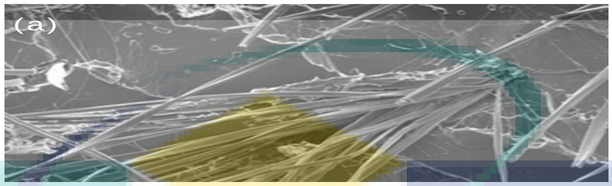
LAMPIRAN B

TEMPLATE
BUKU PROFIL PENYELIDIKAN SKIM GERAN PENYELIDIKAN FUNDAMENTAL (FRGS) FASA 1/2013 DAN FASA 2/2013



CHARACTERIZATION OF BIODEGRADABLE COMPOSITES BASED ON PINEAPPLE LEAF FIBRE AND TAPIOCA BIOPLASTIC RESIN

Name of Project Leader
JANUAR PARLAUNGAN SIREGAR

Name of co-researchers
MOHD. SAPUAN SALIT
MD. MUSTAFIZUR RAHMAN
MOHD. RUZAIMI BIN MAT REJAB
ROSLI BIN ABU BAKAR
TEDI KURNIAWAN
DANDI BACHTIAR
AHMAD SYAHRIZAN BIN SULAIMAN
YULI PANCA ASMARA

IPT/ Faculty / School/ Centre/Unit
UNIVERSITI MALAYSIA PAHANG

E-mail
januar@ump.edu.my

FRGS Field
TECHNOLOGY AND ENGINEERING

ABSTRACT (120 words)

The study of natural fiber composite in the field of materials has indeed sparked interest among many due to its essential biodegradability feature. As such, pineapple leaf fiber (PALF) is not only biodegradable, but also environmental friendly, as opposed to synthetic fiber. Hence, this paper investigates the effect of fiber loading, as well as the inclusion of maleic anhydride polyethylene (MAPE) to the mechanical properties of PALF reinforced polylactic acid (PLA) composites. Therefore, untreated PALF with 0, 5, 10, and 15% of weight content ratio, as well as PALF at 10% weight ratio treated with 2, 4, and 6% of MAPE, had been prepared via roll mill mixing at 190 ºC and followed by hot compression molding to prepare the specimen sheets. The results obtained from this study revealed that the tensile strength (TS) and the Young's modulus were at their highest levels for untreated 10% PALF, while the impact and the flexure properties displayed a decrease as the content of fiber increased. Other than that, the inclusion of MAPE indicated that the tensile properties exhibited lower value compared to that of untreated. However, the flexural and the impact properties of composites increased with the presence of MAPE. As a conclusion, the study demonstrates that the mechanical properties depended on two major factors; i) fiber loading, and ii) the compatibility between matrix polymer and fiber.

1. INTRODUCTION

In recent years, human has acknowledge that if the environment and nature is not being taken care of, their own species will be endangered by the over usage of natural resources as well as significant reduction of fresh air production in the world (Cheung, Ho, Lau, Cardona, & Hui, 2009). As the world population continue to increase, so as the consumption level of raw substances such as crude oil and finished products (Neto, Araujo, Souza, Mattoso, & Marconcini, 2013). In Malaysia, population growth has been increasing approximately at a rate of 2.4% per year which is about 600,000 per annum since the year of 1994. On par with this trend of population growth in Malaysia, the municipal solid waste (MSW) produced also increases. In year 2003, the mean amount of MSW produced in Malaysia was represented by 0.5-0.8 kg/person/day. The amount of generated MSW is expected to increase to 1.7-2.24 kg/day/person in major cities in the year of 2020-2024. This large amount of MSW generated is mostly contribution of plastics waste in form of rigid, film and foam (Manaf, Samah, & Zukki, 2009; Periathamby, Hamid, & Khidzir, 2009; Saeed, Hassan, & Mujeebu, 2009). With this alarming rate of generated waste, it has been a major concern for engineers and scientist to find a solution to reduce MSW especially plastic wastes. For that reason, the utilization of renewable resources such as biopolymer and natural fiber from animal and plant known as natural fiber-reinforced biopolymeric composite has become a crucial design criteria in designing and manufacturing components for almost every industrial products (Cheung et al., 2009).

Natural fiber is a hair-like material extracted from either animals or plants. Natural fiber from animal includes wool, hair and secretions such as silk whereas natural fiber such as pineapple leaves (PALF), kenaf, hemp, flax, jute, sisal, bamboo, coir and elephant grass are from plants (Asim et al., 2015; T. Mukherjee & Kao, 2011). Plant fiber such as PALF has complex structures and made up of several organic compound like waxes, pectins, lignin, fatty acids, fats, hemicelluloses are among the others (Rowell, Han, & Rowell, 2000). The decent mechanical properties of lignocellulosic fibers are predominantly depends on their cellulosic fraction because they are in charge of the fiber's crystalline structure. PALF is suitable for commercial applications due to their high crystallinity (Reddy & Yang, 2005; Tomczak, Satyanarayana, & Sydenstricker, 2007).

Bio-based polymers or biopolymers materials obtained from renewable sources (Weber, Haugaard, Festersen, & Bertelsen, 2002). Biopolymer may split into three main categories depending on their production and origin. The first category is where the polymers are directly extracted from biomass. For instance, polysaccharides such as cellulose and starch, chitin and proteins like casein and gluten (Ruban, 2009). The second category is where the polymers are generated by micro-organisms or genetically modified bacteria. Polyhydroxyalkonoates (PHA) appear mainly in this group of biopolymer (Cutter, 2002). The third category is where polymers are obtained by using renewable bio based monomers. An example of this polymer is polylactic acid (PLA) (Kandemir et al., 2005).

PLA is a natural and renewable thermoplastic polymer that can be produced from agriculture sources such as corn. As much as over 140,000 tons of PLA were produced annually (Shen, Worrell, & Patel, 2010). PLA offers a wide range of advantages such as low amount of energy used and low emission of greenhouse gases such as carbon dioxide (CO_2). However, PLA is expensive compared to other petroleum based products making it less competitive (T. Mukherjee & Kao, 2011).

In recent years with the increasing global energy crisis, plant fiber reinforced polymer composites are being researched and has becomes a renewed engineering interest in material science due to what they has to offer such as high strength to weight ratio, corrosion resistant property, safe to handle, low production cost, less machine wear, reduction in carbon dioxide emission, less dependence on crude oil and most importantly they are fully biodegradable that means there will be a significant reduction on polymer waste generation (Arib, Sapuan, Ahmad, Paridah, & Zaman, 2006; Asim et al., 2015; Cheung et al., 2009; Herrera-Franco & Valadez-Gonzalez, 2005; T. Mukherjee & Kao, 2011). Several researchers compounded these plant fiber with biopolymer such as PLA, cellulosic plastic, soybean plastics and starch plastic to make a 100% biodegradable composites material (Zhang, Rong, & Lu, 2005).

There are approximately 30 million tons of natural fiber generated annually and being used to manufacture varieties of products such as clothing, packaging, paper production, automobiles components, building construction materials and sports equipment. These fiber initially seen as waste are being transform into something useful and low cost (Jawaid & Khalil, 2011).

1.1 PROBLEM STATEMENT

Approximately 150 million tons of plastics are produced every year all around the world and this figure is expected to increase as the world population increases. Almost all of these plastic products are made of petroleum based material that will increase the utilization of crude oil. As a result, these plastic materials ironically contribute to serious environmental pollution due to wasted and undegraded polymer (Okada, 2002).

In tropical country where agriculture is active, a lot of agriculture wastes will be produced each year. Brazil is the third nation in the world that produces the most pineapple with over 7% of world production. In 2004, the nation's production was around 1.4 million tons of fiber. However due to the lack of knowledge of its economic potential, these fibers are being discarded and burned (Neto et al., 2013). The disposal method of these wastes through burning will cause air pollution and further harm the environment.

Thus, an engineering research in natural fiber-reinforced biopolymeric composite such as pineapple leaf fibre (PALF)- reinforced polylactic acid (PLA) composites is crucial to provide an alternative to replace non-biodegradable polymer and convert these waste fibers into useful industrial and commercial product and to substitute the use of conventional synthetic fiber that is expensive in processing and not environmental friendly.

1.2 SIGNIFICANCE OF STUDY

During the extraction process and forming of the raw natural fibers into cordage, roughly 10% of waste is formed. Instead of disposing these wastes that could potentially harm the environment as a result of open combustion, they could be used in manufacturing polymer reinforced composites since they possess attractive mechanical and physical properties. These waste fibers consist of approximately 60% of cellulose pulp that could be used to reinforce or enhance polymeric materials instead of being solely discarded where pollution can be reduced. Natural fiber impart the composites with several advantages such as biodegradable low density, not hazardous to human health and less machine wear during processing compared to synthetic fiber such as carbon and glass fiber (Herrera-Franco & Valadez-Gonzalez, 2005). Biodegradable polymer matrices such as PLA can be reinforced with natural fiber such as PALF to produce “green composites” that are environmentally beneficial (T. Mukherjee & Kao, 2011). This study proposes the utilization of PALF and PLA to create a biocomposite where PALF serve as reinforcing agent. This can reduce the usage of PLA and contribute to further reduction of cost since PLA is expensive and at the same time able to preserve the environment.

1.3 OBJECTIVES

The objectives of this project are as follow:

- To study the effect of weight percentage of PALF and polylactic acid (PLA) to mechanical properties of the composites.
- To study the effect of compatibalizing agent on the mechanical properties of PALF reinforced PLA composite.

1.4 SCOPES OF STUDY

The scopes of this project are as follow:

- Material used for testing are PALF and PLA. This experiment is conducted by mixing PALF and PLA as biocomposite where they are prepared in different composition such as 5%, 10% and 15% weight percentage of PALF and their mechanical properties are investigated
- Compatibalizing agents used are maleic anhydride polyethylene (MAPE). Compatibalizing agent composition is such as 2%, 4% and 6% weight percentage of MAPE. These agents are added to the composite to observe if there is any change in their mechanical properties.
- Composites are prepared by roll mill mixing and hot compression molding. The material is first roll mixed followed by using hot compression molding and cut into dog-bone shape using pedestrian grinder.
- Specimen test is according to ASTM D638, ASTM D790 and ASTM D256.

2. RESEARCH METHODOLOGY

INTRODUCTION

This chapter will describe in detail on the method used in the experiment. The material preparation and experimental setup will be discussed. In this experiment, composite with different weight ratio of 5, 10, 15% PALF content will be tested. The tensile property of each different specimen will be compared. The addition of 2, 4, 6 wt.% MAPE into the composite will be studied to determine if there is any enhancement in the tensile property.

FLOWCHART

The methodology is illustrated in a flowchart for better understanding on the step by step preparation. Figure 3.1 below shows the complete process flowchart of the experiment.

PREPARATION OF RAW MATERIAL

The PALF was washed and dried under direct sunlight. After the PALF was completely dried, the PALF was cut into a short dimension of 2-4 cm, followed by grinding and sieving processes in order to obtain the required dimension of PALF at around 2-4 mm. Afterwards, the PALF was dried again by using a vacuum oven at 80 ^{o}C for 24 hours to remove the moisture content before it was stored in sealed containers [30, 31]. The PALF was blended with PLA and MAPE in the roll mixer machine. The mixing process was continued at 190 ^{o}C with the speed of the roller set at 50 rpm. The composite, later, was cooled at room temperature after completing the mixing process. The process was repeated at different percentages of composition fractions by adhering to the weight ratio displayed in Table 1. After the composite was cooled at room temperature, it was placed into a crusher machine in order to achieve pellet size of the composite. Besides, a laboratory-sized hot compress molding machine was employed to compress the pelletizer composites into plate form composite with a dimension of 20 x 20 x 0.3 cm.

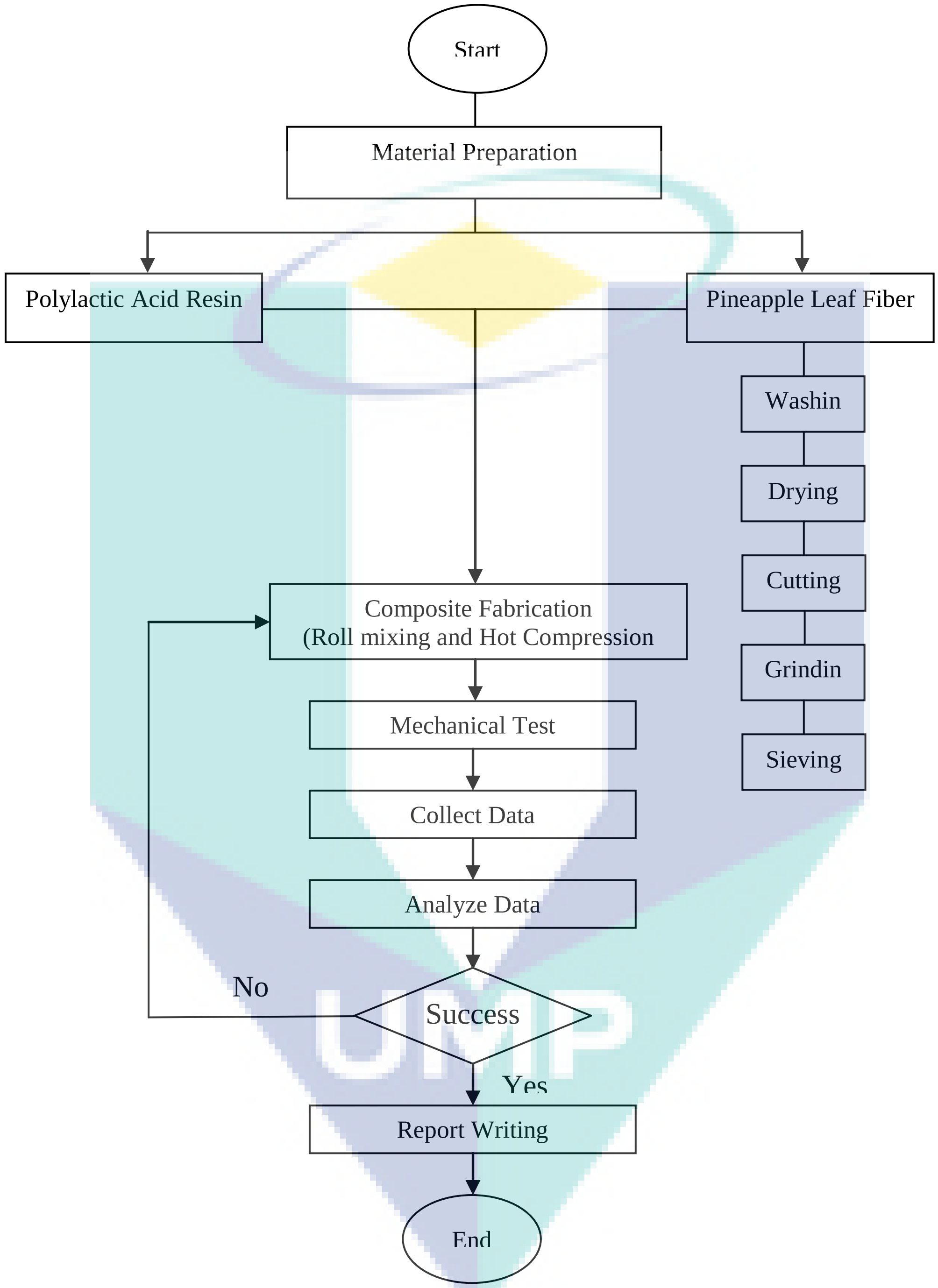


Figure 3.1: Flowchart of experiment

The pressure and the temperature that had been set for the hot compress machine were 15 MPa and 190 ^{o}C respectively. Then, the specimen was cut with a table saw by adhering to the ASTM standards of D638, D790, and D256.

Table 1 Mixing ratio of PLA, PALF and MAPE

Sample	Mixing Ratio (wt.%)		
	PLA	PALF	MAPE
Pure PALF	100	-	-
Fibre5	95	5	-
Fibre10	90	10	-
Fibre15	85	15	-
MAPE2	88	10	2
MAPE4	86	10	4
MAPE6	84	10	6

Mechanical Testing

Tensile and flexural tests were conducted according to ASTM D638 by using a Universal Testing Machine Instron model 3369. The tests were performed at a crosshead speed of 1 mm/min with 5 kN load cell. Each value obtained represented the average of six samples. On the other hand, the flexural specimens were tested in accordance with ASTM D790. The span distance between the two supporting points was 48 mm, while the crosshead speed was at 1 mm/min with a 10 kN. Each value achieved represented the average of five samples. Meanwhile, the Charpy impact tests were conducted on a Universal Impact Machine (Zwick 5113 pendulum impact tester). The methods of the tests were carried out based on ASTM D256. In addition, all the test specimens were un-notched. The impact load applied was a 4 J pendulum at a maximum pendulum height of 160^{o}. Hence, five specimens were tested for each sample parameter to obtain the average value. Another note to highlight is that all the mechanical properties were tested at room temperature.

Scanning electron microscope (SEM)

The morphology of tensile fracture specimen in PALF/PLA composites was analyzed by using the Zeiss Evo50 scanning electron microscope. The samples were mounted onto SEM holder using double-sided electrically conducting carbon adhesive tapes to prevent surface charge on the specimens when exposed to the electron beam. The PALF-PLA composites were then sputtered with titanium prior to their morphological observation.

LITERATURE REVIEW

In recent years, awareness upon the deteriorating state of the environment has sparked tremendous interest among researchers concerning natural resources materials, such as natural fiber, approximately 30 million tons of natural fiber are utilized to manufacture a variety of products, due to their excellent characteristics of recyclability, environmental safety, and low in cost [1,2]. As such, a great driving force has generated fellow researchers in conducting endless studies pertaining to natural fiber reinforcement in polymer composite for application in numerous fields like clothing, packing, paper production, automobile components, building construction materials, and sports equipment [3-5]. Application of natural fiber based composites in automobile field had been studied by several researchers [6-8]. For instance, jute based composites door panels had started by Mercedes-Benz which into its A-Class vehicles [9]. Cicala and team worker had studied to investigate hybridization of glass fiber with natural fiber for application in the piping industry [10]. In addition, kenaf reinforced glass hybrid composite given a great attentiveness investigated to researchers for advanced in passenger car bumper [6]. Natural fiber, as it is, is a hair-like material extracted from either animals or plants. Natural fiber from animal includes wool, hair, and secretions, such as silk; whereas pineapple leaf fiber (PALF), kenaf, bamboo, coir, sisal, rice husk, hemp, flax, jute, and banana fiber, to name a few, are obtained from plants [11,12]. Furthermore, the production of these natural fibers has been growing rapidly because they are renewable, cheaper in price, emit lower pollutant, pose less health risks, can be easily obtained, and they are comprised of eco-friendly materials when compared to synthetic fiber [11, 13, 14].

Besides, environmental topics related to massive crop wastes derived from agriculture sector and plastic wastes are a huge concern at this present time. In addition, nearly 150 million tons of plastics are produced worldwide every year and this figure is expected to escalate with the increasing trend of the world population [15, 16]. On top of that, as almost all these plastic products are made of petroleum-based material, the utilization of crude oil is deemed to increase; contributing to serious environmental pollution as they are made of non-degradable polymer [17]. In a tropical country like Malaysia where agriculture is active, a lot of agriculture wastes are produced each year. In 2009, Thailand produces 1.894 million tons, the Philippines produced 2.198 million tons, and Brazil produced only1.43 million tons of massive agricultural waste producer, as shown in Fig.1 [11]. Thailand is one of the largest countries in the world for pineapple production and thus, tons of pineapple leaves turn into agricultural waste after harvesting [18], whereas Malaysia generates approximately 1.2 million tons of agricultural residuals on an annual basis [19]. Another instance is Brazil; the third largest nation in the world that produces pineapple with over 7 % of world production produced about 1.4 million tons of fiber in 2004. Unfortunately, these useful fibers are discarded and burned due to limited knowledge of their economic potential [20]. Besides, the disposal method of these wastes via burning causes air pollution that harms the environment. Hence, a research from the engineering aspect to further probe into natural fiber-reinforced biopolymeric composite, such as pineapple leaf fiber (PALF)-reinforced polylactic acid (PLA) composites, is indeed crucial in providing an alternative solution to replace non-biodegradable polymer, to convert these waste fibers into useful industrial and commercial products, as well as to substitute the use of conventional synthetic fiber that is not only expensive in processing, but also non-environmental friendly. PLA is often used for biodegradable packing plastics due to their potentially hydrolysable ester bond [21]. However, poor interfacial adhesion between the polymeric matrix and the natural fiber had been found to cause inefficient stress transfer under load. Consequently, these composites exhibit low mechanical strength [22].

As such, this study looked into the effect of fiber loading on mechanical properties for pineapple leaf fiber reinforced polylactic acid (PLA) composites. Furthermore, Li and Taj et al., claimed that the chemical composition of PALF content is as follows: 70-82 wt% of cellulose, 5-12.7 wt.% of lignin, 11.8 wt.% of moisture content, and 14^{o} of microfibrillar [23, 24]. Cellulose has hydrophilic properties that belong to the hydroxyl group, which causes poor interface and low resistance to moisture absorption when natural fiber is reinforced with hydrophobic matrix [25]. Other than that, previous studies [26-28] have revealed that natural fiber reinforced PLA composite displayed higher mechanical properties compared to natural fiber reinforced propylene or polyethylene. Although poor interfacial bonding exists between natural fiber and PLA matrix, its mechanical properties can be improved by adding surface treatment or compatibilizing agent [29]. Besides, the inclusion of compatibility agent like MAPE had been proven to significantly improve the in mechanical properties [23]. Therefore, this study investigated the effects of maleic anhydride polyethylene (MAPE) on the mechanical properties in PALF/PLA composite.

Fig. 1 A pi-chart massive agricultural waste producer

3. FINDINGS

Tensile properties

Fig. 2 illustrates the graph pertaining to tensile strength (TS) against fiber composition. An increment of 12.22% in TS was discovered as the fiber content was increased from 5% to 10%. However, a decrease by 4.22% was detected in TS as the fiber content was further increased to 15%. Nonetheless, all the results obtained did not exceed the TS of pure PLA, which portrays a value of 53 MPa. Meanwhile, the results of TS after the addition of MAPE are presented in Fig. 3. The TS was found to decrease after MAPE was added into the composite. The TS reduced from 34.62 MPa (0 wt.% of MAPE) to 27.17 MPa (6 wt. %), which displayed a decrease by 21.52%.

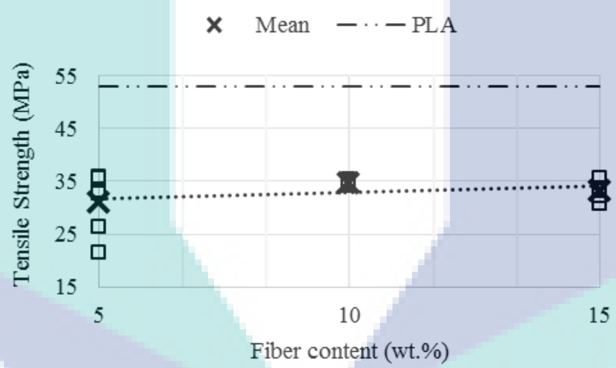


Fig. 2 Effect of fibre content on TS of PALF/PLA composites

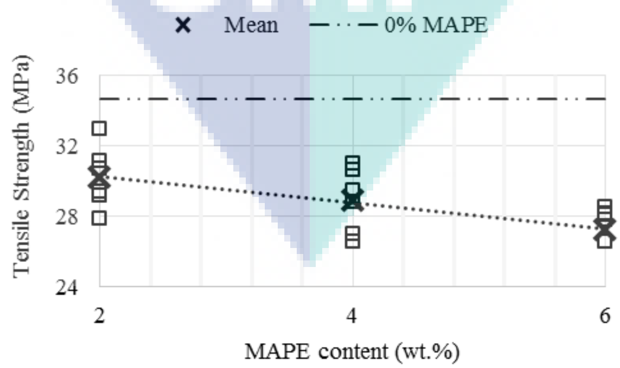


Fig. 3 Effect of MAPE on TS of PALF/PLA composites

Other than that, the graph of Young's modulus against fiber composition is given in Fig. 4. An increment of 17.14% was observed in Young's modulus as the fiber content was increased from 5 wt. % to 10 wt.%, but a decrease of 2.46% in Young's modulus was noticed as the fiber content was further increased to 15 wt.%. This indicted that the Young's modulus of the composite is about half less superior than the pure PLA that served as control. Moreover, the composite's tensile properties (TS and Young's modulus) of the composite exhibited a decrease and thus, are far less superior compared to pure PLA that served as control. This is due to the incompatibility of the hydrophilic nature (presence of hydroxyl and other polar group in the fiber) of PALF and the hydrophobic nature of PLA that lead tol result in poor interfacial adhesion and obstructed stress propagation between them [32]. Therefore, due to poor interfacial adhesion and incompatibility of PALF, the fiber is regarded as void and does not contribute to the composite as stress is not distributed among it. As such, the porosity of the composite is increased, thus the resulting in a decrease in TS.

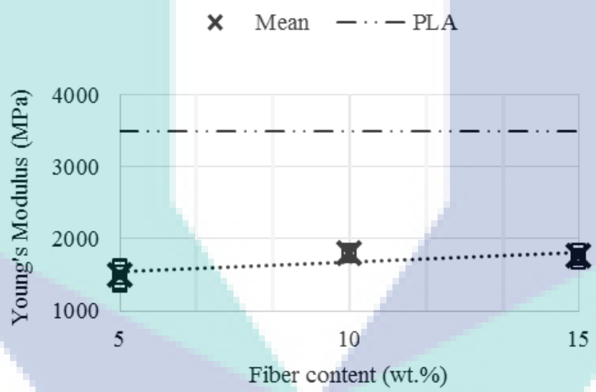


Fig. 4 Effect of fibre content on tensile modulus of PALF/PLA composite

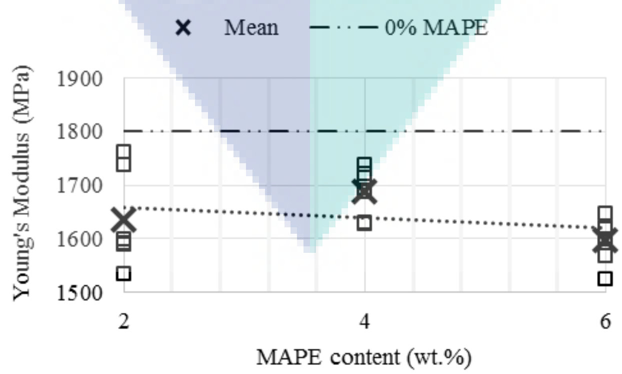


Fig. 5 Effect of compatibilizing agent (MAPE) on tensile modulus of PALF/PLA composite

On top of that, the effect of MAPE upon Young's modulus is shown in Fig. 5. After MAPE was added into the composite, the Young's modulus did not show much improvement compared to the untreated composite. Besides, the trend of Young's modulus revealed in this experiment is almost similar to that conducted previously by other researcher on thermoplastic rice starch (TPRS)/Cotton composite [33]. However, the value of Young's modulus increased when 4 wt.% of MAPE was added into the composite because the fibers actually turned brittle. Moreover, a decrement was noted with further addition of MAPE at 6 wt.%. This could due to the plasticizing effect from the MAPE that has a lower molecular weight compared to PLA. The plasticizing effect eventually lowers the rigidity of the composite thus, decreasing the Young's modulus [34].

On the other hand, the scanning electron micrograph that was taken at 400x magnification of PALF composite displayed poor adhesion between the PALF and the PLA matrix, as presented in Fig. 6a. It is also evident from SEM micrograph that fiber (PALF) pullout and cracks in PLA matrix led to a weak interfacial bonding between the PLA and the PALF.

In addition, Fig. 6b and Fig. 6c illustrate the fractured surface of the composites with the addition of 10 and 15 wt.% of PALF respectively. The TS and Young's modulus demonstrated a slight increase at 10 wt.% PALF content. This could be due to the domination of fiber over matrix as the PALF content was increased. As PALF increases, more fibers are available to constrain the matrix thus; the slight increase is further reflected in TS and Young's modulus [35-37]. Nevertheless, it showed a decrease at 15 wt.% PALF content. This is mainly due to high fiber content, in which the fibers behave as flaw and they are not properly aligned with the matrix. Moreover, the interfacial shear strength is low and the void content is higher. Furthermore, Fig. 6d and Fig. 6e show the SEM micrograph for the addition of 2 and 4 wt.% of MAPE in composites. The MAPE, nonetheless, did not show any enhancement in tensile properties. The tensile properties of the composite are far less superior after the addition of MAPE. This is due to the existence of compatibalizer molecules that further enlarge the gap between PALF and PLA matrix. In fact, further addition of MAPE leads to further reduction of strength and this is due to the existence of many byproducts that have formed and interfered with the coupling reaction, which results in weak bonding strength at the interface [38]. Even though MAPE has failed to contribute to better bonding or tensile properties of the composite, its presence functions as void, thus increasing the porosity of the composite and reducing the TS due to the weakening composite.

Flexural properties

Fig. 7 depicts that 5 wt.% of PALF/PLA composite withstands greater value of flexural strength with the mean value of 71.02 MPa. The increase in fiber loading, nonetheless, decreased the flexural properties of 10 wt.% and 15 wt.% fiber content by 37.7% and 77.4% respectively. The average flexural strength for treated PALF/PLA composite is show in Fig. 8, in which the average flexural stress increased gradually as the MAPE increased. At 6 wt.% of MAPE, the highest average flexural strength was about 51.27 MPa.

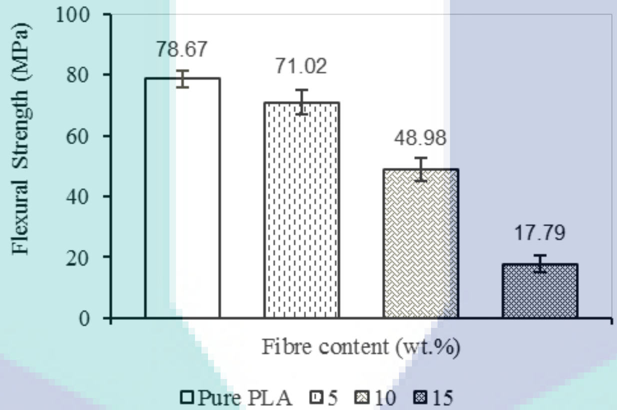


Fig. 7 Effect of fibre content on flexural strength of PALF/PLA composites

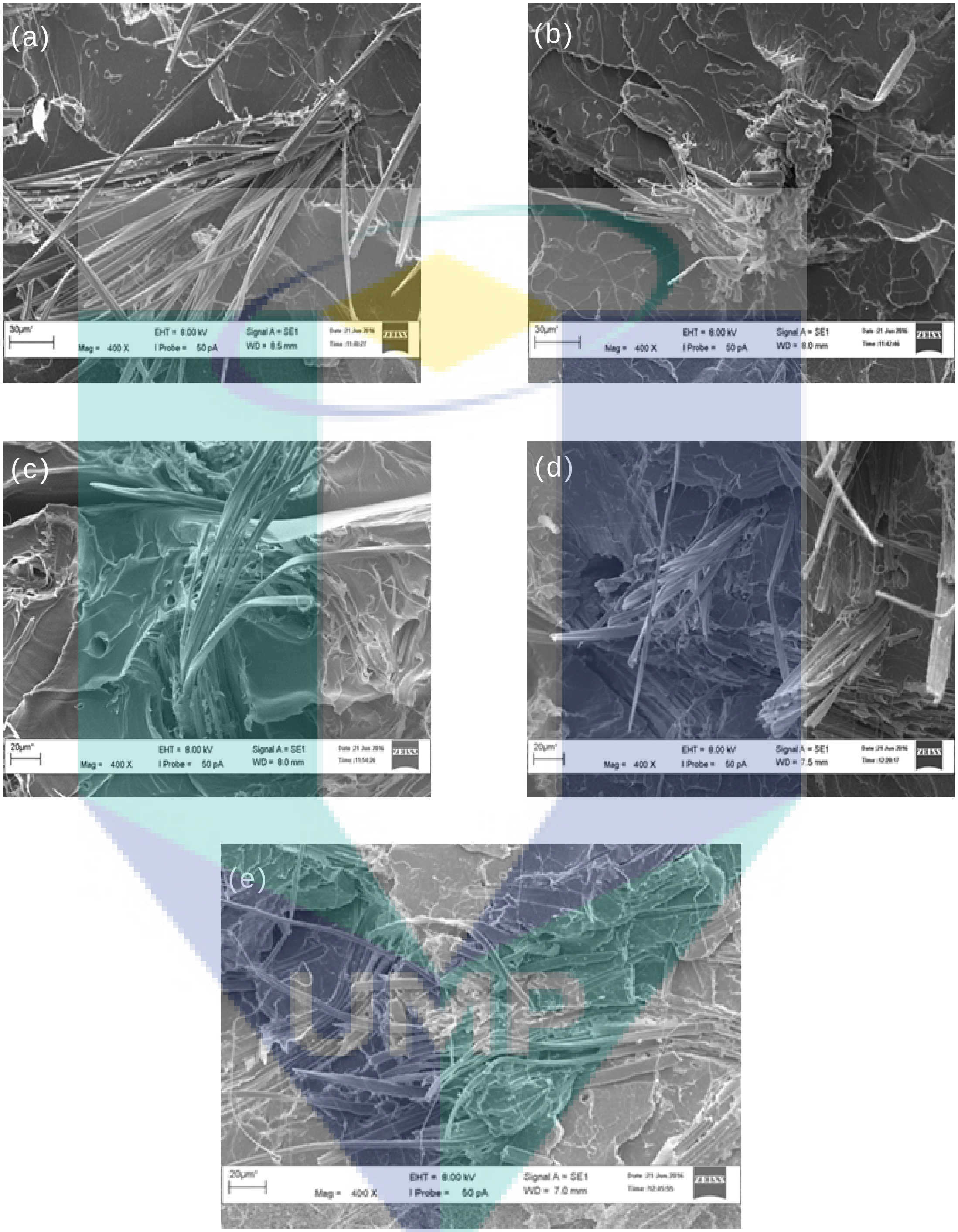


Fig. 6 SEM micrographs of tensile fracture of (a) 5 wt.% of PALF, (b) 10 wt.% of PALF, (C) 15 wt.% of PALF, (D) treated PALF with 2 wt.% of MAPE, and (E) treated PALF with 6 wt.% of MAPE

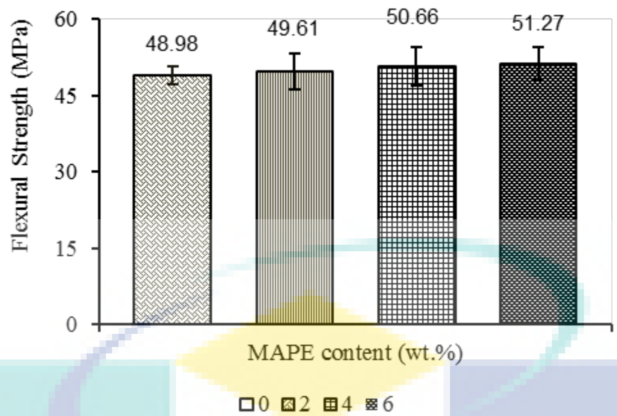


Fig. 8 Effect of MAPE on flexural strength of PALF/PLA composites

Meanwhile, Fig. 9 and Fig. 10 exemplify the flexural modulus for both untreated and treated PALF/PLA composites. In Fig. 8, the value of Young's modulus decreased as the fiber content was increased. However, a higher value of Young's modulus was obtained with 5 wt. % fiber content, which is 3449.78 MPa. On the other hand, Figure 9 portrays that after the compatibilizing agent was added into the composite, a couple of decrease by 6.7% and 5.57% had been noted for 2 wt.% and 4 wt.% of MAPE. The highest Young's modulus was achieved at 6 wt.% of MAPE with 3374.61 MPa. Therefore, the flexural results shows that the flexural performance of pineapple leaf fiber reinforced polylactic acid composites had been were higher for 5 wt.% of fiber loading, but generated a decrease in the properties for the next fiber loading.

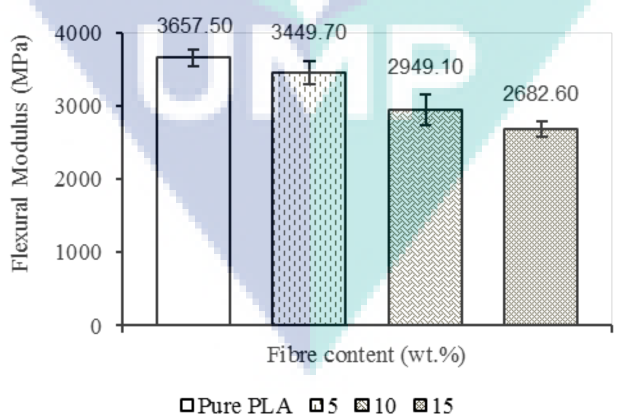


Fig. 9 Effect of fibre loading on flexural modulus of PALF/PLA composites

The 5 wt.% of pineapple leaf fiber also displays higher flexure properties among other fiber contents due to good interfacial bonding between the hydrophilic natural fiber and the hydrophobic polymer. The higher fiber content in composites has successfully affected the flexural properties of composites. This is mainly due to the weak interfacial adhesion between hydrophilic natural fibers and hydrophobic polymer. Hydrophilic natural fibers tend to increase the content of moisture in it. The moisture is dependent from voids and also has non-crystalline parts in the fiber. Nevertheless, poor interfacial bonding due to partial spaces between matrix and fiber material generates the weak structure of composite materials.

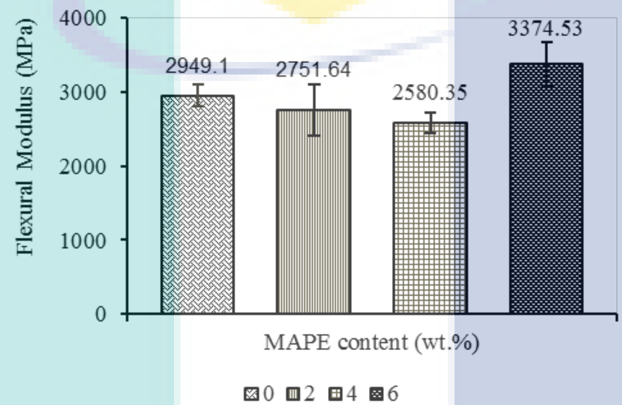


Fig. 10 Effect of MAPE on flexural modulus of PALF/PLA composites

Meanwhile, the effect of compatibilizing agent has increased the flexural properties for 10 wt.% of pineapple leaf fiber. This shows that the addition of compatibilizing agent has indeed improved the interfacial bonding between the hydrophilic natural fibers and the hydrophobic polymer. In other words, a compatibilizing agent chemically links hydrophilic and hydrophobic fibers. Besides, the compatibilizing agent also increases the performance in the aspect of flexurality, whereby the greatest flexural performance was attained at 6 wt.% of compatibilizing agent. Moreover, pineapple leaf fiber contains a high amount of cellulose. Due to the higher cellulose content, cracks can occur through weak bonding between the cells and cause intercellular fracture, but they do not influence the removal of microfibrils [39].

Charpy impact properties

The effect of fiber loading on the impact strength of the PALF/PLA composites can be observed in Fig. 11. With the increase in fiber content, the un-notched impact strength displayed a decrease linearly. This is similar to the results reported by several researchers [40, 41]. In fact, a total of 9.14 kJ/m^2 (17.22%) decreased from 0% to 5% of fiber content, whereas a reduction of 22.27 kJ/m^2 (41.96%) was noted from 0% to 10%. On the other hand, from 0% to 15% of fiber content, the impact strength demonstrated a drop that is almost half of the initial value of 26.45 kJ/m^2 (49.84%).

The decreasing impact strength is duly caused by poor interfacial adhesion between fiber and matrix. The poor interfacial bonding is comprised of micro-spaces between the fiber and the matrix polymer; prompting numerous micro-spaces or micro-cracks when an impact occurs. Hence, crack propagation and crack initiation could take place easily [42]. Besides, the increase in weight of fiber decreases the related strength due to the incompatibility between PALF and PLA. This occurs because PALF is hydrophilic in nature, which has lower compatibility with hydrophobic polymer. The hydrophilic behavior has the tendency to become wet because of water. Therefore, PALF can easily attract hydroxyl group better than hydrophobic polymer. This causes poor interface and low resistance to moisture absorption when natural fiber is reinforced with hydrophobic matrix [25]. Hence, a coupling agent is required to enhance the compatibility of hydrophilic fiber with hydrophobic polymer.

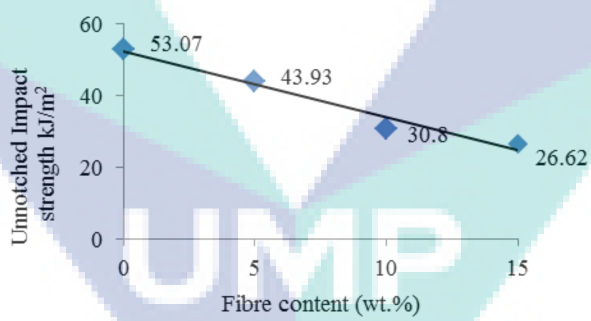


Fig. 11 Effect of fibre loading on impact strength of PALF/PLA composites

Fig. 12 presents the effect of MAPE on the impact strength of PALF/PLA composites. The highest increment was discovered at 4 wt.% with the impact value of 37.34 kJ/m^2, which is an increase by 21.23%. However, it decreased to 31.16 kJ/m^2 at 6 wt.%. Moreover, the percentage of performance for 4 and 6 wt.% decreased to about 16.55% (6.18 kJ/m^2). The impact strength of PALF/PLA composite further increased when the wt.% of compatibilizing agent was increased up to 4 wt.%. This observation is also similar to those reports retrieved from literature review [42-44]. The compatibilizing agent of MAPE enhances the impact strength because MAPE reacts with hydroxyl group on the surface of lignocellulose to form a linkage or bond. Nevertheless, the polyethylene (PE) tail from the MAPE forms a bond with the melted matrix. As a result, the formation of mechanical linkage between hydrophilic lignocellulose and hydrophobic polymer is generated [45]. However, the impact strength dropped with 6 wt% of MAPE. This is because; the increase in compatibilizing agent highly enhances the adhesion bonding between fiber and matrix polymer. Therefore, the crack begins at the fiber itself, but not at the interface as the impact happens. This is due to the fact that the matrix becomes less brittle than the fiber [42]. As a result, the impact strength of the composite displayed a decrease.

Moreover, there are also several other factors that affect the mechanical properties of composite and the interfacial adhesion bond between fiber and matrix, such as the processing method, the length of fiber, and the fiber orientation. These are some the factors that should be considered in improving the mechanical properties of a composite in order to produce a composite with excellent mechanical properties. On top of that, agglomeration of fiber takes place is formed as the fiber loading is increased during the roll mill mixer process, which resulting in poor mechanical properties.

These results are in reported to agreement with the findings obtained by several researchers. Moreover, low energy demand initiates crack at the area of agglomeration in the fiber [43]. Hence, a better mixing method should be considered, such as internal mixer and extrusion, which can hinder avoid agglomeration from occurring. This is indeed a crucial step to further improve the mechanical properties of composites.

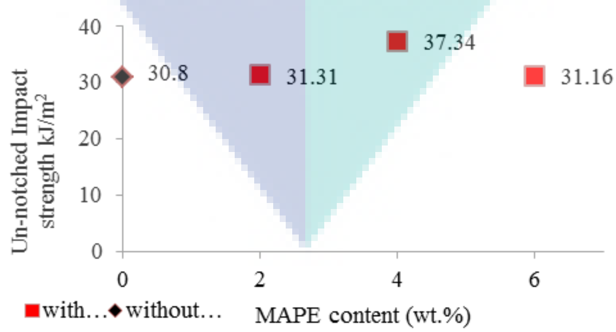


Fig. 12 Effect of MAPE on impact strength of PALF/PLA composites

4. CONCLUSION

In conclusion, as fiber loading was increased in the experiments, composites formed without compatibilizing agent displayed the highest values of TS and Young's modulus with 10 wt.% of PALF, in which the impact and flexure properties decreased. Meanwhile, the addition of MAPE indicated that the tensile properties possess lower value compared to those untreated. On the other hand, the flexural and impact properties of the composites were increased with the presence of MAPE. Hence, as a conclusion, the mechanical properties largely depend on fiber loading and the compatibility between matrix polymer and fiber.

5.3 RECOMMENDATIONS

These are some recommendations that can be consider to obtain better and more accurate results in future:

I. Treat the fibers prior to testing by using Sodium Hydroxide (NaOH) solution. This surface treatment will remove the wax, lignin and other unwanted residue from the fiber's surface therefore providing better adhesion with the matrix.

II. Use internal and extrusion machine instead of using roll mill mixer and crusher. This will ensure more uniform and better distribution of the fiber and PLA.

III. Ensure the fibers are completely dried to avoid moisture content as it may result in poor bonding with the matrix.

IV. Use long fiber instead of short fiber to fabricate the composite. Long fiber has larger surface area thus provide better entanglement with the matrix resulting in strongerbonding.

ACHIEVEMENT

i) Name of articles/ manuscripts/ books published

- The study of mechanical properties of pineapple leaf fibre reinforced tapioca based bioplastic resin composite, MATEC Web of Conference, 2016.
- Study on properties of tapioca resin polymer, International Journal of Automotive and Mechanical Engineering, 2016.
- The Mechanical Properties of Alkaline Treated Pineapple Leaf Fibre to Reinforce Tapioca Based Bioplastic Resin Composite, Materials Science Forum, 2017.

ii) Title of Paper presentations (international/ local)

1. The study of mechanical properties of pineapple leaf fibre reinforced tapioca based bioplastic resin composite, ICMER 2015
2. Study on properties of tapioca resin polymer, ICMER 2015
3. The Mechanical Properties of Alkaline Treated Pineapple Leaf Fibre to Reinforce Tapioca Based Bioplastic Resin Composite, ICMST, 2016

iii) Human Capital Development

iv) Awards/ Others

v) Others

REFERENCES

1. Singha, A. and Thakur, V. K., "Mechanical properties of natural fibre reinforced polymer composites," Bulletin of Materials Science, vol. 31, no. 5, pp. 791-799, 2008.
2. Jawaid, M. and Abdul Khalil, H. P. S., "Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review," Carbohydrate Polymers, vol. 86, no. 1, pp. 1-18, 2011.
3. Satyanarayana, K. G., Sukumaran, K., Mukherjee P. S., Pavithran, C. and Pillai, S, G, K., "Natural Fibre-Polymer Composites," vol. 12, no. August 1989, pp. 117-136, 1990.
4. Mohammed, L., Ansari, M. N., Pua G., Jawaid, M. and Islam, M., "A review on natural fiber reinforced polymer composite and its applications," International Journal of Polymer Science, vol. 2015, 2015.
5. Dicker, M. P., Duckworth, P. F., Baker A. B., Francois, G., Hazzard, M. K. and Weaver, P. M., "Green composites: A review of material attributes and complementary applications," Composites part A: applied science and manufacturing, vol. 56, pp. 280-289, 2014.
6. Davoodi, M. M., Sapuan, S. M., Ahmad D., Ali, A., Khalina, A and Joonobi, M., "Mechanical properties of hybrid kenaf/glass reinforced epoxy composite for passenger car bumper beam," Materials & Design, vol. 31, no. 10, pp. 4927-4932, 2010.
7. Mohanty, A.. Misra, M. and G. Hinrichsen., "Biofibers, biodegradable polymers and biocomposites: an overview," Macromolecular materials and Engineering, vol. 276, no. 1, pp. 1-24, 2000.
8. Bledzki, A. K., Faruk, O. and Sperber, V. E., "Cars from bio-fibres," Macromolecular Materials and Engineering, vol. 291, no. 5, pp. 449-457, 2006.
9. Suddell, B. C. Sand Evans, W. J., "Natural fiber composites in automotive applications," Natural fibres, biopolymers and biocomposites. CRC, Boca Raton, vol. 37, 2005.
10. Cicala, G., Cristaldi, G., Recca G., Ziegmann, G., El-Sabbagh, A. and Dickert, M., "Properties and performances of various hybrid glass/natural fibre composites for curved pipes," Materials & Design, vol. 30, no. 7, pp. 2538-2542, 2009.
11. Asim, M., Abdan, K., Jawaid, M., Nasir, M., Dashtizadeh, Z., Ishak, M.R. and Hoque, M., "A Review on Pineapple Leaves Fibre and Its Composites," International Journal of Polymer Science, pp. 1-17, 2015.
12. Mukherjee, T. and Kao, N., "PLA based biopolymer reinforced with natural fibre: a review," Journal of Polymers and the Environment, vol. 19, no. 3, pp. 714-725, 2011.
13. Bongarde, U. S. and Shinde, V. D., "Review on natural fiber reinforcement polymer composites," International Journal of Engineering Science and Innovative Technology (IJESIT), vol. 3, no. 2, pp. 431-436, 2014.
14. Ku, H., Wang, H., Pattarachaiyakoop, N. and Trada, M., "A review on the tensile properties of natural fiber reinforced polymer composites," Composites Part B: Engineering, vol. 42, no. 4, pp. 856-873, 2011.
15. Hempel, F., Bozarth, A. S., Lindenkamp, N., Klingl, A., Zauner, S., Linne, U. and Maier, U. G., "Microalgae as bioreactors for bioplastic production," Microbial Cell Factories, vol. 10, no. 1, pp. 81, October 17, 2011.
16. Rochman, C. M., Browne, M. A., Halpern, B. S., Hentschel, B. T., Hoh, E., Karapanagioti, H. K., Rioz-Mendoza, L. M., Takada, H., Teh, S. and Thompson, R. C., "Policy: Classify plastic waste as hazardous," Nature, vol. 494, no. 7436, pp. 169-171, 2013.
17. M. Okada, "Chemical syntheses of biodegradable polymers," Progress in Polymer Science, vol. 27, no. 1, pp. 87-133, 2002.
18. Kengkhetkit, N. and Amornsakchai, T., "Utilisation of pineapple leaf waste for plastic reinforcement : 1 . A novel extraction method for short pineapple leaf fiber," Industrial Crops & Products, vol. 40, pp. 55-61, 2012.
19. Yusof, Y., Yahya, S. A. and Adam, A., "Novel Technology for Sustainable Pineapple Leaf Fibers Productions," Procedia CIRP, vol. 26, pp. 756-760, 2015.
20. Neto, A. R. S., Araujo, M. A., Souza, F. V., Mattoso, L. H. and Marconcini, J. M., "Characterization and comparative evaluation of thermal, structural, chemical, mechanical and morphological properties of six pineapple leaf fiber varieties for use in composites," Industrial Crops and Products, vol. 43, pp. 529-537, 2013.
21. Graupner, N., Herrmann, A. S., and Müssig, J., "Natural and man-made cellulose fibre-reinforced poly(lactic acid) (PLA) composites: An overview about mechanical

characteristics and application areas," Composites Part A: Applied Science and Manufacturing, vol. 40, no. 6–7, pp. 810-821, 2009.

22. Orue, A., Jauregi, A., Peña-Rodriguez C., et al., "The effect of surface modifications on sisal fiber properties and sisal/poly (lactic acid) interface adhesion," Composites Part B: Engineering, vol. 73, pp. 132-138, 2015.
23. Taj, S., Munawar, M. A.and Khan, S., "Natural fiber-reinforced polymer composites," Proceedings-Pakistan Academy of Sciences, vol. 44, no. 2, pp. 129, 2007.
24. Li, X., Tabil, L. G. and Panigrahi, S., "Chemical treatments of natural fiber for use in natural fiber-reinforced composites: a review," Journal of Polymers and the Environment, vol. 15, no. 1, pp. 25-33, 2007.
25. V. A. Alvarez, R. A. Ruscekaite, and A. Vazquez, "Mechanical properties and water absorption behavior of composites made from a biodegradable matrix and alkaline-treated sisal fibers," Journal of composite materials, vol. 37, no. 17, pp. 1575-1588, 2003.
26. Ganster, J. and Fink, H. P., "Novel cellulose fibre reinforced thermoplastic materials," Cellulose, vol. 13, no. 3, pp. 271-280, 2006.
27. Oksman, K., Skrifvars, M. and Selin, J. F., "Natural fibres as reinforcement in polylactic acid (PLA) composites," Composites science and technology, vol. 63, no. 9, pp. 1317-1324, 2003.
28. García, M., Garmendia, I. and García, J., "Influence of natural fiber type in eco-composites," Journal of Applied Polymer Science, vol. 107, no. 5, pp. 2994-3004, 2008.
29. Jia, W., Gong, R. H. and Hogg, P. J., "Poly (lactic acid) fibre reinforced biodegradable composites," Composites Part B: Engineering, vol. 62, pp. 104-112, 2014.
30. Siregar, J. P., Sapuan, S. M., Rahman, M. Z. A., Dahlan, H. M. D. K., "Thermogravimetric Analysis (TGA) and Differential Scanning Calometric (DSC) Analysis of Pineapple Leaf Fibre (PALF) Reinforced High Impact Polystyrene (HIPS) Composites," Pertanika Journal of Science & Technology, vol. 19, no. 1, pp. 161-170, 2011.
31. Siregar, J.P., Sapuan, S. M., Rahman, M. Z. A and Dahlan, H. M. D. K., "Effects of alkali treatments on the tensile properties of pineapple leaf fibre reinforced high impact polystyrene composites," Pertanika Journal of Science & Technology, vol. 20, no. 2, pp. 409-414, 2012.
32. Nampoothiri, K. M., Nair, N. R.and John, R. P., "An overview of the recent developments in polylactide (PLA) research," Bioresource technology, vol. 101, no. 22, pp. 8493-8501, 2010.
33. Prachayawarakorn, J., Sangnitidej, P. and Boonpasith, P., "Properties of thermoplastic rice starch composites reinforced by cotton fiber or low-density polyethylene," Carbohydrate Polymers, vol. 81, no. 2, pp. 425-433, 2010.
34. Khalid, M., Ali, S., Abdullah L. C., Ratnam, C. T. and Choong, S. T., "Effect of MAPP as coupling agent on the mechanical properties of palm fiber empty fruit bunch and cellulose polypropylene biocomposites," International Journal of Engineering and Technology, vol. 3, no. 1, pp. 79-84, 2006.
35. Kalapakdee, A. and Amornsakchai, T., "Mechanical properties of preferentially aligned short pineapple leaf fiber reinforced thermoplastic elastomer: Effects of fiber content and matrix orientation," Polymer Testing, vol. 37, pp. 36-44, 2014.
36. Murty, V. and De, S., "Short jute fiber reinforced rubber composites," Rubber Chemistry and Technology, vol. 55, no. 2, pp. 287-308, 1982.
37. Coran, A., Boustany, K. and Hamed, P., "Short-fiber-rubber composites: The properties of oriented cellulose-fiber-elastomer composites," Rubber Chemistry and Technology, vol. 47, no. 2, pp. 396-410, 1974.
38. Lu, J. Z., Wu, Q. and Negulescu, I. I., "Wood-fiber/high-density-polyethylene composites: Coupling agent performance," Journal of Applied Polymer Science, vol. 96, no. 1, pp. 93-102, 2005.
39. Sukumaran, K., Satyanarayana, K., Pillai S. G. K., and Ravikumar, K. K., "Structure, physical and mechanical properties of plant fibers of Kerala," Metals Materials and Processes, vol. 13, no. 2/4, pp. 121-136, 2001.

40 Karmarkar, A., Chauhan, S., Modak J. M. and Chanda, M., "Mechanical properties of wood–fiber reinforced polypropylene composites: Effect of a novel compatibilizer with

isocyanate functional group," Composites Part A: Applied Science and Manufacturing, vol. 38, no. 2, pp. 227-233, 2007.

41 Yang, H. S.. Kim, H. J., Son J., Park, H. J, Lee, B. J. and Hwang, T. S., "Rice-husk flour filled polypropylene composites; mechanical and morphological study," Composite Structures, vol. 63, no. 3, pp. 305-312, 2004.

42 Yang, H. S. Wolcott, M. P., Kim, H. S., Kim, S. and Kim, H. J.., "Effect of different compatibilizing agents on the mechanical properties of lignocellulosic material filled polyethylene bio-composites," Composite Structures, vol. 79, no. 3, pp. 369-375, 2007.

43 Rana, A..K., Mandal, A. Mitra B, C., Jacobson., Rowell, R. and Banerjee, A. N., "Short jute fiber-reinforced polypropylene composites: effect of compatibilizer," Journal of Applied Polymer Science, vol. 69, no. 2, pp. 329-338, 1998.

44 Rana, A. K., Mandal, A. and Bandyopadhyay, S., "Short jute fiber reinforced polypropylene composites: effect of compatibiliser, impact modifier and fiber loading," Composites Science and Technology, vol. 63, no. 6, pp. 801-806, 2003.

45 Rowell, R. M., "Challenges in biomass–thermoplastic composites," Journal of Polymers and the Environment, vol. 15, no. 4, pp. 229-235, 2007.

APPENDIXES