CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

The natural fibre reinforced composite material is currently gaining worldwide recognition and is growing rapidly, replacing inorganic fibre reinforced composites used in the industries [1-2]. In the past, inorganic fibre composites have been widely used in construction, building and automotive industries [1, 3]. Inorganic fibres such as glass and carbon fibres do posses good mechanical properties but have drawbacks. Fortunately, in the recent years, researchers have come up with a way to solve this problem that is by replacing the inorganic fibre with organic fibre [1]. These organic fibres are abundantly available almost everywhere in the world. It is easy to obtain and inexpensive. Organic fibre materials offer many environmental benefits when used as the reinforcing filler in the composites such as biodegradability, lightweight, low cost, easy to obtain, reasonably strong, do not produce residue or toxic fume when burnt, and reduce erosion of the manufacturing machinery [1].

Among the applications of the bio-composites are in the automotive industry where they are used as automotive parts. Industrial automotive practitioners such as BMW, Honda, Ford, Mercedes-Benz and DaimlerChrysler, have used bio-composites extensively in their automotive components such as doors, ducting, rear shelves, interior panels and truck floors [3-4]. By employing the bio-composites as automotive components, they have achieved a product that is better in terms of material weight, manufacturing cost, recyclability, and fuel consumption [3]. In terms of recyclability, European and Asian countries have released stringent guidelines on the automotive end-of-life requirement which drives most of the automakers to re-evaluate the vehicle’s lifecycle, from raw material selections to manufacturing and to disposal. In 2006, European Union

Legislation required 80% of a vehicle to be reused or recycled and will increase to 85% in 2015 [3]. In Japan, a vehicle is to be recovered 88% by 2005 and increases to 95% by 2015 [3]. Beside the automotive industries, bio-composites are also used in the building and construction sectors. They are used as construction materials such as decking and railing products, window frames, roof tiles and door frames [1-2, 7].

Among the organic fibres which can be found in Malaysia are oil palm empty fruit bunch (OPEFB), sawdust and coconut fibre. These organic fibres are by-products which are unwanted and are disposed and burned causing economic issues and pollutions. Utilizing these organic fibres as the reinforcing fillers for the composite material can minimize the economic and pollution problems faced.

1.2 PROBLEM STATEMENT

Humid ageing is widely recognized as one of the main causes of long-term failure of organic fibre composites. Bio-composites absorb moisture due to the hydrophilic nature of the reinforcing filler causing dimensional change of the bio-composites in terms of volume expansion and swelling thickness thus causing internal stresses [2, 5]. Ingression of water on fibre composites also destroys the adhesion of the polymer-matrix adhesion [6]. Long term exposure of the bio-composites in a humid environment can result in a significant drop on mechanical properties such as strength and modulus of the bio-composites causing the bio-composites to degrade [2, 7]. Many researchers have studied ways to overcome this situation and they have found out that by varying the reinforcing filler composition in the mixture of the bio-composites, water absorption behaviour and mechanical properties of that bio-composites will be varied as well [1].

This project aims to study and investigate on the influence of the filler loadings onto the mechanical and water absorption properties of the bio-composites. A set of tests are conducted based on similar work done before in order to obtain a better understanding of the properties of the bio-composites.

1.3 OBJECTIVES

The objective of this project is to study the water absorption behaviour and the mechanical properties of the OPEFB-HDPE composites as the composition of the natural filler are varied through tests conducted using established standards.

1.4 SCOPE OF STUDY

The investigation is focused on the mechanical properties and water absorption behaviour of the bio-composites. The natural filler employed for this project is oil palm empty fruit bunch (OPEFB) which is in particulate form (425 µm) and the matrix polymer used is high-density polyethylene (HDPE). Upon obtaining the filler and the matrix of the composites, the mixture of the bio-composites was prepared at four different filler loadings (0, 5, 10 and 15 wt.%). The prepared composites were tested for its mechanical properties (tensile and flexural) and the water absorption characteristics. After the mechanical testing, the morphology of the bio-composites fractured surface was examined in order to study and understand the filler-matrix adhesion of the bio-composites.

CHAPTER 2

THEORY/LITERATURE REVIEW

2.1 THEORY

2.1.1 Oil Palm Empty Fruit Bunch (OPEFB)

Oil palm production is a major agriculture industry in Malaysia and contributes as much as US$ 7.3 billion in export earnings yearly [8]. There are more than 3 million hectares of oil palm plantation throughout Malaysia which produce as much as 90 million mt of by-products of oil palms such as trunks, shells, palm press fibre, and empty fruit bunches (OPEFB) [8] as shown in Figure 2.1. The empty fruit bunches alone occupy as much as 9% from the total output of the by-products produced. OPEFB are the residues left after the fruit bunches are pressed at oil mills, and the oil extracted. In the past years, OPEFB are mainly used as a fuel source to generate steam at the mills and the ashes produced from the combustion were used as fertilizers. In recent year, due to the increasing air pollution in Malaysia, burning of the OPEFB is prohibited by regulations in order to prevent more environmental issues [8]. Now OPEFB are used mainly as mulch. OPEFB is composed of 45-50% cellulose and equal amounts of hemicelluloses and lignin which are 25-35%. OPEFB is very fibrous and wet [9], and the fibres stick together to form vascular bundles [8].

Figure 2.1: Oil Palm Empty Fruit Bunch (OPEFB) in the pulverized form.

2.1.2 Injection Moulding

The vast majority of articles made from fibre reinforced thermoplastics are produced by injection moulding and most type of injection moulding machines are of the reciprocating screw type (Archimedian screw) in which the polymer is melted in a barrel within [6]. The material which is in the form of granules or pellets is supplied to the barrel through a hopper which is located on top of the barrel. The material falls on to one end of the screw and as the screw turns, the material moves forward into a zone heated by electric resistance heaters attached around the outside of the barrel [6]. During this stage, the material melts and due to the turning of the screw through the viscous melt, further heating is obtained. The shank of the screw has a larger diameter at the forward end which makes the channel defined by the flights shallower and causes the work done on the material to intensify [6]. During the process of feeding the material forward, the screw moves backward along the barrel axis allowing charges of homogenized melt to gather at the front end of the barrel.

With sufficient material present at the front end of the barrel, the screw now acts as a ram, thrusting forward forcing the melted material to fill the mould cavity and the runner system through a nozzle that is held tightly against the entrance to the mould cavity [6]. The material in the mould is now left to cool for a specific period of time to let it solidify. In order to minimize thermal shrinkage of the melted material, the force of the screw is maintained for a period of the cooling time. This also enables the mould to be supplied continuously with the melted material. This is often most satisfactorily achieved using a holding pressure that is less than the injection pressure [6]. The melt is then admitted into the mould cavity from the runner system through a narrow constriction called a gate and once the material in the gate has frozen, no more supplies of melted material should be provided. Now the holding pressure can be released, and the screw can now prepare for the next cycle. An extra period of cooling must be allowed to ensure that the moulded material has sufficiently solidified before being ejected from the injection moulding machine [6].

2.1.3 Water Absorption

Bio-composites which are exposed to an aqueous environment undergo dimensional changes in the structures of the bio-composites. This is caused by the water absorption of the bio-composites and the dimensional change is usually in the form of volume expansion and swelling thickness [2, 5]. Natural fibres are hydrophilic in nature and it contains hydroxyl groups (-OH) which has the ability to form intermolecular hydrogen bond with the hydroxyl group present in water [7]. The bio-composites face incompatibility issues between the hydrophilic natural fibre reinforcing filler and the hydrophobic thermoplastic and thermoset polymer making the bond between those materials to suffer [10]. The poor bonding area between the hydrophilic filler and the hydrophobic matrix polymer causes an increase in the number of micro voids within the composites and through the micro voids, the water molecules enter the composites and bond with the hydroxyl groups present in the filler of the composite [1]. The water absorption rate of the bio-composites varies between each bio-composite due to several factors such as the amount of filler loadings present in the bio-composite mixtures [1], the strengthening of the interfacial bonding within the composites through incorporations of compatibilizers, coupling agents, or other chemical modifications [1-2], the effects of temperature [10] and many more.

2.2 LITERATURE REVIEW

Yang H-S et. al [1] studied on the effects of varying the mixing ratio between the polymer matrix and lignocellulosic reinforcing filler on the water absorption and mechanical properties of injected moulded lignocellulosic filler-polyolefin bio-composites. The experiment used rice-husk flour (RHF) and wood flour (WF) as the reinforcing filler of the bio-composites mixture. The matrix polymers used were low-density polyethylene (LDPE), polypropylene (PP), and HDPE. During the extrusion of PP and HDPE with the RHF and WF, four levels of filler loading (10, 20, 30 and 40 wt.%) were used. Five levels of filler loadings (10, 20, 30, 40 and 60 wt.%) were used during the extrusion of LDPE with RHF and WF. 3 wt.% maleated polypropylene

(MAPP) and maleated polyethylene (MAPE) were also introduced into the bio-composites mixture as the compatibilizing agent. Results obtained by Yang H-S et. al [1] indicated that the thickness swelling and water absorption rate of the bio-composites slightly increased with increased filler loadings. Through the addition of compatibilizing agents, the bio-composites exhibited significant drop in swelling thickness and water absorptions making them suitable to be used in damp places. The mechanical properties of the bio-composites decreased as the filler loading increased but retained an acceptable level of strength.

H.M Akil et. al [7] investigated the water absorption effects on mechanical properties of pultruded jute fibre reinforced unsaturated polyester composites. For this research, jute fibre was used as the reinforcing filler while the matrix polymer used was unsaturated polyester resin. The composites were prepared by using a thermoset pultrusion machine. The average diameter of all the composites used for this project was 12.7 mm. The composites were immersed in three (3) different aqueous environments that is distilled water, acidic solutions (pH 3), and sea water (pH 8) at room temperature for a period of up to three (3) weeks. H.M Akil et. al [7] discovered that the water absorption of the composites exhibited a pseudo-Frickian behaviour, where moisture weight gained never reached the equilibrium after initial take-off, or in a simpler term, the composites absorbed more water with increased immersion time. Moisture content was highest for composites immersed in distilled water followed by acidic solution and sea water. As the content of the water absorbed increases, the mechanical properties of the composites such as compression and flexural strength decreased. This is due to the weakening of the interfacial bonding between the fibre and matrix. However, the maximum flexural strain showed an increase with the increased moisture content in the composites. This was due to the plasticization effect where the water molecules absorbed fill into the cavities and cracks within the composites and acts as a plasticizer rendering the structure of the composites to become more flexible.

Another research on the water absorption effects on mechanical properties of a natural fibre composites were conducted by H.N. Dhakal et. al [10]. The natural fibre used as the reinforcing filler for this research was hemp fibre and the matrix polymer used was unsaturated polyester. The matrix polymer was mixed with the catalyst, methyl ethyl ketone peroxide (MEKP) at a concentration of 0.01 w/w of the matrix. Hemp fibre reinforced unsaturated polyester (HFRUPE) composites specimens containing 0, 0.10, 0.15, 0.21 and 0.26 fibre volume fraction were prepared using a combination of hand lay-up and compression moulding. The HFRUPE specimens were immersed in a de-ionized water bath at 25°C for different time durations and weighed regularly at 24, 48, 98, 196, 392 up to 888 hours. Similarly, the specimens were immersed in water at 100°C and weighed at different time intervals up to 31 hours of exposure until the water content reached saturation. Results obtained by H.N. Dhakal et. al [10] showed that the water absorption increases with increased fibre volume fraction of the composites. With increasing fibre volume fraction, the micro voids and cellulose content within the HFRUPE composites also increases. Temperature also sped up the water absorption uptake. From this research, the composites at elevated temperature (100°C) experienced an accelerated moisture absorption behaviour. This was due to the increased diffusivity rate of the water molecules into the cracks within the composites and resulted in a faster degradation rate. The tensile and flexural properties of the composites experienced significant drops with increased water absorption as a result of the degradation of the fibre-matrix interfacial bonding.

C.P.L. Chow et. al [11] have investigated on the effects of hot water immersion treatment on the tensile and impact fracture characteristics of sisal fibre reinforced polypropylene (SF/PP) composites. The reinforcing filler used in this research was sisal fibre (SF) with varied level of loading (10, 20, and 30 wt.%) and the matrix polymer used was polypropylene homopolymer (PP). Maleic anhydride grafted polypropylene (MA-g-PP) was used as the compatibilizer for the SF/PP composites in order to improve the interfacial adhesion composites. The fibre, matrix, and compatibilizer were extruded using a single screw extruding machine and then moulded into ASTM type-I tensile bars using an injection moulding machine. SF/PP specimens were immersed in water bath at

90°C for different time duration. Results obtained showed that water absorption in the form of weight gain was highest for the SF/PP composites with highest filler loading. As the immersion time increased, the weight gained of the composites also increased but after a period of time (induction period), the weight gain suddenly decreased. This phenomenon was caused by the dissolution of the lignaceous material and the waxy substances on the sisal fibre surface. Mechanical properties of the SF/PP composites such as tensile modulus and tensile strength decreased with increased moisture uptake due to the weakening of the interfacial bonding of the filler-matrix bonding within the SF/PP composites. However, the ductility and impact strength of the SF/PP composites increased with increased moisture absorbed. This condition was due to the plasticization effect occurring within the SF/PP interface.

CHAPTER 3

METHODOLOGY

3.1 MATERIALS

3.1.1 Matrix Polymer

The thermoplastic polymer used in this project is high-density polyethylene (HDPE) supplied by Titan Petchem (M) Sdn. Bhd. in the form of pellets with a melting point of 130°C and a density of 0.941 g/cm^3.

3.1.2 Reinforcing Filler

The reinforcing filler which is used in this project is oil palm empty fruit bunch (OPEFB). The OPEFB was supplied by Sabutek (M) Sdn. Bhd. in the form of particulate sized filler.

3.1.3 Distilled Water

Distilled water that is used in this project is supplied by Shapadu Trading Sdn. Bhd.

3.2 FILLER PREPARATION

The OPEFB were grounded using Rocklabs Type B.T.R.M Model 1A. In order to obtain a specific particulate size of 425 µm, the grinded OPEFB were sieved using Endecotts EFL2000 Sieve Shaker Set together with MaTest Sieve Type 0.425 mm. The OPEFB are then oven dried at 80°C for 24 hours in order to adjust their moisture content to 4% or less.

3.3 COMPOSITE PREPARATION

Matrix polymer and reinforcing filler was mixed and moulded into dog-bone shaped specimens (according to ISO 527-2, type 1B specimen) using an injection moulding machine 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). Four levels of filler loadings (0, 5, 10 and 15 wt.%) were used during the moulding process of the specimens. The dog-bone shaped specimens produced from the moulding processes were used for subsequent mechanical testing.

3.4 CHARACTERIZATION TESTING

3.4.1 Mechanical Testing

The specimens have undergone two types of mechanical testing, tensile test and flexural test. Both tests were conducted using the LLYOD Instruments LR5K Universal Testing Machine by following the standards set in ISO 527-2 and ISO 178, respectively. For the flexural testing, specimens with dimensions of 80 x 10 x 4 mm^3 and crosshead speed of 2 mm/min were employed. For the tensile testing, dog-bone shaped specimens with crosshead speed of 5 mm/min were used. Each test was repeated three (3) times for each of the bio-composite specimens. For the flexural test, the flexural strength (σ_f) were calculated using Eq. 3.2,

$$\sigma_f = \frac{3FL}{2bd^2} \tag{3.1}$$

Where F is the maximum force (N), L is the distance between the support span (mm), b is width of the specimen (mm), and finally d which is the thickness of the specimen (mm). The unit of the flexural strength calculated is in MPa.

3.4.2 Water Absorption Testing

Samples of dimension 30 x 10 x 4 mm^3 are used for the water absorption tests. The composite specimens were soaked in distilled water in order to measure its water absorption behaviour through the change in its volume. Three (3) samples were tested for each formulation. The samples were first dried in an oven at 50°C for 24 hours, then cooled in a dessiccator and weighed to the nearest 0.1 mg. The specimens are then soaked in the distilled water and are left for specified time intervals. Later the specimens are removed from the solutions, dried, and immediately weighed using a Mettler Toledo balance. Percentage of water uptake for each specimen during the water absorption test were determined by Eq. 3.1,

$$\%\ \text{Water Uptake} = \frac{Mass_i - Mass_o}{Mass_o} \times 100\% \tag{3.2}$$

Where Mass_i is the mass of the specimens at specified time intervals (mg) and Mass_o is the initial mass of the specimen (mg).

3.4.3 Electron Microscopy

Analysis of the specimen filler morphology and fracture were conducted using Oxford Leo 1430 Scanning Electron Microscopy (SEM). The specimens were mounted on aluminium stubs and sputtered-coated with a thin layer of gold to avoid electrostatic charging. Micrographs of the fractured surface of the specimens from the tensile testing were studied.

CHAPTER 4

RESULT AND DISCUSSION

4.1 FILLER'S MORPHOLOGIES

The OPEFB used in this project were oven dried at 80°C for 24 hours. After the drying process, samples taken from OPEFB filler were observed under the SEM to study the filler's morphologies. SEM pictures of the samples before drying were also taken for comparison purposes. Figure 4.1 shows the pictures taken using the SEM.

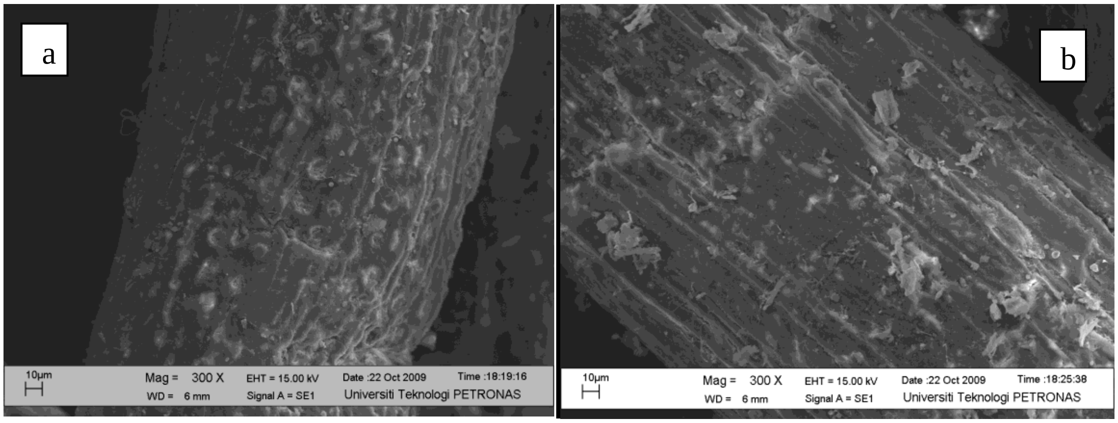

Figure 4.1: SEM of OPEFB; (a) before drying (b) after drying.

As seen in Figure 4.1(a), the texture and surface of the strand seemed to differ before drying as compared to the texture and surface of the strand after drying, as in Figure 4.1(b). The change in the surface texture observed is may be due to the content of water present in the strand which were eliminated after the drying process due to the heat supplied during the process. This makes the texture of the strand to be much smoother and flakes were seen appearing on the surface. It is also noted that from previous study [12] the surface of OPEFB should show great number of silica-bodies which are attached to circular craters that are scattered uniformly through the filler's strand as shown in Figure 4.2. However these silica-bodies are not observable through SEM. This explains why Figure 4.1(a) and 4.1(b) did not show any silica-bodies on the surface of the strand. Within the OPEFB strand exists a network of siliceous pathways and that during the growth season, basic silica element is transported through this pathway and deposed onto the craters on the surface of the strand which are called the silica-bodies [12]. These silica-bodies are spiky and round-shaped. It measures up to 10-15 µm in diameter [12]. Silica-bodies can easily be dislodged from the strand through mechanical means such as hammering and grinding [12]. It is predicted that the strand of the OPEFB for this project contain less silica-bodies due to the grinding done earlier during the progress of this project. The result from the removal of the silica-bodies would enhance chemical penetrations into the strand of the OPEFB [12].

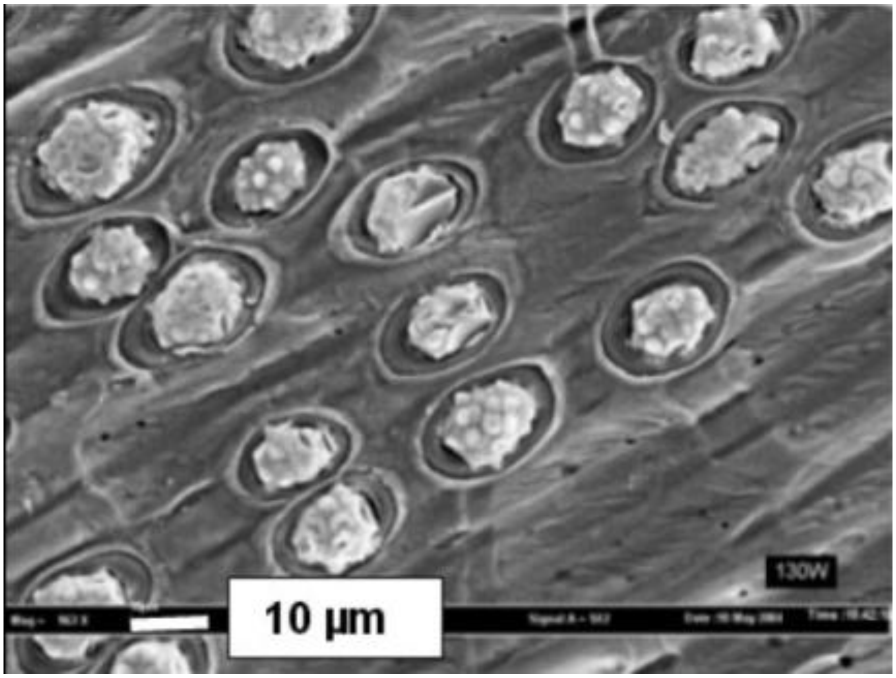

Figure 4.2: Surface of OPEFB strand with silica-bodies [12].

4.2 MECHANICAL PROPERTIES

4.2.1 Tensile Strength

Samples of various filler content were prepared, from 0, 5, 10 to 15 wt.%. Results obtained from the tensile testing for each samples were presented in Figure 4.3. From Figure 4.3, it is observed that the samples with no filler have the highest average value of tensile strength followed by samples with 5 wt.%, 10 wt.%, and 15 wt.% filler. The pure HDPE composites (0 wt.%) average tensile strength is 26.3 MPa and for composites with 15 wt.% of filler, the average tensile strength is 20.4 MPa. The decrease in tensile strength is reported at 23% as the filler content increases from 0 to 15 wt.%.

Generally, the pattern of the tensile strength follows that with previous researches done [1, 7, 10-11]. As the filler loading of the composites increases, the mode of failure of the composites also changes from ductile to brittle deformation.

As filler loading increases, the interfacial area of the composites also increases, thus worsening the interfacial bonding between the filler and the matrix. The poor bonding between the filler and the matrix causes the tensile strength of the bio-composites to suffer. Higher filler content results in more void formation during processing thus making the adhesion between the filler-matrix bonding to suffer and promotes micro crack formation at the interface [1] and therefore reduces the tensile strength. The void formation present inside the composites is due to the uneven and inefficient filler distribution during the composites processing stage earlier [14]. Higher filler content also results in higher filler agglomeration which reduces the adhesion between the filler and the matrix.

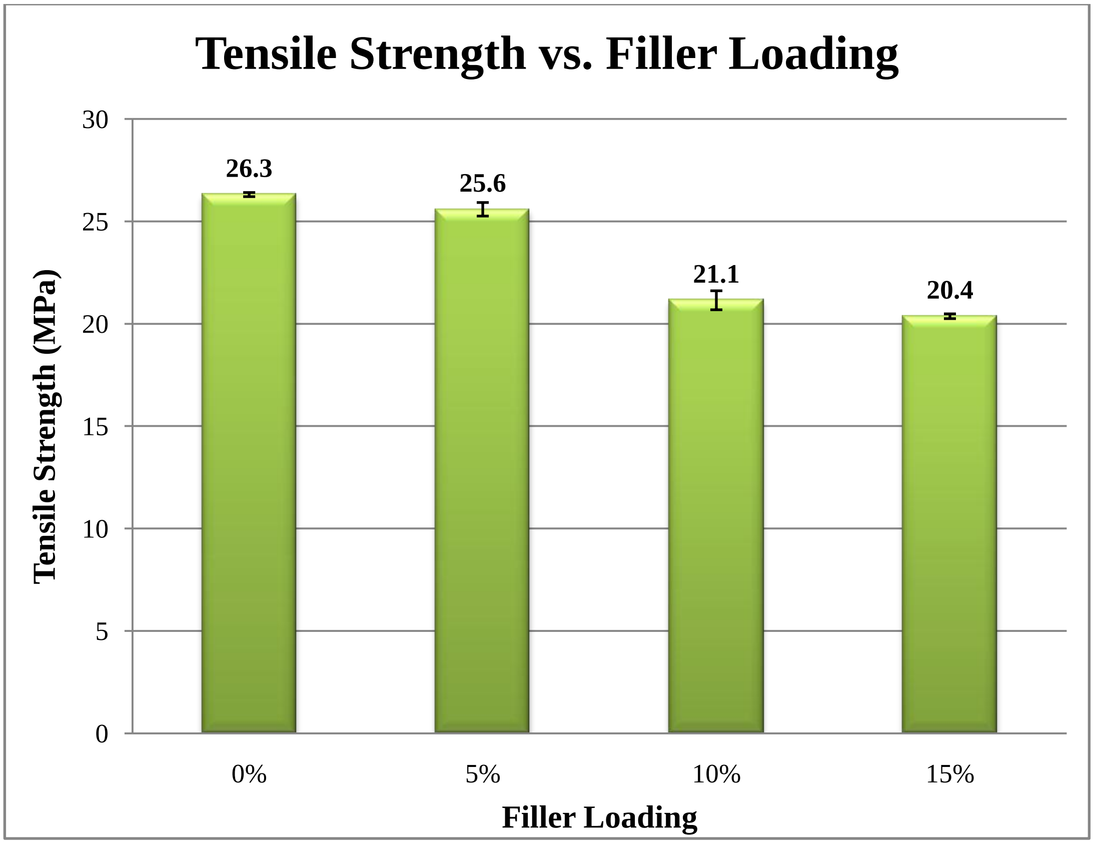

Figure 4.3: Tensile strength of composites at different filler loadings.

4.2.2 Flexural Strength

Samples fabricated were also tested for their flexural strength. Results obtained from the flexural testing were presented in Figure 4.4. It is observed that as the filler loading of the composites increases from 0 to 5 wt.%, the flexural strength of the composites decreases for as much as 5%. However, as the filler loading increases from 0 to 15 wt.%, the increase in flexural strength is calculated for as much as 15%. Generally, it is seen that, as the filler loading increases, the flexural strength of the composites also increases.

The pattern of the results obtained follows that which are reported from previous studies [13]. As filler loading of the composite increases, the value of flexural strength of the composite also increases.

Flexural loading causes multiple forces which are tensile, compression and shear to develop within the composites [13]. The presence of the filler inside the composites aids in absorbing and transferring the multiple forces developed within the composites. This causes the composites able to withstand greater load [13]. With increasing amount of filler, higher amount of forces and load can be tolerated by the composites. The forces are able to be distributed to the fillers present inside the composites resulting in higher flexural strength at higher filler loadings.

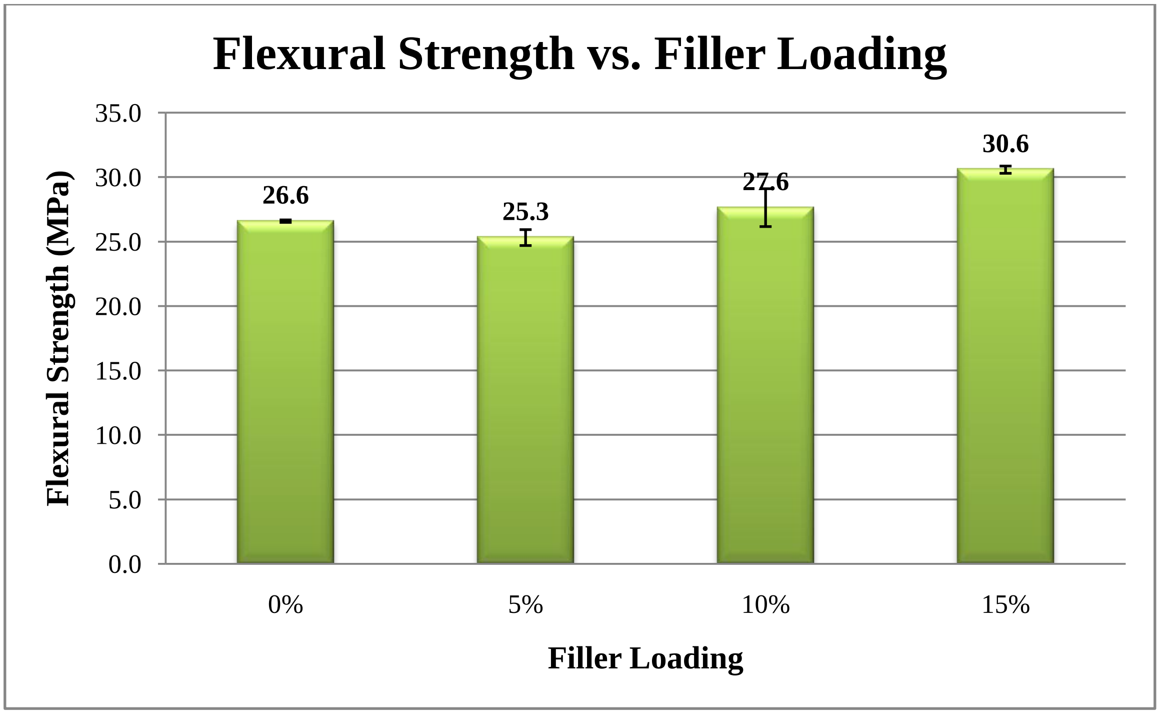

Figure 4.4: Flexural strength of composites at different filler loadings.

4.3 WATER ABSORPTION BEHAVIOUR

Water absorption test were done within a period of up to thirty (30) days and the setup for the experiment is shown in Figure 4.5. All the data collected were calculated and summarized in a graph as shown in Figure 4.6. From the graph, it is seen that as immersion time increases, the amount of water uptake for all the composites also increases. It is also noted that as the content of the filler increased, the amount of water absorbed also increased. However, for pure HDPE composites (0 wt.% of filler), there are no water uptake recorded throughout the entire period of the test. At the end of the test period, the value of water absorbed for composites with 5, 10 and 15 wt.% are 0.3, 0.7 and 7.8% respectively.

The results obtained from this project followed the pattern of the work done from previous studies and research [1, 7, 10-11]. As the filler content increases, the water absorption of the natural filler composites also increases.

The main cause of the water intake of the OPEFB-HDPE bio-composites is because of the difference in polarity between the OPEFB and the HDPE polymer. The polar property of the OPEFB is incompatible with the non-polar property of the HDPE polymer. OPEFB are hydrophilic in nature and have the tendency to absorb water. While OPEFB is hydrophilic, HDPE is known for its hydrophobic nature in which makes this polymer highly resistant to water. At lower filler loading (5 wt.%), the amount of OPEFB present in the composite is less as compared to the amount of HDPE present. Due to this, the amount of water absorbed by the composites with 5 wt.% of filler is very low as compared to composites with 15 wt.% filler. In the composites with 15 wt.% filler, the amount of OPEFB present increases and causes the amount of water absorbed to also increases. Increasing filler loadings also leads to the increase of the amount of poor bonded area between the filler and matrix polymer causing many micro voids within the structure of the composites. Through this micro voids, water will enter through and forms hydrogen bonding with the hydroxyl groups present within the filler thus weakening the adhesion between the filler and polymer bonding [1, 11]. It is also observed that for the composite at 15 wt.% filler, the fillers inside the sample are more exposed to the surrounding as compared to composite at 10 and 5 wt.% filler as shown in Figure 4.9, 4.8 and 4.7 respectively. This condition allows more water to go into the interface of the sample thus enabling more water to be absorbed. This explains the marked increase of the water absorbed for composite with 15 wt.% filler as compared with composites at 5 and 10 wt.% filler.

Figure 4.5: Water absorption test setup.

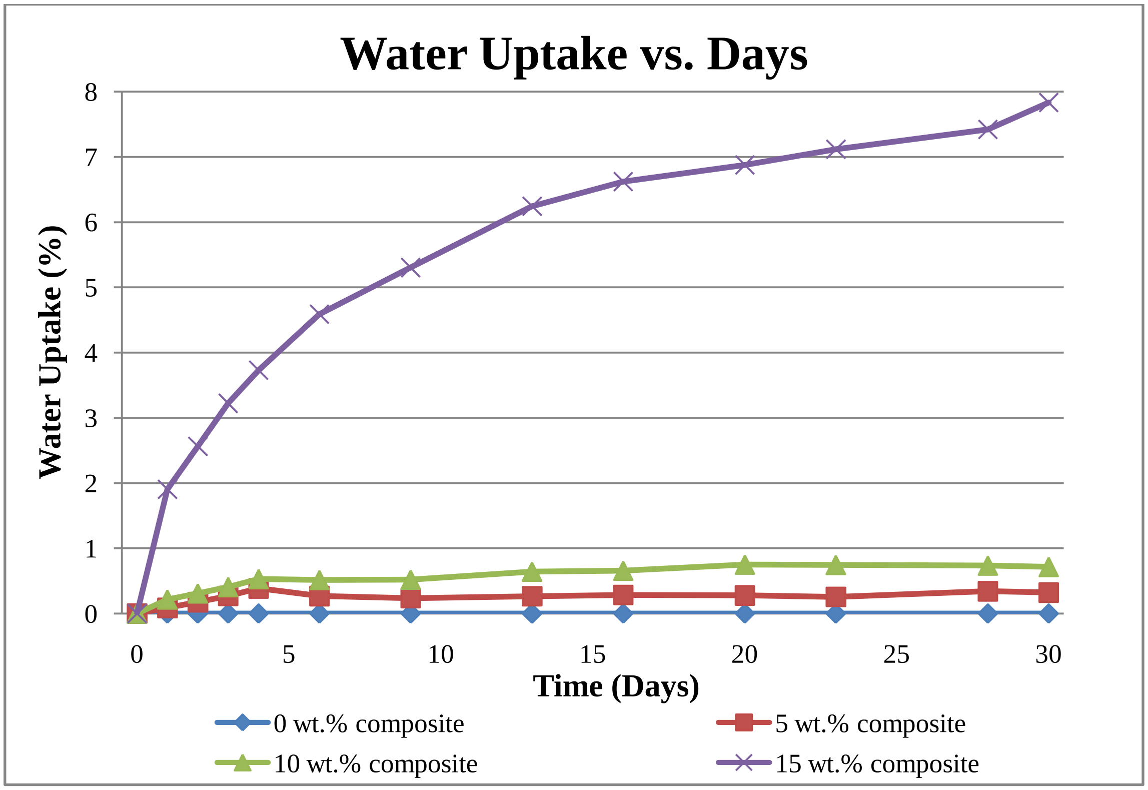

Figure 4.6: Water uptake for composites at different filler loadings.

Figure 4.7: Side of sample at 5 wt.% filler loading.

Figure 4.8: Side of sample at 10 wt.% filler loading.

Figure 4.9: Side of sample at 15 wt.% filler loading.

4.4 FRACTURE SURFACE MORPHOLOGIES

According to the morphological studies of the tensile-fractured surface using SEM, the failure modes of the composites with low filler loading (5 wt.%) are dominated by matrix tearing as illustrated in Figure 4.7. Also at 5 wt.% filler loading, few filler particles are seen at the tensile fracture surface of the composite. The fracture surface is mainly covered with HDPE polymer matrix. The composite at 5 wt.% filler possess ductile properties and its main mode of failure is plastic deformation [13].

For composites with higher filler loading (10 and 15 wt.%), more filler particle can be seen at the fracture surface of the composites and fewer matrix polymer is observed. Small holes or cavities are observed at both filler loadings (10 and 15 wt.%) which were caused by the pullout of the filler from the surface of the fracture of the composites. This indicates that the adhesion between the filler and the matrix are weak. Also void formation is clearly visible at the fracture surface of the composites. Comparing Figure 4.8(a) and 4.9(a), the number of void formations and cavities is greater at composite with 15 wt,% filler. The main mode of failure for both composite (10 and 15 wt.%) are dominated by debonding and pullout mechanism as illustrated in Figure 4.8 and Figure 4.9. Debonding or loss of adhesion between the filler and the matrix would first occur before the filler is being pulled out from the matrix [13]. Both composite at this level of filler loading (10 and 15 wt,%) experience brittle deformation but however, composite with 10 wt.% filler do retain some of the ductility of the polymer matrix as matrix tearing are observed at the fracture surface of the composite.

From the observations of the fracture surface of the composites, it is seen that as filler loading increases, interfacial area increases thus worsening the interfacial bonding between the filler and the matrix of the composite [1]. Also more void formations are observed [1].

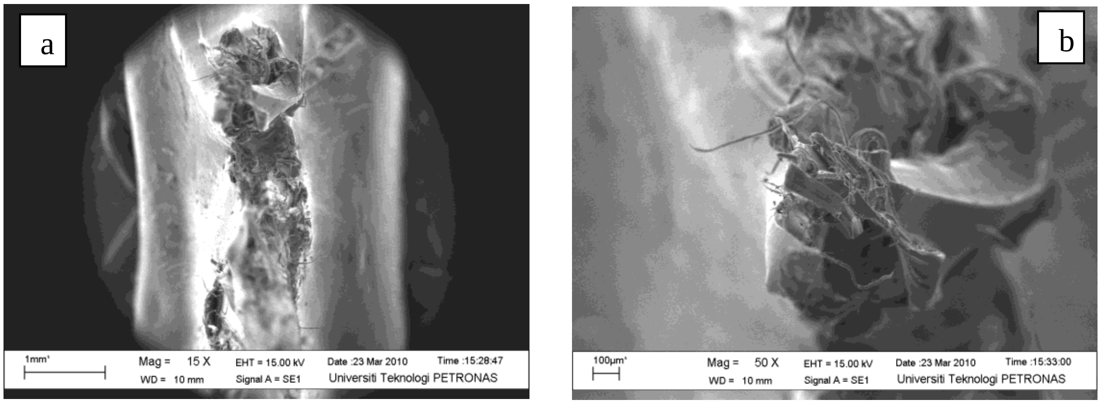

Figure 4.10: SEM of tensile-fractured surface of composites at 5 wt.% filler loading;(a) magnification = 15 X (b) magnification = 50 X.

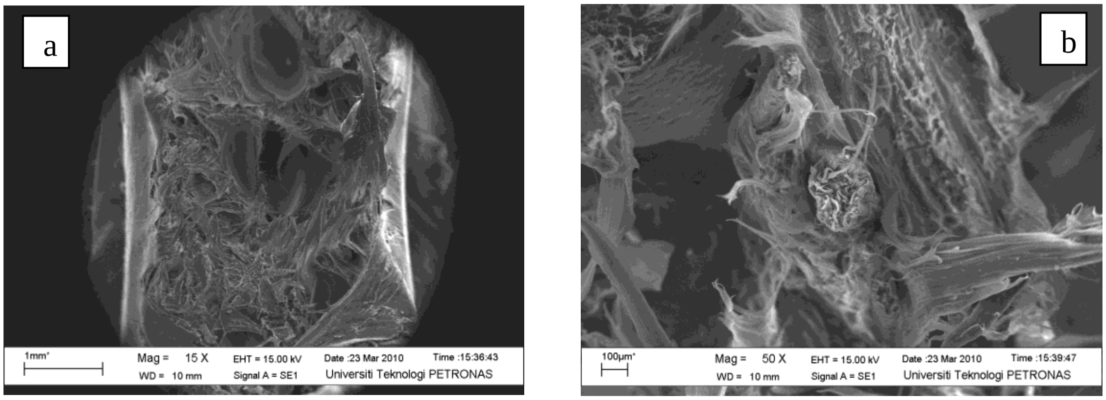

Figure 4.11: SEM of tensile-fractured surface of composites at 10 wt.% filler loading; (a) magnification = 15 X (b) magnification = 50 X.

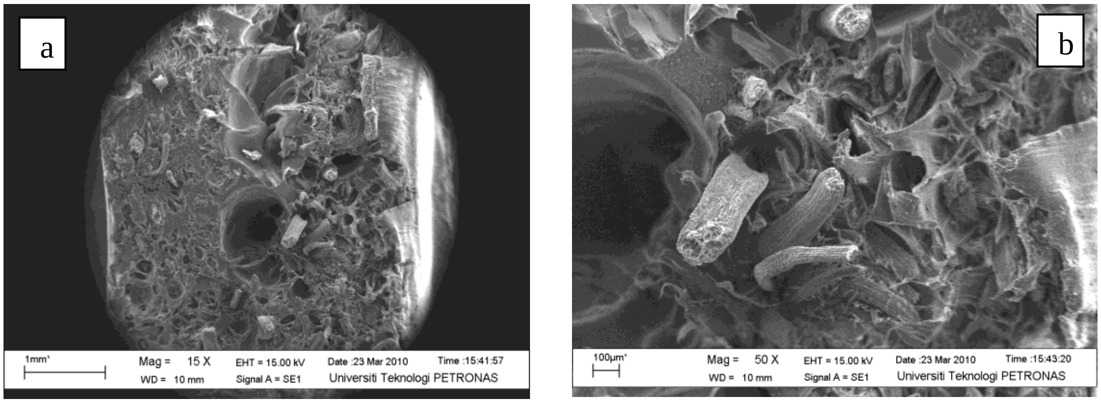

Figure 4.12: SEM of tensile-fractured surface of composites at 15 wt.% filler loading; (a) magnification = 15 X (b) magnification = 50 X.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

From the results obtained, the mechanical and water absorption properties of the OPEFB-HDPE bio-composites were examined.

From the SEM pictures of the OPEFB used for this project, it is observed that the texture and surface of the strand seemed to differ before drying as compared to the texture and surface of the strand after drying. The change in the surface texture observed is may be due to the content of water present in the strand which were eliminated after the drying process due to the heat supplied during the process. This is important as the content of moisture could affect the results obtained from the test. Elimination of the moisture ensures a more accurate and presentable data for this project.

From the tensile test, the results showed that the tensile strength of the composites agrees with that of the previous researches. As filler loading increases, the tensile strength decreases. Increasing of the filler loading causes the interfacial area of the composite to also increase, thus worsening the interfacial bonding between the filler and the matrix. This causes the adhesion between the filler and matrix to suffer. For the flexural test, it is observed that as the filler loading increased, the flexural strength of the composite also increased. Forces exerted by the flexural test were absorbed and transferred to the filler particles of the composite making the composite able to withstand higher loads. Higher amount of filler results in higher flexural strength for the composite.

Increase of filler content causes the amount of water absorbed by the OPEFB-HDPE bio-composites to increase. The effect of mixing reinforcing filler with HDPE polymer is clearly seen as the pure HDPE composite does not absorbs any water. This indicates that the water absorbed is caused by the hydrophilic nature of the OPEFB filler. As filler loading increases, the amount of hydrophilic filler present inside the composite also increases, causing more water to be absorbed by the composite.

According to the morphological studies of the tensile-fractured surface using SEM, few filler particles can be seen at the fracture surface of the composite at 5 wt.% as compared to composites at 10 and 15 wt.%. Void formation and cavities are also observed at the fracture surface of composites at 10 and 15 wt.% filler loading which indicates the poor and weak adhesion of the interfacial bonding between the filler and the matrix. This causes the tensile strength of the composites to decrease as filler loading increase and also causes the ductility to decrease rendering the composite to become more brittle. However due to the amount of filler particle present at higher filler loadings, the flexural strength of the composite improves as the loads exerted onto the composite were absorbed and distributed to the filler particles present in the composite.

The objective of this project, to study the mechanical and water absorption properties of OPEFB-HDPE composite as the filler loadings are varied has been achieved. Different filler loadings cause the water and mechanical properties of the composite to be varied. However further study and examination needs to be done as the research on natural filler composites are far from over. There are still rooms for improvement for these bio-composites and with time, bio-composites may become a leading material that can be used widely in every aspect of construction, automotive, building and other sectors.

5.2 RECOMMENDATIONS

Further studies on the effect of chemical modifications, coupling agents, and compatabilizers on the adhesion between the filler and the matrix should be carried out. As reported from previous research [1-2], addition of compatabilizing agent greatly limits the water absorption properties of the bio-composites. The mechanism of the compatabilizing agent is as shown in Figure 5.1. From the upper part of Figure 5.1, it shows how the compatibilizing agent will chemically bond with the hydroxyl (-OH) group in the natural fillers. The bonding between the compatibilizing agent and the natural filler limits the water absorption of the bio-composites [1] as shown in the lower part of Figure 5.1. The right half of the figure shows that the hydroxyl group of the natural filler reacts with the hydroxyl group present in water to form hydrogen bonds while in the left part of the figure shows that the bonding between the natural filler and compatibilizing agent prevents the natural filler and water from forming hydrogen bonds.

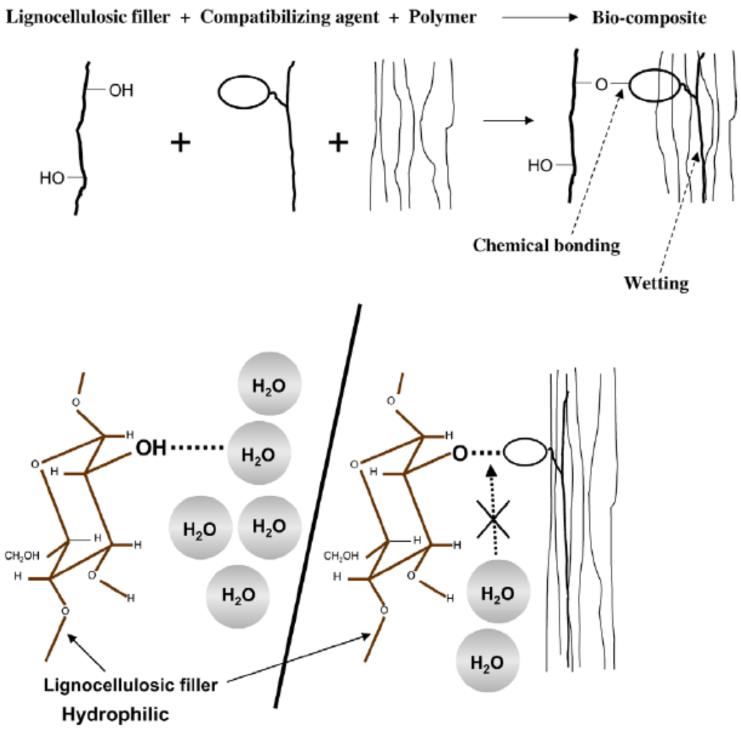

Figure 5.1: Schematic of the function of the compatibilizing agent in the lignocellulosic filler-polyolefin composite system [1].

The additions of such modificators also influence the mechanical properties of the bio-composites. Addition of compatibilizing agent will give significant improvement in stiffness and strength of the composite. The improvement in flexural strength can range from 10 to 90% [6].

Also, the effect of water absorption onto the mechanical properties of the bio-composites should be investigated as well. As reported from previous studies [7, 10-11], the increase in water absorption causes a decrease in the mechanical properties of the bio-composites such as the tensile strength and tensile modulus. However, ductility and impact strength of the bio-composite will be enhanced due to plasticization effect occurring within the bio-composite interface.

Other factors which could affect the mechanical and water absorption properties such as temperature, processing parameters, aqueous environment, and many more should be investigated.

With proper research and studies, the future of the natural filler composite will be brighter and promising. With new techniques and method discovered, it is possible to use higher natural filler loadings within the mixture of the composites. Using higher filler loadings into a mixture will cut the manufacturing cost for the composites as natural fillers are abundant and cheap and also provide other environmental benefits such as biodegradability and absence of toxic fume when burned.

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APPENDICES