A STUDY ON THE EFFECT OF PHYSICAL, MECHANICAL AND, MORPHOLOGICAL PROPERTIES OF PINEAPPLE LEAF FIBER REINFORCE CORNSTARCH BIODEGRADABLE PLASTIC COMPOSITE

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DECLARATION

I declare that this thesis entitled “The Effect Of Pineapple Leaf Fiber Reinforce Cornstarch Biodegradable Plastic Composite To The Physical, Mechanical, And Morphological Properties” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :.....

Name :.....

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APPROVAL

I hereby declare that I have read this dissertation/report and in my opinion this dissertation/report is sufficient in terms of scope and quality as a partial fulfillment of Bachelor of Mechanical Engineering.

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ABSTRACT

This research is focused on investigating the effect of fibre loading of PALF reinforced cornstarch biodegradable plastic composite to the physical and mechanical properties. Recently, a lot of research are performed related to the development of biodegradable material especially in green technology. Natural fibre has seen to be the most suitable substitute for replacing the synthetic fibre due to many advantages such as low cost, variety and redundant of sources and its bio-degradability properties. By selecting the PALF, it can help in creating a new eco-friendly polymer and reducing the percentage of PALF waste. The objective of this research is to investigate the effect of PALF fibre loading to the cornstarch reinforcement in term of physical, mechanical and morphological properties. During the research, fibre loading of 5 wt%, 10 wt%, 20 wt%, 30 wt%, 40 wt %, 60 wt % and 70 wt % has been used as the sample. The composites is being fabricated using the hot-press machine. Testing of the composite are divided into two phases. First phase consist of physical and mechanical testing while the second phases consists of morphological analysis. The result from the physical testing, the value each physical properties; density, water absorption and moisture content shows that these properties are affected by the percentage, wt%, of PALF fibre loading. The mechanical testing result shows that PALF with 30 wt% has the highest reading for both tensile and flexural strength. For morphological analysis, composite sample of 30 wt% PALF fibre loading did not has gap between matrix and fibre .For this research, it can conclude that, 30 wt% of fibre loading is the most optimum fibre loading for 3cm length PALF compared to other composition ratio. Further study on characteristic of cornstarch as matrix is recommended in order to analyse the reaction of the matrix and fibres.

ABSTRAK

Penyelidikan ini memfokuskan kepada penyiasatan terhadap kesan kandungan serat komposit serat daun nenas yang diperkuatkan dengan tepung jagung dibiodegradasi terhadap sifat fizikal dan mekanikal. Sedekad kebelakangan ini, banyak penyelidikan yang berkaitan dengan perkembangan bahan boleh dibiodegredasi terutamanya dalam bidang teknologi hijau. Serat semula jadi adalah yang paling sesuai untuk mengantikan serat sintetik kerana mempunyai banyak kelebihan seperti pengurangan kos, sumber yang banyak dan pelbagai serta kebolehan biodegredasi. Dengan memilih serat daun nenas, ia dapat membantu untuk menghasilkan polimer mesra alam yang baru dan mengurangkan peratusan pembaziran daun nenas.Objektif untuk penyelidikan ini adalah untukmenyiasat kesan kandungan serat daun nenas terhadap bahan pengukuh dalam terma sifat fizikal dan mekanikal serta analisis morfologi. Semasa penyelidikan, 5 wt%, 10 wt%, 20 wt%, 30 wt%, 40 wt %, 60 wt % dan 70 wt % kandungan serat telah digunakan sebagai sampel. Bahan composite dihasil menggunakan mesin tekanan panas. Pengujian sampel terbahagi kepada dua fasa. Fasa pertama ialah pengujian terhadap sifat fizikal dan mekanikal dan fasa kedua ialah analisis morfologi. Keputusan daripada pengujian sifat fizikal, data menunjukkan bahawa sifat ketumpatan, kandungan kelembapan serata keserapan air terhadap bahan komposit dipengaruhi oleh peratusan, wt%, kandungan serat. Pengujian sifat mekanikal menunjukkan bahawa kandungan serat daun nenas sebanyak 30 wt% memiliki nilai kekuatan tegangan yang paling tinggi begitu juga dengan keputusan untuk ujian kekuatan lenturan. Untuk analisis morfologi, kandungan serats 30 wt% tidak menpunyai kecacatan yang dominan antara serat dan matriks. Dapat disimpulkan bahawa, untuk penyelidikan ini, kandungan serat sebanyak 30 wt% adalah yang paling optimum untuk serat daun nenas sepanjang 3 sentimeter. Penyelidikan mendalam terhadap sifat tepung jagung sebagai matrik direkomendasikan.

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Abbreviations

PALF	Pineapple Leaf Fibre
PFRR	Polymer From Renewable Resources
PLA	Polyactic acid
PHB	Polyhydroxy Butyrate
SEM	Scanning Electron Microscopy
CFRP	Carbon Fibre Reinforced Polymer
NFRP	Natural Fibre Reinforced Polymer
GFRP	Glass Fibre Reinforced Polymer
TPS	Thermoplastic Starch
RH	Relative Humidity
UTS	Ultimate Tensile Strength

LIST OF SYMBOL

Symbol	
NAOH	Sodium Hydroxide
OH	Hydroxyl
NA	Sodium
H_2O	Water
ρ	Density
m	Mass
V	Volume

CHAPTER 1

INTRODUCTION

1.0 Overview

Lately, the world has been facing so many problems regarding to environmental issues. Some of the issues arise are such as the harmful industrial material that can affected people health, the disposal of the unbiodegradable material such as plastic and the global warming cause by the greenhouse effect. In order to overcome these arising problem, researchers from all over the world are considering in producing environment-friendly material or also known as green material. One of the solution that recently highlighted by the researchers is that replacing the synthetic fibre composites with the natural fibre composites. This is due to the reason that natural fibre has many advantages compared to the synthetic fibre. The advantages of the natural fibre are (Pickering, Afendy and Le, 2016) low in density and high specific strength and stiffness, renewable resource, can be produced at lower cost than synthetic fibre, low hazard manufacturing processes, low emission of toxic fumes when dealing with heat and during incineration at end of life, and less abrasive damage to processing equipment compared with that for synthetic fibre composites. There are many bio-composites products that are being commercialized from a fibre based plant such as kenaf, jute, roselle, sugar palm fibre and banana pseudo stems.

The pineapple leaf fibre (PALF) is one of the natural fibre that potentially to be used as the reinforcing materials in green composite product as it is very marketable in Malaysia

due to the facts that it is one of the most important tropical fruits in Malaysia. This is due to the fact that in Malaysia alone, over 130 distinct species of pineapple are cultivated. Currently, the main focus of this country pineapple industry are the fruits and related foodstuffs while the pineapple leaves are treated as agricultural wastes where it either being let composted or burned by farmers. This lead to the wasting of a very potential source of good natural fibres.

Researchers found that the PALF are vary in their properties according to the plant types, geographical regions, plant age, and weather conditions. Non-treated and treated PALF of various lengths and fibre loadings have been used to reinforce matrices such as polypropylene, polyethylene, polycarbonate and polyester (Mohamed *et al.*, 2009).

Polymers from renewable resources have attracted the attentions of researcher because of two major reasons that is firstly environmental concerns, and secondly the realization about the finite of petroleum resources. Polymers from renewable resources (PFRR) can be classified into three groups where the first group is natural polymers, such as starch, protein and cellulose synthetic polymers, while the second group is from the natural monomers, such as polylactic acid (PLA) and lastly the polymers from microbial fermentation, such as polyhydroxy butyrate (PHB). Many properties of PFRR can also be improved through blending and composite formation like numerous other petroleum-based polymers. In order to prevent premature degradation, it is important to control the environment in which the polymers are used. For instance, the water solubility of majority of natural polymers raises their degradability and the speed of degradation, but this moisture sensitivity will limit their application.

A new direction of developing the biodegradable polymers from renewable resources is provided by the development of synthetic polymers using monomers from natural resource.

One of the most promising polymers in this matter is PLA, since it is made from agricultural products and readily biodegradable (Yu, Dean and Li, 2006).

This study discusses the PALF's mechanical, chemical, thermal, and physical characteristic comparing it with the other established bast fibres like kenaf and roselle. In this research, the PALF was treated using alkali treatment in hopeful to produce a PALF composites that have better physical, mechanical, morphological and thermal properties. The mechanical properties and reaction of the PALF and natural polymer or in this content corn-starch will be observed and valued in this study and hopefully to produce a fully functioning composite that are 100% consist of natural material.

1.1 Problem Statement

Natural fibres are being the main focus of research as it is more environmental friendly if compared to the existing glass and carbon fibres. Other than that, natural fibre has a lot of unexplored potential and advantages which attracted researcher all around the world to conduct the studies. Although natural fibre contains many advantages and potentials, it also has its own shortcomings. Results from previous studies show that natural fibre has a lower strength compared to the synthetic fibre like glass and carbon fibre. To overcome this problem, natural fibre need to be re-strengthen before it can be used as a composite.

The pineapple leaf fibre (PALF) can be abundantly found in Malaysia as it is one of the biggest sector in Malaysian agriculture sector. Generally, the leaves of the pineapple plant are let to composed or burnt as that only the fruits are being used. It is a waste as the leaves can be treated as one of the main resources of natural fibres for natural composites.

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1.2 Research Objectives

For this research, there are two objective that are:

1. To investigate the effect of PALF fibre loading to the cornstarch reinforcement in terms of physical and mechanical properties.

2. To evaluate the effect of PALF fibre loading to the cornstarch reinforcement in terms of morphological properties.

1.3 Scope of Study

The aim of this study is to evaluate the effect of fibre loading on the pineapple leaf fibre (PALF) reinforced corn starch polymer in terms of its morphological, mechanical and thermal properties. In this research, the PALF is treated with alkaline treatment and blended with corn starch and glycerol mixture to form the composite sample. The research's methodology is experimental investigation where it is divide into two phases.

The first phase of this research is to investigate the fibre loading of PALF toward physical and mechanical properties of the composites. The composites were prepared into four fibres loading which are, 5%, 10%, 15%, 20%, 25%, 30%, 40%, 50%, 60% and 70%. The composites are being fabricated by laying up the PALF and corn starch with glycerol mixture into the mould and then will be inserted into the hot press machine. The testing involved in the phase are density test, moisture test, water absorption test, tensile testing, and flexural test.

The second phase involve the analysis of the morphological properties of the PALF reinforced corn starch polymer. The testing that being done is Scanning Electron Microscopy (SEM).

All of these testing is being done by following the standards involved according to each method.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

For the last two decade, researchers and scientist have been attracted to the study about polymer from renewable resources (PFRR) due to environmental concern and finite petroleum resources realization. These problems have made bio composite considerable important and becoming a very wide range of properties of engineering materials. The main advantages of natural polymer are that it has a good potential in management of waste, biodegradability and in lower ash production during the incineration.(Yu, Dean and Li, 2006)

These renewable resources of polymer come in three types that are polymers from natural resources, (starch, protein, cellulose), synthetic based polymer that consist of natural monomer (polylactic acid, PLA), and microbial fermentation based polymer such as polyhydroxy butyrate,(PHB).(Avérous, 2004)

2.1 Natural Fibre

Following the major issues that commonly criticized by the public that is serious environmental problems after disposal of advanced composites as it is hardly to be recycled, the structure from advanced composites may be over strength especially when the carbon fibre reinforced polymer composites (CFRP) are used, the relatively high cost of advanced composites for domestic products, and the petroleum crisis that has been arising for this few years has made researchers to focus on substitute material that able to overcome these problem(Lau *et al.*, 2018). Some of the material that is being considered is the bio composite

which are consist fully of natural material. The development in the rising of the bio based composites are impressive is view from a technical point which can be reflected through their rapid growth in the industrial market.(Faruk *et al.*, 2012) These shows that natural composites have a very high potential to be the perfect substitute of advanced composites.

Bio composites compositions majorly consist of natural fibres. Natural fibres can be classified into two types(Lau *et al.*, 2018) . The first type is the animal based**,** that are silk from cocoon, chicken's feather, wool and silk from spider. These types of fibre are commonly apply in biomedical applications such as implants as it is required to be either biodegradable and biocompatible to avoid harm to human body. The second type is the plant based**.** Jute, hemp, sisal, kenaf, coir, flax, bamboo and banana are example of this type. The plant type nature fibre is usually mixed with polymers to form natural fibre reinforced polymer (NFRP) composites. It can be categorized as renewable sources and can be extracted from the nature without damaging the environment. Can be the substitute of glass fibre as the composites NFRP's mechanical properties are equivalent to glass fibre reinforced polymer (GFRP)

For the plant based natural fibres sources, depending on the utilization, the fibres are divided into primary and secondary where the primary class are those plant which grown for their fibre. Example of primary plant are sisal, jute, kenaf and hemp. While the secondary type of plant is where the fibre is produce as a by-product. Example of secondary plant are pineapple, oil palm and coir.

To exhibit a hierarchical structure, the structure of plant fibres can be further explained through three main components shown in Figure 2.1 below: (Fadzullah and Mustafa, 2017)

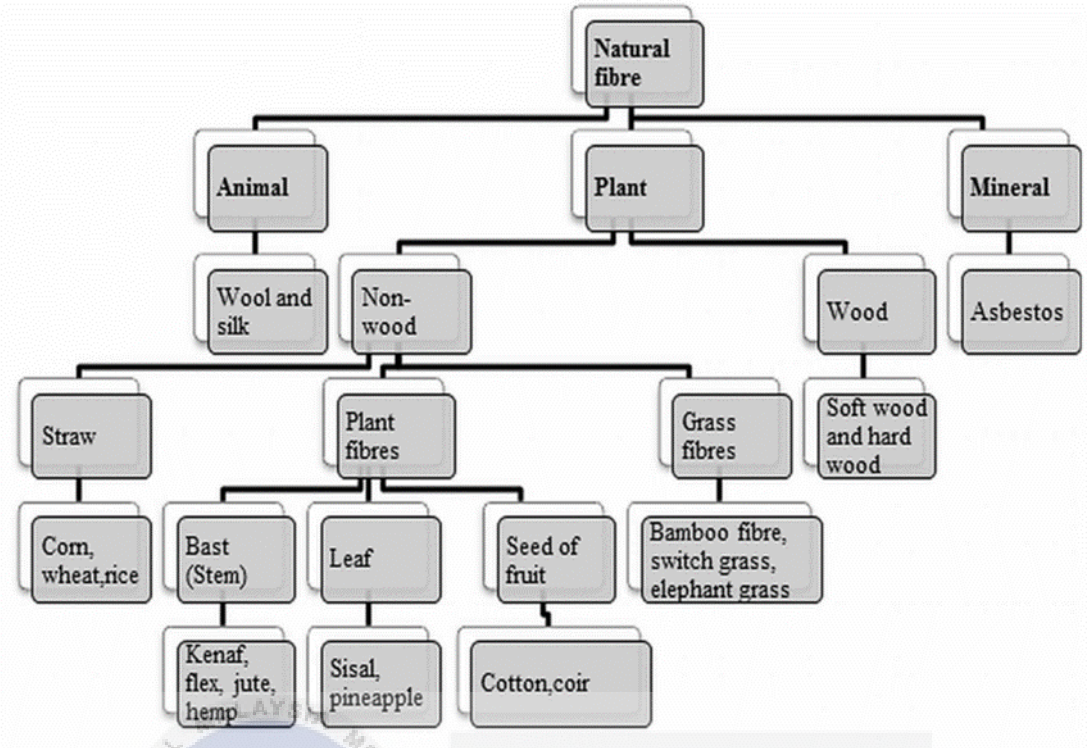

Figure 2.1: Natural Fibre Main Classes (Lau et al., 2018)

Natural fibre properties are varied. This is because the moisture conditions and testing method being used are depending on which type of fibre that are being used. Therefore, different fibre will give different moisture condition and different testing method will be employed. According to study done by researcher(Faruk *et al.*, 2012) the performance of natural fibre is depending on few factors which included the chemical composition of the fibre, dimensions of the cell , angle of microfibrillar, defects, structure, properties of physical, properties of mechanical and the interaction between fibre and polymer. Therefore, it is required to know the behaviour of natural fibre. The same characteristic of natural fibre reinforced polymer are also being listed out in other researcher study (Mohammed *et al.*, 2015). The range values of characteristic are remarkably higher than glass fibre, which is explained through the different of internal fibre structure due to the overall environment situation during the natural fibre growth. Natural fibre structure includes a functional group

known as hydroxyl group which contribute to the hydrophilic characteristic in natural fibre. Due to the present hydroxyl group, a weak interfacial bonding appeared between hydrophilic natural fibre and hydrophobic polymer matrices during the manufacturing process of NFRP. Not only that, the hydrophilic properties in natural fibre influences the natural fibre's mechanical properties especially for all the cellulose-fibre as the moisture content of fibres is dependent on the non-crystalline content and the fibre void content. Table 2.1 shows the equilibrium moisture content of some natural fibres:

Table 2.1:The Equilibrium Moisture Content Of Natural Fibres

Fiber	Equilibrium moisture content (%)
Sisal	11
Hemp	9.0
Jute	12
Flax	7
Abaca	15
Ramie	9
Pineapple	13
Coir	10
Bagasse	8.8
Bamboo	8.9

The internal structure of natural fibre is reliant on age and origin of the plants and climate conditions.(Lau *et al.*, 2018)

Natural fibre attracts the attention in many applications due to its satisfactory properties and greater benefit of nature fibre compared to synthetic fibre in terms of its low

weight, require less cost, decrease damages to the equipment, good mechanical properties such as tensile strength and flexural strength, surface finish improvement of moulded parts composites, renewables sources, being abundant, flexibility processing, biodegradable and minimum health hazard.

However, like every other material, natural fibre also has its own downcast. Natural fibre structure comprises of cellulose, hemicellulose, lignin, pectin and waxy substance, allowing the absorption of moisture from the surrounding that has resulted to weak bindings between fibres and polymer.

To overcome the problems, modification using special treatment can be made towards the natural fibres. The special treatment generally focused on the utilisation of reagent functional groups that can respond to the fibre structure and changing their composition that will resulted to reduction of moisture absorption by leading to an excellent enhancement of the incapability between the fibres and matrices. The surface treatment main objective is to enhance the interfacial of fibre and matrix bonding and the transferability of the composites. The improvement in mechanical strength as well as the dimensional stability of NFRP can be achieved when the hydrophilic behaviour of the fibres is reduced when going through chemical treatment such as alkali treatment.(Mohammed *et al.*, 2015)

2.2 Pineapple Leaf Fibre (PALF)

Pineapple Leaf Fibre (PALF) origins from the Ananas comusus leaves or generally known as the pineapple plant. In Malaysia, it is known that pineapple is one of the significant tropical fruits. However, the main centre of the plantation of pineapple industry in our country is just on the fruits and other corresponding foodstuff. The leaf is regarded as an waste where it is either being composted or burned away. This matter has not only lead to the waste of such a very potential source of a good fibre, but the burning of the leaves also causes some pollution towards the environment. To overcome such problems, multiple researches and studies has been conducted related to the possibility of finding other applications to these pineapple leaf(Mohamed *et al.*, 2009). As one of the world's major producers of pineapple, the PALF from Malaysian pineapple cultivars has a very large potential to be utilised as one of the reinforced in NFRP composite.

PALF contain high cellulose, inexpensive and have large resources as it is a waste cultivation product and therefore these inexpensive PALF can be obtained to be used in industries(Faruk *et al.*, 2012).

Pineapple leaves comes in sword-shaped which arise from a stem with an overall dimension ranging from between 0.9 m to 1.5 m in length, while the width between 2.54 m and 5.1 m respectively. The colours of the leaves could come in purely green or with spots of red, yellow or even ivory(Fadzullah and Mustafa, 2017).

According to a research(Mohamed *et al.*, 2009) the comparison of tensile properties between the fibre extracted from pineapple leave, betel nut fruits and barks from the lady finger plant, PALF shown to have the highest tensile strength and intermediate elongation at breaking point. The slight increase of the strength and the high increase of elongation at breaking point is due to the degumming process that has been underwent by the PALF. Degumming process is a process of getting rid of the gummy matters in pineapple leaves

including pectin's, pentosan, and lignin. It can be done using silane, alkaline, or acids(Pardeshi, Jafer Mirji and Goud, no date). Three factors that are crucial for fibres to be suitable as an effective reinfoce stage in composites are the strength of the fibre, the fibre stiffness and the interfacial strength of fibre with matrix.

Like any other natural fibre, PALF is vary in their properties depending on the types of plants, geographical regions, location of the plant, and weather conditions. In Malaysia along, there are more than 130 different types of species of pineapple plant that are cultivated every single years for its fruits and other related stuff(Mohamed *et al.*, 2009).

2.2.1 Extraction Method of PALF

The PALF is extracted by using a novel technology. The extraction of fibre is done using a Pineapple Leaf Fibre Machine (PALFM) as shown in Figure 2.2.

Figure 2.2: PALF Machine (Yusof, Yahya and Adam, 2015)

Instead of crushing the pineapple leaf in order to force out the waxy layer on the leaf, this machine used blades to remove it where the blades are design to be unprecedented. This means that the number of blades that are being used, sizes and the certain angles of the blades

are needed to be considered(Yusof, Yahya and Adam, 2015). This is important as this will ensure so that the leaf will not snap in the middle of the process(Kasim *et al.*, 2016). To understand better the extraction of the PALF, referred to the figure below:

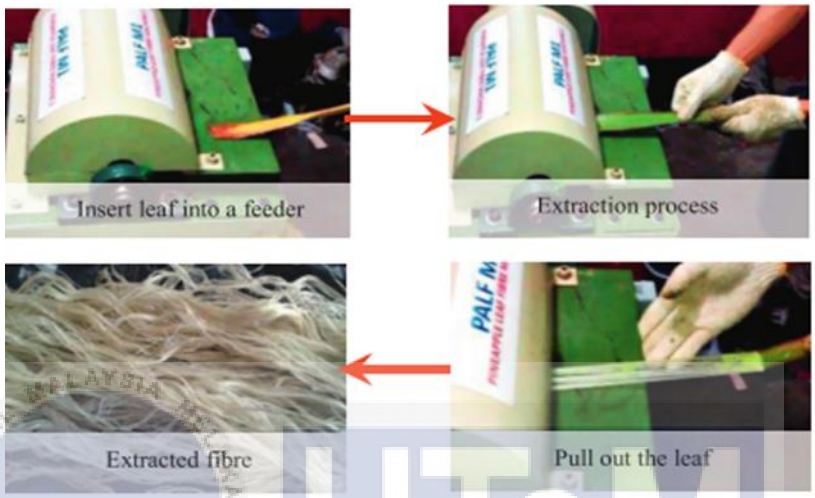

Figure 2.3: Extraction Process of PALF (Yusof, Yahya and Adam, 2015)

Pineapple leaf is inserted between the two blades. After entering the blades, the outer waxy layer of the leaf will be removed. When the leaf is being pulled out, the left over waxy layer will be completely removed from the leaf, resulting the white coloured fibre shown in Figure 2.3.

2.2.2 Pineapple Leaf Fibre Composite

The main features of PALF as reinforcement materials in composite systems are low density, low in cost, nonabrasive, less consumption of energy, high specific properties, biodegradability, and generating rural or agricultural economy(Mishra *et al.*, 2004)(Fadzullah and Mustafa, 2017). There are various approaches in which fabrication process of the PALF composites which include processing method based on matrix materials

such as thermoplastic, thermoset, rubber as well as based on techniques such as melt-mixing, compression moulding or solution mixing.

2.2.2.1 Thermoset and Thermoplastic Properties

Thermoset material is interpreted as a highly cross-linked polymer treated using heat or using heat and pressure with or without irradiation of light. Thermoset material has properties such as high flexibility, great strength, and modulus. While thermoplastic properties are material is defined a material that consist of matrix of two dimensional molecular. This characteristic make those polymers to have the inclination to make the material tender at a high range of heat and rolled back their properties (Mohammed *et al.*, 2015). Table 2.2 shows the comparison of thermoplastic and thermoset matrix.

Table 2.2: Comparison Of Thermoplastic And Thermoset Matrix (Kabir *et al.*, 2012)

Advantages	Disadvantages
Thermoset - Low resin viscosity - Good fibre wetting - Once polymerised, excellent thermal stability - Chemically resistant	**Brittle** - Non-recyclable via standard techniques - Not post-formable
Thermoplastic - Recyclable - Easy to repair by welding and solvent bonding - Post formable - Tough	**Poor melt flow** - For processing purpose, need to be heated above the melting point

Both thermoset and thermoplastic like the unsaturated polyesters, epoxies and phenolics, and polypropylenes, polyethylene and elastomers are commonly used for application of composites where these matrices have distinct structures chemically and went through different reaction with the surface molecules of fibres(Kabir *et al.*, 2012).

Lately, there is an increasing curiosity for the utilization of regular strands to act as strengthening parts for thermoplastic and thermoset. Generally, polymer can be divided into classes of two that is thermoplastic and thermoset. Currently dominating as matrices for bio fibres, thermoplastic materials that is the most frequently used for this purpose are polypropylene (PP), polyethylene, and poly vinyl chloride (PVC) while phenolic, epoxy and polyester resins for thermosetting matrices('Studies on Natural/Glass Fiber Reinforced Polymer Hybrid Composites: An Evolution', 2017). Figure 2.4 and Figure 2.5 shows the mechanical characteristics of thermoset hybrid and thermoplastic hybrid composites respectively.('Studies on Natural/Glass Fiber Reinforced Polymer Hybrid Composites: An Evolution', 2017)

Natural/glass hybrid fiber	Matrix Polymer	Fabrication Technique
Coir/glass fiber	Polyester	Close mold
Oil palm empty fruit bunch/ glass fiber	Phenol-formaldehyde (PF)	Hand lay-up
Banana/glass fiber	Phenol-formaldehyde (PF)	Hand lay-up, Compression molding
Biofiber (pineapple leaf fiber/ sisal fiber)/ glass fiber	Unsaturated polyester	Hand lay-up
Palmyra/glass fiber	Rooflite	Mixing and Sandwiching
Jute/glass fabric	Isothalic polyester	Hand lay-up
Glass/natural fiber	Epoxy vinyl ester	Hand lay-up
Kenaf/glass fiber	Epoxy	Modified sheet molding compound (SMC)
Sisal/jute/GFRP	Epoxy	Hand lay-up
Curaua/glass fiber	Orthophthalic polyester	Compression molding
Sisal/jute/GFRP	Isothalic polyester	Hand lay-up
Sugar palm/ glass fiber	Unsaturated polyester	Hand lay-up
Flax/glass fiber	Phenolic resin	Compression molding
Banana/Hemp/glass fibers	Epoxy	Mold lay-up

Figure 2.4: Work Reported On Mechanical Characteristics Of Thermoset Hybrid Composites ('Studies on Natural/Glass Fiber Reinforced Polymer Hybrid Composites: An Evolution', 2017)

Natural/glass hybrid fiber	Matrix Polymer	Fabrication Technique	References
Bamboo/glass fiber	Polypropylene (PP)	Compression molding	*M.M. Thwe, K.Liao (2002)*
Flax fiber/glass fiber	Polypropylene (PP)	Injection molding	*A. Arbelaiz et al. (2005)*
Empty Fruit Bunch/short glass fiber	Thermoplastic natural Rubbers (TPNR)	Compression molding	*H. Anuar et al.(2006)*
Sisal/glass fiber	Polypropylene(PP)	Injection molding	*K. Jarukumjorn et al. (2009)*
Kenaf/glass Fiber	Thermoplastic natural Rubbers (TPNR)	Melt blending	*W. N. Wan busu et al.(2010)*

Figure 2.5: Work Reported On Mechanical Characteristics Of Thermoplastics Hybrid Composites('Studies on Natural/Glass Fiber Reinforced Polymer Hybrid Composites: An Evolution', 2017)

2.3 Alkaline Treatment

Alkali treatment of fibres with cellulosic properties or also known as mercerization, is the most common technique that is frequently being used by some researcher to create a high-quality fibre reinforce polymer matrix.

The propose of alkali treatment is to erased components of chemical on the structure of PALF, compromising uranic acid. Alkali treatment can lead to extraordinary modifications in the specific interaction of the fibres and at the same time improving the wettability of the fibre. Despite that, the concentration of alkali used (NaOH) are depending to the type of natural fibre used. If the concentration of alkali used is high, it will increase the possibilities of the fibre surface to be damage which can lead up to the decreasing of the fibre's properties of mechanical. The adhesion of hydrophilic natural fibres and the hydrophobic epoxy matrix can be improved by going through alkali treatment. Table 2.3 shows, all types of natural fibre have been treated with the sodium hydroxide (NaOH) before mixed together with the polymer to produce composites(Pickering *et al.*, 2007)(Mwaikambo and Ansell, 2003)

Table 2.3: The Alkali (Naoh) Treatment Natural Fibres.(Kabir *et al.*, 2012)

Fibre	NaOH (%)	Soaking Time	Soaking temperature (°C)	Drying
Hemp	10 or 15	15 or 45 min 30 min	160 or 180 20	80°C for 48 h –
Jute	Up to 28	2 h	-	-
Ramie	15	1 h	25	60°C for 24 h -
Henequen	2	-	-	80°C for 48 h
Curaua	10	20 min	Room temperature Room temperature 60	Room temperature for 48h
Flax	1, 2, 3	3 h	-	80°C 24 h 60°C for 24 h 70°C for 72 h -
Kenaf	3, 6, 9	4 h	25	70°C, until constant weight
Sisal	2	30 min	Room temperature	-
PALF	5	2 h	-	80°C for 48 h –
Bagasse	1, 3, 5	-	-	-
Piassave	10	-	19±2	60°C for 24 h -
Oil Palm	0.5, 1, 2, 4	48 h	160 or 180 20	80°C for 48 h
Coir	5	48 h	-	Room temperature for 48h

The most general method for the treatment of natural fibre is the alkali (NaOH) because this method is inexpensive(Aziz and Ansell, 2004). Apart from that, it changes the orientation of highly packed crystalline cellulose order, forming an amorphous region. This

will provide more access to penetrate chemical. Alkali sensitive hydroxyl (OH) groups present are broken down, and then react with water molecules and exited the fibre structure. The reactive molecules left form fibre cell O–Na groups in between the cellulose molecular chains causing hydrophilic hydroxyl groups to reduce and increase the fibres moisture resistance property. It also takes out hemicelluloses, lignin, pectin, wax and oil materials(Kabir *et al.*, 2012). The fibre surface becomes more uniform due to the elimination of void of micro and then improving stress transfer capacity of the ultimate cells. It also reduces the diameter of the fibre and by that increases aspect ratio (length or diameter) of the fibre and increases the efficient fibre surface area for better adhesion with matrices(Joseph *et al.*, 2003). Mechanical and thermal behaviours of the composite are improved by this treatment. If the alkali concentration exceeded the optimum condition, the excess delignification of the fibre will take place, resulting in weakening or damaging the fibres. Equation 2-1 and equation 2-2 illustrated the common alkali treatment of natural fibre and PALF while Figure 2-6 presents the view of the cellulose fibre structure with and without alkali treatment. Table 2-4 summarizes the results on the effect of alkali treatments of composites(Kabir *et al.*, 2012).

$$Fibre - OH + NaOH \rightarrow Fibre - O^{-}Na^{+} + H_2O$$

Scheme 2-1: Alkali Treatment Of Natural Fibre

$$PALF - OH + NaOH \rightarrow PALF - O^{-}Na^{+} + H_2O$$

Scheme 2-2: Alkali Treatment of PALF

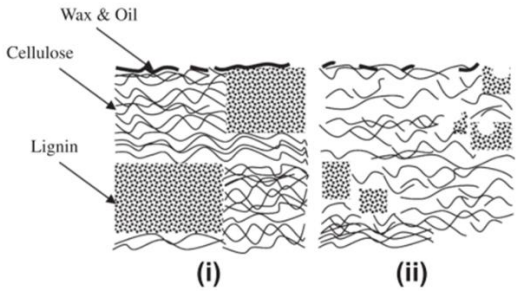

Figure 2.6: Structure Of (I) Untreated And (Ii) Alkalized Fibre(Kabir et al., 2012)

Table 2.4: Alkali Treated Fibre Reinforced Polymer Composites(Kabir *et al.*, 2012)

Composites	Applied treatment	Results
Flax-epoxy	Alkali treatment	30% increase in tensile strength and modulus with the removal of pectin
Sisal-polyester	0.5%, 1%, 2%, 4%, 10% NaOH treatment at room temperature	4% alkali treatment reported maximum tensile strength properties Tensile
Hemp non-woven mat with euphorbia resin	0.16% NaOH for 48 hours	Tensile strength was increased by 30% and doubled the shear strength properties was found compared to the untreated fibre composites
Jute–vinyl ester	5% NaOH for 4, 6 and 8 hours	4 h alkali treated composite accounted 20% and 19% increase in flexural strength and interlaminar shear strength properties
Sisal–polycaprolactone composite	10% NaOH for 1, 3, 24 and 48 h	Increased in elastic modulus with the increased with reaction time
Hemp fibre	8% NaOH treatment 5%	Thermal stability was increased by 4%
Coir–polyester	5% NaOH treatment for 72 hours	Flexural and impact strength was increased by 40% with respect to the untreated fibre composites

2.3 Corn Starch

For the past few years, application of starch resources in non-food applications has experienced a significant advancement. Starch has many benefit such as low in cost, wide resources, and total compost ability. Starch, like many other polymers, uses conventional polymer processing techniques that produced into different end-use forms. For example, extruded, moulded, thermoformed or blown articles. However, starch-based materials are known of having limitations such as poor process ability and properties such as weak mechanical properties, poor long-term stability, and high-water sensitivity.

When plasticizers, elevated temperatures, and shear are present, starch will exhibit thermoplastic properties. The starch's thermoplastic properties are close to synthetic polymers. Therefore, for starch processing it is likely to use the procedure that are developed for synthetic polymer. Granular starch is thermomechanical processed by kneading, extrusion, injection moulding, compression moulding, blow moulding, or heating and casting in an excess water solution with the help of plasticizers such as water, glycerol, or urea and additives such as lecithin or monoglycerides in order to obtain a thermoplastic starch (TPS) material, (van Soest, Benes and De Wit, 1995).

Green plants, such as barley, oats, wheat, rice corn, potato, tapioca, and pea, produced starch as an energy storage appearing in highly organized structures known as starch granules, which different in shape such as round, lenticular and polygonal, the range of the granule diameter size is between 1 to 100μmin, distribution of size either uni or bimodal, association either individual or granule cluster, and chemical composition such as α-glucan, lipid, moisture, protein, and mineral content.

Starch is one of the hydrophilic material. The moisture content of the starch depends to the variation in the relative humidity (RH) of the atmosphere in which it is stored. In cold water granules of starch are insoluble. However, starch granules will swell when put into hot

water. The granules are then undergoing a transformation process, where amylose and amylopectin leach out until the granules break down into a mixture of polymers-in-solution or also known as gelatinization process. Gelatinization temperature is the temperature at which the starch started to gelatinize.(Zhang, Rempel and Liu, 2014)

Based on the research(Romhány, Karger-Kocsis and Czigány, 2003), thermoplastic starch-based composites contain flax fibres arrange in unidirectional and crossed-ply is produced by hot pressing using the film stacking method. The mechanical response and failure of the composites highly relied on the flax content and the flax fibre lay-up. Research(Romhány, Karger-Kocsis and Czigány, 2003) characterized the compounds of corn-starch and glycerol reinforced with cellulose fibres by high performance size exclusion chromatography. Both compounds and composites were prepared in a batch mixer between 150℃ until 160 ℃, with glycerol and fibre contents within the range of 30 until 50 wt% and 1 to 15wt%, respectively. According to the result, the more increase of glycerol content, the less starch degradation, whereas by adding more fibre will led higher degradation. (Romhány, Karger-Kocsis and Czigány, 2003).

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CHAPTER 3

3.0 METHODOLOGY

3.1 Overview of Methodology

The general methodology of this research can be divided in two parts hich are sample preparation and testing method.

PALF was received from Mersing, Johor. The PALF were then being treated with alkaline solution in order to remove impurities on the fibre surface. The treated fibre were then being cut into 3 cm length.

For composites sample, cornstarch powder will be add with a certain ratio of glycerol as a hardener. Then, the cornstarch powder with the glycerol and the PALF were placed together in the mold. The prepare samples were fabricated by using hot presss machine.

Figure 3.1 shows the methodology of this research.

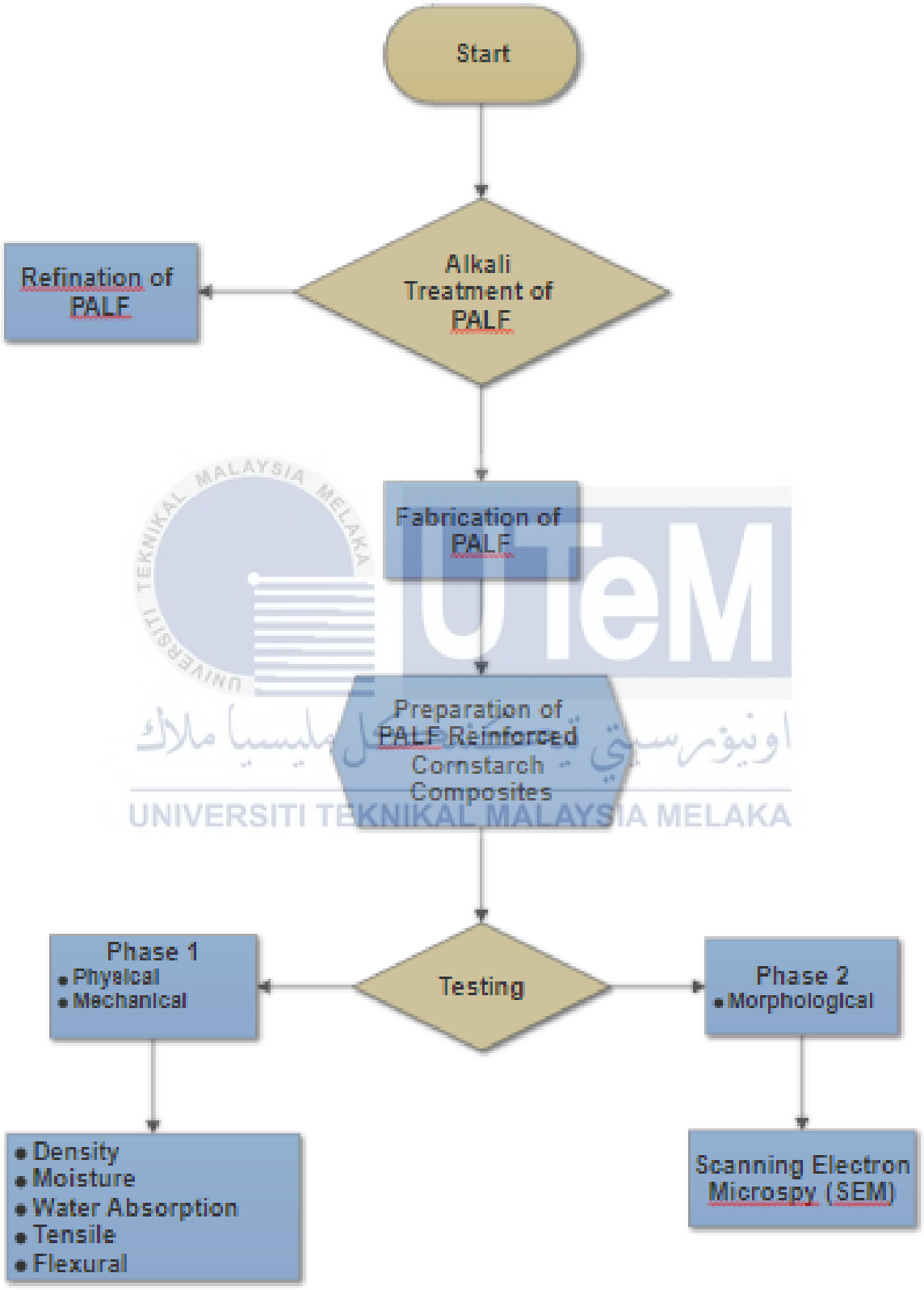

Figure 3.1: Methodology Process

Based on the flow chart of the research, all the job scopes are being list out in Gantt chart to make it easier to evaluate what is the duration of a project should take, help in determining the resources, and plan the flow of the task. It is also helpful for managing the reliance between tasks.

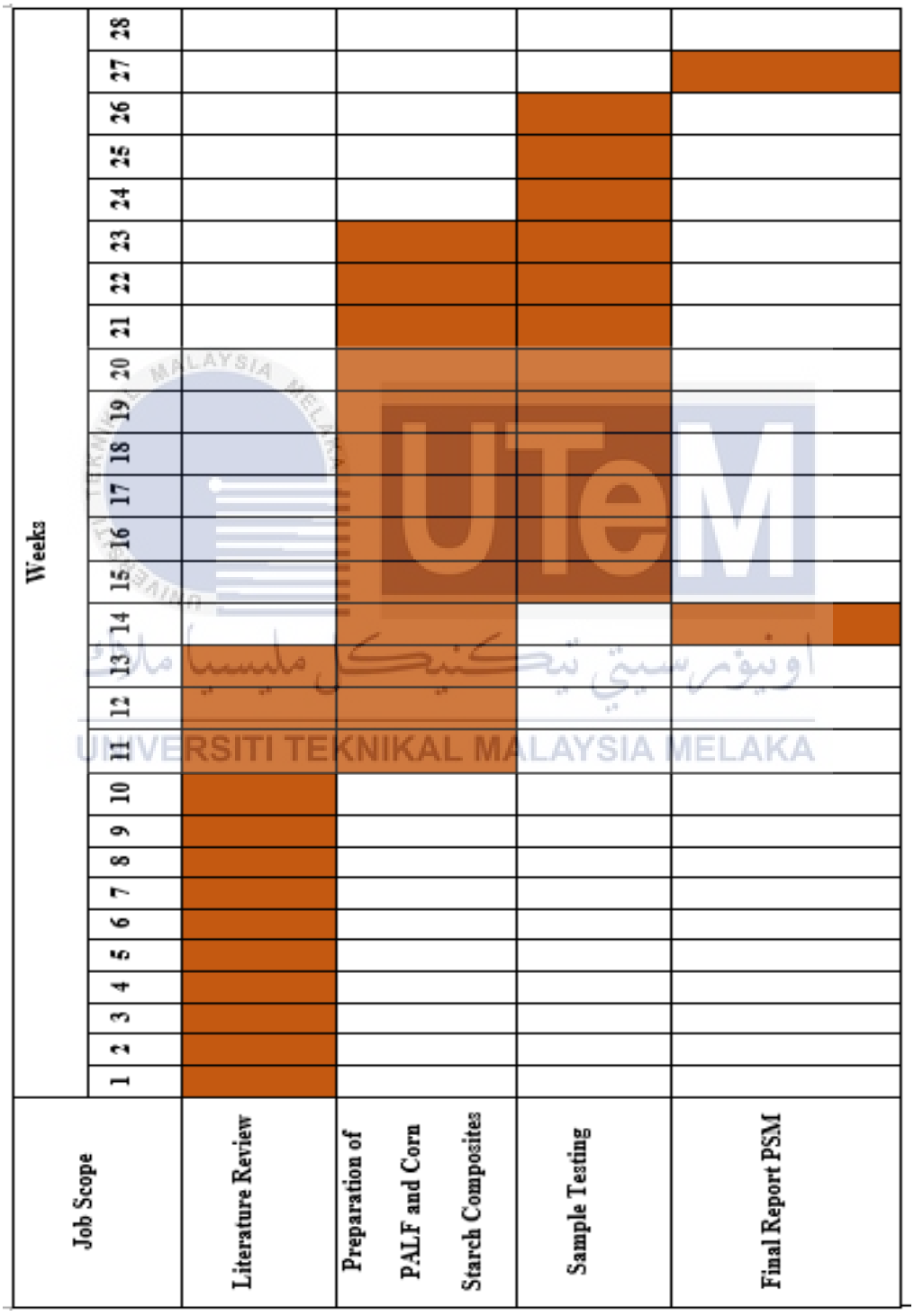

Figure 3.2: Gantt Chart

3.2 Composite Preparation

3.2.1 PALF Preparation

3.2.1.1 Alkali Treatment

The raw PALF was treated using alkali solution in order to remove impurities on the surface of PALF. This is to improve the fibre surface properties of the fibre. The PALF is firstly soaked into the 5% of NAOH solution for 4 hours. After 4 hours, the PALF was clean using distilled water. Then, the fibres are let to dry at room temperature for about 24 hours.

Figure 3.3: PALF soaked in NAOH solution

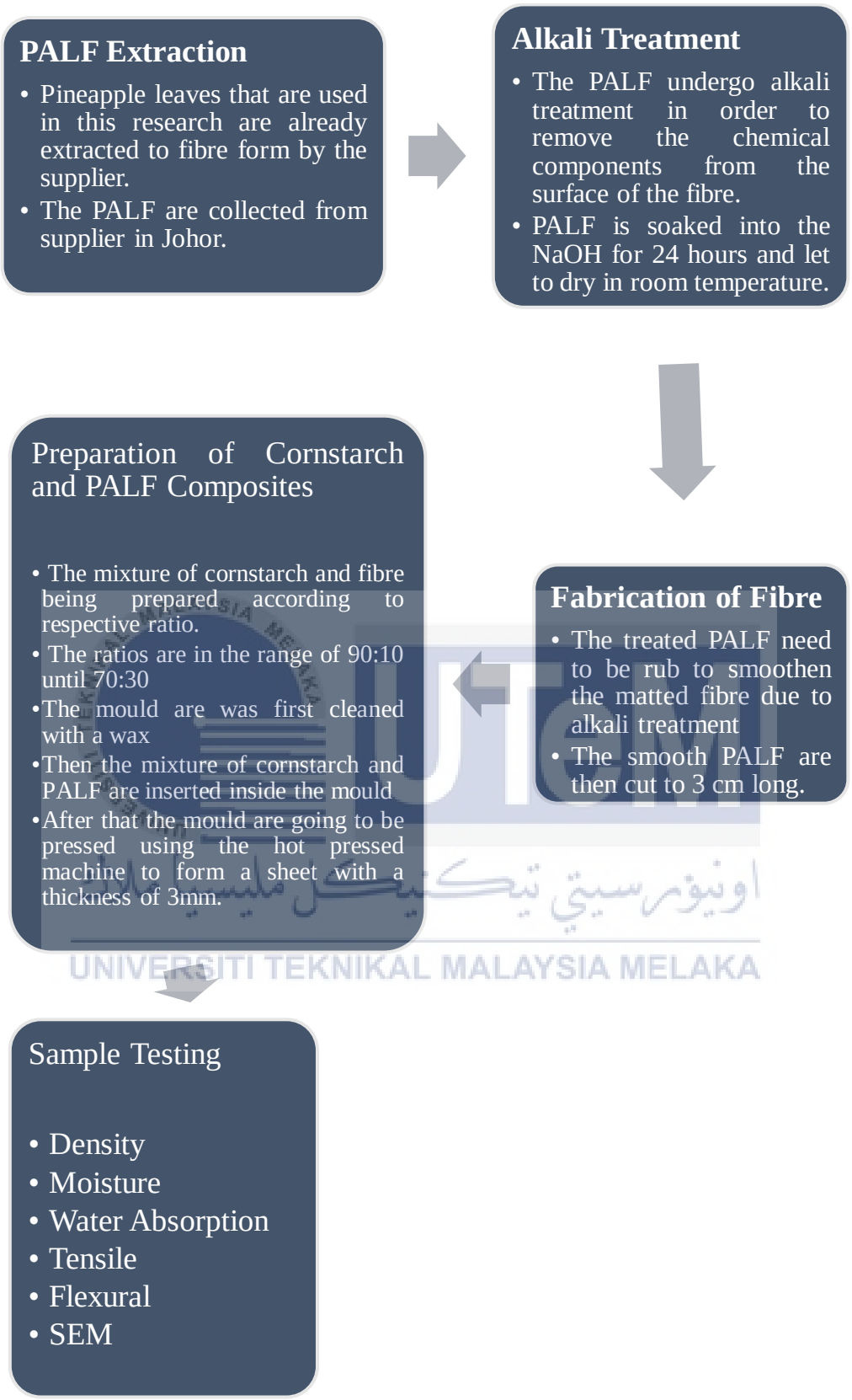

Figure 3.4: Composite Preparation Flowchart

3.2.1.2 PALF Fabrication

The treated PALF is firstly need to smoothen up before it can be used. This is because the fibres are tangle up together during the drying process after the alkali treatment. In order to untangle the PALF, the fibres are being rubbed using brush repeatedly until they are smooth. Figure 3.5 shows the PALF that has been smoothen.

Figure 3.5: Smoothen PALF

The smoothen PALF are then being cut into 3cm long using scissor and cutting guidline tools. Figure 3.6 shows how the PALF being cut.

Figure 3.6: Cutting Process Of Treated PALF

3.2.2 Matrix Preparation

The matrix that used in this research is the mixture of corn starch with glycerol. Glycerol act as hardener which help to reduce the wetting ability of the corn starch, in order to ensure that the composites sample does not effected by the moisture.

The corn starch is firstly being weight into 210 gram while the glycerol is 90 gram. The mixtures are then mix using a mixer, to ensure that the corn starch and the glycerol is uniformly mixed.

Figure 3.7 (a): Corn Starch And Glycerol Mixture, (b) Mixture Being Blend

3.2.3 Composites Preparation

The sample composition that has been decided for this research is shown in the Table 3.1.

Table 3.1: Sample Total Weight Ratio

	CORN STARCH	FIBRE
Fibre Loading (wt %)	**Weight (g)**	**Weight (g)**
5	36.1	1.9
10	34.2	3.8
20	30.4	7.6
30	26.6	11.4
40	22.8	15.2
50	19.0	19.0
60	15.2	22.8
70	11.4	26.6

The sample was fabricated by using hand lay-up method. A metal rectangular mould was used for the process. Figure 3.8 shows the preparation of composites.

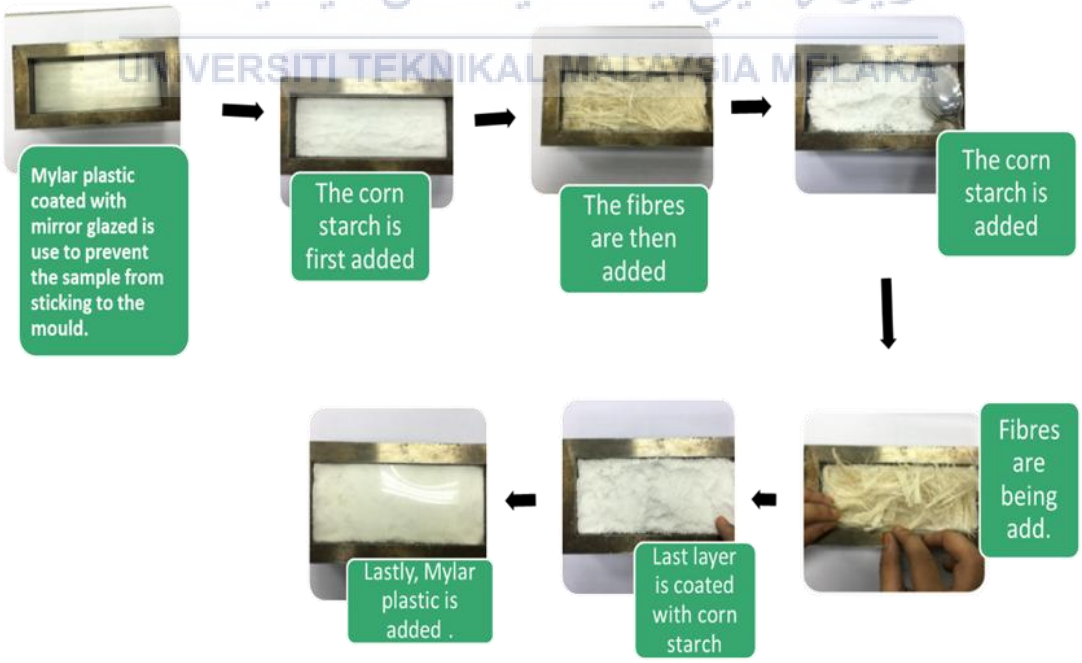

Figure 3.8: Sample Preparation into Mould

Figure 3.8 shows the fabrication process of composites sample.First, PALF and corn starch are lay up into 3 layer; the first layer is the corn starch and glycerol mixture. Then followed by PALF on the second layer. Finally is the mixture and glycerol again. Mylar sheet was being used at the top and bottom of the mould in order to obtain a smooth surface finish.The mixture is divided into three layer because after doing multiple sample, the final product after being pressed show better appearance.

After the sample preparation is completed, the mould sample were then being put under the hot press machine. This process required careful handling as it involved with high temperature and pressure.

The sample is firstly being preheated under the hot press machine about 15 minutes. The temperature and pressure set for the pressing process are 165°C and 350 kPa res. After the pre heated has finished, the mould is then being pressed for another 15 minutes and cooled for about 15 minutes before the sample can be taken out from the mould.

Figure 3.9: Sample Being Pressed By Hot Press Machine

3.3 Testing Method

3.3.1 Characteristic of Physical Properties

3.3.1.1 Density

The density of the PALF reinforced cornstarch biodegradable plastic composites is determined by using the electronic densimeter.

Figure 3.10: Electronic Densimeter

6 sample for each fibre loading for PALF reinforced conrnstarch composites were prepared for density measurement. Firstly, before immersed into water, the weight of all the samples were being weighed (m). The volume (V) of the samples was recorded by looking at the amount of water before and after the sample immersion. This value is used to determine the density of PALF reinforced cornstarch composites.

$$\rho = \frac{m}{V} \tag{3-1}$$

Where

$\rho\ is\ density\ of\ composites$

$m\ is\ mass\ of\ composites$

$V\ is\ volume\ of\ water$

3.3.1.2 Moisture Content

Six samples (10 x 10 x 3mm) were prepared for the moisture evaluation. All six sample were heated in an oven at 105℃.

Figure 3.11: Oven Used In Moisture Testing

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The weight of the sample before being put into the oven, M_i, and the weight of the sample after being heated, M_f, were measured as these two value will be used to calculate the moisture content. Moisture content of the sample is determined through Eq.2:

$$Moisture\ Content\ \% = \frac{M_i - M_f}{M_i} \times 100 \quad (3\text{-}2)$$

3.3.1.3 Water Absorption

Six samples (10 x 10 x 3 mm) dried in an air circulating oven at 105℃ ±2 for 24 hours to remove the existing moisture.

Figure 3.12: Sample of Water Absorption

The sample were then immersed in water at room temperature (23±1℃) for half an hour and 2 hours. Before immersion, the sample is weighed, W_i, and after the immersion, the sample is weighed again, W_f. The water absorption of the sample is calculated using Eq.3:

$$Water\ content\ \% = \frac{W_f - W_i}{W_i} \times 100 \quad (3\text{-}3)$$

3.3.2 Mechanical Testing

3.3.2.1 Tensile Test

Tensile test is used to obtain the mechanical properties of the biodegradable composites. Some of the properties that can be acquire are Young's modulus and tensile stress. For this research, the testing was carried out by following to ASTM D3039 (Kasim *et al.*, 2015).The size of the samples are 140mm in length, 1 mm width and 3 mm in thickness. The tensile properties of the PALF reinforced cornstarch composites were determined using the Instron Universal Testing Machine, 5980 Series .

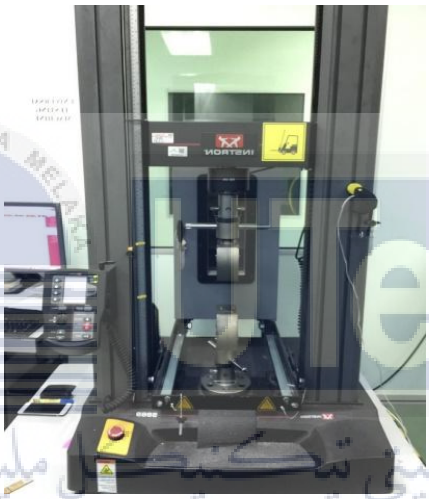


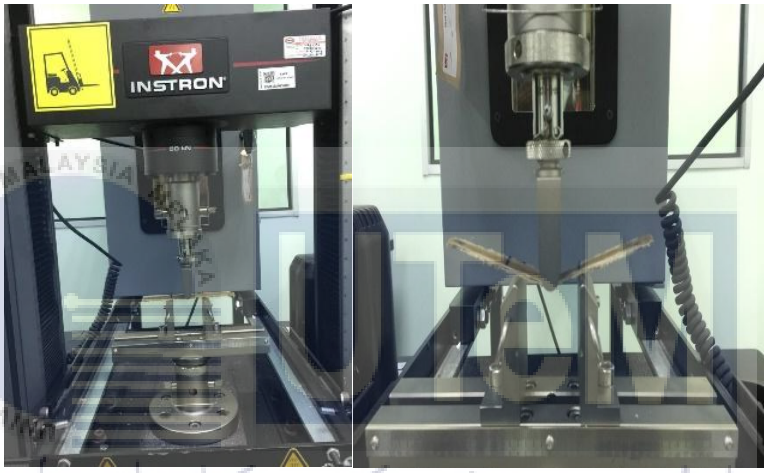
Figure 3.13: Instron Universal Testing Machine, Model 5980 Series

The sample is fixed into pneumatic holders as shown in figure 3.15. Load was hydraulically applied until the sample is rupture. The result is then obtained through the Bluehill 2 software.

Figure 3.14: Sample Position

3.3.2.2 Flexural Test

Using a three point bending set-up as stated by the ASTM D7264, the flexural test was conducted. At least five sample for each fibre loading is tested using Instron Universal Testing Machine, 5980 Series with a load speed of 1mm/min. The dimension for the sample used is 140 x 13 x 3 mm (length x width x thickness). The reading of the flexural strength and modulus is recorded through the Bluehill 2 software.



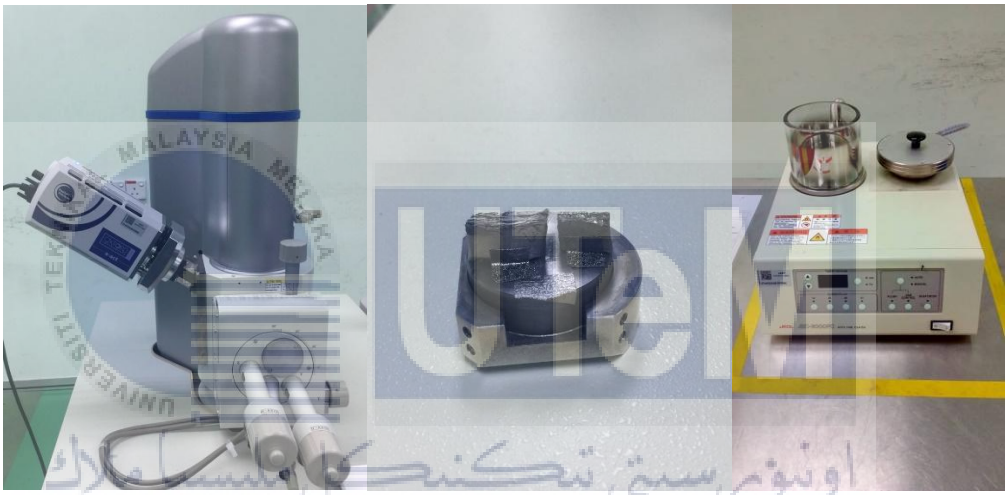
(a) (b)

Figure 3.15: (a) Position Of Sample For Flexural Test, (b) Sample After Being Bend

3.3.3 Morphological

3.3.3.1 SEM

For this research, morphological studie were done in detail on the fractured surface of the tensile test sample. This is performed by using Scanning Electron Microscope (SEM).The sample selected are the sample that contain 10 wt%, 30wt% and 70wt% of fibre loading. The samples were coated with platinum. This is to offer a good electrical conductivity, which will help to obtain a good quality result as the resolution did not significantly affected.



(a) (b) (c)

Figure 3.16: (a) Scanning Electron Microscope , (b) Sample Placement,(c) Sample Coating Machine

CHAPTER 4

4.0 RESULT AND DISCUSSION

4.1 Physical Properties

One of the main factor that influence the properties of the composites product is the physical properties like density, moisture content and water absorption. This section will explain the result for the three physical testing that has been performed on the PALF reinforced cornstarch composites.

4.1.1 Density

Density of a material is defined as the mass per unit its volume. It is a term that is used to show the relation of the composite weight to its size. Density is important as it affected the weight of the sample.

From the Figure 4.1, the density of the composite seems to increased with the increment of the fibre loading. This means that the higher the weight percentage of fibre loading, the higher the density of the PALF reinforced cornstarch composites.This can be seen through the value given on the figure 24. When the fibre loading is 5 wt%, the density recorded for the composite is only 1.2924 g/cm^3. However, when the value of weight percentage(wt%) of fibre loading increased, the density also keep on increasing. The increament from 1.2924 g/cm^3 at 5 wt% of fibre loading to 1.396 g/cm^3 at 70 wt% of fibre loading.

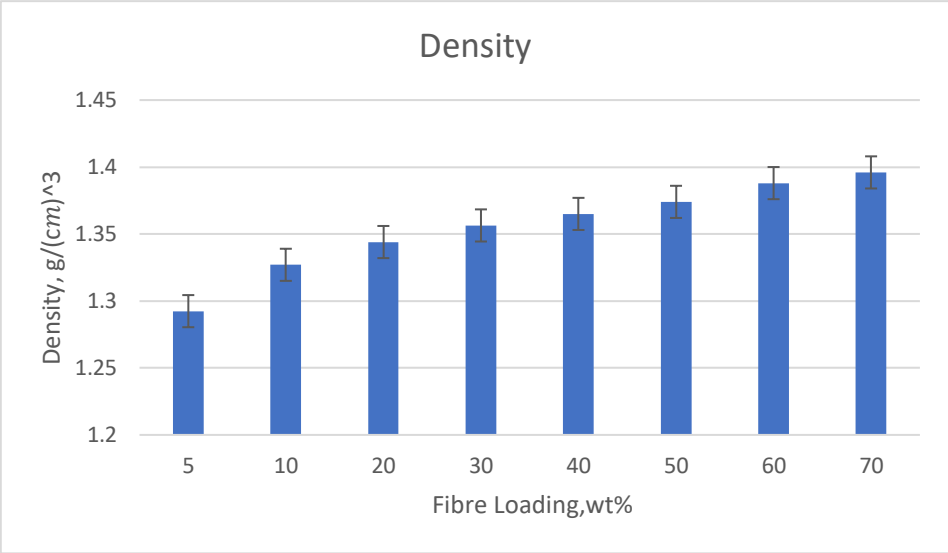


Figure 4.1: Result Of The Effect Of Fibre Loading Towards The Composite Density

It can be conclude that the present of fibres do affect in the density of a composites. The higher the fibre loading, the higher the density of the composites. This will affect the weight of the composites as the density is directly related to the weight of a substance or in this case, the composites.

4.1.2 Moisture Content and Water Absorption

Eventhough natural fibre have many advantages related to their usage as a reinforcement material, it still have some weakness. Natural fibre has the drawback in obtaining a good adhesion between fibre and matrix due to its hydrophilic behaviour. Thus resulting the natural fibre to has high moisture content and high water absorption properties. This will weaken the application of the composite product (C.W. NGUONG, S.N.B. LEE, 2013). Nevertheless, this disadvantages is overcome by performing surface treatment to nature fibre or in this research the PALF. From the past studies, it shows that treated nature fibre has better hydrophilic adhesion compared to the untreated fibre (Pickering, Afendy and Le, 2016). In natural fibre-reinforced composites, water are transported through multiple natural plant mechanism. Penetration of water molecule are enable by the micro-crack in

the matrix of the polymer. Other than that, water may also be transported through the fibre and matrix interface which will resulted into an unwanted canges or deformation of the mechanical properties. For example swelling, plasticizing and degradation.

Figure 4.2 illustrated, the moisture content of the PALF reinforced composite increase directly with the fibre loading wt%. At 5 wt%, the moisture content is 0.045 which is the lowest reading. While for the highest moisture reading is at 70 wt% fibre loading with a moisture content of 0.089. These reading shows that the moisture content of a composite is affected by its fibre loading. The higher the present of fibre in the composition, the higher the moisture content.

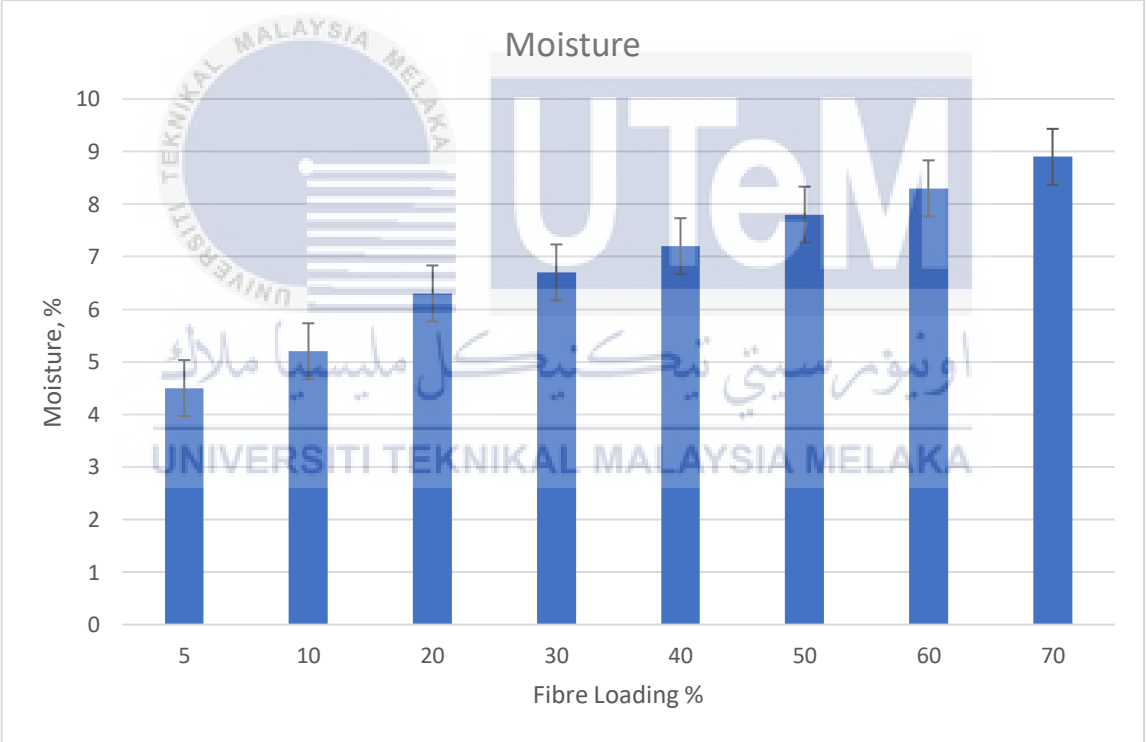


Figure 4.2: Moisture Content Of PALF Reinforced Cornstarch Composite To Its Fibre Loading

As conclusion, moisture content of the composites is effected by its fibre loading. From this study, it proved that higher fibre loading will lead to higher moisture content. High moisture content effect the interface between the fibre with the matrix.

For water absorption, the testing is divided to its soaking time. The sample soaking time are half an hour and 2 hours. From the Figure 4.3 below, it can be observed that the water absorption shows different result depending on its soaking time. The composite that is soaked for 2 hours absorb more water compared to the sample that has been soaked for only half an hour. Not only that, the fibre loading also effect the water absorption. Higher fibre loading sample has larger water absorption. This can be seen through the comparison of the sample for both soaking time time each fibre loading. For example, the sample with 30 wt% fibre loading has different water absorption reaction for both soaking time. The water absorption when the sample is soaked for 2 hours is larger compared to the sample that is being soaked for half an hour.

Comparing by looking to the fibre loading, higher percentage of fibre loading have higher water absorption. Looking from the figure 26, fibre loading of 5 wt% has lower water absorption compared to 70 wt% fibre loading.

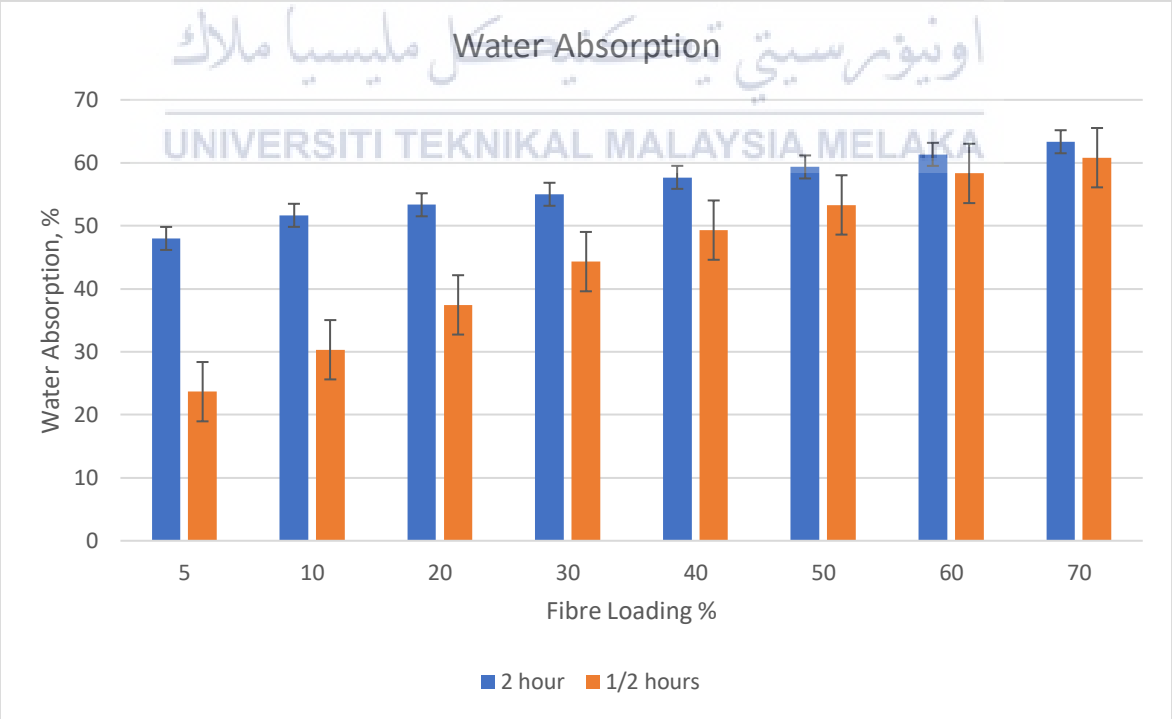


Figure 4.3: Water Absorption Of The PALF Reinforced Cornstarch Composite To The Fibre Loading

To conclude this, it can be observed that water absorption of the composite can be affected by the soaking time and the fibre loading. The longer the soaking time, the higher the water absorption of composites. Same with moisture content, the bigger the percentage of fibre loading present, the higher the water absorption. High water absorption will cause the degradation of the composite which will lead to disfunction of the the composite to its application.

4.2 Mechanical Testing

Mechanical testing is performed in order to study the behaviour of composites under different loads. In specific, is to investigate the relationship of the acting force and the resulting deformation and the limit stresses that caused the failure of the composites. The properties obtained from the testing will be used in the material development for further applications. For this research, the involve mechanical testing are tensile testing, flexural testing and hardness testing.

4.2.1 Tensile Test

Tensile test is one of the essential test that is used onto a material where the sample used will be subjected to a controlled tension/load until it failed. The material properties that are measured during this test are ultimate tensile strength, breaking strength and maximun elongation. Properties like Young's modulus and yield strength can also de defined through this testing.

The effect of different fibre loading to the composites is shown on the Figure 4.4. From the figure, the tensile strength of the composite increased with the addition of the PALF loading. The highest increment of the tensile strength is at 30 wt% of the fibre loading with ultimate tensile strength (UTS) of 10.03 MPa while at 40 wt% of fibre loading, the UTS of the sample starts to show a decreasing value.The lowest UTS for the sample of the composites is at fibre loading of 70 wt% with 3.87 MPa.

The UTS value starts to drop after the sample has reached it highest UTS at 30 wt% fibre loading. In can be simplify that the decreasing value in sample's UTS reading is due to the reason that when the fibre loading is higher than the matrix, the fibre behave as a defect causing the adhesion is not bonded perfectly between the matrix and the fibre itself (Kasim *et al.*, 2015). According to (Threepopnatkul, Kaerkitcha and Athipongarporn, 2009), the adhesion between the fibre and the matrix affected the stress transferring inside the

composite. In order to make the stress transfer more feasible, good fibre and matrix adhesion is a must(Kasim *et al.*, 2015). It also help in improving the composite's strength.

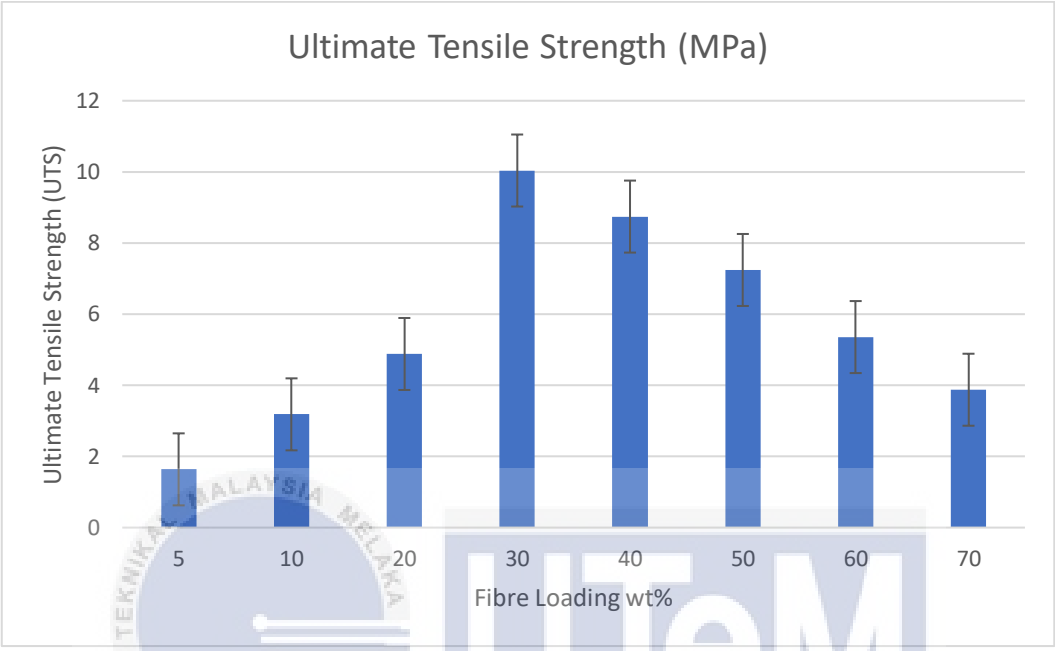


Figure 4.4:Tensile Strength Of PALF Reinforced Cornstarch Composite To The Fibre Loading

The reason of the lowest UTS reading at 70 wt% of fibre loading as shown in Figure 4.4 is that, at this fibre loading, the elasticity of the cornstarch which act as the matrix has decreased along with the increase of the fibre loading (Kasim *et al.*, 2015). This has resulted the decrease of the tensile strength which lead the composite to become more brittle compared to the smaller percentage of fibre loading. This can be due to the fact that the cornstarch was not perfectly bonded together with the PALF.

From this tensile test, it can be concluded that the percentage of fibre loading gave a significant effect on the mechanical properties of the PALF reinforced cornstarch composite. The fibre content and properties, matrix properties, and interfacial bonding between fibre and matrix are thoroughly related to tensile strength.

4.2.2 Flexural Testing

Flexural testing is a test that is performed on a material in order to determine the properties of flexural or the bending of material. The test is conducted by placing the sample between the supports and putting the load using a third point which known as the three point bend. Flexural test gives information on the value of the modulus of elasticity in bending and flexural stress of the material tested.

From Figure 4.5 below, the PALF reinforced cornstarch's flexural stress and the modulus of elasticity at the 5 wt% fibre loading is 1.95 MPa and 72.409 MPa respectively. Starting from 5 wt% fibre loading, both of the flexural test and modulus of the sample composite shows increament until it finally reached the fibre loading of 30 wt% fibre loading where the highest reading is recorded. The reading are 10.59 MPa for flexural stress and 532.41 MPa for the elasticity. However, after the 30 wt% onward, the flexural stress and the modulus starts to decrease until 70 wt% of fibre loading.

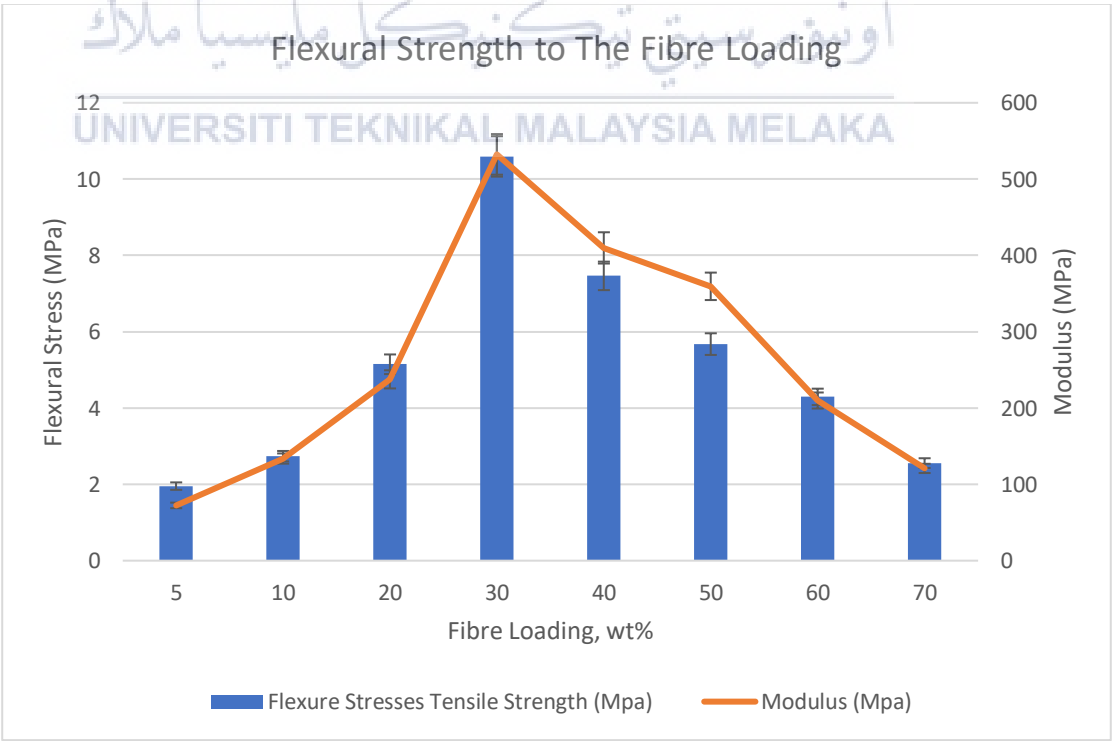


Figure 4.5: Flexural Strength To The Fibre Loading

The adhesion between the PALF and cornstarch can be the reason to the changes of reading. At the range of 5 wt% until 30 wt% of fibre loading, the stress is increasing due to the reason that the adhesion between the fibre and the matrix is strong and completely binded the fibre. While for the 40 wt% until 70 wt% fibre loading, the value for both properties stars to drop. This may due to the increase of fibre loading in the composite composition. The high percentage of fibre loading effect the adhesion bond between the cornstarch and PALF. This is due to the reason that the matrix is unable to cover all the fibre due to the decreasing percentage of cornstrach use. The cornstarch is unable to disperse completely between the matrix, resulting into a poor binding between the PALF and cornstarch(R.M.N. Arib *et al.*, 2006).

As conclusion, the percentage of fibre loading do effect the flexural properties of the PALF reinforced cornstarch composite. This can be proved by the result that has been explained before. The sample' flexural stress and modulus of elasticity is most optimum at 30 wt% as it has the most high value of both properties. However when the fibre loading starts to overload, the matrix is unable to disperse as the fibre loading is higher than the matrix itself. This resulted some problem like wetting and void.

4.3 Morphological

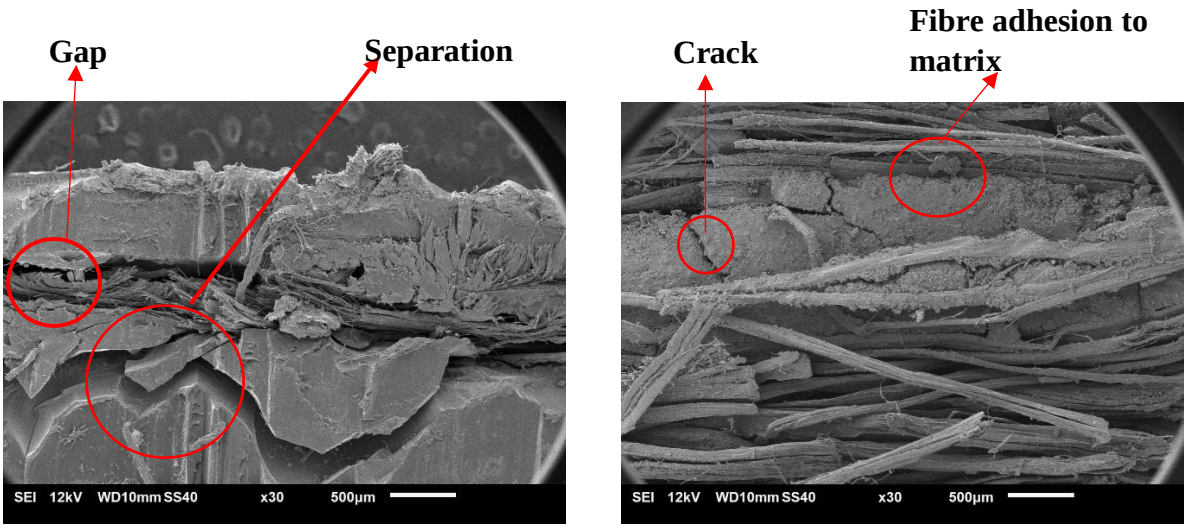
4.3.1 Scanning Electron Microscopic (SEM)

Using SEM, the morphological analysis on the PALF reinforced cornstarch composite is done. This test is performed in order to analys the composite particle characteristic after undergo tensile test. For this analysis, three sample from the 10 wt%, 30 wt% and 70 wt% is chosed. 10 wt% is chosed as the initial sample as it contain appropriate amount of fibre to be analyzed compared to 5 wt% fibre loading. While 30 wt% is chosed based on the tensile test result where at this fibre loading, the PALF reinforced cornstarch material has the highest Ultimate Tensile Strength (UTS) thus making it as the most optimum sample compared to the other fibre loading. The 70 wt% fibre loading is choosen as the final sample due to the fact that it shows the lowest UTS reading compared to other fibre loading after the maximum value of UTS at 30 wt% of fibre loading.

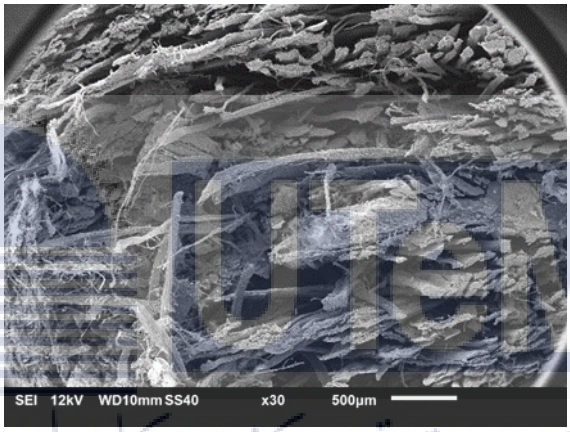
From Figure 4.6 (a), it can be seen that there is a clear gap between the PALF and the cornstarch. A separation between the matrix of the composites can also be observed. These defects are due to the low weight percentage of the fibre in the composite, thus effecting the bonding strength of the composites. Resulting the sample of 10 wt% fibre loading having a low tensile strength value. Figure 4.6 (b) shows the internal condition of the most optimum fibre loading sample which is at 30 wt%. At this fibre loading, the adhesion between the fibre and matrix shows no gap. It can be observed that the PALF is covered completely by the cornstarch. Eventhough there are some crack within the matrix, it seems that the strength of the adhesion bond is strong enough to overcome the defect. The failed sample is shown at figure 4.6 (c). According to the tensile test result, the sample start to decreased in tensile strength at the 40 wt% fibre loading. By observing the figure 4.6 (c), the PALF are not fully covered by the cornstarch. Many gaps can be seen between the fibre and matrix.

The gap that happen in the sample of 10 wt% and 70 wt% fibre loading may due to the insufficient alkali treatment towards the PALF resulting to the surface of the fibre to be not so smooth. Thus effecting the adhesion between the fibre and matrix. According to past study by (Siregar *et al.*, 2010), alkaline treatment help in making the fibre surface to be more uniform by eliminate the micro void thus improving the transfer of stress capacity and also increasing the aspect ratio and indirectly increase the surface area of the fibre for a better adhesion with the matrices. Other than that, the separation between the cornstarch that can observed in figure 4.6 (a) may due to glycerol content is not enough to bind the cornstarch resulting the matric to break apart during the hot pressing process. The mechanical properties of the sample are affected as the adhesion of fibre surface and the matrix is not strong enough making the sample to have a low tensile strength.

At 30 wt% fibre loading, it can be seen that it is the most optimum condition as it has the most appropriate fibre loading compared to the other sample. The effect of fibre loading to the tensile properties can be observed as this 30 wt% fibre loading has the highest ultimate tensile strength. Thereotically the higher fibre loading in the composition, the more stress can be fully transfer to the reinforcement. Furthermore, the adhesion of the fibre with the matrix also supported the 30 wt% to has the optimum condition as the cornstarch held the PALF firmly which help to increase the sample mechanical properties(Kasim *et al.*, 2015).



(a) (b)



(c)

Figure 4.6: (a) 10 Wt% Fibre Loading Sample, (b) 30 Wt% Fibre Loading Sample, (c) 40 wt% Fibre Loading Sample

CHAPTER 5

5.0 CONCLUSION AND RECOMMENDATION

As conclusions, many research has been conducted in past few years on the development of nature fibre compsites, where the finding is focusing on the selection of fibre, extraction and surface treatment of the fibre (Pickering, Afendy and Le, 2016). For this research, it is more focusing on the effect of PALF reinforced cornstarch biodegradable plastic composite on the physical, mechanical and morphological properties.

In this research, the physical, mechanical and morphological of the PALF to eight different fibre loading that are, 5 wt%, 10 wt%, 20 wt%, 30 wt%, 40 wt%, 50 wt%, 60 wt% and 70 wt% are investigated through various of testing like density, tensile and flexural. The effect of alkali treatment on the PALF are also being study and based on the comparison to previous researches, it clearly show that the treated PALF has better mechanical properties as it has been proved that the fibre adhesion with the matrix can be improved through the surface treatment compared to the untreated one (Siregar *et al.*, 2010).

The effect of the fibre loading toward the physical, mechanical and morphological properties of PALF reinforced cornstarch composite are analysed. For the physical test, it can be proved that, the higher the fibre, the higher the value recorded for each test. This means that for the density, water absorbtion and moisture content, the percentage of fibre loading are affected directly by the fibre loading. This can be proved by comparing the result of 5 wt% fibre loading with the 70 wt% fibre loading where the latter fibre loading has the higher value for the three physical testing. It can be seen that for this research, the highest ultimate tensile strength (UTS) recorded by the PALF reinforced cornstarch composite is at the fibre loading of 30 wt%. After the stated fibre loading percentage, the value of the UTS

starts to drop, indicating that the sample starts to failed at 40 wt%. The same result is also applied to the flexural testing where fibre loading of 30 wt% recorded the highest flexural stress and modulus of elasticity compared to the other. These finding are supported with the morphological analysis where the internal particle of the PALF reinforced cornstarch are being performed. The bond between the fibre and the matrix is being observed through this analysis. Therefore, it can be concluded that for this research, the 30 wt% fibre loading is the most optimum fibre loading for the 3cm length PALF compared too the other composition ratio stated previously. The mechanical properties of the composites is also effected by the percentage of void and interfacial bonding between the PALF with the cornstarch(Kasim *et al.*, 2015).

For future study, the improvement on the bond between the PALF and cornstarch should be conducted in order to produce the most optimum natural fibre composites. Other than that, further study about the characteristic of the cornstarch as the matrix should be performed as for current time, there is limited information about the characteristic of the cornstarch, thus making it difficult to analyse the interaction of the cornstarch with the PALF.

REFERENCES

Avérous, L. (2004) 'Biodegradable Multiphase Systems Based on Plasticized Starch: A Review', *Journal of Macromolecular Science, Part C: Polymer Reviews*, 44(3), pp. 231–274. doi: 10.1081/MC-200029326.

Aziz, S. H. and Ansell, M. P. (2004) 'The effect of alkalization and fibre alignment on the mechanical and thermal properties of kenaf and hemp bast fibre composites: Part 1 – polyester resin matrix', *Composites Science and Technology*. Elsevier, 64(9), pp. 1219–1230. doi: 10.1016/J.COMPSCITECH.2003.10.001.

C.W. NGUONG, S.N.B. LEE, D. S. (2013) 'A review on natural fibre reinforced polymer composites', *World Acad Sci Eng Techno1 Int J Chem Nucl Metall Mater Eng,*. Available at: https://www.google.com/amp/s/www.researchgate.net/publication/284413174_A_review_on_natural_fibre_reinforced_polymer_composites/amp.

Fadzullah, S. H. S. M. and Mustafa, Z. (2017) 'Fabrication and Processing of Pineapple Leaf Fiber Reinforced Composites', in *Materials Science and Engineering*. IGI Global, pp. 876–893. doi: 10.4018/978-1-5225-1798-6.ch035.

Faruk, O. *et al.* (2012) 'Biocomposites reinforced with natural fibers: 2000-2010', *Progress in Polymer Science*. Elsevier Ltd, 37(11), pp. 1552–1596. doi: 10.1016/j.progpolymsci.2012.04.003.

Joseph, P. V. *et al.* (2003) 'The thermal and crystallisation studies of short sisal fibre reinforced polypropylene composites', *Composites Part A: Applied Science and Manufacturing*. Elsevier, 34(3), pp. 253–266. doi: 10.1016/S1359-835X(02)00185-9.

Kabir, M. M. *et al.* (2012) 'Chemical treatments on plant-based natural fibre reinforced polymer composites: An overview', *Composites Part B: Engineering*. Elsevier Ltd, 43(7), pp. 2883–2892. doi: 10.1016/j.compositesb.2012.04.053.

Kasim, A. N. *et al.* (2015) 'Effect of pineapple leaf fiber loading on the mechanical properties of pineapple leaf fiber ??? Polypropylene composite', *Jurnal Teknologi*. doi: 10.11113/jt.v77.6617.

Kasim, A. N. *et al.* (2016) 'Mechanical properties of polypropylene composites reinforced with alkaline treated pineapple leaf fibre from josapine cultivar', *International Journal of Automotive and Mechanical Engineering*. doi: 10.15282/ijame.13.1.2016.3.0263.

Lau, K. *et al.* (2018) 'Properties of natural fibre composites for structural engineering applications', *Composites Part B: Engineering*. Elsevier, 136(September 2017), pp. 222–233. doi: 10.1016/j.compositesb.2017.10.038.

Mishra, S. *et al.* (2004) 'A Review on Pineapple Leaf Fibers, Sisal Fibers and Their Biocomposites', *Macromolecular Materials and Engineering*. WILEY-VCH Verlag, 289(11), pp. 955–974. doi: 10.1002/mame.200400132.

Mohamed, A. R. *et al.* (2009) 'Characterization of pineapple leaf fibers from selected Malaysian cultivars', *Journal of Food, Agriculture and Environment*, 7(1), pp. 235–240. doi: 10.1016/j.trac.2007.09.004.

Mohammed, L. *et al.* (2015) 'A Review on Natural Fiber Reinforced Polymer Composite and Its Applications', *International Journal of Polymer Science*, 2015, pp. 1–15. doi: 10.1155/2015/243947.

Mwaikambo, L. Y. and Ansell, M. P. (2003) 'Hemp fibre reinforced cashew nut shell liquid composites', *Composites Science and Technology*. Elsevier, 63(9), pp. 1297–1305. doi: 10.1016/S0266-3538(03)00101-5.

Pardeshi, S., Jafer Mirji, M. and Goud, V. (no date) 'Extraction of Pineapple Leaf Fiber and its Spinning: A Review'. Available at: https://images.fibre2fashion.com/ArticleResources/PdfFiles/67/6621.pdf (Accessed: 13 December 2017).

Pickering, K. L. *et al.* (2007) 'Optimising industrial hemp fibre for composites', *Composites Part A: Applied Science and Manufacturing*. Elsevier, 38(2), pp. 461–468. doi: 10.1016/J.COMPOSITESA.2006.02.020.

Pickering, K. L., Afendy, M. G. A. and Le, T. M. (2016) 'A review of recent developments in natural fibre composites and their mechanical performance', *Composites Part A: Applied Science and Manufacturing*. Elsevier, 83, pp. 98–112. doi: 10.1016/J.COMPOSITESA.2015.08.038.

R.M.N. Arib *et al.* (2006) 'Mechanical properties of pineapple leaf fibre reinforced polypropylene composites', *Materials and Design 27*. Available at: http://ac.els-cdn.com.libproxy.utem.edu.my/S0261306904002973/1-s2.0-S0261306904002973-main.pdf?_tid=385a9274-6063-11e7-b693-00000aacb35d&acdnat=1499136672_9df729c5e02d7b644f10b1beeffee13a (Accessed: 4 July 2017).

Romhány, G., Karger-Kocsis, J. and Czigány, T. (2003) 'Tensile Fracture and Failure Behavior of Thermoplastic Starch with Unidirectional and Cross-Ply Flax Fiber Reinforcements', *Macromolecular Materials and Engineering*, 288(9), pp. 699–707. doi: 10.1002/mame.200300040.

Siregar, J. P. *et al.* (2010) 'The effect of alkali treatment on the mechanical properties of short pineapple leaf fibre (PALF) reinforced high impact polystyrene (HIPS) composites', *Journal of Food, Agriculture & Environment Journal of Food Agriculture & Environment*, 88(22), pp. 1103–1108. Available at: http://world-food.net/download/journals/2010-issue_2/e47.pdf (Accessed: 4 July 2017).

van Soest, J. J. G., Benes, K. and De Wit, D. (1995) 'The Influence of Acid Hydrolysis of Potato Starch on the Stress-Strain Propoerties of Thermoplastic Starch', *Starch - Stärke*, 47(11), pp. 429–434. doi: 10.1002/star.19950471106.

'Studies on Natural/Glass Fiber Reinforced Polymer Hybrid Composites: An Evolution' (2017) *Materials Today: Proceedings*. Elsevier, 4(2), pp. 2739–2747. doi: 10.1016/J.MATPR.2017.02.151.

Threepopnatkul, P., Kaerkitcha, N. and Athipongarporn, N. (2009) 'Effect of surface treatment on performance of pineapple leaf fiber–polycarbonate composites', *Composites Part B: Engineering*. Elsevier, 40(7), pp. 628–632. doi: 10.1016/J.COMPOSITESB.2009.04.008.

Yu, L., Dean, K. and Li, L. (2006) 'Polymer blends and composites from renewable resources', *Progress in Polymer Science (Oxford)*, 31(6), pp. 576–602. doi: 10.1016/j.progpolymsci.2006.03.002.

Yusof, Y., Yahya, S. A. and Adam, A. (2015) 'Novel technology for sustainable pineapple leaf fibers productions', *Procedia CIRP*, 26, pp. 756–760. doi: 10.1016/j.procir.2014.07.160.

Zhang, Y., Rempel, C. and Liu, Q. (2014) 'Thermoplastic Starch Processing and Characteristics-A Review', *Critical Reviews in Food Science and Nutrition*, 54(10), pp. 1353–1370. doi: 10.1080/10408398.2011.636156.

APPENDIX A

ASTM D3039

Designation: D 3039/D 3039M – 00$^{\epsilon 1}$

Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials[1]

This standard is issued under the fixed designation D 3039/D 3039M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

ε[1] NOTE—Eq 5 was revised editorially in December 2002.

1. Scope

1.1 This test method determines the in-plane tensile properties of polymer matrix composite materials reinforced by high-modulus fibers. The composite material forms are limited to continuous fiber or discontinuous fiber-reinforced composites in which the laminate is balanced and symmetric with respect to the test direction.

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the text, the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement[2]

D 883 Terminology Relating to Plastics[2]

D 2584 Test Method for Ignition Loss of Cured Reinforced Resins[3]

D 2734 Test Method for Void Content of Reinforced Plastics[3]

D 3171 Test Methods for Constituent Content of Composites Materials[4]

D 3878 Terminology for Composite Materials[4]

D 5229/D 5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials[4]

E 4 Practices for Force Verification of Testing Machines[5]

E 6 Terminology Relating to Methods of Mechanical Testing[5]

E 83 Practice for Verification and Classification of Extensometers[5]

E 111 Test Method for Young's Modulus, Tangent Modulus, and Chord Modulus[5]

E 122 Practice for Choice of Sample Size to Estimate a Measure of Quality for a Lot or Process[6]

E 132 Test Method for Poisson's Ratio at Room Temperature[5]

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods[6]

E 251 Test Methods for Performance Characteristics of Metallic Bonded Resistance Strain Gages[5]

E 456 Terminology Relating to Quality and Statistics[6]

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[6]

E 1012 Practice for Verification of Specimen Alignment Under Tensile Loading[5]

E 1237 Guide for Installing Bonded Resistance Strain Gages[5]

3. Terminology

3.1 *Definitions*—Terminology D 3878 defines terms relating to high-modulus fibers and their composites. Terminology D 883 defines terms relating to plastics. Terminology E 6 defines terms relating to mechanical testing. Terminology E 456 and Practice E 177 define terms relating to statistics. In the event of a conflict between terms, Terminology D 3878 shall have precedence over the other standards.

3.2 *Definitions of Terms Specific to This Standard:*

NOTE—If the term represents a physical quantity, its analytical dimensions are stated immediately following the term (or letter symbol) in fundamental dimension form, using the following ASTM standard symbology for fundamental

[1] This test method is under the jurisidiction of ASTM Committee D30 on Composite Materials and is the direct responsibility of Subcommittee D30.04 on Lamina and Laminate Test Methods.

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[2] *Annual Book of ASTM Standards*, Vol 08.01.

[3] *Annual Book of ASTM Standards*, Vol 08.02.

[4] *Annual Book of ASTM Standards*, Vol 15.03.

[5] *Annual Book of ASTM Standards*, Vol 03.01.

[6] *Annual Book of ASTM Standards*, Vol 14.02.

APPENDIX B

ASTM D 7264

Designation: D 7264/D 7264M – 07

Standard Test Method for Flexural Properties of Polymer Matrix Composite Materials[1]

This standard is issued under the fixed designation D 7264/D 7264M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method determines the flexural stiffness and strength properties of polymer matrix composites.

1.1.1 *Procedure A*—A three-point loading system utilizing center loading on a simply supported beam.

1.1.2 *Procedure B*—A four-point loading system utilizing two load points equally spaced from their adjacent support points, with a distance between load points of one-half of the support span.

NOTE 1—Unlike Test Method D 6272, which allows loading at both one-third and one-half of the support span, in order to standardize geometry and simplify calculations this standard permits loading at only one-half the support span.

1.2 For comparison purposes, tests may be conducted according to either test procedure, provided that the same procedure is used for all tests, since the two procedures generally give slightly different property values.

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the text, the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 790 Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials

D 2344/D 2344M Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates

D 3878 Terminology for Composite Materials

D 5229/D 5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials

D 5687/D 5687M Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation

D 6272 Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials by Four-Point Bending

D 6856 Guide for Testing Fabric-Reinforced "Textile" Composite Materials

E 4 Practices for Force Verification of Testing Machines

E 6 Terminology Relating to Methods of Mechanical Testing

E 18 Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials

E 122 Practice for Calculating Sample Size to Estimate, With a Specified Tolerable Error, the Average for a Characteristic of a Lot or Process

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E 456 Terminology Relating to Quality and Statistics

E 1309 Guide for Identification of Fiber-Reinforced Polymer-Matrix Composite Materials in Databases

E 1434 Guide for Recording Mechanical Test Data of Fiber-Reinforced Composite Materials in Databases

2.2 *Other Documents:*

ANSI Y14.5-1999 Dimensioning and Tolerancing—Includes Inch and Metric[3]

ANSI B46.1-1995 Surface Texture (Surface Roughness, Waviness and Lay)[3]

3. Terminology

3.1 *Definitions*—Terminology D 3878 defines the terms relating to high-modulus fibers and their composites. Terminology E 6 defines terms relating to mechanical testing. Terminology E 456 and Practice E 177 define terms relating to statistics. In the event of a conflict between terms, Terminology D 3878 shall have precedence over the other documents.

[1] This test method is under the jurisdiction of ASTM Committee D30 on Composite Materials and is the direct responsibility of Subcommittee D30.04 on Lamina and Laminate Test Methods.

Current edition approved April 1, 2007. Published April 2007. Originally approved in 2006. Last previous edition approved in 2006 as D 7264/D 7264M – 06.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

APPENDIX C

ASTM D 5229

Designation: D 5229/D 5229M – 92 (Reapproved 2004)

Standard Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials[1]

This standard is issued under the fixed designation D 5229/D 5229M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

INTRODUCTION

Consistent evaluation and comparison of the response of polymer matrix composites to moisture absorption can only be performed when the material has been brought to a uniform through-the-thickness moisture profile. The procedures described in Test Method D 570 and Practices D 618 do not guarantee moisture equilibrium of the material. A similar, but more rigorous, procedure for conditioning to equilibrium is described by this test method, which can also be used with fluid moisture other than water, and which, additionally, can provide the moisture absorption properties necessary for the analysis of single-phase Fickian moisture diffusion within such materials.

1. Scope

1.1 This test method covers a procedure (Procedure A) for the determination of moisture absorption or desorption properties in the through-the-thickness direction for single-phase Fickian solid materials in flat or curved panel form. Also covered are procedures for conditioning test coupons prior to use in other test methods; either to equilibrium in a non-laboratory environment (Procedure B), to equilibrium in a standard laboratory atmosphere environment (Procedure C), or to an essentially moisture-free state (Procedure D). While intended primarily for laminated polymer matrix composite materials, these procedures are also applicable to other materials that satisfy the assumptions of 1.2.

1.2 The calculation of the through-the-thickness moisture diffusivity constant in Procedure A assumes a single-phase Fickian material with constant moisture absorption properties through the thickness of the specimen. The validity of the equations used in Procedure A for evaluating the moisture diffusivity constant in a material of previously unknown moisture absorption behavior is uncertain prior to the test, as the test results themselves determine if the material follows the single-phase Fickian diffusion model. A reinforced polymer matrix composite material tested below its glass-transition temperature typically meets this requirement, although two-phase matrices such as toughened epoxies may require a multi-phase moisture absorption model. While the test procedures themselves may be used for multi-phase materials, the calculations used to determine the moisture diffusivity constant in Procedure A are applicable only to single-phase materials. Other examples of materials and test conditions that may not meet the requirements are discussed in Section 1.4.

1.3 The evaluation by Procedure A of the moisture equilibrium content material property does not assume, and is therefore not limited to, single-phase Fickian diffusion behavior.

1.4 The procedures used by this test method may be performed, and the resulting data reduced, by suitable automatic equipment.

1.5 This test method is consistent with the recommendations of MIL-HDBK-17B (1),[2] which describes the desirable attributes of a conditioning and moisture property determination procedure.

1.6 The values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the text the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

[1] This test method is under the jurisdiction of ASTM Committee D30 on Composite Materials and is the direct responsibility of Subcommittee D30.04 on Lamina and Laminate Test Methods.

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[2] The boldface numbers in parentheses refer to the list of references at the end of this standard.