

CHAPTER 1

INTRODUCTION

1. 1 Background of Study

Fibre reinforced polymeric composite materials have been prominent in nationwide industries for the past few decades. Extensive research and engineering on these composite materials have led to the production of such material that is now widely used in aerospace, leisure, construction and sporting industries [1, 2]. Inorganic reinforced fibres such as aramid, carbon and glass fibres possess fairly good mechanical properties but have serious drawbacks especially in terms of environmental concerns. Due to this, natural fibres reinforced polymer composites have attracted more research interest as an alternative to artificial fibre composites [3]. In comparison to synthetic fibre composites, natural fibres have low density, low cost, low in energy consumption, no abrasion to machine, and no health risk when inhaled [3]. Natural fibres are carbon dioxide neutral and unlike those otherwise, will release carbon dioxide to the atmosphere upon burning leading to the greenhouse effect [4].

As new environmental regulations are progressively adapted worldwide, new materials, products and processes are introduced to ensure these regulations are met. Incorporating bioresources into materials can reduce the dependency on petroleum based reserves. The development of biocomposites focuses on a new generation of fibre-reinforced plastics which are competitive with glass-fibre-reinforced composites that are environmentally safe and compatible due to the biodegradability of its nature [5].

Natural fibres are major renewable resource materials in the world and natural fibres such as jute, sisal, banana, flax, and hemp are abundantly available in countries such

as Brazil, China, India, Philippines and South African countries. The Government of Mexico and UNIDO underwent a co-operative research project to develop work on low cost building materials based on henequen, palm, sisal fibres and unsaturated polyester resin to fully exploit these natural resources [6]. Moreover, automotive components which is reinforced with natural fibres are practiced by many vehicle manufacturers until now which includes Audi, Opel, Daimler-Chrysler, Fiat, Ford, Mercedes Benz, Peugeot, Renault, Volvo, VW, Volkswagen, and BMW [7]. Bio-based composites would enhance mechanical strength and acoustic performance, reduce material weight, energy/fuel consumption and processing time, lower production cost, improve passenger safety and shatterproof performance under extreme temperature changes, and improve biodegradability for the auto interior parts [8].

Waste products of food processing such as sugarcane bagasse and coconut husk (coir) can be properly utilized in order to provide cheap engineering materials due to their characteristics. Coir, the fibre from coconut shells are found in tropical countries and possess hard-wearing quality and durability which is used in making floor furnishing materials, yarn, rope and other industrial products as seen in Figure 1-1 [9-11].

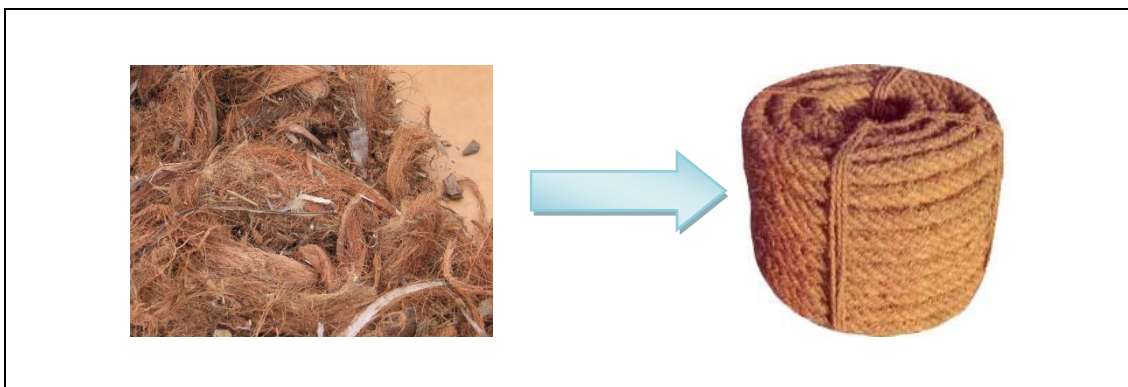


Figure 1-1 An example of coir utilization to produce ropes.

On the other hand, sugarcane bagasse is a value-added industrial product in automotive, agricultural and other industrial sectors [12]. These fibres have only been utilized in a small percentage to the total world production even though they are cheap and are abundantly available. Therefore, natural fibres should be fully

exploited not only due to its capability as a material and its cheap price, but it will also provide a clean and greener environment.

1.2 Problem Statement

Natural fibre reinforced composites have been studied in many ways especially for its mechanical properties to fully understand their characteristics. Different types of natural fibres such as hemp, jute, sisal, sugarcane bagasse and coconut husk (coir) were reinforced with polymer matrix to produce biocomposites with good mechanical properties [13-17]. One other important factor in determining the mechanical properties of biocomposites is fibre volume fraction or filler loading [18]. The higher amount of filler content in the biocomposite would generally improve the mechanical properties. Wambua et. al [3] conducted a research on the mechanical properties of different biocomposites and found that the tensile and flexural strength of hemp fibre was higher than kenaf, sisal and jute biocomposites and increasing the filler loading increased these properties.

The strength of these biocomposites differs from each other due to its different fibre chemical properties which includes the content of lignin, cellulose and hemicellulose. The properties which provides strength of a fibre is the cellulose content, and bagasse has relatively high content. On the other hand, coir has high lignin contents which contribute to high elongation values which makes it an attractive resource. Approximately, 54 million dry tons of bagasse is produced annually throughout the world and the annual world production of coconut is about 42 million, which would equate to almost 50 billion coconuts [19-20]. Lack of studies was conducted on coir and bagasse as reinforcements in biocomposites eventhough these resources are abundantly available.

Therefore, more research should be done in order to ensure that the mechanical properties of these biocomposites are equally capable to composites which are reinforced with inorganic fibres. It is also important to understand the effects of chemical treatment on the fibre as well as the fibre content in a biocomposites on its mechanical properties.

1.3 Objective

The objective of the study is to investigate the effect of filler loading on the mechanical properties of coir and bagasse reinforced high density polyethylene (HDPE) biocomposites.

1.4 Scope of Study

The research focuses on the influence of different filler loading on the mechanical properties of the biocomposites. Coir and bagasse fillers were used as reinforcement in the HDPE matrix. The filler content was varied from 0, 5, 10 and 15 wt%. To improve the fibre-matrix adhesion, chemical treatment namely silane with 3 wt% was performed on the fillers. The fillers and the matrix were compounded using injection moulding process. The mechanical properties of the composites which includes tensile and flexural were studied. The morphology was closely observed by microscopic inspection of chemical treated fillers and tensile fractured surfaces of the biocomposite specimens.

CHAPTER 2

THEORY AND LITERATURE REVIEW

2.1 Theory

2.1.1 Composite

Composite consists of two or more materials which have different physical or chemical properties that are combined together and remain distinguishable [21]. These materials are called constituents, and most composites consist of two constituent materials namely a binder or matrix, and a reinforcement. The reinforcement which is stronger and stiffer than the matrix will improve the mechanical properties of the composite. The matrix serves the purpose of holding the reinforcements together by maintaining their relative positions and it helps to transfer load among the reinforcement since reinforcements are usually discontinuous.

Reinforcements are divided into three main forms: particulate, discontinuous fibre or short fibre and continuous fibre or long fibre [22, 22-23]. Particulate size would have almost equal dimensions in all directions but not necessarily spherical. Discontinuous reinforcement has fibre length varying from a few millimetres to a few centimetres.

Fillers can be categorized into two which are synthetic and natural fillers. Synthetic fillers come from synthetic materials such as polyolefins, polyester, polyurethane, and polyvinyl chloride [24]. Natural fillers are made from plants, animal and mineral sources [5]. Vegetable fillers have been of interest in many research and they are comprised of mainly cellulose such as cotton, jute, flax, sisal, hemp, and oil palm empty fruit bunch [5].

Matrix materials are usually made out of plastic or better known as resin solution. Some of the common polymers used are polyester, polyethylene, epoxy, polyimide, polyamide, polypropylene and others [21].

2.1.2 High Density Polyethylene

The properties of polyethylene depend on the molecular structure which includes the degree of crystallinity, branching, degree of polymerization and molecular weight distribution [25]. Ethylene is one of the most important petrochemicals which maybe be polymerized to produce products as diverse as low-molecular-weight waxes to highly crystalline, high-molecular-weight polyethylene (HDPE) [24]. The properties of the two extreme polyethylene grades which are low density (LDPE) and HDPE are given in Table 2-1. When HDPE goes through injection moulding, the temperature is set from 200-300°C and the mould temperatures is set between 10 to 90°C [25].

Table 2-1 Properties of commodity polyolefin [24].

Property	ASTM	LDPE	HDPE
Specific gravity	D792	0.91 – 0.93	0.94 – 0.97
Crystallinity, %	-	50 – 70	80 – 95
Melt Temperature	-	98 – 120	127 – 135
Tensile strength, MPa	D638	4.1 – 16	21 – 38
Tensile modulus, GPa	D638	0.10 – 0.26	0.41 – 1.24
Elongation-to-break, %	D638	90 – 800	20 – 130
Impact strength, Notched Izod, J m ⁻¹	D256	No break	27 – 1068
Heat-deflection temperature, °C, at 455 kPa (66 psi)	D648	38 – 49	60 – 88

2.1.3 Natural fillers

The depletion of natural resources, imposed of strict regulations on the usage of synthetic material, growing environmental concerns and economic considerations are

some of reasons to look into renewable resources such as biomass in various industrial applications. Cheap lignocellulosic agricultural by-products such as coir, sugarcane bagasse, corn stover, banana leaves are available in large quantities.

Several methods are employed to extract natural cellulose fillers from lignocellulosic by-products such as using bacteria and fungi, mechanical, and chemical methods [10]. One of the most common chemical retting methods uses alkalis, mild acids and enzymes [10]. Mechanical separation methods usually use decorticating machines, steam explosion (STEX), ammonia fibre extraction, and Tilby process [10].

The chemical composition of natural fillers especially the cellulose, hemicelluloses, and lignin content generally affects its mechanical properties. Table 2-2 shows the various types of natural fillers and its composition. Cellulose is the main structural component which provides strength and stability to the filler [5, 10]. Hemicellulose acts as the filler in between the cellulose and lignin which affects the stiffness and strength of fibres or individual cells [10]. On the other hand, lignin provides plant tissue and individual fibres with compressive strength and the content influences the structure, morphology, flexibility and rate of hydrolysis [10]. Table 2-3 shows the mechanical properties of various natural fillers compared to conventional fillers used as reinforcements.

Table 2-2 Availability and composition of natural fillers [10].

Fibre source	Availability <i>10³ tonnes</i>	Cellulose %	Hemicellulose %	Lignin %
Corn stover	727	38-40	28	7-21
Pineapple leaf fibre	-	70-82	18	5-12
Coir	100	36-43	0.15-0.25	41-45
Bagasse	100	32-48	19-24	23-32
Banana	-	60-65	6-8	5-10
Wheat straw	568	33-38	26-32	17-19
Rice straw	5799	28-36	23-28	12-14
Sorghum stalks	252	27	25	11
Barley straw	195	31-45	27-38	14-19

Table 2-3 Mechanical properties of natural and conventional fillers [26].

Fibre	Density (g/cm³)	Elongation (%)	Tensile Strength (MPa)	Young's Modulus (GPa)
Cotton	1.5-1.6	7.0-8.0	287-597	5.5-12.6
Jute	1.3	1.5-1.8	393-773	26.5
Flax	1.5	2.7-3.2	345-1035	27.6
Hemp	-	1.6	690	-
Ramie	-	3.6-3.8	400-938	61.4-128
Sisal	1.5	2.0-2.5	511-635	9.4-22.0
Coir	1.2	30.0	175	4.0-6.0
Viscose (Cord)	-	11.4	593	11.0
Soft wood kraft	1.5	-	1000	40.0
E-glass	2.5	2.5	2000-3500	70.0
S-glass	2.5	2.8	4570	86.0
Aramide (normal)	1.4	3.3-3.7	3000-3150	63.0-67.0
Carbon (standard)	1.4	1.4-1.8	4000	230.0-240.0

2.1.4 Injection Moulding

Injection moulding is one of the most common methods in manufacturing industry which produces many of available plastic products available now such as bottles [27]. It has the ability of producing parts from thermoplastic and thermosetting plastic materials. Injection moulding is suitable for all thermoplastics but only some thermosets and elastomers are suitable for this process [25]. Injection moulding has the advantage in high production rates, repeatable tolerances, low labour cost, minimal scrap losses and minimal finishing need to be done on the parts [28]. The schematic representation of an injection moulding machine is shown in Figure 2-2.

The process of injection moulding involves feeding granular plastic by gravity through a hopper by gravity into a heated barrel. The plastic granules are forced into a heated chamber by a screw-type plunger when it is melted. The melted granules will be forced through a nozzle by the plunger allowing it to enter the mould cavity

through a gate and runner system. The plastic solidifies when it is filled into the cooled mould.

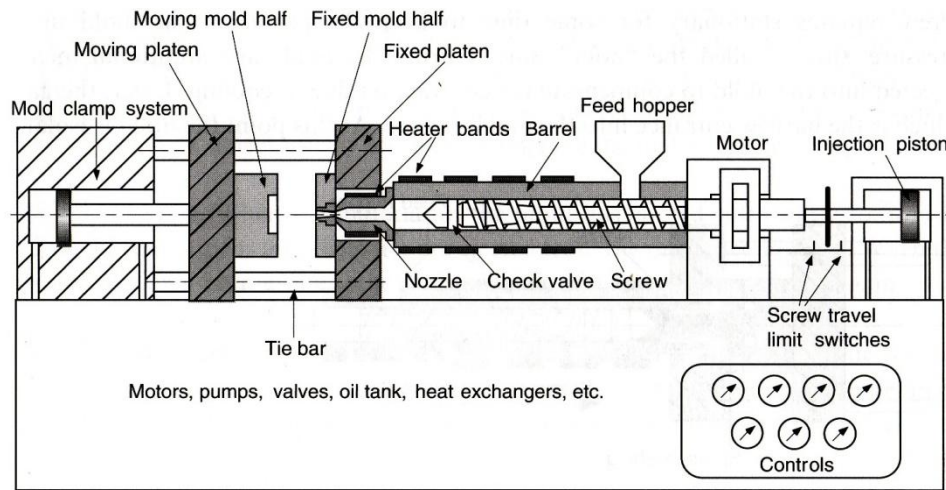


Figure 2-1 Schematic diagram of a typical injection moulding machine [29].

2.1.5 Silane Treatment

The main component of natural fibres is cellulose and due to its chemical structure, many hydroxyl groups are available for interaction with water molecules by hydrogen bonding [5]. The major disadvantage of cellulose fibre is their polar nature which is incompatible with nonpolar polymers. To increase the interfacial bonding between natural fibres and polymer, fibres can be treated with silane.

Chemical bonding theory stated that the bifunctional silane molecules which link the surface of cellulose through a siloxane bridge while its organofunctional group bonds with the polymer resin [5]. The general chemical formula of silane is X_3Si-R , where R is a group which can react with the resin, and the X -group can hydrolyze to form a silanol group in aqueous solution which in turn reacts with the cellulose surface [5].

As the treated fibres are dried, the silanol and $-OH$ groups on the cellulose fibre surface forms a polysiloxane layer which bonds to the surface due to reversible condensation [5]. The R -groups on the treated fibre surface will react with the functional groups present in the polymer resin which will form a chain of primary strong covalent bonds [5]. Treating the fibres with silane as coupling agents improve

the interfacial adhesion which will also improve the mechanical properties of the composite [5, 17].

2.2 Literature Review

Most published work concentrated on the chemical treatment of fibres to enhance the adhesion between the fibre and the matrix to further improve the mechanical properties. For both coir and bagasse biocomposites, studies had shown that tensile and flexural strength of these biocomposites increased with higher filler content, not forgetting proper chemical treatment. Fibre morphology was also conducted in most research to support the data obtained for the mechanical properties after testing these biocomposites. Bagasse fibre received less attention as reinforcement in research when compared to coir fibre. However, no research was conducted on these fibres in particulate form as reinforcements in HDPE matrix with silane as the chemical treatment agent.

Studies were done on the influence of fibre loading on the mechanical properties of natural fibres reinforced polymer matrix [12, 17-18, 30]. In an experiment which studied the influence of fibre microstructure on mechanical properties of natural fibre reinforced polypropylene, the content of natural fibres which were sisal, banana, jute and flax were varied between 20 and 45 wt% [17]. The results showed the increase in modulus when the fibre content was increased except for banana. Oksman et. al [17] stated that the addition of fibres increases the modulus in all composites with jute the highest increase from 1.3 GPa of pure PP to 4.9 GPa for the composites with 44 wt% jute. Oksman et. al [17] also indicated that increasing the fibre loading did not affect the flexural strength which was an indication of poor adhesion between the fibres and the matrix as the stress cannot be transferred from the matrix to the stronger fibres.

Another research was done on the physico-mechanical properties of chemically treated palm and coir fibre reinforced polypropylene composites [30]. In the research, treated and untreated palm and coir of 3 mm in length were compounded with fibre content at 0, 15, 20, 25, 30 and 35 wt%. The results showed the tensile strength of the biocomposite using raw fibre decreased with the increase of fibre content whereas the treated fibre showed optimum tensile strength with 15 wt% fibre

loading. Haque et. al [30] indicated that the flexural strength of the fibres increases with higher fibre loading but decreases from 30 to 35 wt% due to the decrease in fibre/matrix adhesion. Therefore, the proposed fibre content of both palm and coir fibres were 30 wt% to yield optimum mechanical properties of the biocomposites.

In a study on the effect of fibre surface treatment and fibre loading on the properties of bagasse fibre-reinforced unsaturated polyester composites, bagasse was compounded through vacuum bagging technique with varying fibre content of 0, 10, 15 and 20 vol% [12]. The results showed that the tensile strength and the flexural strength increased with the increase of fibre loading and the best mechanical properties of the biocomposite was at 20 vol% fibre.

Various natural fibres such as sisal, kenaf, hemp, jute and coir were used as reinforcements in natural fibres: can they replace glass in fibre reinforced plastics? [3]. Among the natural fibres, hemp fibres displayed the highest tensile and flexural strength. Wambua et. al [3] reported that coir fibre showed the lowest tensile and flexural but higher in impact strength compared to jute and kenaf biocomposites. Wambua et. al [3] explained that the low tensile and flexural strength in coir biocomposites was due to its low cellulose content and high microfibrillar angle.

Fibre size also played a significant role in determining the mechanical properties of biocomposites. In a research on the mechanical properties of polyethylene-oil palm empty fruit bunch composite, three sizes of empty fruit bunch particle size were used; mesh 35 (270-500 μm), 60 (180-270 μm), and 80 (75-180 μm) [18]. The results showed that samples with smaller particle size filler show higher modulus of elasticity at 30 wt% with no significant difference with higher loading. Tensile strength for all sizes decreased as filler loading was increased but mesh 35 remained the lowest. Rozman et. al [18] stated that the decreasing trend in tensile strength is due to irregular-shaped fillers which made the filler unable to support stresses transferred from the polymer matrix. The tensile strength and tensile modulus for mesh 35 are the highest among the other two sizes used as reinforcements.

Coupling agents were utilized in many composite fabrications to improve the adhesion between natural fibres with polymer matrix [12, 17, 19, 30-31]. Oksman et.

al [17] improved the interfacial adhesion between the reinforcing fibres and the matrix by introducing maleated polypropylene (Epolene 43 WAX). The results showed that the coupling agent improved strength and stiffness of the composite. Oksman et. al [17] stated that good interfacial adhesion is important in obtaining good mechanical properties. Vilay et. al [12] treated sugarcane bagasse with sodium hydroxide and acrylic acid treatments and the biocomposites inhibited higher average tensile strength and tensile modulus compared to untreated fibres and reduction in water absorption which aided the adhesion between the matrix and fibres.

Mulinari et. al [31] explained that the modification of sugarcane bagasse cellulose with zirconium oxychloride improved that tensile strength of the biocomposite compared to the unmodified filler where the sugarcane bagasse cellulose/HDPE composites were obtained by extrusion. The bagasse fibres were treated and compounded using extruder and compression moulding process at 10 wt% filler loading. The results indicated that treating the bagasse reduced the biocomposite elongation by 26% and increased the tensile modulus by 50% compared to untreated bagasse.

In another study, natural fibres were treated with alkali, urethane derivative of polypropylene glycol (PPG), permanganate, maleic anhydride and toluene diisocyanate (TDI). Joseph et. al [32] stated that fibre-matrix interface was important in determining the physical and mechanical properties of the composites. The results showed that the tensile properties of PP/sisal composites improved when treated with maleic anhydride compared to other chemically treated sisal fibre. Joseph et. al [32] also stated that the chemical treatment had reduced the hydrophilic nature of the fibre which improved the fibre-matrix interfacial bonding.

Natural fillers were also treated with silane as coupling chemicals. Abdelmouleh et. al [33] claimed that silane was commercially available in large scale. Also, by looking at the molecular structure of silane, they bear alkoxy silane groups at one end which were capable of reacting with OH-rich surface, and at the other end, they have a large number of functional groups which can be tailored as a function of the matrix to be used. The results showed that the fibre-natural rubber adhesion was enhanced.

The SEM observation showed the fibres broke off near the surface without any voids on the fractured surface which was an evidence of the adhesion improvement.

CHAPTER 3

METHODOLOGY

3.1 Materials

3.1.1 Matrix

High Density Polypropylene (HDPE) was supplied by Titan Petchem (M) Sdn. Bhd. with a melt flow index of 7 g/10 min and a density of 0.961 g/cm³.

3.1.2 Reinforcement

Coir and bagasse were used as natural fibres and were obtained locally. The fibres were in its raw form.

3.2 Processing of Composite Material

3.2.1 Fibre Preparation

Particulate fillers were used in this study. The raw fibres were grinded and sieved using 425 µm ELE International Lab Test to obtain the ideal filler size. The moisture content of the fillers was removed by putting it in the oven at 80°C for 24 hours.

3.2.2 Silane Treatment

To improve interfacial and adhesive properties, the fillers was treated with 3 wt% of vinyltriethoxysilane (VTS) in an ethanol/water (60/40) solution for 1 hour under agitation and the pH of the solution and was controlled to 3.5-4 with acetic acid. The fillers were left in the oven again to dry at 80°C for 24 hours.

3.2.3 Composite Preparation

The fillers were compounded using injection moulding machine type Tat Ming ME20 III with an injection pressure of 80 bar and temperatures of 120°C (zone 1) and 180°C (zone 2 and 3) to produce dog-bone shaped specimens for mechanical testing. The filler content of each specimen type was varied from 0, 5, 10 and 15 wt%. Five specimens were produced for each set of filler content.

3.3 Characterization Testing

3.3.1 Mechanical Testing

To test on the mechanical properties of the specimens, LLOYD Instruments LR5K Universal Testing Machine was employed. Tensile and flexural testings were performed on the specimens by following ISO 527-2 and ISO 178, respectively. The dog bone shaped specimens with crosshead speed of 5 mm/min and 2 mm/min will be used for the tensile and flexural tests respectively.

Some important formula that were used in the calculations are:

For tensile strength,

$$\sigma_t = \frac{P}{bd} \quad (1)$$

where; σ_t = tensile strength (MPa)
P = load (N)
b = width of specimen (mm)
d = thickness of specimen (mm)

For flexural strength,

$$\sigma_f = \frac{3PL}{2bd^2} \quad (2)$$

where; σ_f = flexural strength (MPa)
L = distance between support span (mm)

3.3.2 Scanning Electron Microscopy (SEM)

The morphology of the silane treated fillers and the fracture surface of the specimens was studied using Oxford Leo 1430 Scanning Electron Microscope with the resolution of 137 eV at 5.9 KeV. The specimens were mounted on aluminium stubs and sputtered-coated with thin layer of gold to avoid electrostatic charging.

3.3.3 Project Activities

The detailed Gantt chart of the project activities is in Appendix I.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Scanning Electron Microscopy

Coir and bagasse fillers surface morphology before processing after drying and silane treated were examined using SEM.

4.1.1 Coir Morphology

Figure 4-1 (a) showed the coir fillers at initial condition before drying to remove the moisture content. Figure 4-1 (a) illustrates that surface is covered with a layer of substances which include pectin, lignin, and other impurities [34]. A porous structure is also observed. Figure 4-1 (b) showed that the pores and nodes are less visible and surface appeared smoother after drying. After silane treatment was done on the coir fillers, the surface became rougher, textured and damaged as can be seen in Figure 4-1 (c). The coupling agent had penetrated into the micro-pores which formed a mechanically interlocked coating on its surface [11]. These modifications on the fibre surface is ideal since it will effectively results in improved surface tension, wetting ability, swelling, adhesion and compatibility with polymeric materials when compounded together [11].

4.1.2 Bagasse Morphology

Figure 4-1 (d) showed the residue of bagasse filler initially as mostly pith and exhibits porous structure [12]. Vilay et. al [12] explained that all natural cellulose fillers are multi cellular and the individual cells are bounded by natural polymers such as lignin and pectin. The hollow cavity which is lumen exists in unit cell of biofibres. The porous size on the filler surface was greatly reduced after oven drying as seen in Figure 4-1 (e). After silane treatment, the surface structure of the fibre did

not show much change when compared with the initial except for minimal damage. A more compressed cellular structure and the reduction of void content in the filler is ideal for good fibre adhesion to the polymer matrix [12].

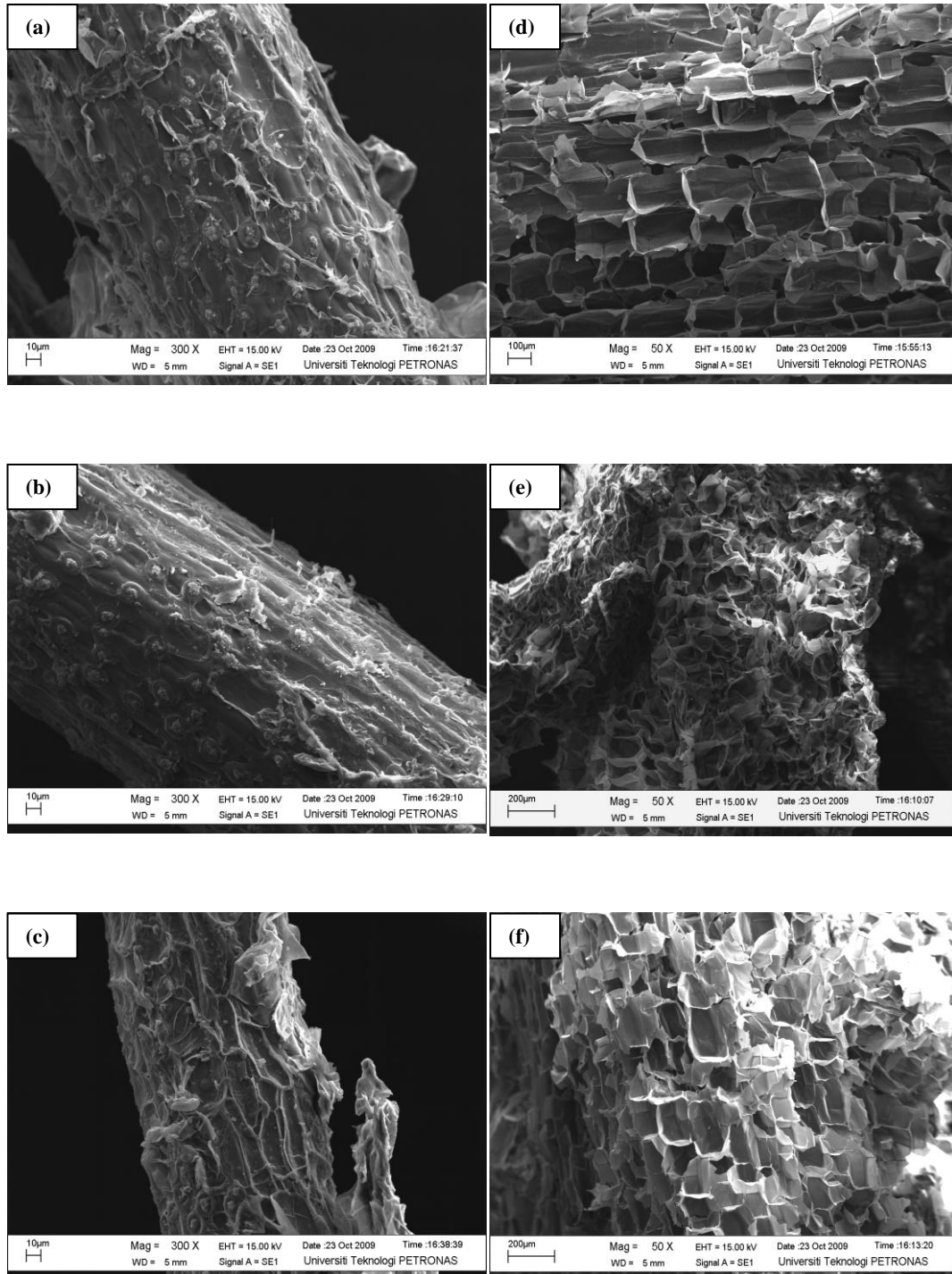


Figure 4-1 Fibre surface morphology of: coir – (a) at initial, (b) oven dried, (c) silane treated, bagasse – (d) at initial, (e) oven dried, (f) silane treated.

4.2 Effect of Filler Loading on the Mechanical Properties

4.2.1 Tensile strength

The effect of filler loading on the tensile strength of coir and bagasse filler reinforced biocomposites is shown in Figure 4-2. Incorporating coir with HDPE resulted in a 21% decrease in tensile strength of coir biocomposite from 25.1 MPa to 19.6 MPa for coir biocomposite and 24% drop to 19.0 MPa for bagasse biocomposite. In this study, there were no significant differences in tensile strength when the filler loading was increased. Coir showed a decrement of 8% in tensile strength when comparing filler loading at 5 wt% with 15 wt% filler, a reduction from 19.6 MPa to 18.0 MPa. On the other hand, bagasse showed a slight decrease of 6% when filler loading was increased from 10 to 15 wt% filler, a decrease from 19.4 MPa to 18.2 MPa.

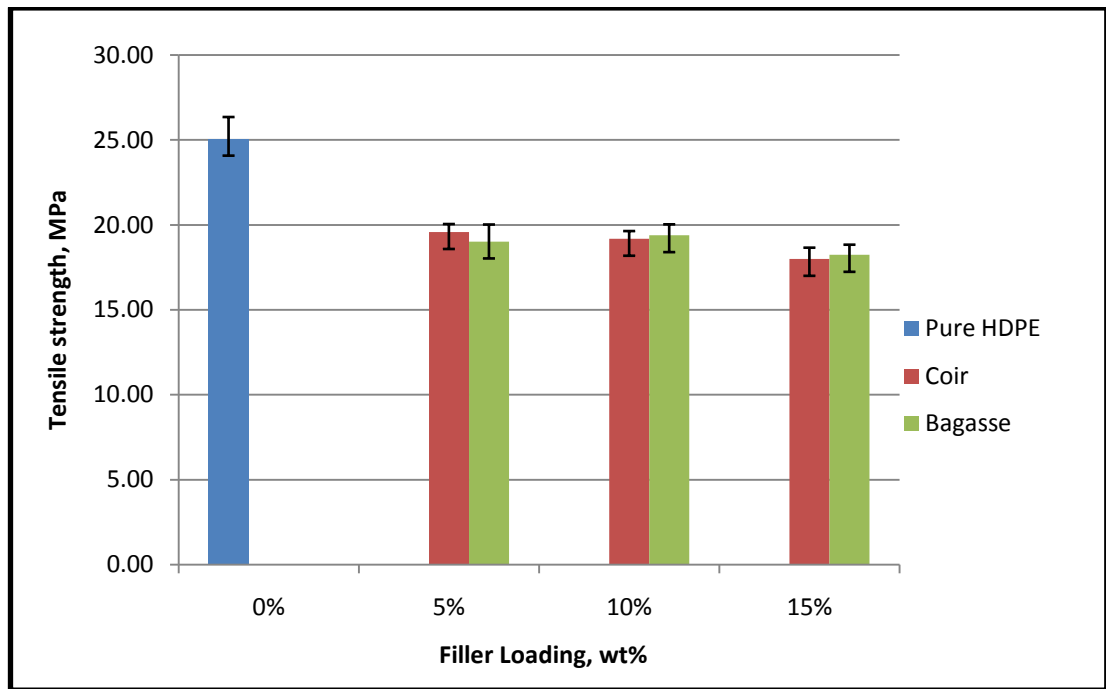


Figure 4-2 The effect of filler loading on tensile strength.

The decrease in tensile strength after adding natural fillers into the polymeric matrix was similar to the results obtained by Rozman et. al [18]. This is due to the irregularity in the filler shape and size [18]. According to Rozman et. al [18], natural fillers are inconsistent in their uniform circular cross section and aspect ratio and consistency in size normally improves the strength. Due to this irregularity, these fillers were unable to support stresses transferred from the matrix, which therefore

decreases the tensile strength of biocomposites. The results obtained by Haque et. al [30] using raw coir fibre showed almost similar trending to this study when coir fibre was introduced into PP matrix. Haque et. al [30] indicated that after treating coir fibre with benzene diazonium salt solution, the tensile strength was higher than pure polypropylene. Haque et. al [30] explained that poor bonding between the fibre and matrix and poor wetting caused the decreased in tensile strength due to the incompatibility of coir fibre and PP. Other than that, agglomerations which are considered to be a defect also caused the decrease in tensile strength when adding reinforcements into the matrix which causes inefficient fibre dispersion inside the matrix [31].

Therefore, the results obtained from these studies had shown that silane treatment is not effective in improving the adhesion between coir and bagasse with HDPE matrix causing fibre pullouts. Moreover, the reduction in tensile strength of the biocomposites when compared to pure HDPE and as well as the insignificant changes with different filler loading indicates that these natural fillers are less effective as reinforcing material with HDPE.

4.2.2 Flexural Strength

Flexural strength of coir and bagasse reinforced biocomposites at different filler loading is shown in Figure 4-3. The flexural strength of these biocomposites showed a slight decrement as these natural fillers were introduced into the HDPE matrix. The flexural strength of coir biocomposite decreased by 6% from 28.0 MPa to 26.4 MPa, a decrement from pure HDPE to 5 wt% filler. On the other hand, the flexural strength of bagasse biocomposite at 5 wt% was 25.5 MPa, a 9% decrement from pure HDPE flexural strength. Increasing the filler content did not have much effect the flexural strength of coir biocomposite, and the flexural strength was observed lowest at 10 wt% filler, a 8% decrement from pure HDPE. However, a gradual decrement was seen for bagasse biocomposite when filler loading was increased. A 11% and 14% drop was observed at 10 wt% and 15 wt% filler, respectively when the flexural strength of bagasse biocomposites at these filler contents were compared with pure HDPE. Other than that, the results also indicated the flexural strength of coir biocomposite is higher than bagasse biocomposite due to higher lignin content in coir

fillers compared to bagasse [35]. The flexural strength of coir biocomposite was 11% higher than of bagasse biocomposite at 15 wt% filler.

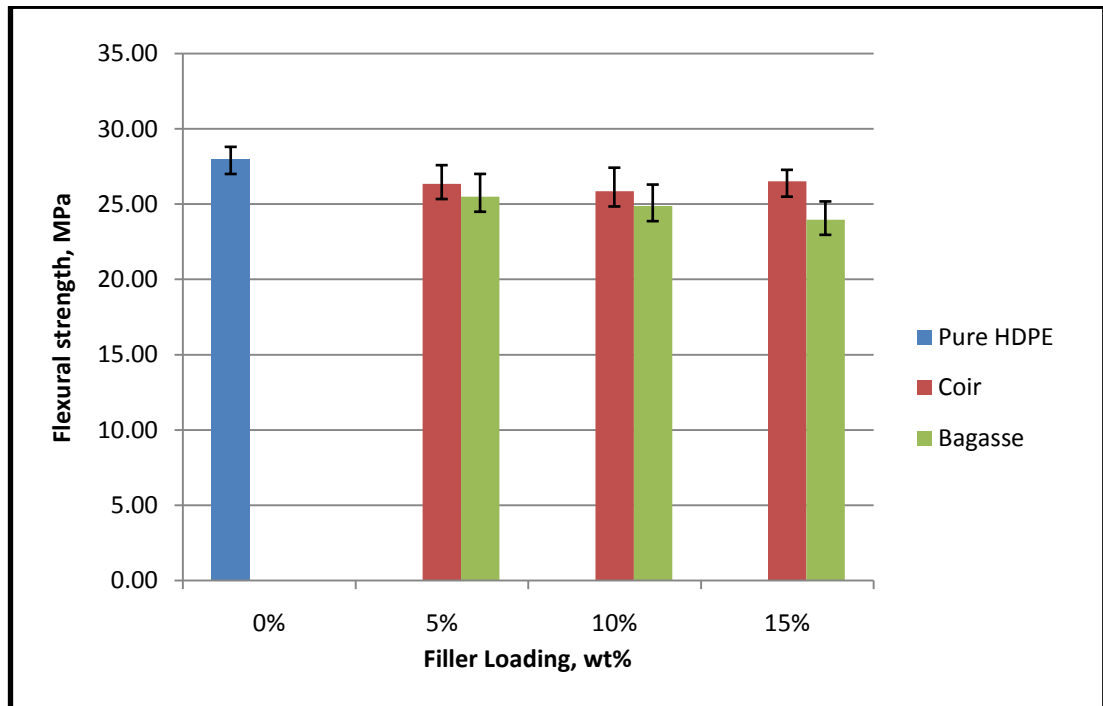


Figure 4-3 The effect of filler loading on flexural strength.

The results obtained by Oksman et. al [17] and Rozman et. al [18] revealed that the filler content had little effect on the flexural strength of the biocomposites due to poor bonding between the filler and the matrix. The reduction in flexural strength for bagasse biocomposite as filler content was increased is also due to the decrease in fibre and matrix adhesion [30]. Fibre and matrix adhesion is important as it enables stresses to be transferred from the matrix to the fillers [17, 30]. Once again, the results signified that these natural fillers were not effective as reinforcements with HDPE matrix.

4.3 Morphological Analysis

4.3.1 Coir biocomposites

Scanning electron micrograph of the fracture surface for coir biocomposites is shown in Figure 4-4 to 4-6. At 20X magnification, the overview of the fracture surface indicated the specimen at 5 wt% was more of a ductile fracture as seen in Figure 4-4 (a). At 15 wt%, the specimen showed a more brittle fracture as indicated in Figure 4-

4 (b). At 50X magnification, poor fibre distribution due to agglomeration can be seen in Figure 4-5 (a) for 5 wt% coir biocomposite.

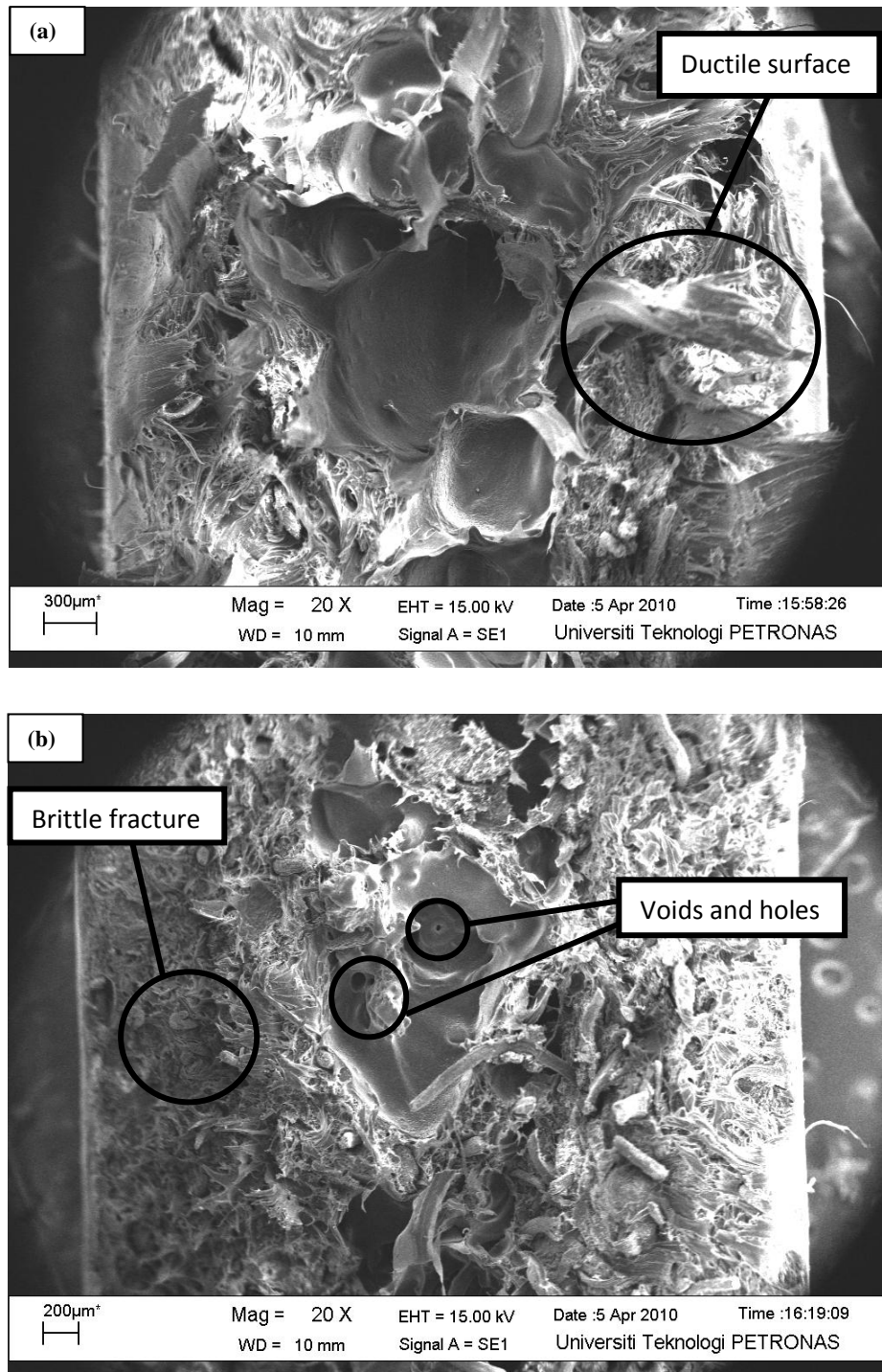


Figure 4-4 Micrographs of coir biocomposites at 20X magnification for: (a) 5 wt% and (b) 15 wt% filler.

Figure 4-5 (b) showed several voids and holes due to poor fibre adhesion which consequently contributes to fibre pullout as well as irregular shape and size fillers. Poor wetting can also be seen which also contributes to poor tensile strength of the biocomposites. The fracture of the fibre after sustaining load can be seen 500X magnification in Figure 4-6 for both 5 and 15 wt% filler.

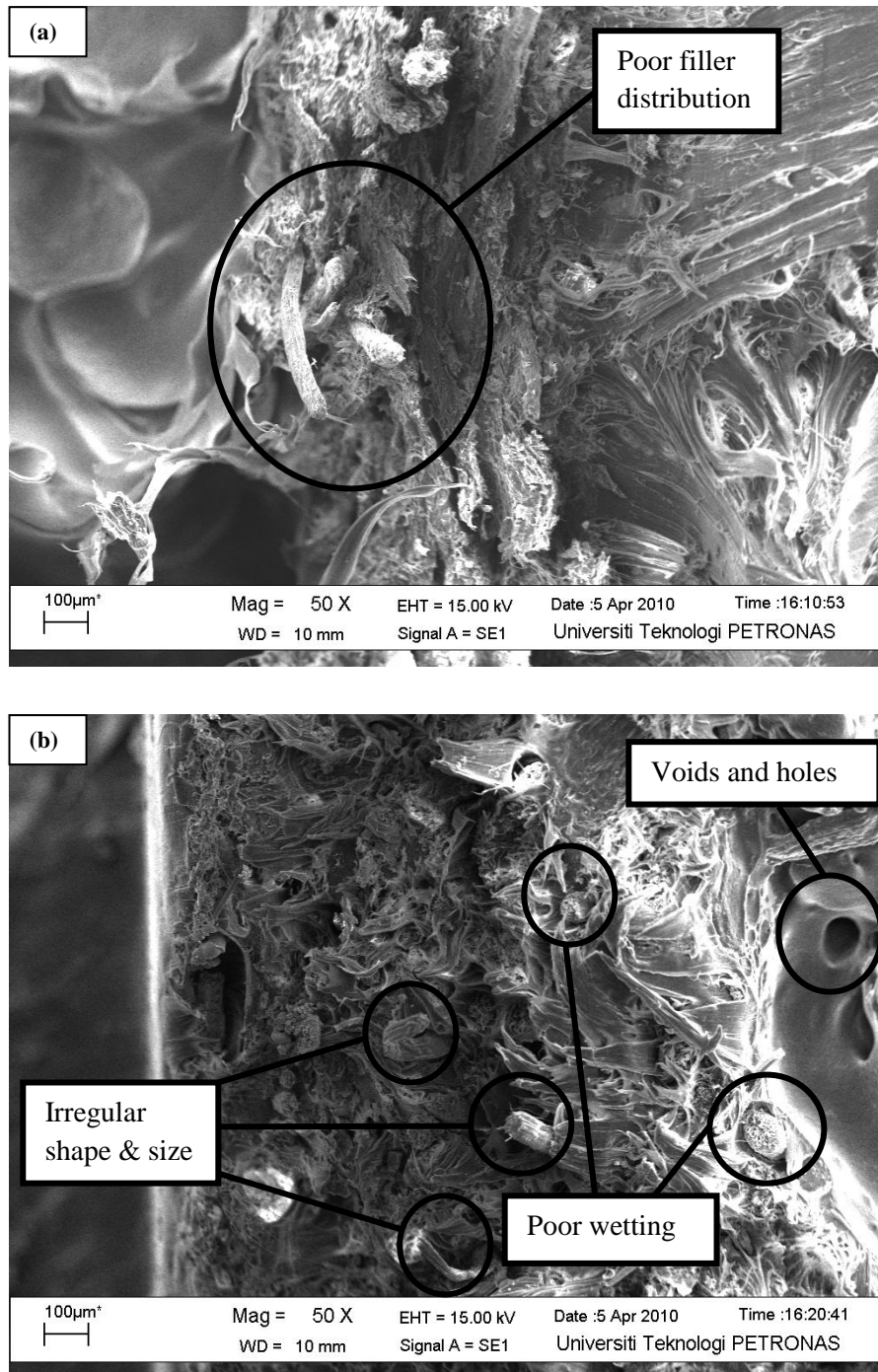


Figure 4-5 Micrographs of coir biocomposites at 50X magnification for: (a) 5 wt% and (b) 15 wt% filler.

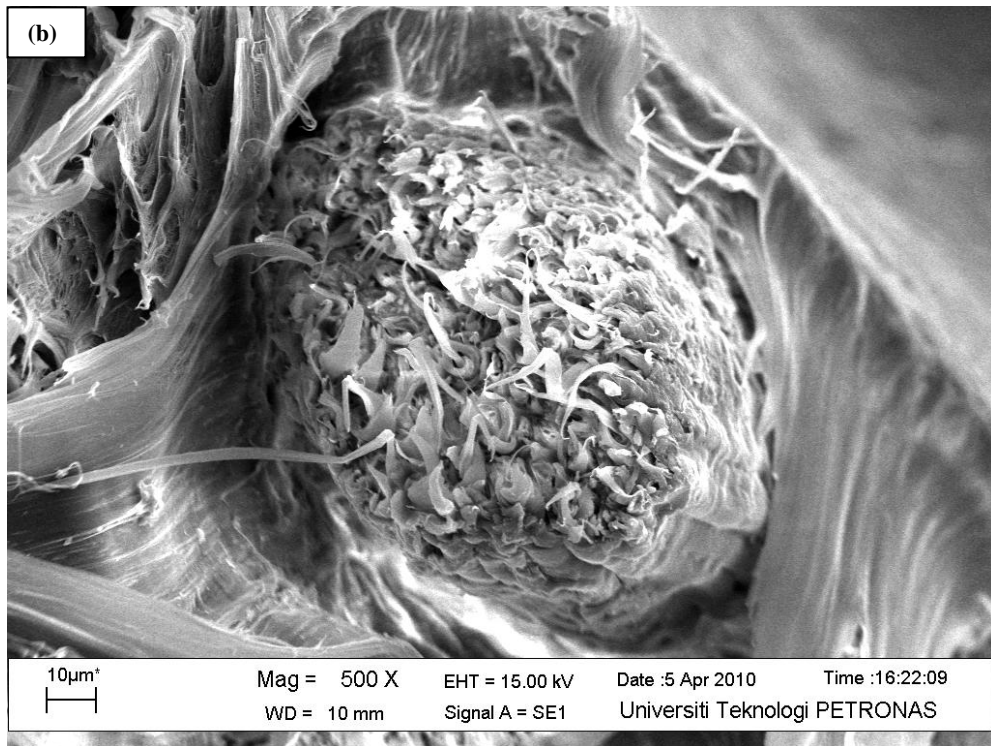
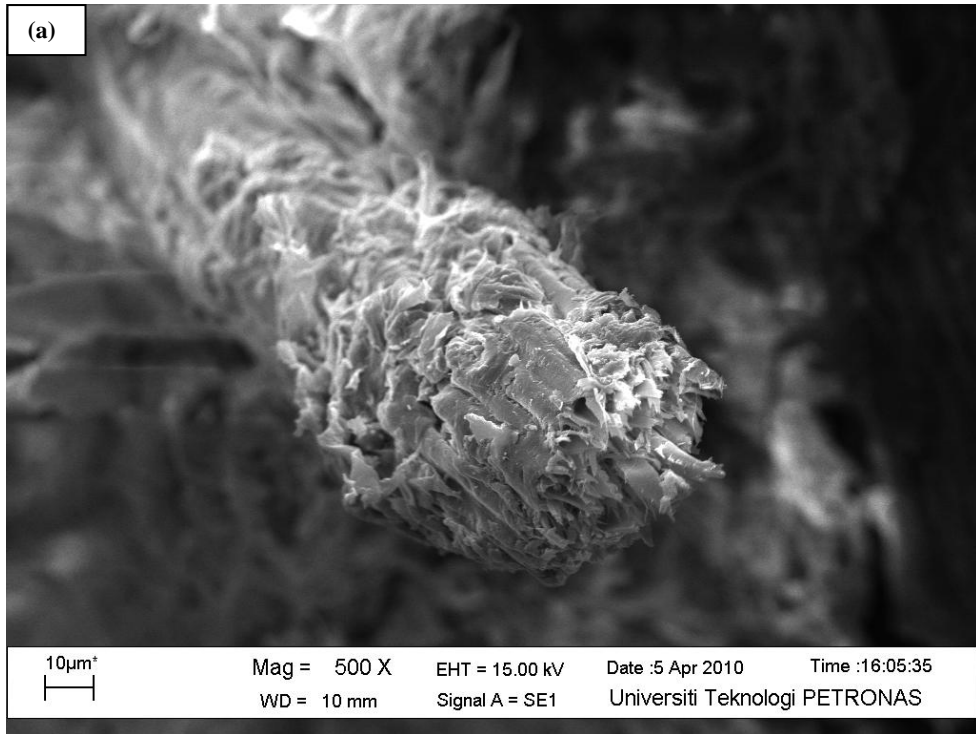


Figure 4-6 Micrographs of coir biocomposites at 500X magnification for: (a) 5 wt% and (b) 15 wt%.

4.3.2 Bagasse biocomposites

The micrograph of the fracture surface for bagasse biocomposites at 5 wt% and 15 wt% are shown in Figure 4-7 and Figure 4-8. The visibility of bagasse fillers at the fracture surface was limited due to the ductility of the biocomposites and also the physical structure of the bagasse itself. However, a single compressed and fractured fibre can be seen in Figure 4-7 and Figure 4-8.

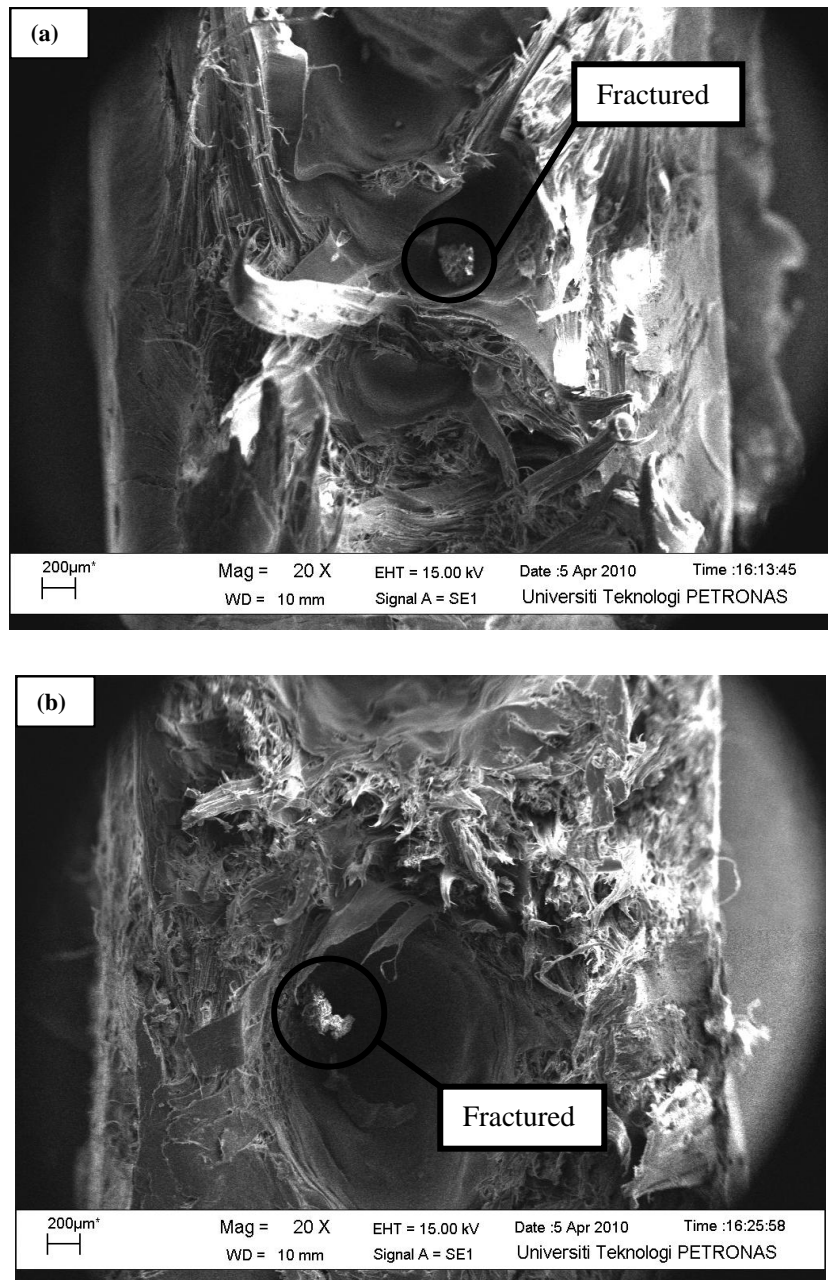


Figure 4-7 Micrographs of bagasse biocomposites at 20X magnification for: (a) 5 wt% and (b) 15 wt% filler.

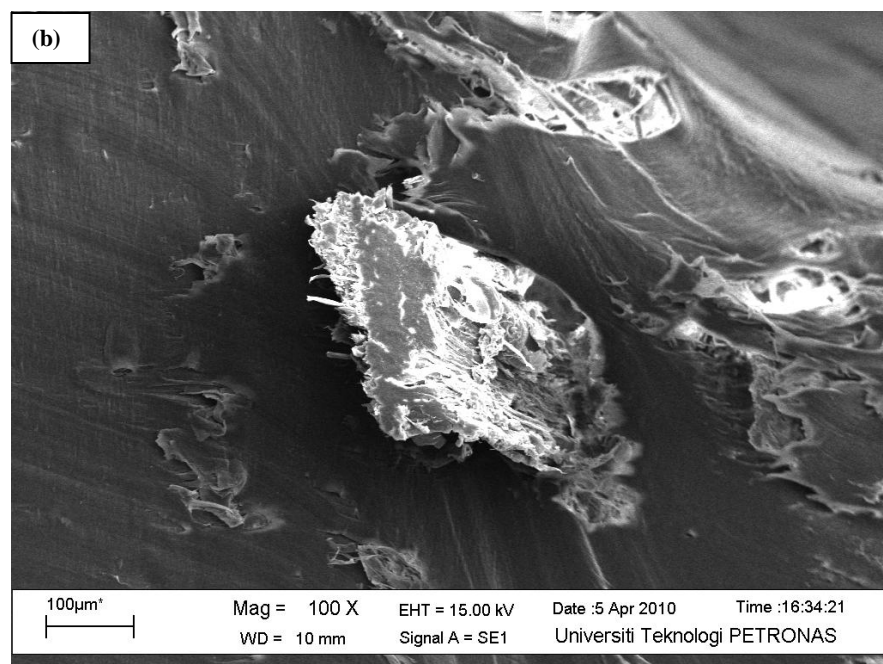
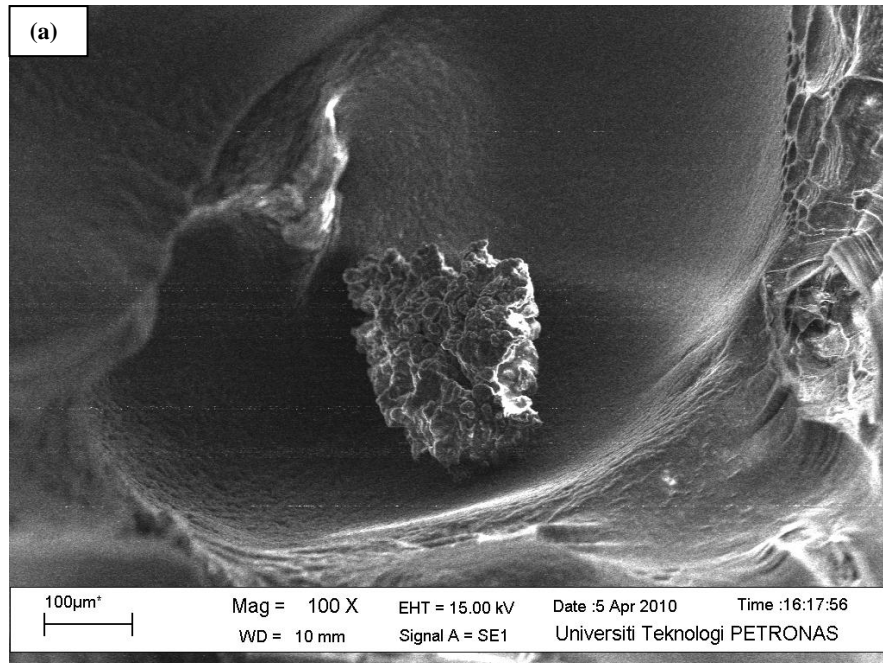


Figure 4-8 Micrographs of bagasse biocomposites at 500X magnification for: (a) 5 wt% and (b) 15 wt% filler.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The integration of coir and bagasse filler with HDPE as the polymeric matrix to create biocomposites was investigated. The SEM micrograph had shown the grafting of silane as the chemical treatment on coir filler, but had minimal effect on bagasse filler. Based on the results obtained from tensile testing, both biocomposites exhibited almost similar results in tensile strength especially when these natural fillers were introduced into the HDPE matrix. A significant drop was observed after adding 5 wt% of natural fillers due to irregularity of natural filler sizes, poor bonding between the filler and matrix, as well as fibre agglomerations which caused poor filler dispersion. No significant changes were observed for the tensile strength when the filler loading was increased from 5 wt% to 15 wt% which also indicates poor fibre and matrix bonding.

The flexural strength of coir biocomposite had no significant influence by the filler content up from 0 wt% to 15 wt% filler. However, the flexural strength of bagasse biocomposite decreased as the filler content was increased from up to 15 wt%. These obtained results indicate the effect of poor filler and matrix adhesion especially in the case for bagasse biocomposite. Other than that, coir biocomposite had shown higher flexural strength compared to bagasse biocomposite due to higher lignin content in its nature. For further investigation, SEM was conducted at the fracture surface of these biocomposites and fibre agglomerations, fibre pullouts, and poor wetting were identified through the micrographs. The presence of these defects signified their contribution in resulting poor mechanical properties on these biocomposites. Therefore, coir and bagasse fillers were found not to be effective reinforcements with HDPE matrix.

The results had indicated the tensile strength for both coir and bagasse were not affected by filler loading from 5 wt% to 15 wt%, but had a significant reduction from 0 wt% to 5 wt%. Other than that, filler loading from 0 wt% to 15 wt% had reduced the flexural strength of bagasse biocomposite. However, the flexural strength for coir biocomposite was not influenced by the filler loading from 0 wt% to 15 wt%.

5.2 Recommendations

The adhesion between fillers and matrix is important to further improve the mechanical properties of biocomposites. Coir biocomposite had shown an improvement in flexural strength, which indicated that chemical treatment using silane was proper. However, silane treatment had very minimal effect on bagasse filler, which resulted in poor mechanical properties. Therefore, it is vital for proper chemical treatment to be conducted according to different types of natural fillers.

Other than that, dispersion of these fillers in the biocomposites greatly affects the mechanical properties. In this study, the biocomposites were compounded using injection moulding process, which would result in poor dispersion. The fillers and matrix should be well mixed and have good distribution throughout the specimens in order to achieve best results. A proper process would be to compound these fillers and matrix using an extruder before moulding it to acquire the specimens.

Generally, HDPE has higher melting temperature compared to other thermoplastics. Higher temperature during the compounding process would cause natural fillers to be burnt, and higher filler loading causes more filler to be burnt before the HDPE melts. It would be more feasible to select a polymer matrix which has lower melting temperature to prevent the fillers from being burnt during the compounding process.

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APPENDIX I – GANTT CHART

APPENDIX II – MECHANICAL TESTING RESULTS

a) Tensile strength readings

Reading	Tensile Strength (MPa)					
	Coir 5 wt%	Coir 10 wt%	Coir 15 wt%	Bagasse 5 wt%	Bagasse 10 wt%	Bagasse 15 wt%
1	19.32	19.13	17.68	19.36	19.52	18.01
2	19.29	19.81	18.60	19.68	20.32	17.99
3	20.12	18.87	17.98	17.54	19.25	17.56
4	10.81	18.67	17.08	19.51	18.55	18.47
5	9.40	19.42	18.64	13.45	19.32	19.13
Average	19.58	19.18	18.00	19.02	19.39	18.23
StDev	0.47	0.45	0.66	0.99	0.64	0.60

b) Flexural strength readings

Reading	Flexural Strength (MPa)					
	Coir 5 wt%	Coir 10 wt%	Coir 15 wt%	Bagasse 5 wt%	Bagasse 10 wt%	Bagasse 15 wt%
1	30.36	32.16	31.12	27.60	25.72	27.13
2	28.19	30.17	30.78	27.31	27.11	27.92
3	27.64	29.11	28.61	27.85	27.16	25.07
4	30.00	28.20	30.16	27.12	30.15	23.43
5	29.95	28.27	30.46	31.21	26.30	27.22
Average	29.23	29.58	30.22	28.22	27.29	26.15
StDev	1.23	1.65	0.97	1.70	1.71	1.86

c) Pure HDPE

Reading	Tensile Strength, MPa	Flexural Strength, MPa
1	24.06	27.06
2	26.45	26.06
3	25.89	28.28
4	25.51	29.01
5	23.44	29.67
Average	25.07	28.01
StDev	1.27	1.46

APPENDIX III – TEST SPECIMEN SPECIFICATIONS

	Specimen	Weight, g	Width, mm	Thickness, mm
Pure HDPE	P1	12.17	4.12	10.03
	P2	12.15	4.12	10.02
	P3	12.17	4.16	10.05
	P4	12.15	4.17	10.03
	P5	12.09	4.18	10.05

	Specimen	Weight, g	Width, mm	Thickness, mm
Coir 5 wt%	A3	12.08	4.20	10.07
	A4	12.11	4.19	10.10
	A7	12.12	4.21	10.14
	A13	12.19	4.19	10.08
	A14	12.15	4.18	10.07

	Specimen	Weight, g	Width, mm	Thickness, mm
Coir 10 wt%	C4	12.21	4.24	10.11
	C6	12.22	4.27	10.11
	C15	12.19	4.21	10.18
	C16	12.20	4.26	10.13
	C17	12.19	4.27	10.16

	Specimen	Weight, g	Width, mm	Thickness, mm
Coir 15 wt%	E1	12.22	4.22	10.22
	E3	12.23	4.25	10.15
	E5	12.20	4.21	10.14
	E8	12.19	4.26	10.26
	E14	12.23	4.21	10.21

	Specimen	Weight, g	Width, mm	Thickness, mm
Bagasse 5 wt%	B2	11.99	4.19	10.16
	B4	12.05	4.18	10.10
	B9	12.12	4.17	10.08
	B10	12.11	4.19	10.11
	B12	12.02	4.19	10.11

	Specimen	Weight, g	Width, mm	Thickness, mm
Bagasse 10 wt%	D4	12.21	4.17	10.02
	D6	12.32	4.20	10.05
	D7	12.25	4.18	10.07
	D9	12.24	4.19	10.05
	D10	12.28	4.16	10.01

	Specimen	Weight, g	Width, mm	Thickness, mm
Bagasse 15 wt%	F2	12.13	4.21	10.09
	F9	12.22	4.23	10.17
	F10	12.25	4.07	10.10
	F11	12.31	4.11	10.12
	F12	12.29	4.14	10.11

APPENDIX IV – ISO 527 & ISO 178

Tensile Properties: ASTM D638-94b vs. ISO 527-93E		
	<u>ASTM</u>	<u>ISO</u>
Preferred Specimen Type:	Type I	Type 1A (ISO 3167)
Specimen Dimensions (mm):		
Overall Length:	165 (min)	150 (min)
Length of Narrow Section:	57±0.5	80±2
Radius (tab to gage):	76±1	20-25
Width @ ends:	19±6.4	20±0.2
Width of narrow portion:	13±0.5	10±0.2
Preferred thickness:	3.2±0.4	4±0.2
Gauge Length:	50±0.25	50±.5
Initial grip distance:	115±5	±1
Test Speed (mm/min)	5, 50, 500mm/min as specified by the material spec. or based on time to rupture	50mm/min for ductile materials. 5mm/min for brittle materials (Per ISO 10350)

Flexural Properties: ASTM D790-92 vs. ISO 178-93E		
	<u>ASTM</u>	<u>ISO</u>
Preferred Specimen:	length: 127mm width: 12.7mm thickness: 3.2mm	length: 80mm±2mm width: 10mm±0.2mm thickness: 4mm±0.2mm
Support Span:	Span to depth ratio of 16	Span to depth ratio of 16
Support Radius	5±0.1mm or 3.2mm minimum up to 1.5 times the depth for 3.2mm or greater specimen thickness	5±0.1
Loading Nose Radius	5±0.1mm or 3.2mm minimum up to 4 times the specimen depth	5±0.1mm
Test Speed:	1.3mm/min±50% for the preferred specimen	2mm/min±20% for the preferred specimen
Maximum allowable strain:	5%	3.5% (at conventional deflection of 1.5 x height)