to work in a wide range of temperatures, resist to absorb moisture, besides possess better electrical and thermal conductivity [18].

2.1.1.3 Polymer matrix composite (PMC)

PMC are the most common composite used in daily application. It consists of a polymer matrix combined with a fibre. The other name of PMC are Fibre Reinforced Polymers (FRPs) where matrix that was used is from polymer based such as epoxy, polyester, poly-lactic acid (PLA) combined with variety of fibre such as glass, carbon, aramid including natural fibre [19]. PMCs can be classified into 2 sub group which is non-bio-degradable and bio-degradable composite. For bio-degradable, it can be divided into partially bio-degradable or fully bio-degradable.

For partially bio-degradable composites, natural fibre are reinforced with petroleum based synthetic polymers. Completely bio-degradable composites use natural fibres reinforced with bio-degradable polymers. For this project, the focused will be on bio-degradable composite since the project involves with natural fibre of PLF and bio-degradable thermoplastic polymer which is PLA. Figure 2.1 shows the classification of the PMC [20].

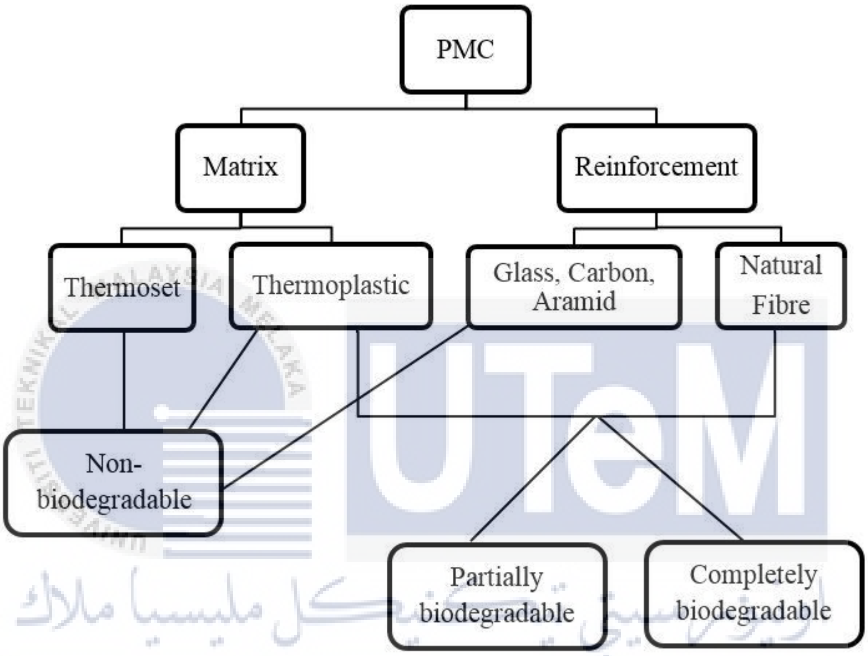


Figure 2.1: Classification of PMC [21]

2.2 Bio-degradable composite

The constituents inside the bio-degradable composite consist of reinforcement from natural fibre and matrix from natural polymer. Bio-degradable composite totally comply with the green composite concept where all the material are from natural source. Bio-degradable composite become prominent product since it is eco-friendly and safe too human application.

2.2.1 Reinforcement

Reinforcement is an element that provides strength and firmness for the compound material. It gives support for the structural load inside the material. The reinforcement material that is chosen in this study is PLF which is known for its low density, has good bio-degradable nature and easy to fabricate. For this study, the natural fibre were chosen to replace the current synthetic fibre glass since natural fibre are more environmental friendly and low in cost.

2.2.1.1 Natural Fibre

Research using natural fibre as main idea or topic is not new since many experiment or testing had been carried out to produce a better result. Among example of natural fibre that had been used for studies are bamboo fibre, vetiver grass fibre, coconut fibre, banana fibre and kenaf [22]. Besides, the scientists and researchers now are more aware with the environmental consciousness issue thus led them to use or do a research by using eco-friendly material [23].

Natural fibre in simple explanation can be define as fibre that are not made by human or synthetic. The fibre can be obtained naturally either from animals or plants. For the plants that produced cellulose, the category of fibre can be divided into bast fibres, seed fibres, leaf fibres, grass and reed fibres, and other kind of fibre like wood and root as shown in Figure 2.2.

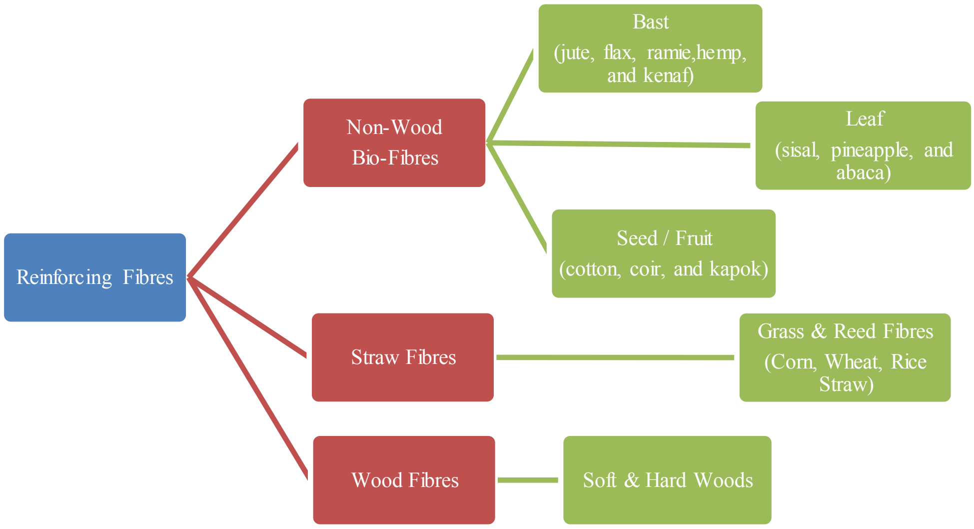


Figure 2.2: Type of Plant Natural Fibre

For plant natural fibre, the structure consist of cellulose, hemicelluloses, lignin, pectin, and waxy substances which brings a little problem in term of humidity where this kind of structure allow moisture that come from surrounding to be trap inside it. This cause weak joint between the fibre and matrix thus resulting low value of stress transfer between the interfaces in the composite. To overcome this problem, many research or cases start the experiment by doing a pre-treatment of the fibre surface where this process is a must to enhance the fibre-matrix adhesion [15].

The way of natural fibre being process could also produce different mechanical properties result. They are influenced by the area of the growth, its climate and the age of the plant. Besides, the extraction of the natural fibre too could affect the structure and characteristic of the fibres. The length of the specimen and its refinement also bring significant change in determining the mechanical properties [24]

2.2.1.1.1 Pineapple Leaf Fibre (PLF)

PLF is a one of the example of leaf type for non-wood bio-fibres that can be used as a reinforcement due to its good properties. PLF is abundantly available in our country since this fruit is one of the Malaysia local fruit. Due to its high cellulose content, PLF fibre were selected as one of the best reinforcement material for composite industry purpose. In Malaysia, the pineapple fruit became the focused after the fruit ripe and leaves the other part of the plant become waste just like that. The farmer usually will burnt down the leaves after taking the fruit thus remove the potential of good source fibres [21]. Due to that, numerous study had been made to make full use of this fibres. PLF has become one of the prominent fibre to replace synthetic fibre especially in industry application. Table 2.1 below shows the specific properties of the PLF.

Table 2.1 Properties of PLF: [25]

Properties	**Value**
Density (g/cm³)	1.526
Softening Point (°C)	104
Tensile Strength (Mpa)	170
Young's Modulus (Mpa)	6260
Specific Modulus (Mpa)	4070
Elongation at Break (%)	3
Moisture regain (%)	12

2.2.2 Matrix (Binder)

The matrix, or binder maintains the position and orientation of the reinforcement. Besides, other function of matrix is to transfer load of one fibre to other fibre. For this study, the matrix that were used are starch. Starch are natural polymer and it is produced by combination of carbon dioxide and water during photosynthesis process in plants [26]. It occurs at stems, roots or in seeds of plants. Natural polymers gives the advantages such as bio-degradability, bio-compatibility and also non-toxic material [27]. Due to its abundance, low cost, and potential application, starch had be seen as an arising material to be studied [28]. Belong to polysaccharides class polymer, starch is mainly composed of two homo-polymers of D- glucopyranose, amylose and the branched amylopectin. Amylose is looked linear in structure and linked by α-1, 4 molecules. For branched amylopectin, it having the same structure as amylose but with many α-1, 6-linked branch points as shown in the Figure 2.3 [29].

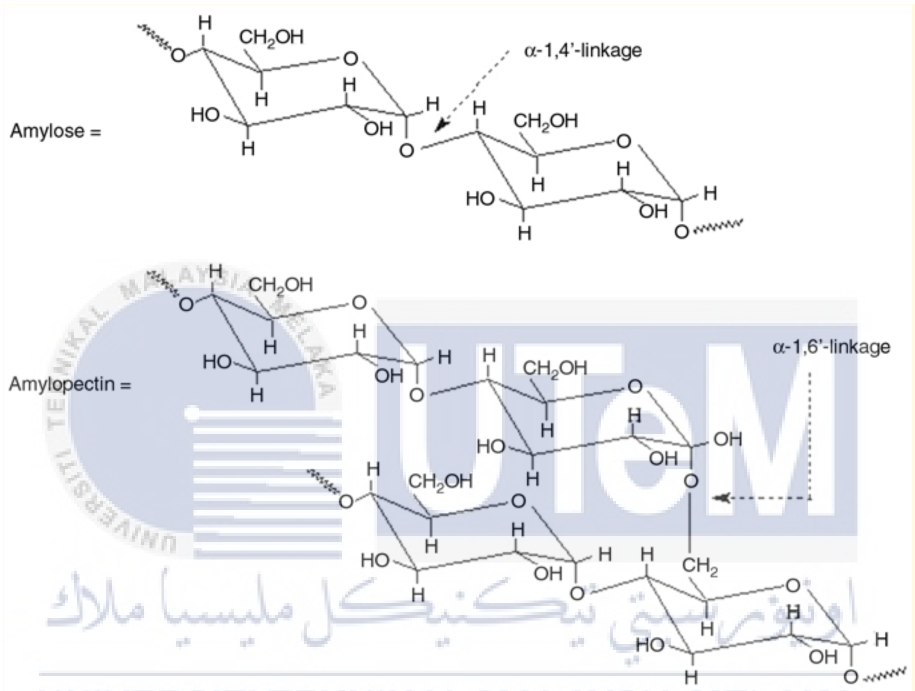


Figure 2.3: Molecular Structure of Amylose and Amylopectin [26]

From previous study has shown that SH as a most selected polymer to be use as matrix material. Even though SH is non-thermoplastic material but due to its advantage, the starch has been modified by adding chemical or plasticizer. After adding new material, SH has display good polymerization properties and can be used on a few fabrication technique like extrusion, injection and compression moulding [30].

2.2.3 Fibre Orientation

What is mean by orientation is the direction or arrangement of element inside the material. The orientation of the fibre can be classified into 3 sub-group which is long, short and in particle orientation. For this project, the orientation of fibre will be focused on long fibre length and perpendicular orientation. From previous research, the performance and efficiency of the natural fibre reinforced composites depends on the interface and the capability of adhesion of matrix to the fibre. To maximize it, the bonding between fibre and matrix need to be increased and also changing the length from short fibre to long fibre of the composites. This can be say that the type of distribution function for fibre length or fibre orientation do affect the final mechanical properties [31].

2.3 Bonding Agent

PLA is an aliphatic (non-aromatic compound) and biodegradable thermoplastic bio-polymer material. It is derived from the renewable source and were produced by the polymerization of lactic acid molecules. PLA production is quite famous as it represents the satisfaction of the dream of low cost, non-petroleum plastic production which means environmental friendly product. The huge benefit of PLA as a bioplastic is its versatility and the fact that it is bio-degradable which naturally degrades when exposed to the surrounding [32].

The properties exhibit by the PLA is comparable to those of product plastics made from petroleum in term of transparency, good process ability, and also mechanical properties [28]. The usage of PLA is used widely in biodegradable packing materials. Besides, from several research and tests have shown that PLA is also suitable as matrix for the implanting of fibre in composites [33]. Table 2.2 shows the properties of the PLA [34]

Table 2.2 Properties of PLA [34]

Properties	Value
Glass Transition Temperature, T_g (◦C)	40 to 70
Melting Temperature, T_m (◦C)	130 to 180
Tensile strength (Mpa)	48 to 53
Tensile modulus (Mpa)	3500
Elongation at break (%)	30 to 240

2.4 Fabrication Technique

They are several technique involved in fabrication of bio-degradable composite such as injection moulding, extrusion, compression moulding, stampable sheet processing and reaction injection moulding [35]. However in this project, compression moulding is selected to fabricate the PLF/(SH/PLA) composite. Before undergo fabrication process, the fiber need to receive surface pre-treatment first to help in adhesion of fibre-matrix bonding. Among all surface pre-treatment that had been studied, alkaline treatment is selected to treat the PLF reinforced material.

2.4.1 Alkaline Treatment

PLF have disadvantages in term of moisture and humidity where this kind of problem need to be avoid to get excellent result. One of the remedy to avoid this problem is doing chemical treatment on the fibre before undergone fabrication process. There are different kind of chemical treatment for this purpose such as alkalization, silane, using acetylation and benzoylation [36].

From previous research, alkaline treatment were stated as one of the best method to enhance the matrix-fibre adhesion. The fibre need to be soaked in NaOH solution for certain time and concentration. Undergone the treatment within limits exhibit better interfacial bonding and produce improvement in term of mechanical properties. The fibre will then be left to dry for 2-3 days to make sure it is fully dried. In this treatment, the NaOH were used to loosen the bonding between hydrogen in the fibre's cellulose structure. This will increase the surface roughness of the fibre. NaOH solution enhance the properties by removes the waxy and fatty acids from the cell walls [37].

2.4.2 Hot-Press Compression Moulding

Hot-press compression moulding one of the fastest as well as cheapest technique to form a sheet of composite compared to others. Besides, this technique is also suitable for manufacturing process that require high pressure. Other good things of compression moulding technique are it capable to mould extra-large and complicated components [38]. Before undergone this process, sample preparation need to be done. Different material for the sample need to be mixed first by using manual mixing method then the mixture will be placed on the mould.

Next the sample will be pre-heated at certain temperature and time in order to soften them. After that the pre-heated sample will be compressed at the same temperature to match to the mould shape. After the process is done, the compressed sample will be let to cool whether under pressure or under room temperature [38].

Figure 2.4: Hot-Press Compression Moulding Machine [38]

2.5 Mechanical Testing

The specimen that had been fabricated need to undergo several testing to determine the mechanical properties exhibit from the composition. That standard that has been used as the reference are based on the American Standard Testing Method (ASTM). The testing that usually done to determine the properties of the composite are tensile test, flexural test, hardness test, density measurement and macrostructure analysis.

2.5.1 Tensile Test

For tensile test, ASTM D3039 standard were referred. This test method determines the tensile properties of polymer matrix composite (PMC) materials reinforced by high-modulus fibres. The forms of composite are restricted to continuous fibre or discontinuous fibre-reinforced composites in which the laminate is balanced and symmetric with respect to the test direction.

The thin flat of the specimen basically having a constant rectangular cross section is mounted in the grips of a mechanical testing machine. The mechanical testing machine used in this test is Instron Universal Testing Machine as shown in Figure 2.5.

Figure 2.5: Instron Universal Testing Machine [39]

A monotonically loading will be applied in tension while the load is being recorded. The ultimate strength of the material can be determined from the maximum load carried before fracture. The ultimate tensile strain, tensile modulus of elasticity, Poisson's ratio, and transition strain can be derived from the test method [40]. For general requirements of the test, the follow requirement is needed in term of shape, dimensions, and tolerances as shown in Table 2.3.

Table 2.3 Tensile Specimen Geometry Requirements [40]

Parameter	Requirement
Coupon Requirement:	
Shape	Constant rectangular cross-section
Minimum length	Gripping +2 times width + gage length
Specimen width	As needed
Specimen width tolerance	± 1% of width
Specimen thickness	As needed
Specimen thickness tolerance	± 4% of thickness
Specimen flatness	Flat with light finger pressure
Tab Requirements (if used):	
Tab material	As needed
Fibre orientation (composite tabs)	As needed
Tab thickness	As needed
Tab thickness variation between tabs	± 1% tab thickness
Tab bevel angle	5 to 90°, inclusive
Tab step at bevel to specimen	Feathered without damaging specimen

For the recommendation, the following requirement is being listed as listed in Table 2.4.

Table 2.4 Tensile Specimen Geometry Recommendations [40]

Fibre Orientation	Width (mm)	Overall Length (mm)	Thickness (mm)	Tab Length (mm)	Tab Thickness (mm)	Tab Bevel Angle (º)
0º	15	250	1.0	56	1.5	7 or 90
90º	25	175	2.0	25	1.5	90
Balanced and symmetric	25	250	2.5	Emery cloth	-	-
Random – discontinuous	25	250	2.5	Emery cloth	-	-

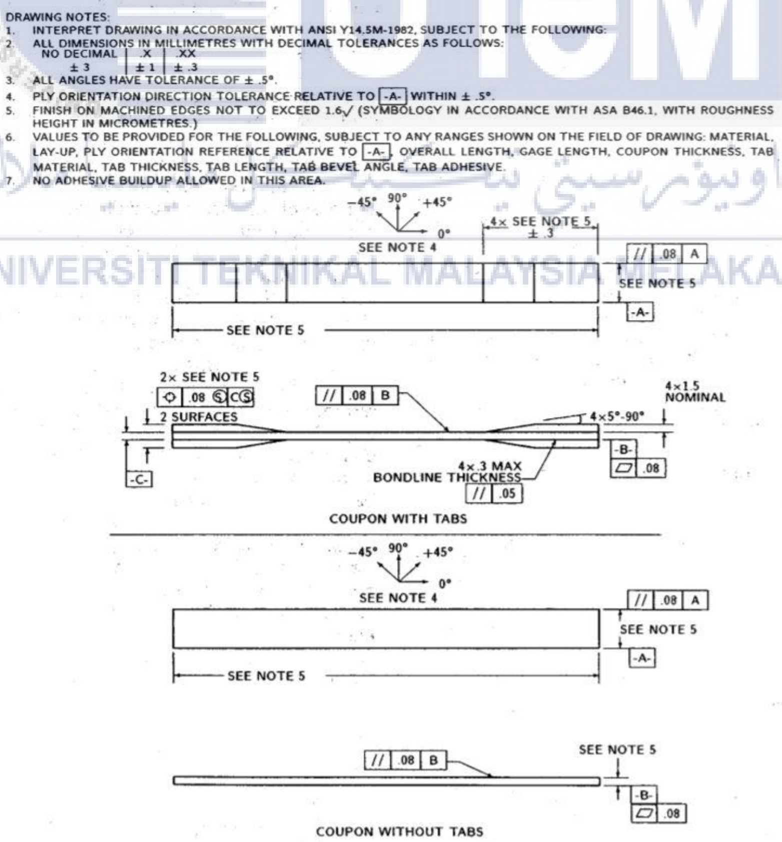


Figure 2.6: Tension Test Specimen Drawing [40]

2.5.2 Flexural Test

Flexural test were done usually because to gain strength and ductility information on a brittle material. This kind of testing is preferred for brittle materials because to avoid any unwanted crack to happen due to surface flaws on the material or because of the machine grip that will affect the result. In other word, flexural test were done so that the strength can be measured without having to worry as much about surface flaws [41].

Flexural test were done according to ASTM D790 where it is done to determine the flexural properties of unreinforced and reinforced plastics, including high-modulus composites and electrical insulating materials. The specimen has to be in the form of rectangular bars molded directly or cut from sheets, plates, or molded shapes. Figure 2.7 shows the schematic diagram of the specimen for flexural test.

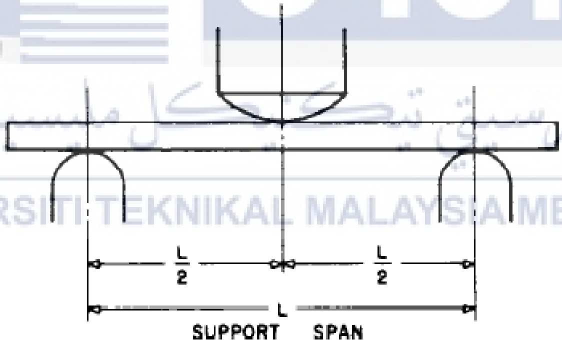


Figure 2.7: Schematic diagram of the specimen for flexural test [42]

When the material is tested in flexure as a simple beam supported at two points and loaded at the midpoint, the maximum stress in the outer surface of the test specimen occurs at the midpoint. This stress may be calculated for any point on the load-deflection curve by means of the following equation:

$$\sigma_f = 3PL/2bd^2$$

Where:

σ = stress in the outer fibres at midpoint, Mpa,

P = load at a given point on the load-deflection curve, N

L = support span, mm,

b = width of beam tested, mm, and

d = depth of beam tested, mm.

2.5.3 Hardness Test

Hardness test were done by using Analogue Shore Scale “D” type Durometer to measure the hardness on specimen. The sample of the composite was placed on a flat surface and the indenter was pressed against the sample. The hardness of the samples was measured by the depth of the indentation and the reading was display on the reading scale of the device. Figure 2.8 shows the device used for taking the hardness measurement value.

Figure 2.8: Analogue Shore Scale “D” type Durometer

2.5.4 Density Measurement

Density measurement will be taken by using Digital Electronic Densimeter (MD-300S) to determine the specific densities of the prepared composites. The standard referred to conduct this test is ASTM D792. These test methods describe the determination of the specific gravity (relative density) and density of solid plastics in forms such as sheets, rods, tubes, or molded items. The density of the sample was measured by weighing the sample first, then immersing it in distilled water immediately. The density value of the sample was taken when the reading reached the equilibrium value. Figure 2.9 shows the device used to take the measurement.

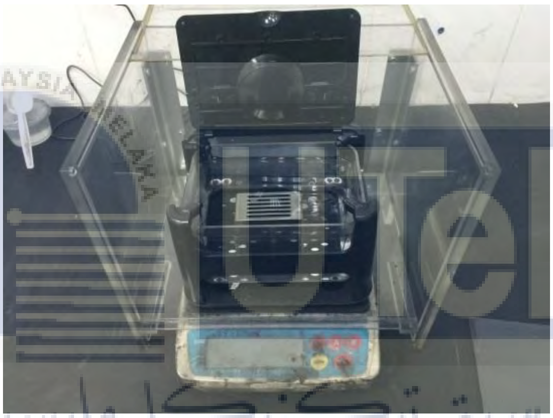


Figure 2.9: Digital Electronic Densimeter (MD-300S)

2.5.5 Macrostructure Analysis

The purpose of this analysis is to see interface bonding between the matrix-fibre as well as other material on the sample surface. By doing this analysis, the result from the mechanical testing will be proved since its macrostructure is being studied.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the methodology used in this project to obtain desired result from the combination of raw materials. As shown in flow chart in Figure 3.1, there is a steps to be followed for a preparation of bonding agent and matrix material to produce a sample of composites.

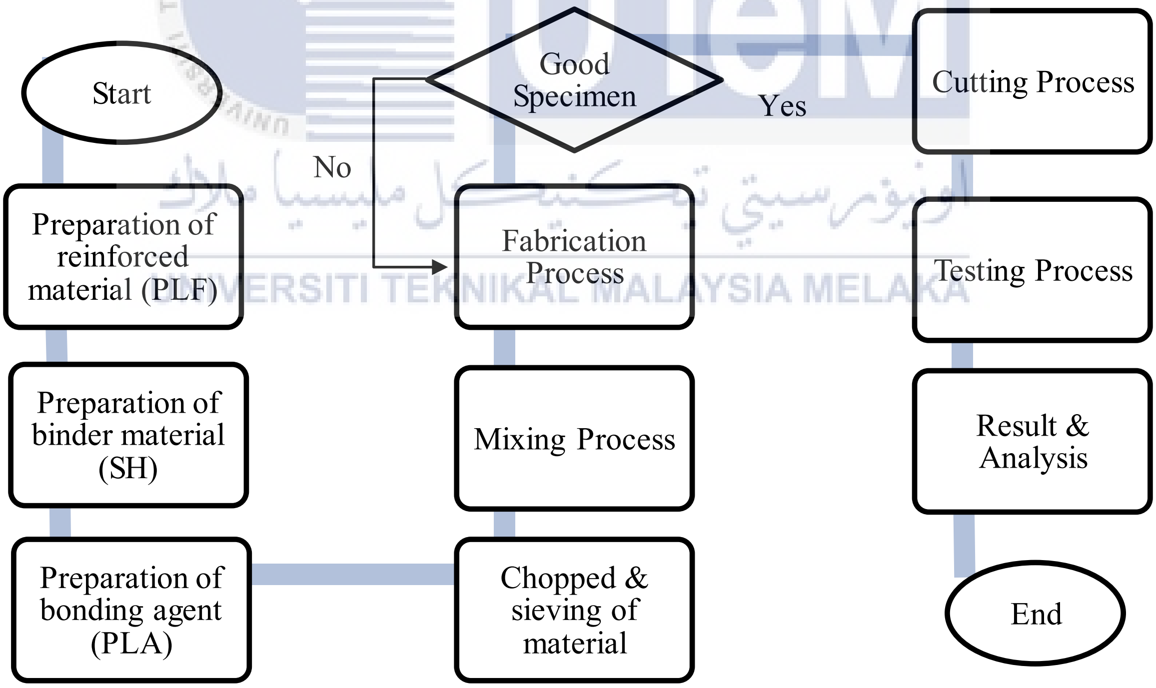


Figure 3.1: Flow chart of the process

3.2 Preparation of Raw Material

For this project, the raw material used required a thorough preparation in order to get the correct result. All the steps and procedure need to be understand first before fabricating the sample.

3.2.1 Reinforcement Material (PLF)

In this project, the reinforcement material that were chosen is natural fibre and not synthetic fibre since natural fibre has many advantages and need to be studied more before being commercialised. Among several choices, Pineapple Leaf Fibre or PLF were chosen since it contents highest cellulose that will give good result of mechanical properties plus it is cheap in cost. PLF is a plant with spiky thorn on its leaves. The waste pineapples leaves were collected after the harvesting. Before further with any process, the leaves will be processed first using extraction machine to get its fibre.

Figure 3.2: Pineapple Plant

3.2.1.1 Alkaline Treatment

Done with the extraction process, the fibre then will undergone alkaline treatment by using sodium hydroxide solution (NaOH). The NaOH that being used in this project are in pellet form as shown in Figure 3.3. So to get the NaOH solution, the pellet form need to be mixed with some water. 0.5% from the concentration needed is equal to 35g of NaOH pellet which then were mixed with a little amount of water.

(a) (b)

Figure 3.3 (a) and (b): The sodium hydroxide (NaOH) in form of pallet form

Next, the fibre was immersed in the alkaline solution of the NaOH combine with 7 litre of distilled water. The immersed fibre then were left for 2 hour. After that the PLF were cleaned using distilled water several time and left to dry under the hot sun for 2 days. The PLF need to be ensure dried carefully in order to avoid surface damage due to humidity.

Alkaline treatment process will helps to remove all the impurities on the PLF and on the same time it will helps to improves the adhesion property between the fibre and the matrix/binder. This also may help to destroy or remove the cellulose on the fibre itself. After the PLF is completely dried, the next process is to remove the excess lignin and the cellulose around the fibre manually by using the spoon.

Figure 3.4: The PLF after undergone the process of removing the excess lignin and cellulose

3.2.2 Bonding Agent (PLA)

Material chosen as bonding agent that need to be studied in this project are poly-lactic acid or known as PLA. PLA is one of the biodegradable material and were categorized under thermoplastic bio-polymer. In this project, the PLA was in pellet form as shown in Figure 3.5 and need to be processed to get its powder.

Figure 3.5: PLA pellet

3.2.2.1 Processing Method

To get PLA in powder form, several steps need to be done. The PLA which is bigger in size need to be grind first using pulveriser machine as shown in Figure 3.6 and then will be blend next to get more finer size. During the preparation, the PLA that use pulveriser machine had some difficulties where it getting burnt while operating which results darker colour of PLA in flakes shape. To overcome this, the time operation were changed from 500 sec to 50 sec.

Figure 3.6: Pulveriser Machine

3.2.3 Composition

For this project, the SH/PLA matrix and PLF/(SH/PLA) composite will be tested to determine their physical and mechanical properties. There were several composition that has been selected with certain condition parameters for the experiment.

3.2.3.1 Composition of SH/PLA

The composition of PLA will be vary in the range of 20 up to 40 % in SH/PLA matrix. The compound then will be tested to determine the mechanical properties of the material. The selected composition is shown in Table 3.1 below.

Table 3.1 Composition of SH / PLA

SH / PLA Composition	Total weight of the sample (g)	SH (g)	PLA (g)
80 / 20	20	16	4
70 / 30	20	14	6
60 / 40	20	12	8

3.2.3.2 Composition of PLF/(SH/PLA)

For PLF/(SH/PLA) composition, the range are vary from 50 up to 70%. The composite then will be tested for their mechanical properties. The selected composition as shown in Table 3.2.

Table 3.2 Composition of PLF / SH with PLA

PLF / SH Composition	Total weight of the sample (g)	PLF (g)	SH (g)	PLA (g)
70 / 30	20	14	3.6	2.4
60 / 40	20	12	4.8	3.2
50 / 50	20	10	6.0	4.0

3.2.4 Mixing Process

Mixing process of all raw material involved in this project were done manually. The SH and PLA which is in powder form were mixed thoroughly together first before adding any PLF. To get the right composition of this powder mixture of SH and PLA, there are several composition had been chosen and done to get the appropriate parameter.

3.2.5 Determine Appropriate Parameter

The purpose of finding the appropriate parameters is to get the best composition for the composite sample. SH and PLA mixture undergone hot-press compression moulding process with several parameters allocated to them. Table 3.3 shows the mixture with selected composition and parameters for the process.

Table 3.3 SH and PLA composition with parameter chosen for the sample

Sample	Composition (%)		Weight (g)	PLA size	Time for each pre-heat & heat process (Min)	Temperature (°C)
	SH	PLA				
1	80	20	4	Fine	10	165
3			4	Rough	15	165
2	70	30	4	Fine	15	165
4			4	Rough	10	165
5			4	Rough	15	165
6	60	40	4	Rough	15	165
7			4	Fine	15	165
8			40	Rough	15	165
9			40	Rough	25	165

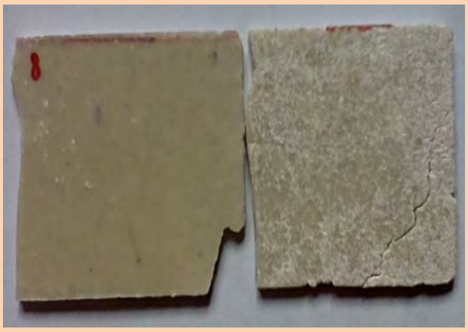
3.2.5.1 Preliminary Results

From the parameter and composition chosen for SH and PLA mixture as shown in Table 3.1, several samples have been fabricated through hot-press compression moulding. All samples that had been fabricated is shown in Table 3.4.

Table 3.4 Fabricated samples of SH / PLA according to selected compositions and parameters

Sample / parameters	Result	Remarks
Sample 1 **Composition:** 80/20 **Weight**: 4 g **PLA size**: Fine **Time for each pre-heat & heat process**: 10 min **Temperature**: 165 °C		• Easily breaks • Some of the material is still in powder form.
Sample 3 **Composition:** 80/20 **Weight**: 4 g **PLA size**: Rough **Time for each pre-heat & heat process**: 15 min **Temperature**: 165 °C		• Easily break • Most of the material is still in powder form
Sample 2 **Composition:** 70/30 **Weight**: 4 g **PLA size**: Fine **Time for each pre-heat & heat process**: 15 min **Temperature**: 165 °C		• Very easy to break • Thin

Sample 4 **Composition:** 70/30 **Weight**: 4 g **PLA size**: Rough **Time for each pre-heat & heat process**: 10 min **Temperature**: 165 °C		• The material not fully melt and adhere together.
Sample 5 **Composition:** 70/30 **Weight**: 4 g **PLA size**: Rough **Time for each pre-heat & heat process**: 15 min **Temperature**: 165 °C		• The material not fully melt and adhere together.
Sample 6 **Composition:** 60/40 **Weight**: 4 g **PLA size**: Rough **Time for each pre-heat & heat process**: 15 min **Temperature**: 165 °C		• The material is 90% melt and adhere together, however there is a spot that still in powder form.
Sample 7 **Composition:** 60/40 **Weight**: 4 g **PLA size**: Fine **Time for each pre-heat & heat process**: 15 min **Temperature**: 165 °C		• The material is melt and adhere together nicely. • Easy to break

Sample 8 **Composition:** 60/40 **Weight**: 40 g **PLA size**: Rough **Time for each pre-heat & heat process**: 15 min **Temperature**: 165 °C		• The top part is melt and adhere nicely. • However, the below part are still in powder form.
Sample 9 **Composition:** 60/40 **Weight**: 40 g **PLA size**: Rough **Time for each pre-heat & heat process**: 25 min **Temperature**: 165 °C		• Both top and below part were melt and adhere together nicely.

Based on analysis of each sample as shown in Table 3.2, there is three difference composition of SH/PLA mixture that had been fabricated. That are 80/20 for samples 1 and 3, 70/30 for samples 2, 4 and 5 and 60/40 for samples 6, 7, 8 and 9. From this three composition, the 60/40 shows better result compared to the other two. Sample 7 and 9 are the good one since all the material are melt and adhere nicely together. From this experiment, it can be say that time taken for hot-compression moulding process is also gives big influence on the sample. The longer the time taken for hot-compression process, the better the result.

3.3 Fabrication Process

Done with selecting good parameter for SH and PLA mixture, next is fabrication process of the composite sample. By using the 140mm x 60mm mould as shown in Figure 3.7, the sample of PLF, SH and PLA with weigh at 20 g were put into the mould with 0° orientation of the long fibres.

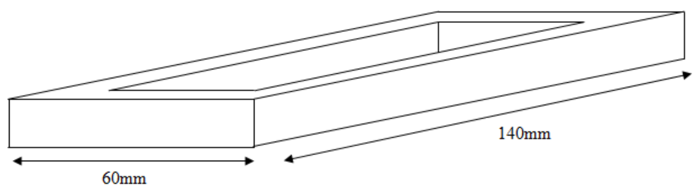


Figure 3.7: Compression Mould [39]

There are several composition tested for this composite samples. The selected composition are as shown in Table 3.5. The mould was placed in hot-press compression moulding machine at temperature 165 °C with zero pressure for pre-heat and heating process. Time taken for the samples are 30 min for each process. Then the mould would undergone the cooling process for 20 minutes. Following this, the composite sheet will be removed from the mould and then cut for testing according to the standard.

Table 3.5: Composition of PLF / SH with PLA

PLF / SH Composition	Total weight of the sample (g)	PLF (g)	SH (g)	PLA (g)
70 / 30	20	14	3.6	2.4
60 / 40	20	12	4.8	3.2
50 / 50	20	10	6.0	4.0

Table 3.6 Fabricated samples of PLF / SH with PLA according to selected compositions and parameters

Composition	Result
Composition: 70/30 **Total Weight**: 20 g **PLF Weight**: 14 g **SH Weight**: 3.6 g **PLA Weight**: 2.4 g	
Composition: 60/40 **Total Weight**: 20 g **PLF Weight**: 12 g **SH Weight**: 4.8 g **PLA Weight**: 3.2 g	
Composition: 50/50 **Total Weight**: 20 g **PLF Weight**: 10 g **SH Weight**: 6.0 g **PLA Weight**: 4.0 g	

3.3.1 Cutting Process

After the fabrication process, the PLF / SH / PLA composite samples will be cut into a specified dimension. For this process, the cutting need to be done manually in order to avoid damaging the fibre. All the dimensions are based on the ASTM International standard. For the flexural test, standard of ASTM D790 is used as the reference and the dimensions for all the specimens are 140 mm length x 23mm width. Figure 3.8 shows the specimens that are cut from each of the samples.

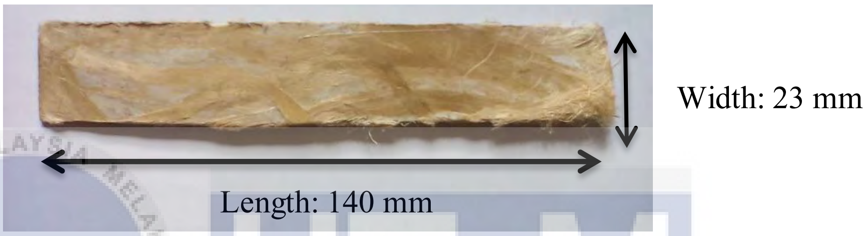


Figure 3.8: Specimen after cutting process

3.4 Mechanical Testing

To study the effect and properties of the sample after fabrication process, several test were conducted on it. Among the tests that were done are flexural test, hardness test, density measurement and macrostructure analysis. Result from all these tests will be analysed to determine the new properties exhibit from the combination of all those material.

The tests were done by abiding all the requirement and procedure as stated in ASTM standard. By following the standard, it provide guarantee for the product in term of safety and reliability. Without standards, the product might not work as expected and also may have inferior quality.

3.4.1 Flexural Test

Flexural Test was conducted following ASTM D790 standard. The purpose for flexural test is to determine the flex or bending properties of the material. There were two types of flexural test which is 3-point loading and 4-point loading system. For this project, the 3-point loading was selected. A bar of rectangular cross section rests on two supports and is loaded by means of a loading nose midway between the supports as shown in Figure 3.10. Before that, the specimen need to be mark first.

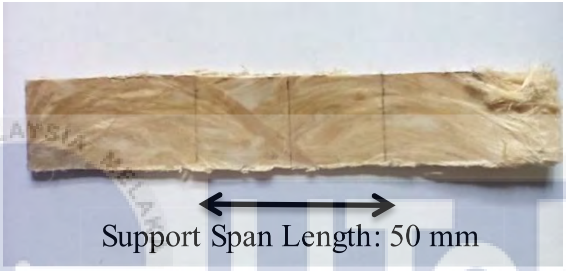


Figure 3.9: Marked specimen for flexural test

Figure 3.10: 3-point loading system for flexural test

The test were done by using Universal Testing Machine Instron 5855 machine and Bluehill software. First, all the specimen specification and setup need to be set on the software and the speed rate was set at 0.1 mm/sec. Next the specimen were placed on the lower flexure fixture and were aligned. The crosshead were lowered until the top fixture is just above the specimen.

Then the test were run until the specimen deflected in the outer surface of the specimen and it can be detected from the graph shown on the monitor. The graph as shown in Figure 3.11 below display decreasing result where it indicates the rupture has occur on the specimen. The test were repeated for other specimen and Figure 3.12 shows the rupture specimen after the test done.

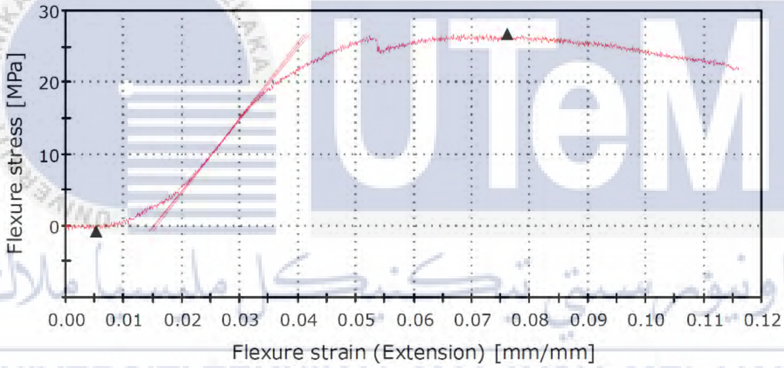


Figure 3.11: Graph of Flexure stress vs Flexure strain

Figure 3.12: Specimen after the flexural test

3.4.2 Hardness Test

Hardness is defined as the resistance to indentation and it is characteristic of a material, not a fundamental physical property. The hardness is determined by measuring the permanent depth of the indentation by using device called Analogue Shore Scale “D” type Durometer. For this test, the sample of the composite was placed on a flat surface and the indenter was pressed against the sample. The hardness of the samples was measured by the depth of the indentation and the reading was display on the reading scale of the device. The reading is recorded and the procedure is repeated 3 times for the other samples and the average reading is calculated.

3.4.3 Density Measurement

Density measurement were done by using a device called MD-300S. The standard referred are based on Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement (ASTM D792). The sample with length 140 mm x 16 mm width were cut into 3 smaller pieces. Next the small piece was put on the container and its mass value was taken after the display reading become stable. Following that, the small piece then were put into the water and need to wait for a little time before taking its mass value. The volume and specific gravity were automatically calculated by this device based on the reading from mass with or without water. The reading value were taken and the steps were repeated with three specimens for each sample and average value then being calculated.

Figure 3.13: Specimen after cut into smaller pieces

3.4.3 Macrostructure Analysis

Macrostructure analysis were done by using Dino Lite Microscope to study the surface morphology and also fracture analysis of the composite samples. Before doing the analysis, several steps need to be done. First, the software need to be installed in the computer because without it, the image of the sample cannot be seen or captured. Second, the USB connector of Dino Lite Microscope need to be connected to the computer. Then the light will be turn on at the device indicate that the setting is done. The sample then were put under the microscope to analyse its behaviour. Using this digital microscope, the image or video can be captured and taken by adjusting the magnification of the lens. Figure 3.14 and 3.15 shows the Dino Lite Microscope instrument and result during analysis of the composite samples.

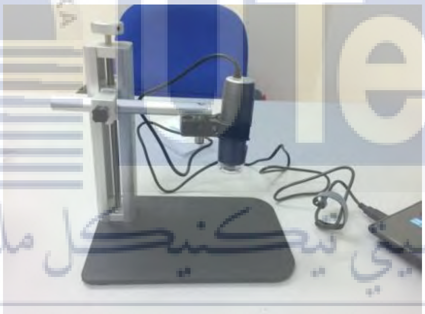


Figure 3.14: Dino Lite Digital Microscope

Figure 3.15: Image captured by the digital microscope

CHAPTER 4

DATA AND RESULTS

4.1 Introduction

This chapter will show all the experimental data and results for all the mechanical testing that have been done to the composite samples. There is four mechanical testing that have been done which are flexural test, hardness test, density measurement and also the macrostructure analysis.

4.2 SH/PLA Composition

Table 4.1 below shows the SH/PLA composition selected for the experiment. From those three ratio, the best composition that had been chosen are 60SH/40PLA. This composition is chosen based from visual observation where 60/40 ratio shows good melting and adhesion properties result.

Table 4.1 SH/PLA composition

SH / PLA Composition	Total weight of the sample (g)	SH (g)	PLA (g)
80 / 20	20	16	4
70 / 30	20	14	6
60 / 40	20	12	8

4.2.1 SH/PLA Flexural Test Result

Flexural test were conducted on SH/PLA with composition 60/40 and the result are shown in Table 4.2.

Table 4.2 SH/PLA Flexural Test Result

Composition	Specimen	Maximum Load, P_{max} (N)	Extension (mm)	Flexural Stress, σ_f (Mpa)	Flexural Strain, ε_f (%)	Modulus of Elasticity, E_f (Mpa)
60SH/40 PLA	1	7.01	4.04	2.54	0.03	310.66
	2	5.98	4.86	2.17	0.03	37.23
	Average	**6.50**	**4.45**	**2.36**	**0.03**	**173.95**

4.3 PLF/(SH/PLA) Composites

For PLF/(SH/PLA) composite, the compositions selected are as shown in Table 4.3. Flexural test were done by using Instron 5585 machine and Blue Hill software. ASTM D790 which is Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials has been referred. The test was run with a constant crosshead speed rate of 0.1 mm/sec. The samples used for the test are consist of the composition of 60SH/40PLA, 50PLF/(50SH/PLA), 60PLF/(40SH/PLA), and 70PLF/(30SH/PLA).

Table 4.3 PLF / (SH/PLA) composition

PLF / (SH/PLA) Composition	Total weight of the sample (g)	PLF (g)	SH (g)	PLA (g)
70 / 30	20	14	3.6	2.4
60 / 40	20	12	4.8	3.2
50 / 50	20	10	6.0	4.0

4.3.1 PLF/(SH/PLA) Composites Flexural Test Result

The results obtained from this test are extension that occur at maximum load (P_{max}), flexural stress (σ_f), flexural strain (ε_f), and modulus of elasticity in bending (E_f) for the composition of 50PLF/(50SH/PLA), 60PLF/(40SH/PLA) and 70PLF/(30SH/PLA). Table 4.4 and Table 4.5 shows the composition and data that were obtained in this test.

According to the data obtained from both tables, the highest average value of load and flexural stress are 99.88 N and 36.19 MPa respectively at the composition of 60PLF/(40SH/PLA). While for the lowest average value of load and flexural stress are 66.37 N and 24.05 MPa respectively at the composition of 70PLF/(30SH/PLA).

The results also shown a same type of data on the modulus of elasticity of the PLF/(SH/PLA) composition which the highest value of the modulus of elasticity shown on the composition of 60PLF/(40SH/PLA) and the lowest value shown is on the 70PLF/(30SH/PLA) composition. For the flexural strain data shows that there is no significance differences on all the data collected which the results show in the range between 0.03 to 0.07 %.

Table 4.4 Maximum load and extension obtained from flexural test

Composition	Specimen	Maximum Load, P_{max} (N)	Extension (mm)
50PLF/(50SH/PLA)	A	73.75	10.56
	B	90.77	8.04
	C	46.92	9.79
	Average	**70.48**	**9.46**
60PLF/(40SH/PLA)	A	85.51	5.03

	B	89.04	5.92
	C	125.10	4.47
	Average	**99.88**	**5.14**
70PLF/(30SH/PLA)	A	56.94	7.31
	B	50.53	4.48
	C	91.63	3.97
	Average	**66.37**	**5.25**

Table 4.5 Result obtained from flexural test

Composition	**Specimen**	**Flexural Stress, σ_f (Mpa)**	**Flexural Strain, ε_f (%)**	**Modulus of Elasticity, E_f (Mpa)**
60SH/40PLA	1	2.54	0.03	310.66
	2	2.17	0.03	37.23
	Average	**2.36**	**0.03**	**173.95**
50PLF/ (50SH/PLA)	A	26.72	0.08	1014.25
	B	32.89	0.06	1378.78
	C	17.00	0.07	454.94
	Average	**25.54**	**0.07**	**949.32**
60PLF/ (40SH/PLA)	A	30.98	0.04	1804.71
	B	32.26	0.04	1085.76
	C	45.33	0.03	3094.23
	Average	**36.19**	**0.04**	**1994.90**
70PLF/ (30SH/PLA)	A	20.63	0.05	793.15
	B	18.31	0.03	1370.19
	C	33.20	0.03	2632.11
	Average	**24.05**	**0.04**	**1598.48**

4.4 PLF/(SH/PLA) Composites Hardness Test

The hardness test of each samples were referred and conducted based on their composition of reinforcement and the matrix of the composite material. The tester device were used to test the hardness of each PLF/(SH/PLA) samples and the value of the hardness is recorded and the average value for the reading is calculated. Table 4.3 shows the data obtained from this testing.

4.4.1 PLF/(SH/PLA) Composites Hardness Test Result

Based on Table 4.6, the hardness test results shows an increment of value for each composition of PLF/(SH/PLA) composite material. This show that the higher the fibre content inside the material, the harder the material.

Table 4.6 Hardness data for each composition

Composition	Hardness (Shore-D)						Average
50PLF/(50SH/PLA)	45	47	50	58	57	62	53.2
60PLF/(40SH/PLA)	58	62	63	61	58	57	59.8
70PLF/(30SH/PLA)	63	57	64	64	55	61	60.7

4.5 PLF/(SH/PLA) Composites Density Measurement

The density test was completed by using the Digital Electronic Densimeter MD-300S and has abide all the requirement as stated in ASTM D792 standard. After done taking display reading and completing all the density test for the all specimens, the results are as shown in Table 4.7.

4.5.1 PLF/(SH/PLA) Composites Density Measurement Result

Based on Table 4.7, it shows that the results for density measurement decrease as the composition of PLF/(SH/PLA) increase. The highest value of density is shows at that composition 50PLF/(50SH/PLA) with the value of 1.228 g/cm^3. The lowest reading density was recorded at composition 60PLF/(40SH/PLA) with the value 1.199 g/cm^3. However, the result of the density for this three composition not showing significance difference since the value is not big enough between each other.

Table 4.7 Density data for each composition

Composition	Density (g/cm^3)			Average Density (g/cm^3)
	Reading 1	Reading 2	Reading 3	
50PLF/(50SH/PLA)	1.251	1.200	1.234	1.228
60PLF/(40SH/PLA)	1.169	1.232	1.198	1.199
70PLF/(30SH/PLA)	1.220	1.264	1.144	1.209

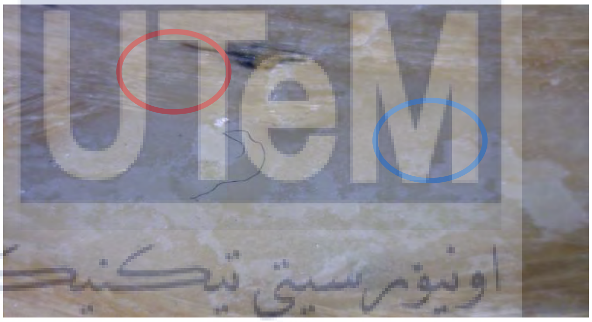
4.6 PLF/(SH/PLA) Composites Macrostructure Analysis

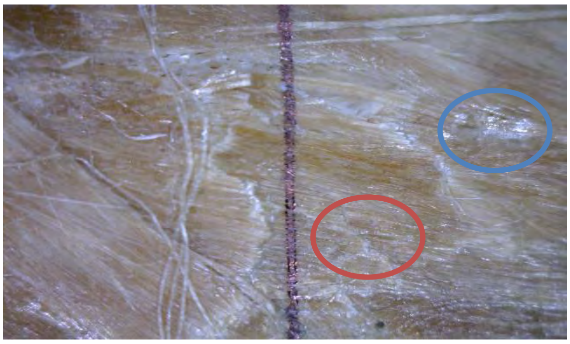
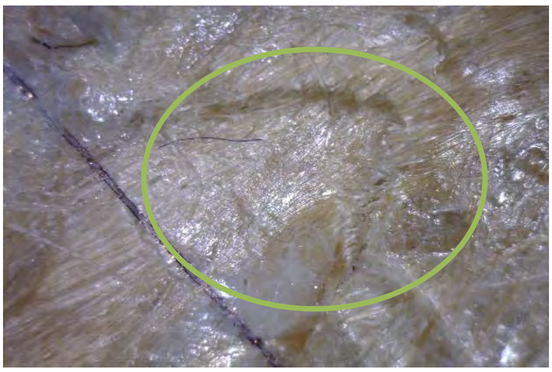
In this section, macrostructure analysis will be conducted in order to view the surface morphology of each sample. The results shown are the structure of the surface to where any fracture, crack or the voids on the samples can be studied based on its composition. Table 4.8 shows the view data for the macrostructure analysis.

4.6.1 PLF/(SH/PLA) Composites Macrostructure Analysis Result

Based on the figures on Table 4.5, the behaviour of PLF and SH/PLA can be seen clearly as the matrix material seem to be accumulated among the PLF with the higher composition percentage. As the PLF composition increases, the SH/PLA matrix spotted to be well mixed with the PLF. This can be seen at the fracture point of the sample.

Table 4.8 Images captured by using digital microscope

Composition	Result
50PLF/(50SH/PLA)	 

60PLF/(40SH/PLA)	 
70PLF/(30SH/PLA)	 

= PLF

= SH / PLA

= Point where fracture occur

CHAPTER 5

DISCUSSION AND ANALYSIS

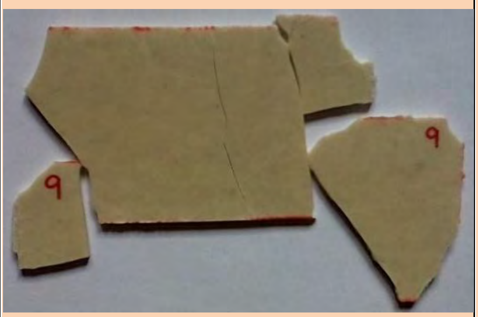
5.1 Parameter Findings

In this chapter, the results from the parameter findings for the SH / PLA mixture is shown and discussed. All the results from the four mechanical testing which are flexural test, hardness test, density measurement and also the macrostructure analysis that have been done are also being discussed and analysed. The parameters for the SH / PLA has been done through fixed composition with the set of 80/20, 70/30 and 60/40.To find an appropriate parameter for the matrix can be consider of fundamental step as it is the key component before the real sample of the composite material can be fabricated. Table 5.1 shows the result obtained from combination of SH / PLA mixture.

Table 5.1 Fabricated sample of SH / PLA mixture according to selected composition and parameter

Sample / parameters	Result	Remarks
Sample 1 **Composition:** 80/20 **Weight**: 4 g **PLA size**: Fine **Time for each pre-heat & heat process**: 10 min **Temperature**: 165 °C		• Easily breaks • Some of the material is still in powder form.

Sample 3 **Composition:** 80/20 **Weight**: 4 g **PLA size**: Rough **Time for each pre-heat & heat process**: 15 min **Temperature**: 165 °C	 	• Easily break • Most of the material is still in powder form
Sample 2 **Composition:** 70/30 **Weight**: 4 g **PLA size**: Fine **Time for each pre-heat & heat process**: 15 min **Temperature**: 165 °C	 	• Very easy to break • Thin
Sample 4 **Composition:** 70/30 **Weight**: 4 g **PLA size**: Rough **Time for each pre-heat & heat process**: 10 min **Temperature**: 165 °C	 	• The material not fully melt and adhere together.
Sample 5 **Composition:** 70/30 **Weight**: 4 g **PLA size**: Rough **Time for each pre-heat & heat process**: 15 min **Temperature**: 165 °C	 	• The material not fully melt and adhere together.

Sample 6 **Composition:** 60/40 **Weight**: 4 g **PLA size**: Rough **Time for each pre-heat & heat process**: 15 min **Temperature**: 165 °C		• The material is 90% melt and adhere together, however there is a spot that still in powder form.
Sample 7 **Composition:** 60/40 **Weight**: 4 g **PLA size**: Fine **Time for each pre-heat & heat process**: 15 min **Temperature**: 165 °C		• The material is melt and adhere together nicely. • Easy to break
Sample 8 **Composition:** 60/40 **Weight**: 40 g **PLA size**: Rough **Time for each pre-heat & heat process**: 15 min **Temperature**: 165 °C		• The top part is melt and adhere nicely. • However, the below part are still in powder form.
Sample 9 **Composition:** 60/40 **Weight**: 40 g **PLA size**: Rough **Time for each pre-heat & heat process**: 25 min **Temperature**: 165 °C		• Both top and below part were melt and adhere together nicely.

As shown in figure inside the table, results obtained from this part are not all successful due to various reason. Ratio of composition that not compromise with each other, time taken for compression moulding process, fibre orientation or wrong method of fabrication can be the reasons why some part are not successfully fabricated. Among all 9 samples that had been fabricated, only 2 samples which is sample 7 and 9 that show good result. Both samples produce shiny but brittle surface and this indicates that the mixture of SH and PLA were melt and adhered nicely together.

5.2 Effect of PLF Loading on Different Composition of PLF/(SH/PLA) Composite on Flexural Stress

The flexural properties of the composites material are shown in Table 4.1 and 4.2 previously where it shows the result based on the different composition from 50PLF/(50SH/PLA), 60PLF/(40SH/PLA) to 70PLF/(30SH/PLA). The results finding that different composition of reinforcement and matrix material will provide a different result significantly.

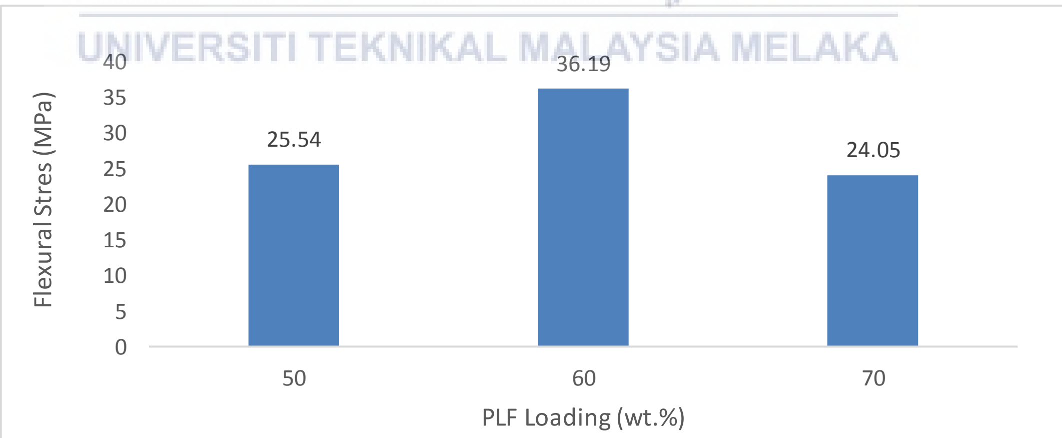


Figure 5.1: Graph of Flexural Stress (Mpa) vs. PLF Loading (wt.%)

Figure 5.1 shows the comparison of average reading of flexural stress for all the fabricated samples. From the figure, the trend can be say that the flexural stresses not increased gradually as expected. At composition 50 wt.% PLF to 60 wt.% PLF, the value are increasing from 25.54 MPa to 36.19 MPa. However, at 70 wt.% PLF, the value drop. The reason for this may be because of high content of PLF loading where it become a flaws and the adhesion between fibres and matrix were not so perfectly bonded as stated by Selamat et al in their research [25]. Other reason that might be a cause of these varies reading is fibres orientation. Fibre distribution do affect the strength properties of the composite. From previous research by Jules et al., a higher fibre out of plane orientation decreases the elastic Young's moduli [43]. From macrostructure result as shown in Table 4.5, the arrangement of the fibres can be say that it is not in 0° orientation. This kind of situation might contribute to fibres agglomeration and effect the testing results. From research done by Wassamon Sujaritjun et al., In Energy Procedia 34 (2013), stated the increasing of fibre agglomeration may be the possible reason for the reduction of strength [44].

5.3 Effect of PLF Loading on Different Composition of PLF/(SH/PLA) Composite on Hardness

Based on Figure 5.2, the graph shows the results of the hardness (Shore-D) with the various percentage of PLF content respectively. The results show that the hardness increases with the increment of the fibre loading and binder materials for all the samples. The experiment had been repeated at six points to get more accurate results. The result obtained shows small increment for the composition of 50PLF/(50SH/PLA) to 70PLF/(30SH/PLA) of the composite material. Since the reinforcement material is in the random discontinuous arrangement, uneven dispersion occur to the matrix. Higher matrix content makes it harder for PLF to blend well with the mixture. This can be say that the sample with the larger content of PLF give the highest value of hardness compare to the lower amount of PLF composition of the composite material.

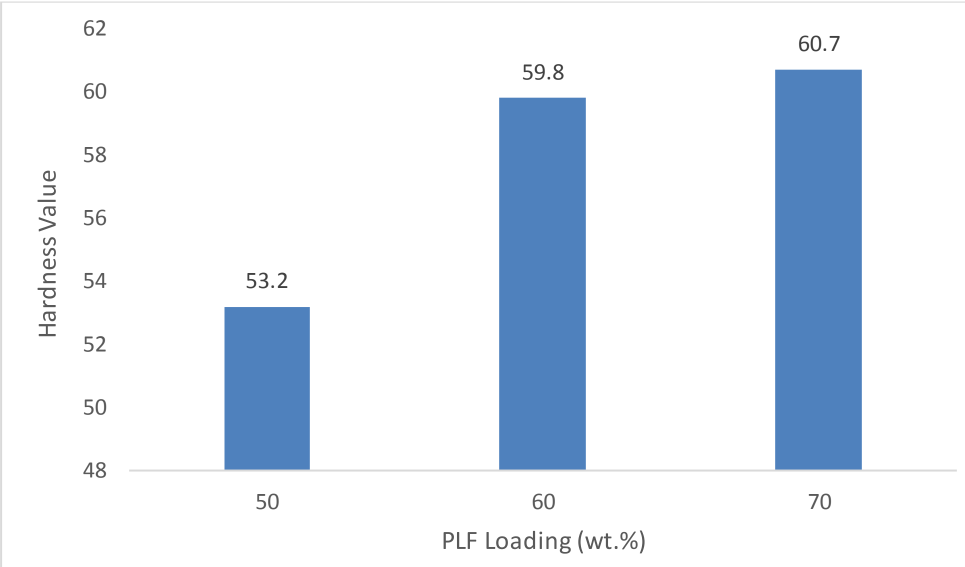


Figure 5.2: Graph of Hardness Value vs. PLF Loading (wt.%)

Composition 50PLF/(50SH/PLA) shows the lowest result while the 70PLF/(30SH/PLA) shows the highest one. The reason for the results may due to the bad surface or the matrix and the fibre are not properly mix during the fabrication process and make the material does not melt properly. Combining different material and melt it with hot press compression machine to get a sample of composite may not get a result as expected since the material has different properties. The unsmooth finishing surface will lead to decreasing value of composite wear resistance. That is why the experiment has to be repeated for a several times in order to get the average result and eliminates the error.

From a research by Selamat and Mashitah (2016) the materials used are PLF for the reinforcement material and SH as the binder. The results shows a compromise result with the results obtained from this experiment which proved that the higher PLF content will increase the results of the hardness test [45].

5.4 Effect of PLF Loading on Different Composition of PLF/(SH/PLA) Composite on Density

Based on the graph in Figure 5.3, the lowest density is in 60wt.% of PLF loading and the highest density is at 50wt.% of PLF loading. The trend of the graph is not as expected since there is an decrement and increment of the result. Previous research obtained by Selamat and Mashitah (2016) stated that the fibre content can affect the density of the composites since the result from their research shows when PLF fibre loading increased, the density also increase [45]. However this experiment shows different result from those research. The higher content of fibre might become obstacle for the water to absorb into the sample thus lead decreasing value of density. To make sure the results is acceptable, the test is repeated with three different specimens for each samples and the average data is taken out as the comparison among all other sample with different composition of PLF/(SH/PLA).

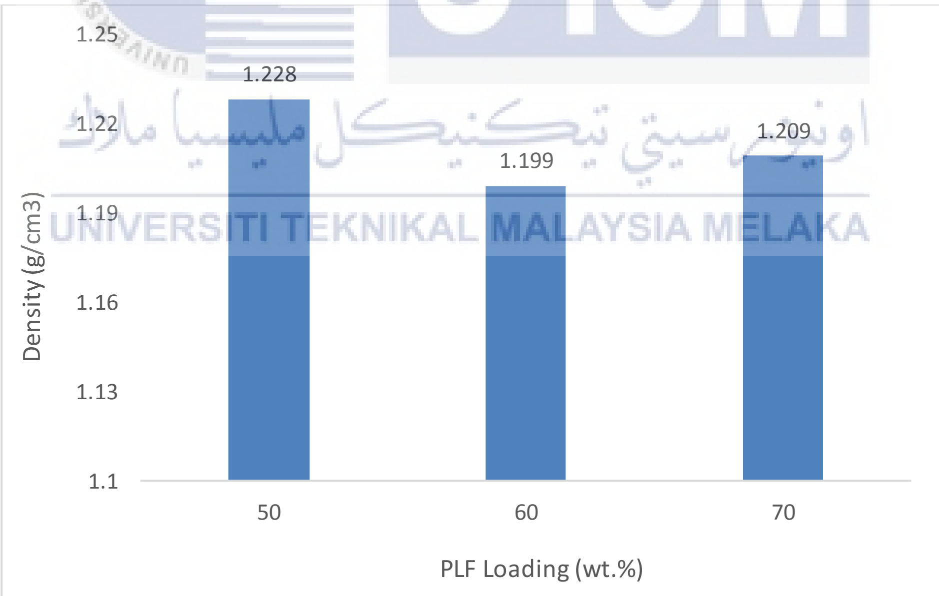
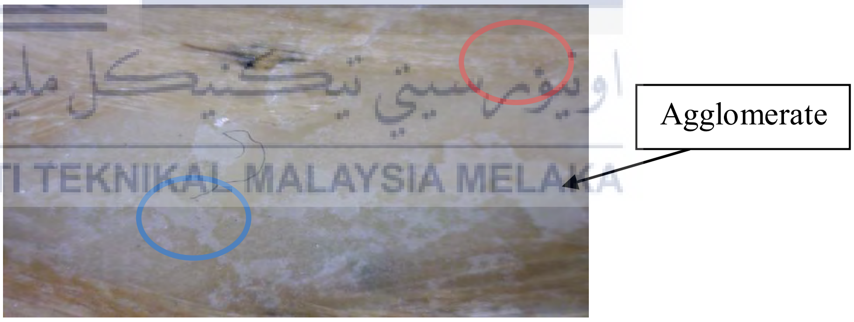
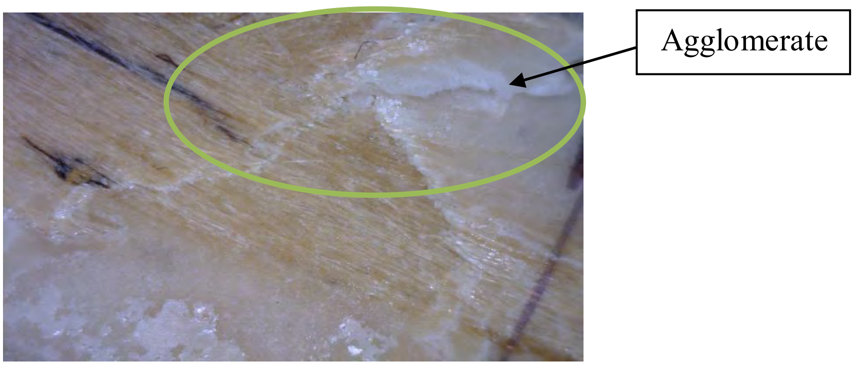


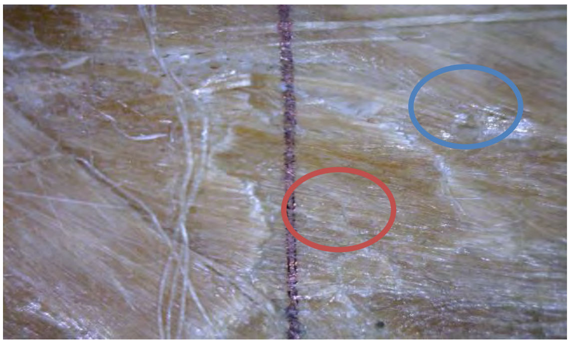
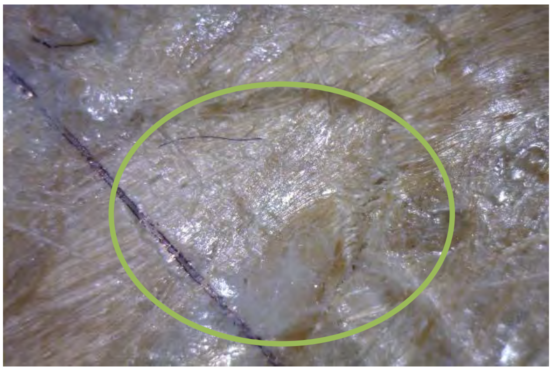
Figure 5.3: Graph of Density (g/cm^3) vs. PLF Loading (wt.%)

5.5 Effect of PLF Loading on Different Composition of PLF/(SH/PLA) Composite on Macrostructure Analysis

Based on Table 5.2 it shows all the macrostructure analysis for all the composition based on the percentage of fibre loading. The sample that with higher composition of PLF tends to have uneven fracture compared to the one who has less PLF content. This is may be due to the higher level of fibre make them hardly to be mix properly with binder material plus probability for the SH to gather at a certain spot is much higher. This condition make the binder more difficult to melt and adhere with the PLF and this make the adhesion bonding is weaker between the fibre and matrix.

Table 5.2 Macrostructure Analysis

Composition	Result
50PLF/(50SH/PLA)	 

60PLF/(40SH/PLA)	 
70PLF/(30SH/PLA)	 

= PLF

= SH / PLA

= Point where fracture occur

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This project is actually focused about bio-degradable composite material where the constituents of the composite is from natural fibre and natural polymer. Bio-degradable composite totally comply with the green composite concept where all the material are from natural source. This kind of composite become prominent product since it is eco-friendly and safe for human application. In this project, the reinforcement material is Pineapple Leaf Fibre (PLF) and the matrix is a combination of Starch (SH) with Poly-Lactic Acid (PLA) as bonding agent. The main objective of this project is to study the effect of PLA loading on the properties Pineapple Leaf Fibre (PLF) / Starch (SH) composite.

The expected result that may be obtained from this project is the greater fibre content will give greater value in the mechanical properties. From the results obtained in this research, the mechanical properties have showed that these bio-degradable materials can be useful in the composite industry. Based on the flexural test result, it can be concluded that the higher percentage of fibre content lead to the higher value of flexural stress. It shows that at composition 60w.t% of fibre loading, the flexural stress is the highest which is 36.19 MPa. For the hardness test, the result shows an increment as the fibre loading increase. The highest result shows at composition of 70w.t% of PLF for the value of 60.7. Based on these findings, it can be concluded that the fibre loading will affect the mechanical properties of the composites material itself. However, poor method of fabrication will lead to poor adhesion bonding between fibre-matrix itself. As can be seen from the density and macrostructure analysis result, the value of density goes up and down and this result may be due to poor adhesion interface between the PLF,SH and PLA.

Some preliminary study were done on the binder and bonding agent mixture before fabricated the samples composite. Several composition and parameter were chosen for SH and PLA mixture. What can be concluded from the preliminary result of SH and PLA combination is, it produce a sample with good rigidity of shape but with brittle type performance. Also from this study, the fabricated time is consider important key point. The longer time taken for the compression moulding process, the better the result. For this SH and PLA combination, composition 60SH/40PLA shows the best result.

6.2 Recommendations

For further research of this study, there are a few recommendations that should be taken as to improve the results of the mechanical properties of PLF/(SH/PLA). The recommendations are basically highlighted the crucial process of this research like the sample preparation and also the fabrication process for producing a better sample in the future. The recommendations are listed as below:

1. Fibre Length

   Fibre length for this project is following the length of the hot-press mould. All the compositions have the same length. So for next study, it is recommended to change the fibre length into several dimension so that the result from different dimension with different composition can be compared. Instead of long fibre, short fibre dimension should be used.

2. Fibre orientation

   Fibre orientation in this project should be in 0° angle. However, they might be some mistake occur while doing fabrication process. So for further studies, it is recommended to do difference orientation of fibre distribution by using short length fibre.

3. Composition of the Composite Material

The composition of the PLF/(SH/PLA) in this research contained of 70PLF/(30SH/PLA), 60PLF/(40SH/PLA) and 50PLF/(50SH/PLA). By changing the composition ratio where matrix percentage is bigger than the fibre, it might could give different view in term of properties of the composites. Besides, composition for matrix material can also be changed by increasing the portion of PLA compared to SH portion. In this project, the composition of SH/PLA is 80/20, 70/30 and 60/40. This can be changed into 80PLA/20SH, 70PLA/30SH and 60PLA/40SH.

4. PLA Preparation

While preparing for fabrication process, it is found that PLA material is hard to be process from pellet into powder form. With lower melting point of temperature and higher friction, it make it difficult to grind and blend the PLA material using normal appliances like home blender because after several turns, the PLA became darky and at certain point, it coagulate and harden inside the blender. This can damage the blender jar as well as its blade. So for further recommendation, it is advised to use PLA that already in powder form. But in case if the PLA need to be processed, use the equipment with higher durability toward high friction material.

REFERENCES

[1] M. P. M. Dicker, P. F. Duckworth, A. B. Baker, G. Francois, M. K. Hazzard, and P. M. Weaver, "Green composites: A review of material attributes and complementary applications," Composites Part A: Applied Science and Manufacturing, vol. 56, no. January 2014, pp. 280–289, 2014.

[2] Shinji Ochi, Tensile Properties of Bamboo Fiber Reinforced Biodegradable Plastics. International Journal of Composite Materials, Vol. 2 No. 1, pp. 1-4, 2012.

[3] Satyanarayana, K. G., Arizaga, G. G., & Wypych, F. Biodegradable composites based on lignocellulosic fibers - An overview. Progress in polymer science, 34(9), 982-1021., 2009

[4] Sahari, J., & Sapuan, S. M. Natural fibre reinforced biodegradable polymer composites. Rev. Adv. Mater. Sci, 30(2), 166-174, 2011.

[5] J. H. Song, R. J. Murphy, R. Narayan and G. B. H. Davies Source. Biodegradable and Compostable Alternatives to Conventional Plastics, Philosophical Transactions: Biological Sciences, Vol. 364, No. 1526, Plastics, the Environment and Human Health, pp. 2127-2139, 2009.

[6] A.K. Mohanty, M. Misra, L.T. Drzal, S.E. Selke, B.R. Harte and G. Hinrichsen, Natural Fibres, Biopolymers and Biocomposites (CRC Press, Boca Raton), 2005.

[7] J. M. Chard, G. Creech, D. A. Jesson, and P. A. Smith, "Green composites: sustainability and mechanical performance," Plastics Rubber and Composites, vol. 42, no. 10, pp. 421–426, 2013.

[8] M. Asim et al., "A Review on Pineapple Leaves Fibre and Its Composites," International Journal of Polymer Science, vol. 2015, pp. 1–17, 2015.

[9] A.N. Kasim, M.Z. Selamat, M.A.M. Daud, M.Y. Yaakob, A. Putra and D. Sivakumar, “Mechanical properties of polypropylene composites reinforced with alkaline treated pineapple leaf fibre from Josapine cultivar,” International Journal of Automotive and Mechanical Engineering (IJAME), vol. 13, no. 1, pp. 3157–3167, 2016.

[10] Pickering, K. L., Efendy, M. A., & Le, T. M. A review of recent developments in natural fibre composites and their mechanical performance. Composites Part A: Applied Science and Manufacturing, 83, 98-112, 2016.

[11] CHAPTER 2. A REVIEW OF COUPLING AGENTS AND TREATMENTS [Online]. Available: etd.lsu.edu/docs/available/etd-1112103-221719/unrestricted/Chapt02.pdf [Accessed: 23 May 2017].

[12] Raj, R. G., B.V. Kokta, D. Maldas, and C. Daneault. Use of wood fibers in thermoplastics. VII. The effect of coupling agents in polyethylene-wood fiber composites. Journal. Appl. Polym. Sci. 37: 1089-1103, 1989.

[13] Pickering. K. L. Properties and Performance of Natural-Fibre Composites, CRC Press, Boca Raton, 2008.

[14] K. Begum and M. a Islam, “Natural Fibre as a substitute to synthetic fibre in polymer composites: A review,” Research Journal of Engineering Sciences, vol. 2, no. 3, pp. 46–53, 2013.

[15] M. R. Sanjay, G. R. Arpitha, L. L. Naik, K. Gopalakrishna, and B. Yogesha, “Applications of Natural Fibres and Its Composites: An Overview,” Journal Natural Resources, vol. 7, pp. 108–114, 2016.

[16] D. Chandramohan, K. Marimuthu, “Tensile and Hardness Tests on Natural Fibre Reinforced Polymer Composite Material,” International Journal of Advanced Engineering Sciences and Technologies (IJAEST), Vol 6, no. 1, 097 – 104.

[17] N.A, "Ceramic Matrix Composites", King's University College, 2014. [Online]. Available: nptel.ac.in/courses/112107085/module6/lecture1/lecture1.pdf. [Accessed: 10 Dec 2016].

[18] AZO Material, "Composite Matrix Materials", 2013. [Online]. Available: http://www.azom.com/article.aspx?ArticleID=9814. [Accessed: 10 Dec 2016].

[19] M. A. Masuelli, "Introduction of Fibre-Reinforced Polymers – Polymers and Composites: Concepts, Properties and Processes," February 2013.

[20] N.A, "Composite Materials: Classification and Applications" 2013. [Online]. Available: nptel.ac.in/courses/112107085/module5/lecture2/lecture2.pdf. [Accessed: 10 Dec 2016].

[21] Mohamed A.R., Sapuan S.M, Shahjahan M, Khalina A, (2008) "Characterization of pineapple leaf fibers from selected Malaysian cultivars". Journal of Food Agriculture and Environment, 2009.

[22] J. P. Dhal and S. C. Mishra, "Processing and Properties of Natural Fibre-Reinforced Polymer Composite," Hindawi Publishing Corporation, Journal of Materials, vol. 2013, 2013.

[23] L. Mohammed, M. N. M. Ansari, G. Pua, M. Jawaid, and M. S. Islam, "A Review on Natural Fibre Reinforced Polymer Composite and Its Applications," Hindawi Publishing Corporation, International Journal of Polymer Science, vol. 2015, 2015.

[24] Adekunle, K. Surface Treatments of Natural Fibres - A Review: Part 1. Open Journal of Polymer Chemistry, 5, 41-46, 2015.

[25] A. N. Kasim, M.Z. Selamat, N. Aznan et al., "Effect of pineapple leaf fibre loading on the mechanical properties of pineapple leaf fibre – Polypropylene composite," Jurnal Teknologi., vol. 77, no. 21, pp. 117–123, 2015.

[26] D. R. Lu, C. M. Xiao, and S. J. Xu, "Starch-based completely biodegradable polymer materials," eXPRESS Polymer Letters, vol. 3, no. 6, pp. 366–375, 2009.

[27] Silva, C. M. D., Bottene, M. K., Barud, H. G. D. O., Barud, H. D. S., Ligabue, R. A., & Jahno, V. D. Wettability and Morphological Characterization of a Polymeric Bacterial Cellulose/corn Starch Membrane. Materials Research, 18, 109-113, 2015.

[28] M. A. Shirai, M. V. E. Grossmann, F. Yamashita, P. S. Garcia, and C. M. O. Müller, "Development of biodegradable flexible films of starch and poly (lactic acid) plasticized with adipate or citrate esters," Carbohydrate Polymers, vol. 92, no. 1, pp. 19–22, 2013.

[29] Martin Chaplin, "Starch" 2016. [Online]. Available: http://www1.lsbu.ac.uk/water/starch.html [Accessed: 14 Dec 2016].

[30] Ibrahim, H., Farag, M., Megahed, H., & Mehanny, S. 2014. Characteristics of starch-based biodegradable composites reinforced with date palm and flax fibers. Carbohydrate polymers, 101, 11-19, 2014.

[31] S. Jeyanthi and J. J. Rani, "Influence of natural long fibre in mechanical, thermal and recycling properties of thermoplastic composites in automotive components," International Journal of Physical Sciences, vol. 7, no. 43, pp. 5765–5771, 2012.

[32] Tony Rogers "Everything You Need To Know About Polylactic Acid (PLA)" 2015. [Online]. Available:https://www.creativemechanisms.com/blog/learn-about-polylactic-acid-pla-prototypes [Accessed: 14 Dec 2016].

[33] N. Graupner, A. S. Herrmann, and J. Müssig, "Natural and man-made cellulose fibre-reinforced poly (lactic acid) (PLA) composites: An overview about mechanical characteristics and application areas" Composites: Part A 40, pp 810–821, 2009.

[34] Clarinval AM, Halleux J. Classification of biodegradable polymers. In: Smith R, editor. Biodegradable polymers for industrial applications. 1st ed. Boca Raton, FL, USA: CRC Press. pp 3–31, 2005.

[35] Roy, S. B., Shit, S. C., Sengupta, R. A., & Shukla, P. R. A Review on Bio-Composites: Fabrication, Properties and Applications, 2014.

[36] Venkatachalam, N., Navaneethakrishnan, P., Rajsekar, R., & Shankar, S. Effect of Pretreatment Methods on Properties of Natural Fiber Composites: A Review. Polymers & Polymer Composites, Vol 24, no 7, pg 555-566, 2016.

[37] Siregar, J. P., Salit, M. S., Ab Rahman, M. Z., Dahlan, M., & Zaman, K. Effects of alkali treatments on the tensile properties of pineapple leaf fibre reinforced high impact polystyrene composites. Pertanika Journal of Science & Technology, 20(2), 409-414. 2012.

[38] Shamsuri, A. A. Compression moulding technique for manufacturing biocomposite products. International Journal of Applied, 5(3), 2015.

[39] 5980 Floor Model Systems for High-Capacity Universal Testing. (n.d.). Retrieved December 14, 2016, from http://www.instron.us/products/testing-systems/universal-testing-systems/electromechanical/5900/5980-floor-model

[40] ASTM D3039 / D3039M-14, Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials, ASTM International, West Conshohocken, PA, 2014, DOI: 10.1520/D3039_D3039M-14www.astm.org

[41] INSTRON 5582 UNIVERSAL TESTER, pp. 1–12 [n.d] Retrieved May 17, 2017 from http://faculty.olin.edu/~jstolk/matsci/Operating%20Instructions/Instron%20Universal%20Tester%20Operating%20Instructions.pdf

[42] ASTM D790-03, Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials, ASTM International, West Conshohocken, PA, 2003, DOI: 10.1520/D0790-15E02. www.astm.org.

[43] Jules, E. J., Tsujikami, T., Lomov, S. V., & Verpoest, I. Effect of fibres length and fibres orientation on the predicted elastic properties of long fibre composites. In Macromolecular Symposia (Vol. 17), 2004.

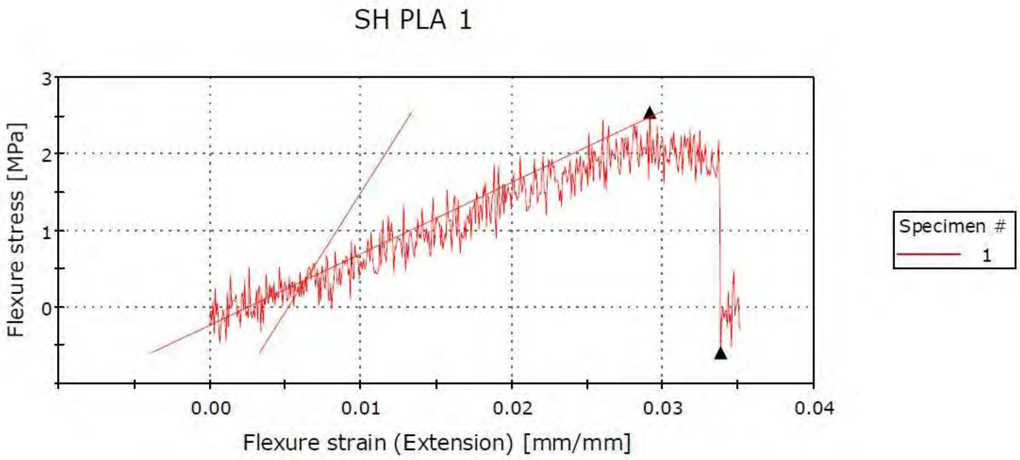
[44] Sujaritjun, W., Uawongsuwan, P., Pivsa-Art, W., & Hamada, H. Mechanical property of surface modified natural fibre reinforced PLA biocomposites. Energy Procedia, 34, 664-672, 2013.

[45] Selamat M. Z, Razi M, Kasim A. N, Dharmalingam, S, Putra A, Yaakob M. Y, M. Daud M. A. Mechanical Properties of Starch Composite Reinforced by Pineapple Leaf Fibre (PLF) from Josapine Cultivar, ARPN Journal of Engineering and Applied Sciences, Vol. 11, No. 16, 2016.

APPENDICES

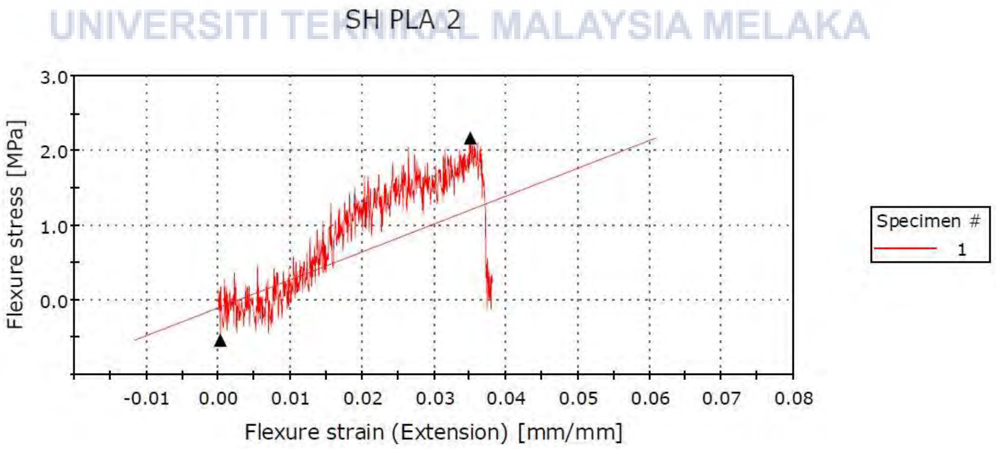
1. Graph Flexural Stress vs Flexural Strain

- **60SH/40PLA**



	Maximum Load [N]	Flexure stress at Maximum Load [MPa]	Modulus (Automatic) [MPa]	Load at Yield (Zero slope) [N]
1	7.013	2.541	310.661	3.706

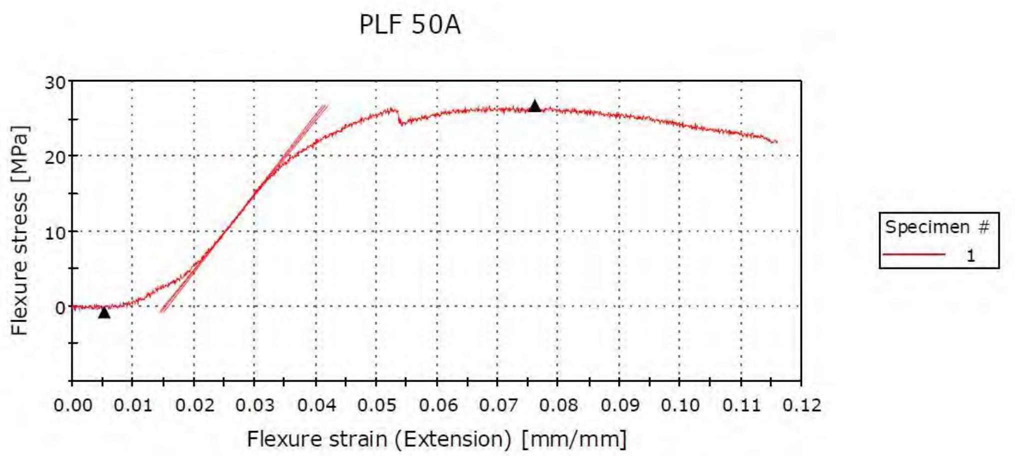
	Flexure stress at Yield (Zero slope) [MPa]
1	1.343



	Maximum Load [N]	Flexure stress at Maximum Load [MPa]	Modulus (Automatic) [MPa]	Load at Yield (Zero slope) [N]
1	5.978	2.166	37.232	1.019

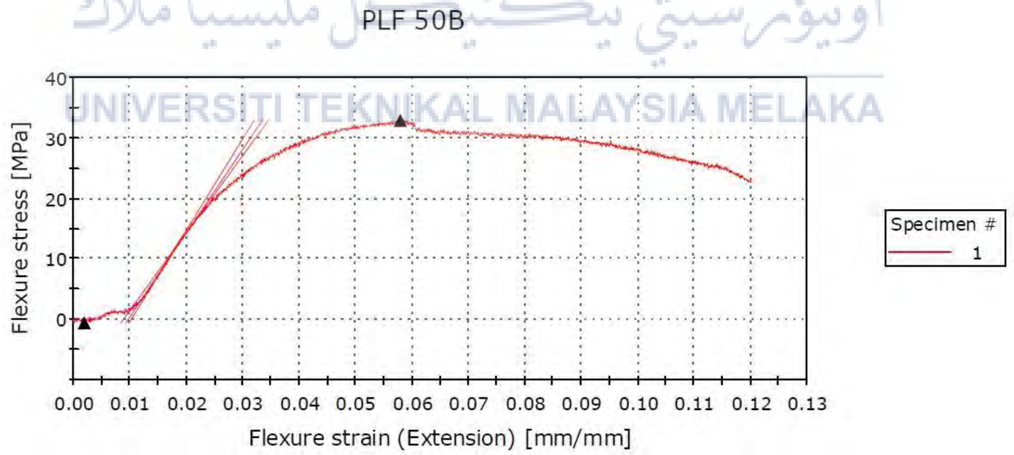
	Flexure stress at Yield (Zero slope) [MPa]
1	0.369

- **50PLF/50SH/PLA**



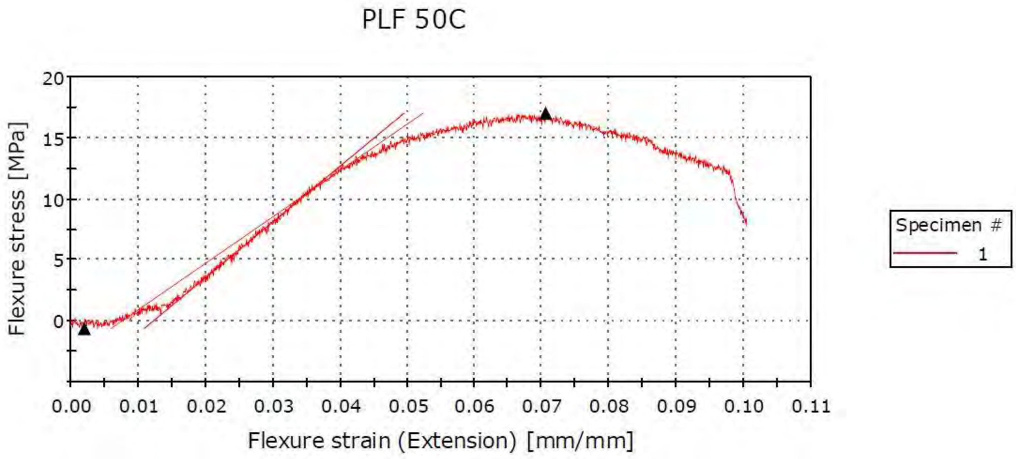
	Maximum Load [N]	Flexure stress at Maximum Load [MPa]	Modulus (Automatic) [MPa]	Load at Yield (Zero slope) [N]
1	73.749	26.721	1014.250	73.705

	Flexure stress at Yield (Zero slope) [MPa]
1	26.705



	Maximum Load [N]	Flexure stress at Maximum Load [MPa]	Modulus (Automatic) [MPa]	Load at Yield (Zero slope) [N]
1	90.773	32.889	1378.778	90.773

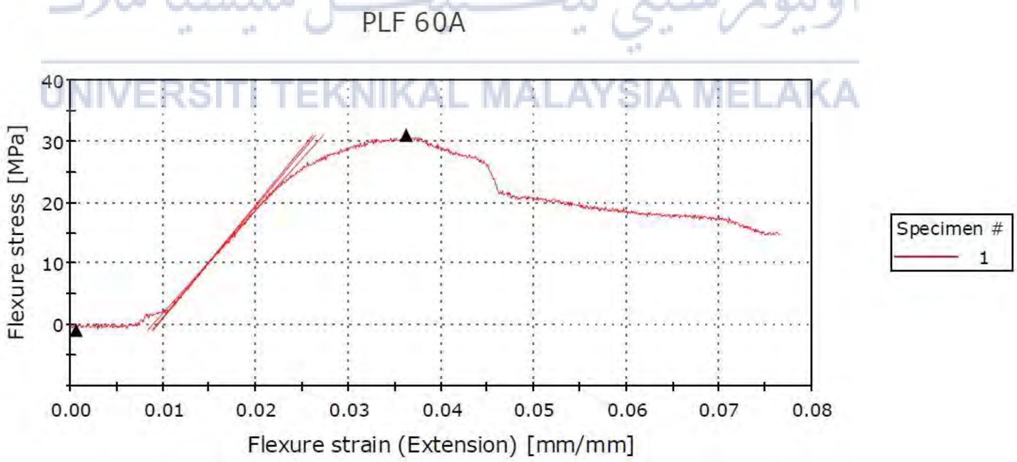
	Flexure stress at Yield (Zero slope) [MPa]
1	32.889



	Maximum Load [N]	Flexure stress at Maximum Load [MPa]	Modulus (Automatic) [MPa]	Load at Yield (Zero slope) [N]
1	46.920	17.000	454.937	46.839

	Flexure stress at Yield (Zero slope) [MPa]
1	16.971

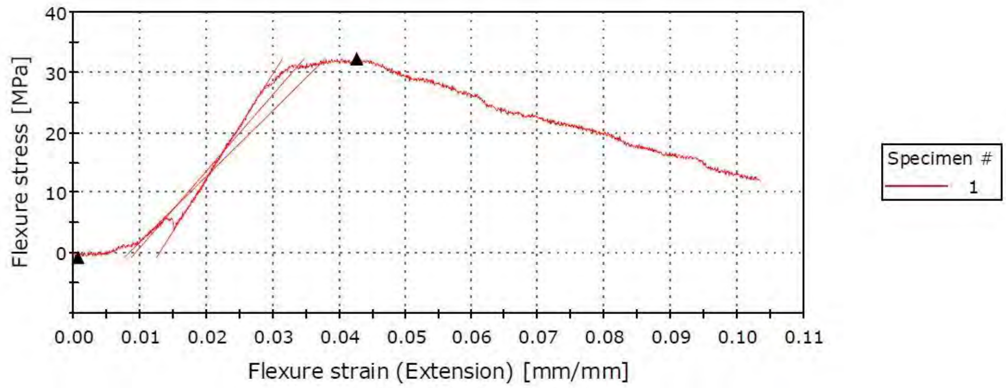
- **60PLF/40SH/PLA**



	Maximum Load [N]	Flexure stress at Maximum Load [MPa]	Modulus (Automatic) [MPa]	Load at Yield (Zero slope) [N]
1	85.508	30.981	1804.710	85.508

	Flexure stress at Yield (Zero slope) [MPa]
1	30.981

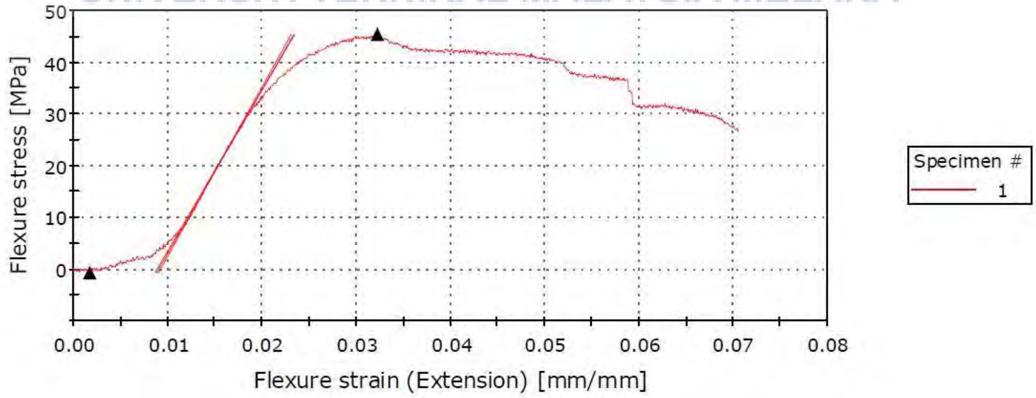
PLF 60B



	Maximum Load [N]	Flexure stress at Maximum Load [MPa]	Modulus (Automatic) [MPa]	Load at Yield (Zero slope) [N]
1	89.040	32.261	1085.763	89.040

	Flexure stress at Yield (Zero slope) [MPa]
1	32.261

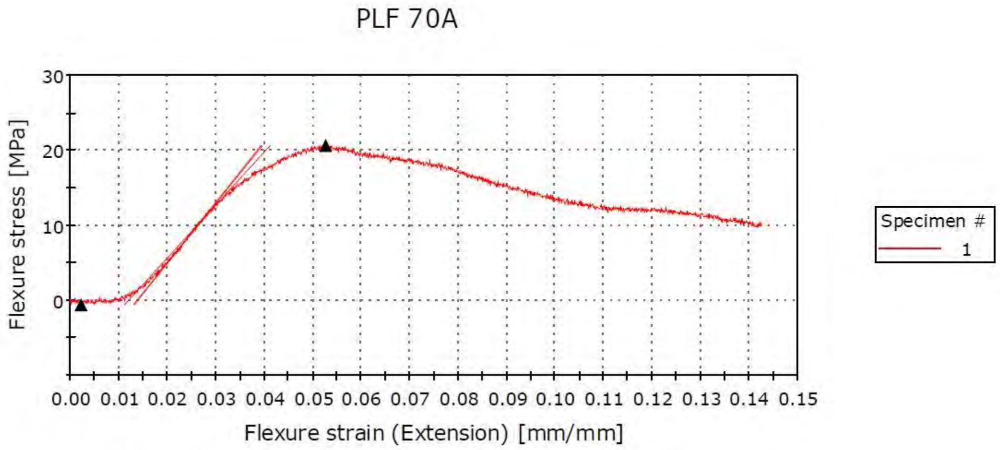
PLF 60C



	Maximum Load [N]	Flexure stress at Maximum Load [MPa]	Modulus (Automatic) [MPa]	Load at Yield (Zero slope) [N]
1	125.098	45.325	3094.234	125.098

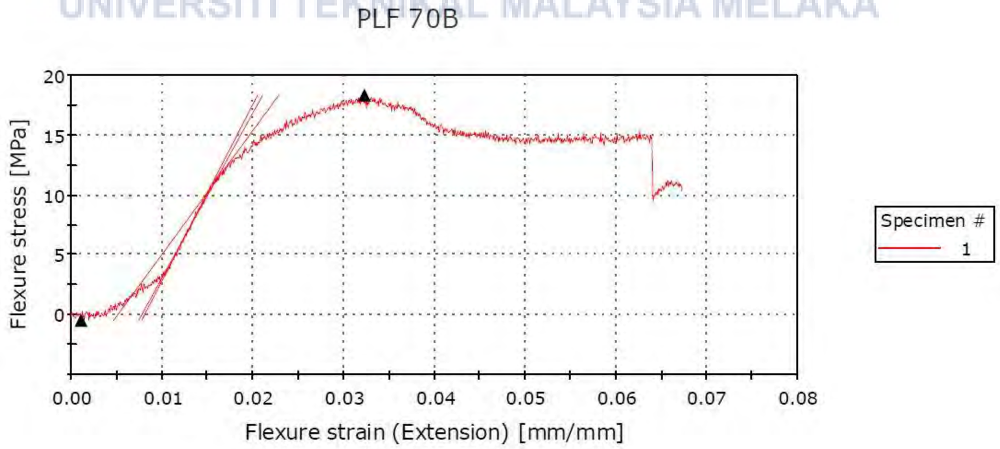
	Flexure stress at Yield (Zero slope) [MPa]
1	45.325

- **70PLF/30SH/PLA**



	Maximum Load [N]	Flexure stress at Maximum Load [MPa]	Modulus (Automatic) [MPa]	Load at Yield (Zero slope) [N]
1	56.942	20.631	793.153	56.942

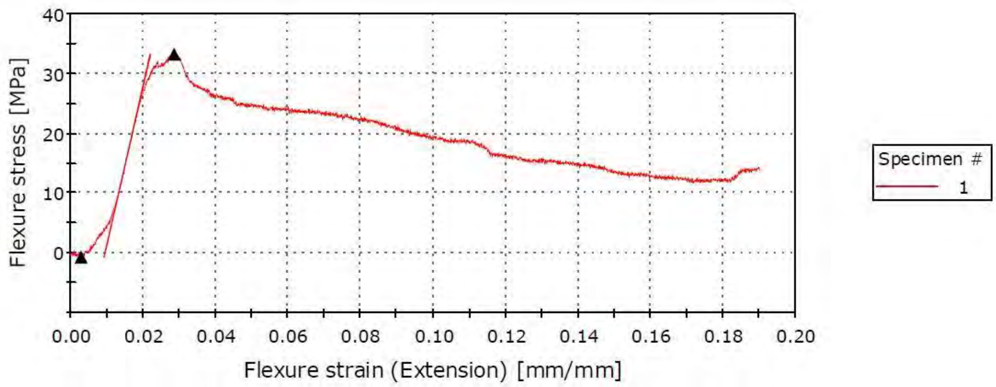
	Flexure stress at Yield (Zero slope) [MPa]
1	20.631



	Maximum Load [N]	Flexure stress at Maximum Load [MPa]	Modulus (Automatic) [MPa]	Load at Yield (Zero slope) [N]
1	50.529	18.308	1370.196	50.529

	Flexure stress at Yield (Zero slope) [MPa]
1	18.308

PLF 70C



	Maximum Load [N]	Flexure stress at Maximum Load [MPa]	Modulus (Automatic) [MPa]	Load at Yield (Zero slope) [N]
1	91.634	33.201	2632.107	91.634

	Flexure stress at Yield (Zero slope) [MPa]
1	33.201

2. PSM 1 Gantt Chart

Task	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Topic Selection														
Literature Review														
Introduction														
PSM 1 Progress Report Submission														
Methodology														
Preliminary Result														
Summary														
PSM 1 Draft Report Submission														

3. **PSM 2 Gantt Chart**

Task	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Briefing for PSM 2														
Material & Sample Preparation														
PSM 2 Progress Report Submission														
Sample Fabrication and Testing														
Result Analysis														
Draft Report PSM 2 Preparation														
PSM 2 Draft Report Submission														